It is to be understood that cap 172 serves as a heat sink and supports contact structures 176a, 176b which connect through vias extending through cap 172 to form interconnect contacts 174a, 174b on the opposite surface of cap 172. These interconnect contacts 174a, 174b are suitable for attachment to an underlying supporting conventional flip chip-type back plate (not shown) providing mechanical support and electrical bonds thereto.

Next in Fig. 15, (similar to Fig. 7) the backside surface of substrate 10 is polished or etched away to expose the lower portions of dielectrically insulated trenches 72a, ..., 72e. Again, the total thickness of substrate 10 and silicon layer 20 is minimized by this removing step to that needed for proper electrical functioning. Next in Fig. 16, backside contacts 178a, 178b are formed, similar to contacts 104a, 104b in Fig. 8. Next in Fig. 17, backside passivation layer 186 is deposited to a thickness of e.g. 0.5 to 2.5 micrometers using oxide or nitride or an oxide-nitride "sandwich" material over the backside surface of substrate 10 and initially over contact areas 178a and 178b, but is then removed from the exposed surfaces by use of a mask which is then patterned, and etching away of the unneeded portions of passivation layer 186. This exposes the bonding area of the power device drain contact 178a and a collector type drain contact 178b if desired. (Again the use of the backside contact depends on the nature of the associated semiconductor devices). Thus the flip chip configuration of Fig. 17 provides both frontside substrate electrical contacts 174a, 174b through cap 172 and also backside contacts 178a, 178b. The frontside leads are beam or tunnel lead structures or types to the transistors.

Again, after the steps of Fig. 17, the entire wafer is conventionally scribed along predetermined

IPR2024-00535
Samsung Electronics Co. Ltd. et al v. Chien-Min Sung
Samsung's Exhibit 1057, Vol. 3
EX1057, Page 541

scribe lines (not shown); thus as a result of scribing the chip is complete (packaged), advantageously without any need for further packaging steps.

Diamond Film Passivation Layer Embodiment

The above-described flip chip type and surface mount embodiments use conventional silicon dioxide or nitride as the dielectric insulation and passivation layer between the semiconductor wafer itself and the heat sink plate. These materials are known to provide relatively poor heat conduction, due to for instance the very low thermal conductivity of silicon dioxide of approximately 2 W/mK. In contrast, diamond film (which is also a good dielectric insulating material) provides thermal conductivities of about 2,000 W/mK. Also diamond is well known to be chemically inert, and due to its having the densest crystal lattice of any known material, the diffusion of other elements into diamond is very low. Thus diamond is not only a good dielectric insulator with excellent thermal conductivity but it is also a material which serves effectively as a passivation layer, providing good corrosion protection.

It has been determined in accordance with invention that diamond film has the best combination of thermal conductivity and electrical resistivity of available materials. Other materials such as aluminum nitride, aluminum oxide, or silicon carbide also provide high dielectric insulation but much less thermal conductivity than diamond. The only materials providing thermal conductivity similar to that of diamond film are electrically conductive metals such as copper and silver, which are not useful for passivation.

It is well known to provide chemical vapor deposition (CVD) of diamond film deposited at

temperatures of 600° to 950°C and at sub-atmospheric pressures. Typically methane or acetylene is used as the carbon source with significant partial pressure of atomic hydrogen. Excitation sources used include microwave and radio frequency plasmas, hot filament and thermal plasmas and combustion flames.

It has also been known to achieve a diamond deposition at temperatures below 600°C, for instance by using other process gas mixtures such as adding rare gases to the commonly utilized mixtures of carbon containing gases and hydrogen, mixtures of alcohols and water, halogenated gases and other gaseous combination. Typically growth rates of about 0.2 micrometers per hour have been achieved at deposition temperatures of about 400°C.

Methods for depositing diamond film in accordance with the present invention include low temperature microwave plasma assisted CVD. An alternative is an arc jet CVD process. It is known to pattern diamond films using conventional oxygen-based RIE (reactive ion etching) processes, as are well known in semi-conductor fabrication.

Thus in accordance with the invention for the above-described surface mount embodiment, a diamond film formed by one of the above described processes (or any other process) is substituted for passivation layer 96. The diamond film is formed to be a layer e.g. approximately 0.5 to 10 micrometers thick (but this is not limiting). Then the next substitution is, instead of using an ordinary epoxy material layer 98, a thermally conductive adhesive such as commercially available silver epoxy is used to bond the plate 100 to the diamond film. All other processing steps are as described above for this embodiment.

Similarly, for the above-described flip chip type embodiment, passivation layer 160 is a CVD (or other

type) diamond film approximately 0.5 to 10 micrometers thick (again this dimension is not limiting). This diamond film is, as described above for the non-diamond film flip chip type embodiment, masked using a mask layer to pattern it to define the contact openings 164A, 164B therethrough. The remaining of the processing is as described above, using a thermally conductive (but electrically insulative) high performance adhesive to bond the heat sink cap 172 to the diamond film passivation layer 160. Thus the process steps in terms of structure are similar to those described above for the non-diamond film flip chip type embodiment, except for the presence of the diamond film passivation layer material.

The above description is illustrative and not limiting; it will be understood by one of ordinary skill in the art that further modifications will be apparent in view of this disclosure, and fall within the scope of the appended claims.

We Claim:

1. An integrated circuit comprising:

A semiconductor substrate having a principal surface;

a plurality of semiconductor devices formed in the substrate;

a pattern of conductive lines formed overlying the principal surface and in electrical contact with the devices;

a diamond film at least partially overlying the pattern of conductive lines;

a thermally conductive plate bonded to the diamond film and overlying the pattern of conductive lines; and

a plurality of insulated trenches extending from the principal surface of the substrate through the substrate and to an opposing backside surface thereof.

2. The integrated circuit of Claim 1, further comprising a plurality of electrically conductive contacts formed on the backside surface of the substrate, each conductive contact being in contact with a selected portion of the backside surface as defined by the plurality of trenches.

3. The integrated circuit of Claim 1, wherein a thickness of the substrate is less than about 50 micrometers.

4. The integrated circuit of Claim 1, further comprising a second pattern of conductive lines juxtaposed to the plate and in electrical contact with the first pattern.

5. The integrated circuit of Claim 1, wherein the substrate defines a plurality of conductive vias extending from the principal surface thereof to the backside surface thereof, each via being in electrical contact on the principal surface with a portion of the pattern of conductive lines, and each via forming an electrical contact on the backside surface.

6. The integrated circuit of Claim 5, wherein the electrical contacts on the backside surface are each a post extending from the backside surface.

7. The integrated circuit of Claim 1, wherein the diamond film has a thickness in the range of 0.5 to 10 micrometers.

8. The integrated circuit of Claim 1, wherein the diamond film is bonded to the plate by a thermally conductive adhesive layer.

9. A method of forming an integrated circuit, comprising the steps of:

providing a semiconductor substrate having a principal surface;

forming a plurality of semiconductor devices in the substrate;

forming a plurality of trenches in the substrate extending from the principal surface thereof into the substrate to a particular depth;

forming a layer of insulating material in each of the trenches;

forming a pattern of conductive lines overlying the principal surface and in electrical contact with the devices;

forming a diamond film layer overlying the substrate;

bonding a thermal conductive plate to the diamond film layer and overlying the principal surface of the substrate; and

removing a portion of the substrate from a backside surface thereof opposing the principal surface, thereby exposing at least a bottom part of each of the trenches.

10. The method of Claim 9, further comprising the steps of:

forming a conductive layer on the backside surface; and

patterning the conductive layer into a plurality of contact regions, each contact region being in contact with a selected portion of the backside surface as defined by the plurality of trenches.

11. The method of Claim 9 wherein the step of removing leaves a remaining thickness of the substrate of less than about 100 micrometers.

12. The method of Claim 9, further comprising the step of forming a second pattern of conductive lines on a surface of the plate prior to the step of bonding;

wherein the step of bonding comprises electrically contacting portions of the second pattern to portions of the first pattern.

13. The method of Claim 9 wherein the step of bonding comprises applying a thermally conductive adhesive between the diamond film layer and the plate.

14. The method of Claim 9, further comprising the steps of:

forming a plurality of vias extending from the backside surface to the principal surface of the substrate, after the step of removing;

providing conductive material in each of the vias, the conductive material in each via being in electrical contact on the principal surface with a portion of the pattern of conductive lines, and the conductive material in each via forming an electrical contact on the backside surface.

15. The method of Claim 14, wherein the step of providing conductive material comprises forming a layer of the conductive material on the backside surface, and further comprising:

forming the layer of conductive material into a plurality of posts extending outward from the backside surface, each post being electrically connected to the conductive material in one of the vias.

16. The method of Claim 9, wherein the diamond film layer is formed to a thickness in a range of 0.5 to 10 micrometers.

AMENDED CLAIMS

[received by the International Bureau on 18 September 1995 (18.09.95); original claims 1,6-9,11,13 and 16 amended; new claims 17 and 18 added; remaining claims unchanged (4 pages)]

1. An integrated circuit comprising:

A semiconductor substrate having a principal surface and a thickness less than about 100 micrometers;

a plurality of semiconductor devices formed in the substrate;

a pattern of conductive lines formed overlying the principal surface and in electrical contact with the devices;

an electrically insulating film at least partially overlying the pattern of conductive lines;

a thermally conductive plate permanently bonded to the insulating film and overlying the pattern of conductive lines; and

a plurality of insulated trenches extending from the principal surface of the substrate through the substrate and to an opposing backside surface thereof.

2. The integrated circuit of Claim 1, further comprising a plurality of electrically conductive contacts formed on the backside surface of the substrate, each conductive contact being in contact with a selected portion of the backside surface as defined by the plurality of trenches.

3. The integrated circuit of Claim 1, wherein a thickness of the substrate is less than about 50 micrometers.

4. The integrated circuit of Claim 1, further comprising a second pattern of conductive lines juxtaposed to the plate and in electrical contact with the first pattern.

5. The integrated circuit of Claim 1, wherein the substrate defines a plurality of conductive vias extending from the principal surface thereof to the backside surface thereof, each via being in electrical contact on the principal surface with a portion of the pattern of conductive lines, and each via forming an electrical contact on the backside surface.

6. The integrated circuit of Claim 5, wherein the electrical contacts on the backside surface are each a post extending from the backside surface.

7. The integrated circuit of Claim 1, wherein the insulating film has a thickness in the range of 0.5 to 10 micrometers.

8. The integrated circuit of Claim 1, wherein the insulating film is bonded to the plate by a thermally conductive adhesive layer.

9. A method of forming an integrated circuit, comprising the steps of:

providing a semiconductor substrate having a principal surface;

forming a plurality of semiconductor devices in the substrate;

forming a plurality of trenches in the substrate extending from the principal surface thereof into the substrate to a particular depth;

forming a layer of insulating material in each of the trenches;

forming a pattern of conductive lines overlying the principal surface and in electrical contact with the devices;

forming an electrically insulating film layer overlying the substrate;

permanently bonding a thermal conductive plate to the insulating film layer and overlying the principal surface of the substrate; and

removing a portion of the substrate from a backside surface thereof opposing the principal surface, thereby exposing at least a bottom part of each of the trenches and reducing a thickness of the substrate to less than about 100 micrometers.

10. The method of Claim 9, further comprising the steps of:

forming a conductive layer on the backside surface; and

patterning the conductive layer into a plurality of contact regions, each contact region being in contact with a selected portion of the backside surface as defined by the plurality of trenches.

11. The method of Claim 9 wherein the step of removing leaves a remaining thickness of the substrate of less than about 50 micrometers.

12. The method of Claim 9, further comprising the step of forming a second pattern of conductive lines on a surface of the plate prior to the step of bonding;

wherein the step of bonding comprises electrically contacting portions of the second pattern to portions of the first pattern.

13. The method of Claim 9 wherein the step of bonding comprises applying a thermally conductive adhesive between the insulating film layer and the plate.

14. The method of Claim 9, further comprising the steps of:

forming a plurality of vias extending from the backside surface to the principal surface of the substrate, after the step of removing;

providing conductive material in each of the vias, the conductive material in each via being in electrical contact on the principal surface with a portion of the pattern of conductive lines, and the conductive material in each via forming an electrical contact on the backside surface.

15. The method of Claim 14, wherein the step of providing conductive material comprises forming a layer of the conductive material on the backside surface, and further comprising:

forming the layer of conductive material into a plurality of posts extending outward from the backside surface, each post being electrically connected to the conductive material in one of the vias.

16. The method of Claim 9, wherein the insulating film layer is formed to a thickness in a range of 0.5 to 10 micrometers.

17. The integrated circuit of Claim 1, wherein the insulating film is a diamond film.

18. The method of Claim 9, wherein the insulating film is a diamond film.

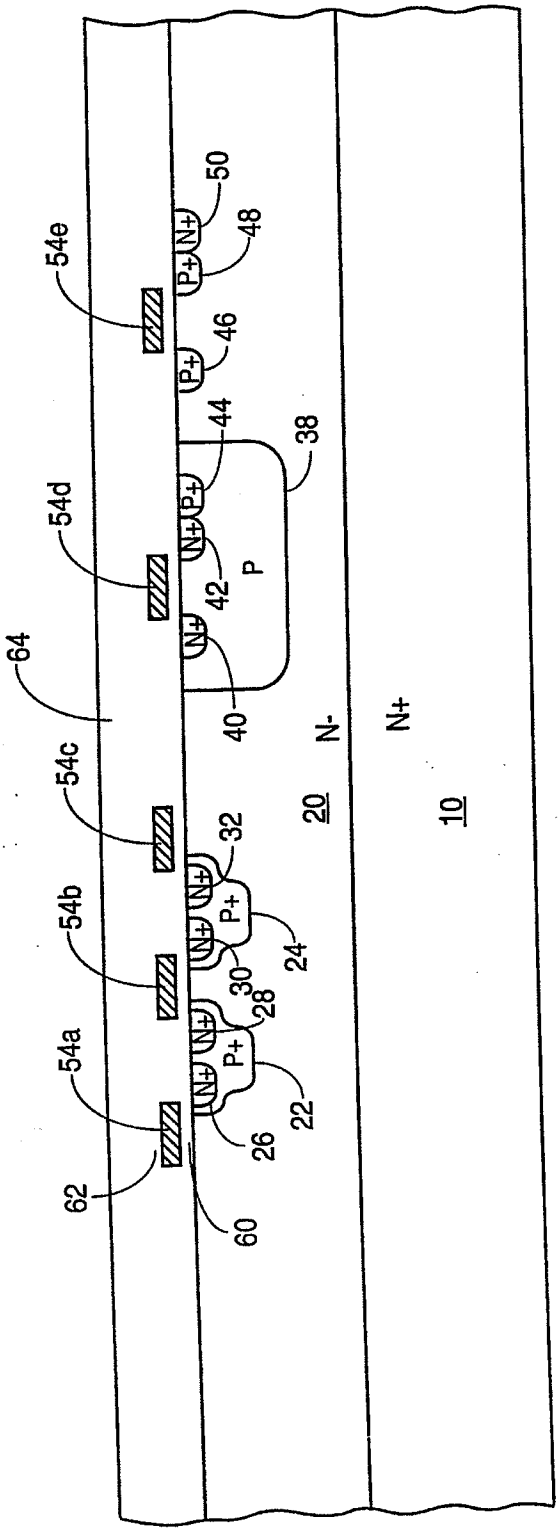

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Fig. 1

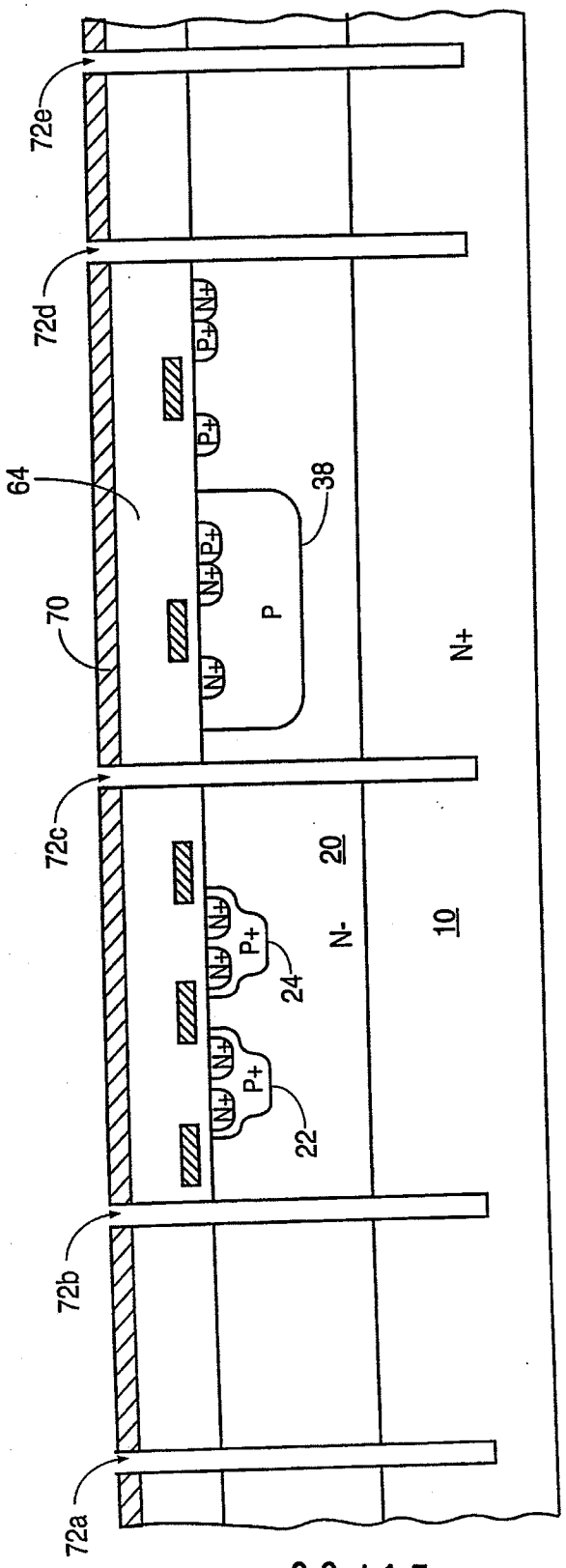


Fig. 2

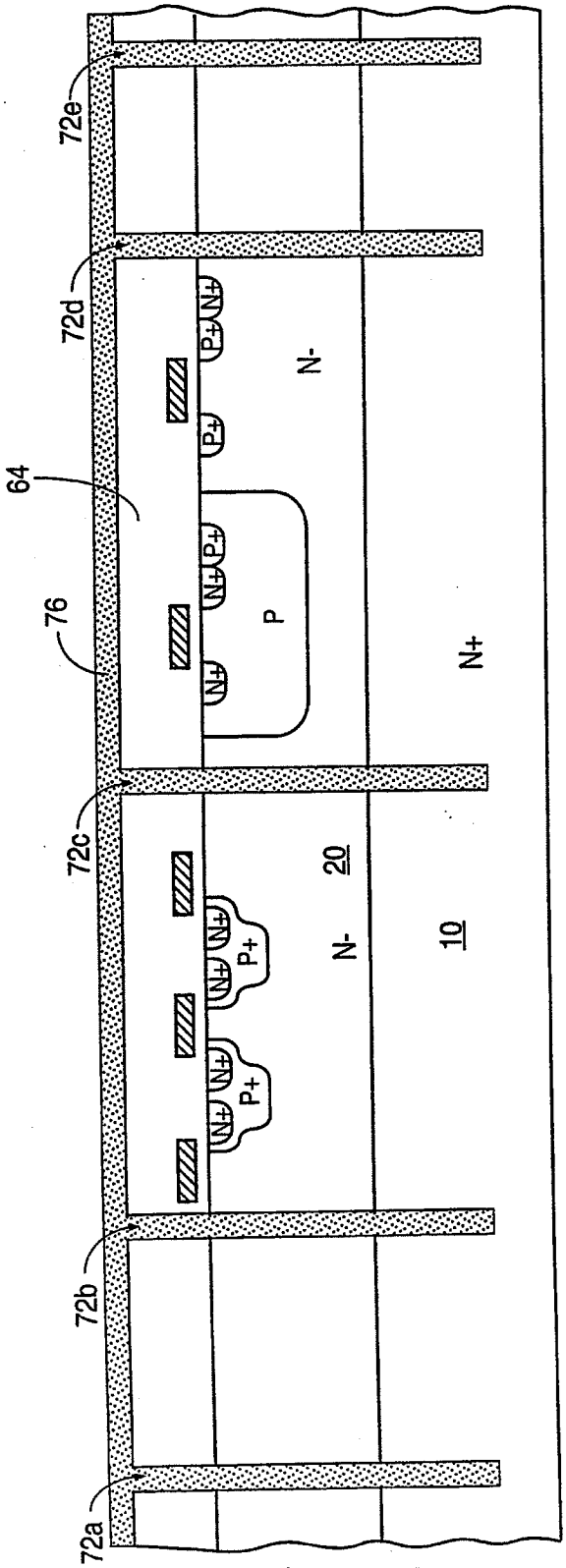


Fig. 3

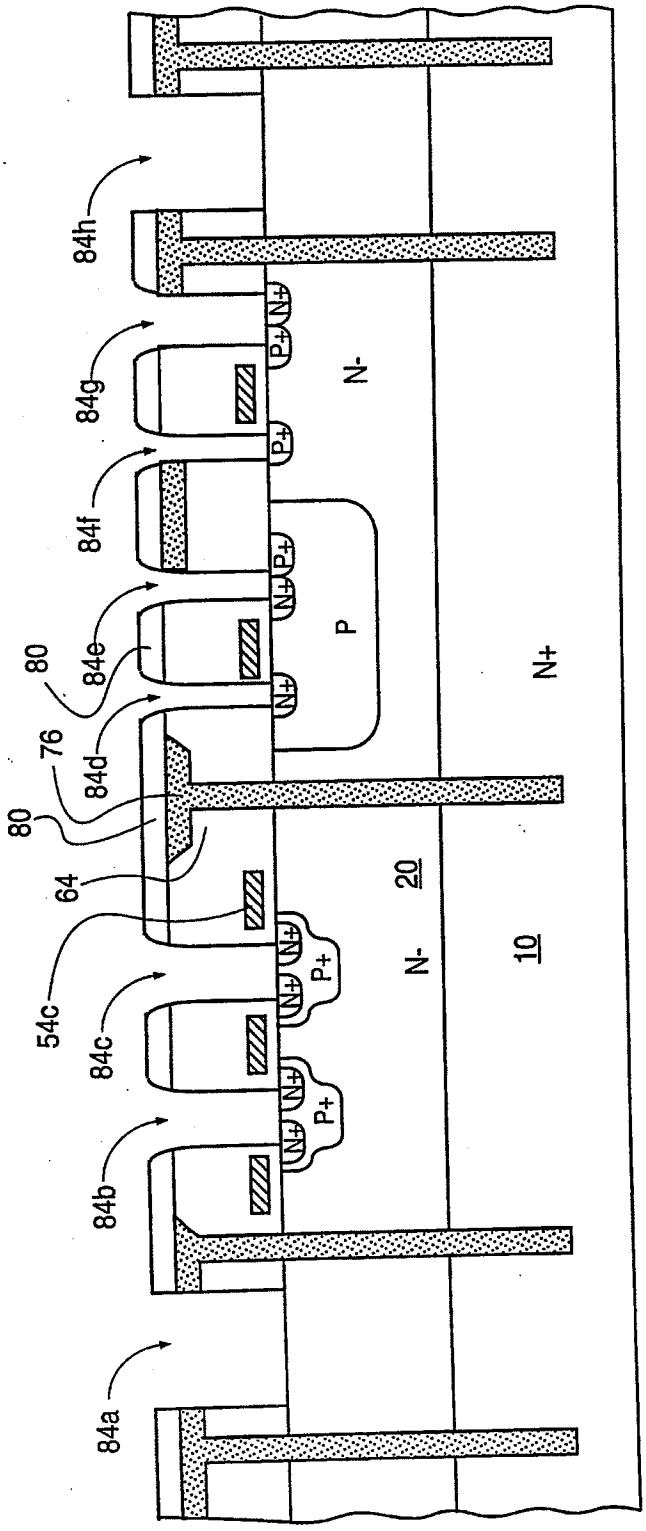


Fig. 4

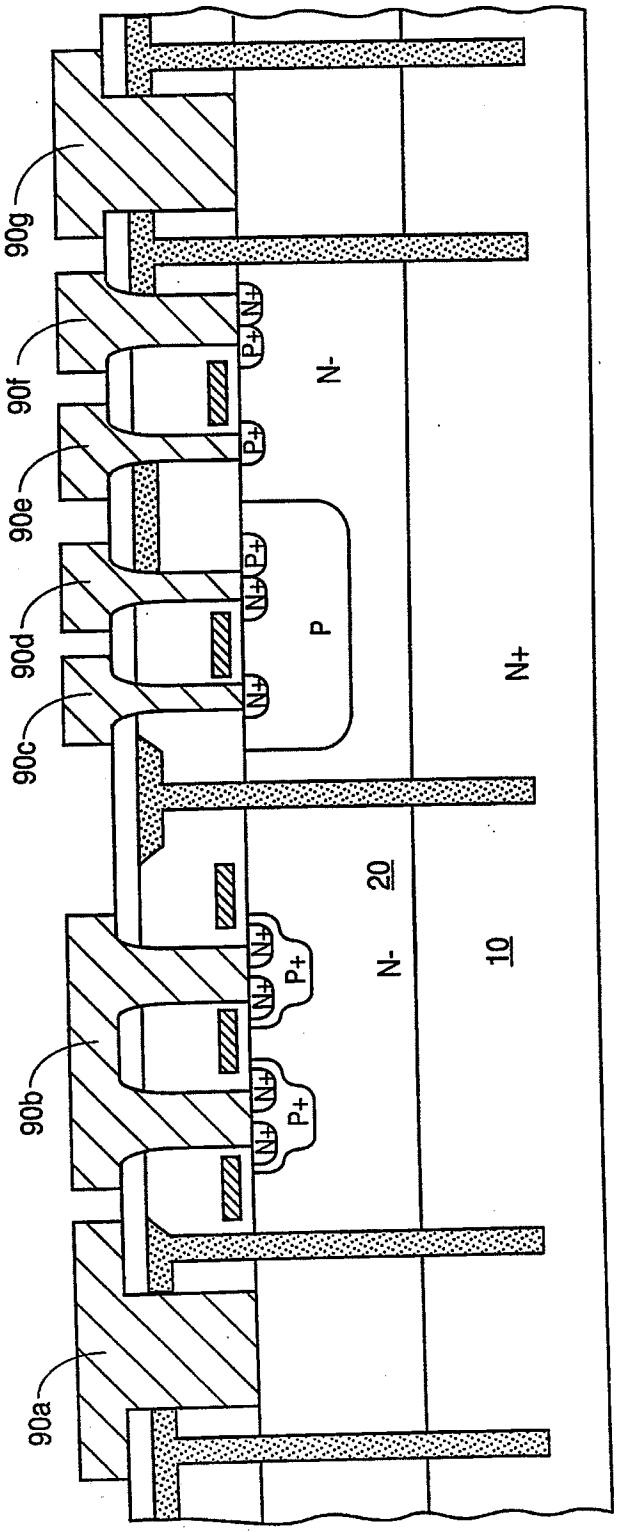


Fig. 5

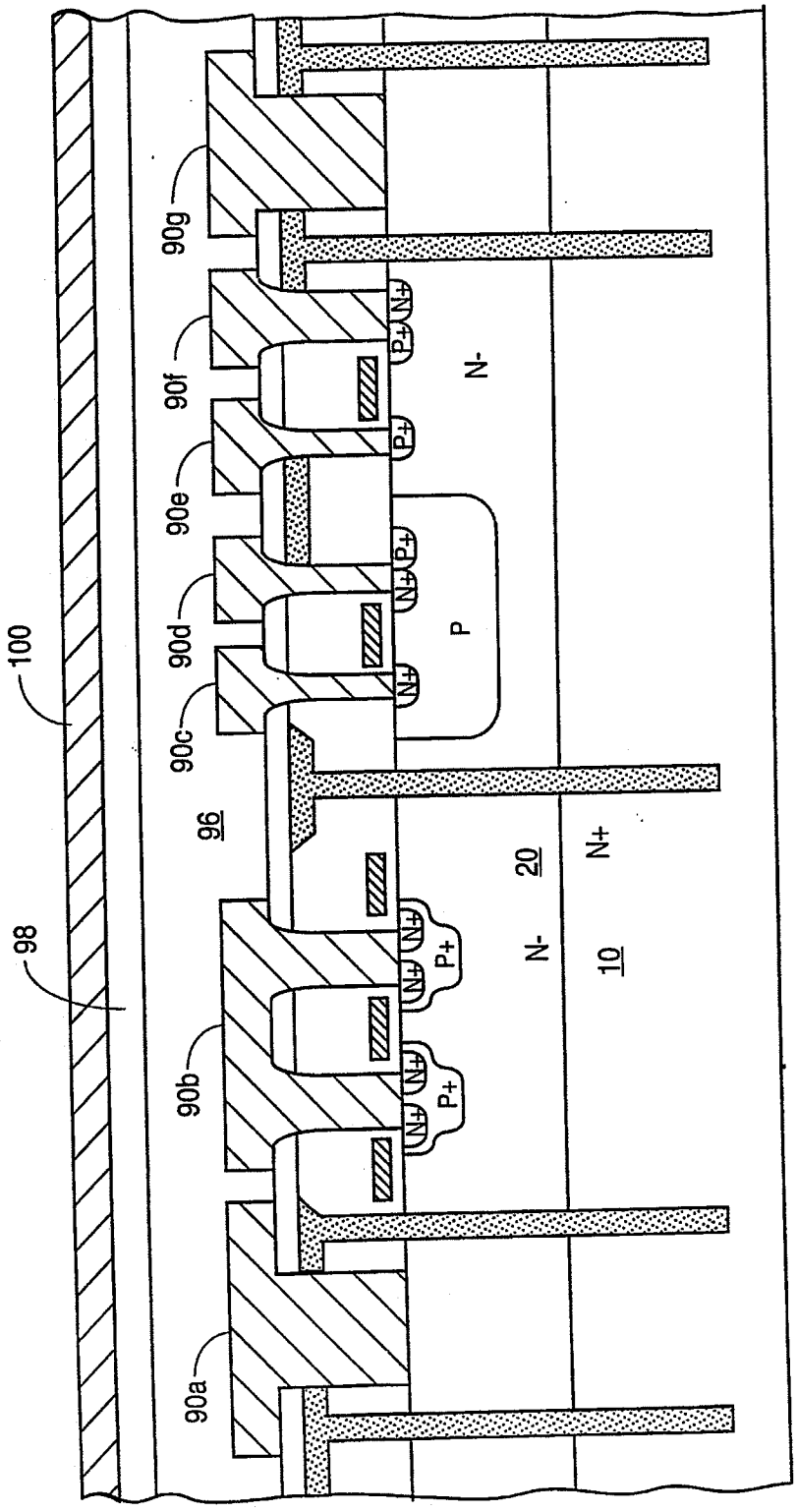


Fig. 6

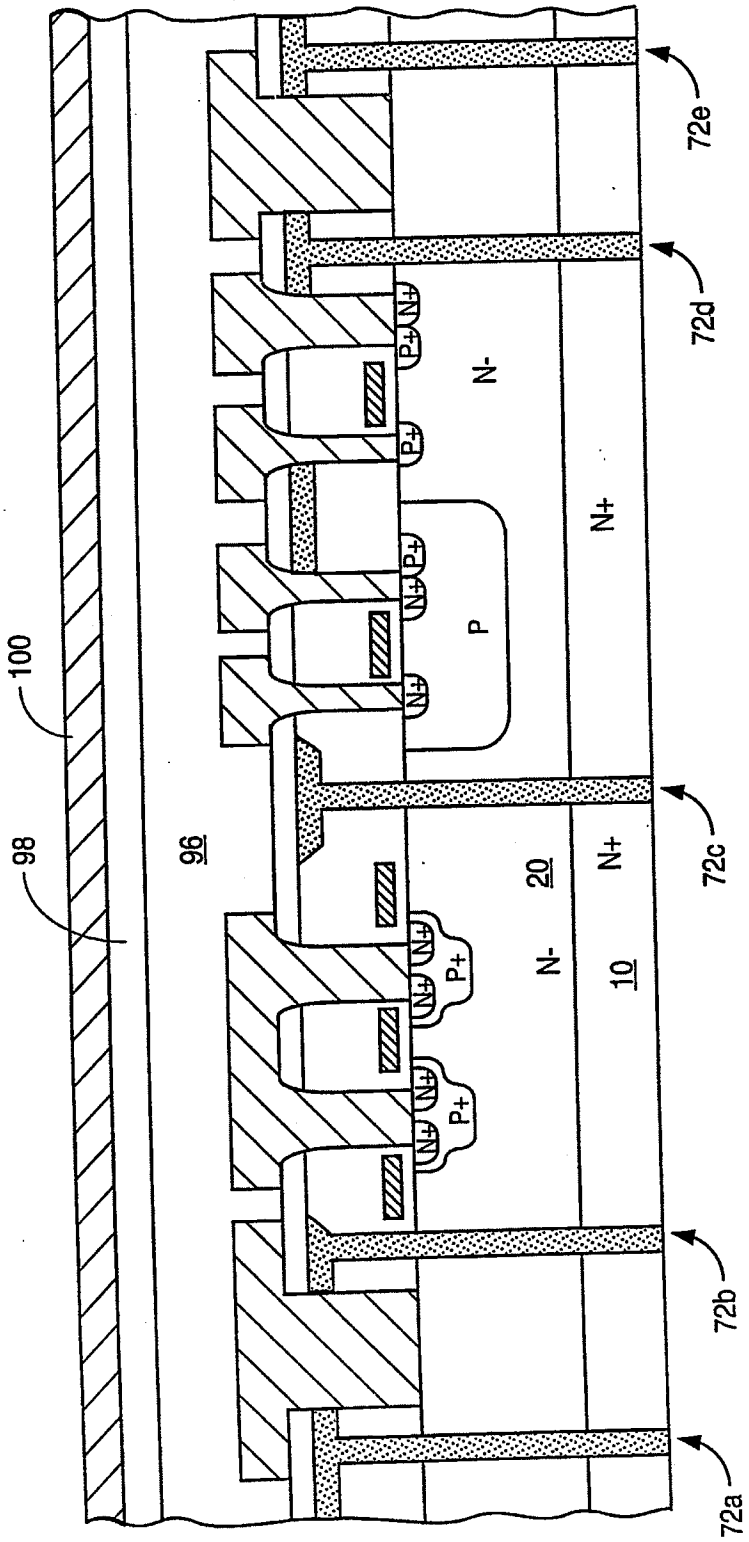


Fig. 7

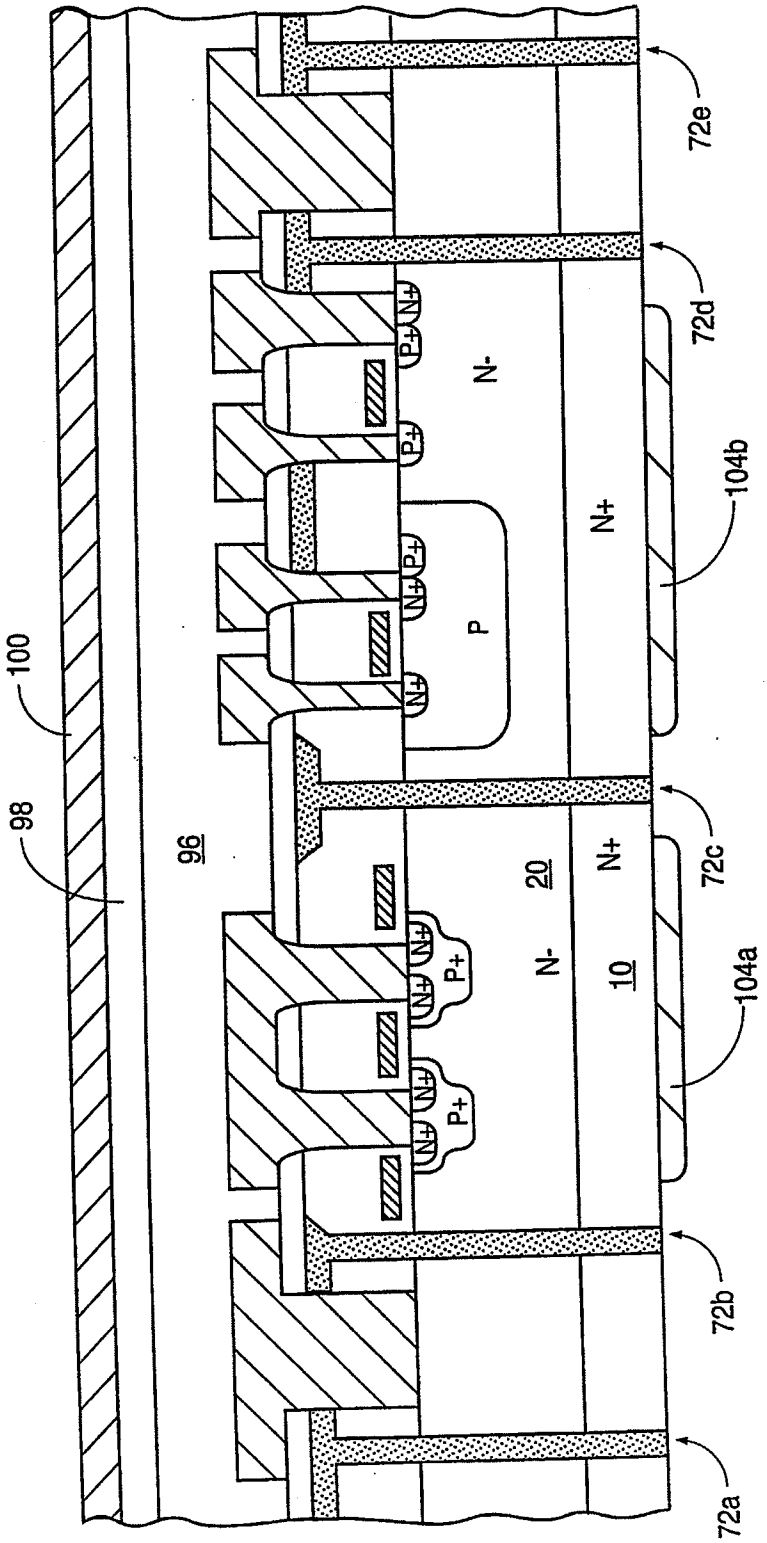


Fig. 8

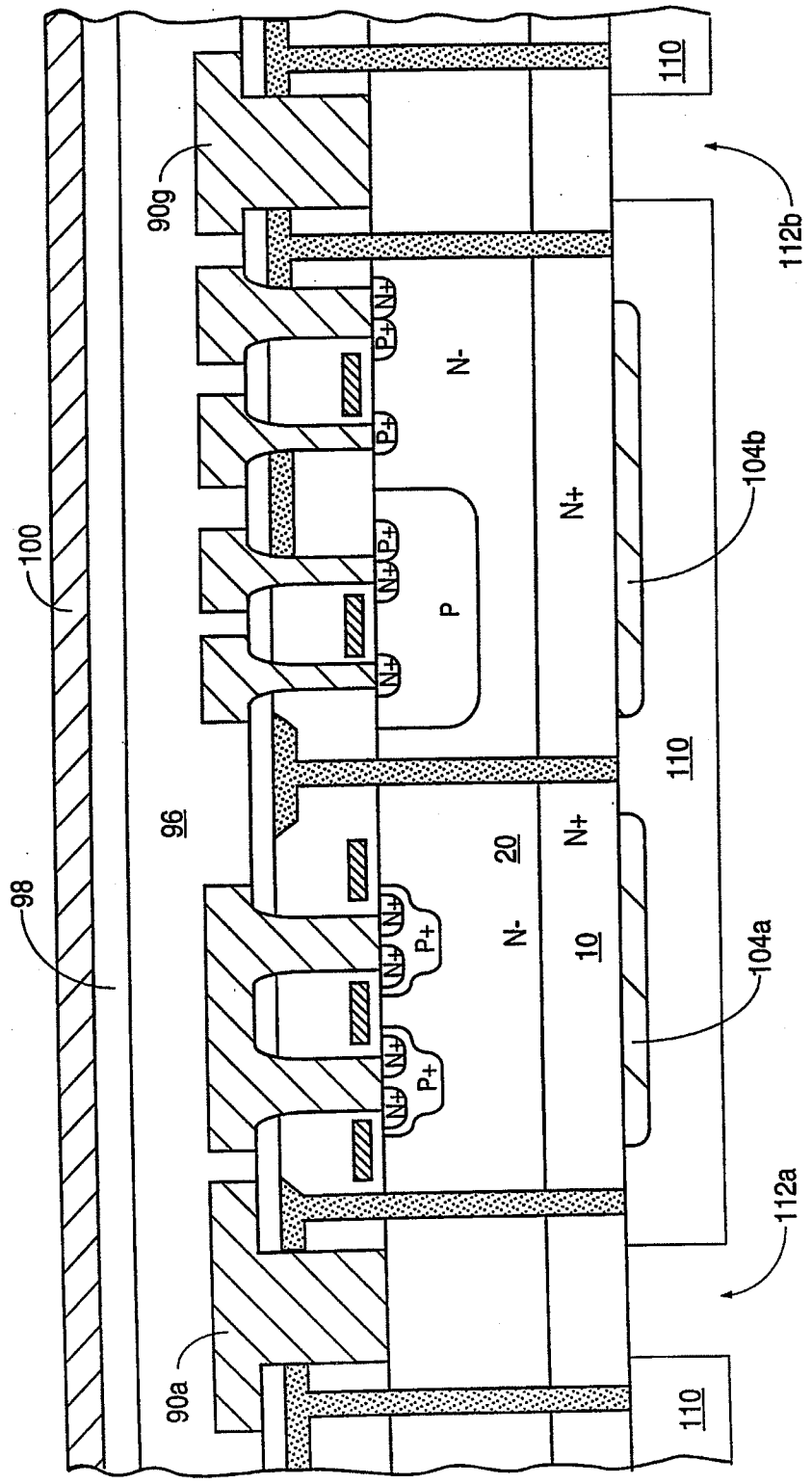

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P+
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P
N+
N+
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P+
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N+
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N+
P+
N+
112a
90a
110

Fig. 9

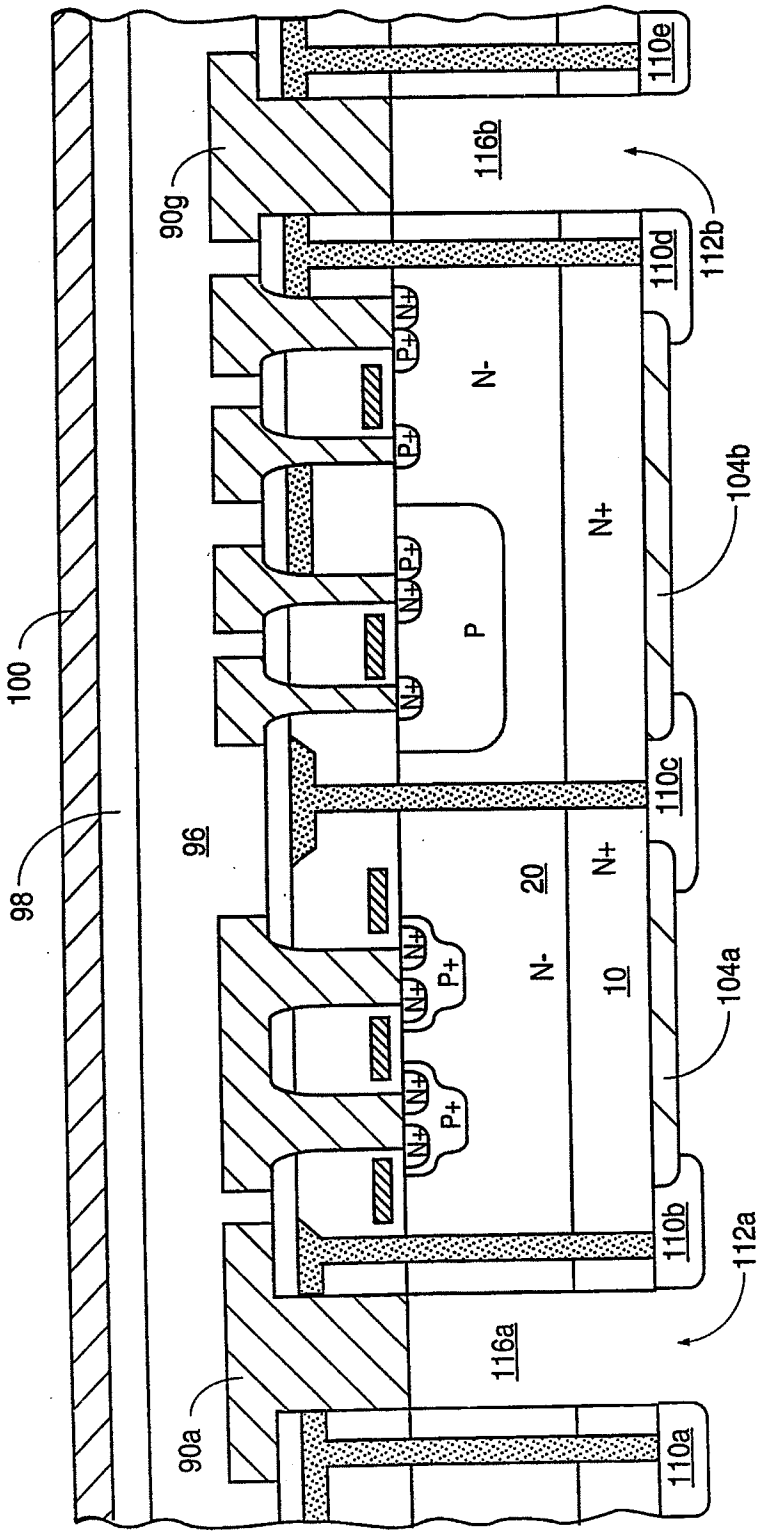

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90a
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Fig. 10

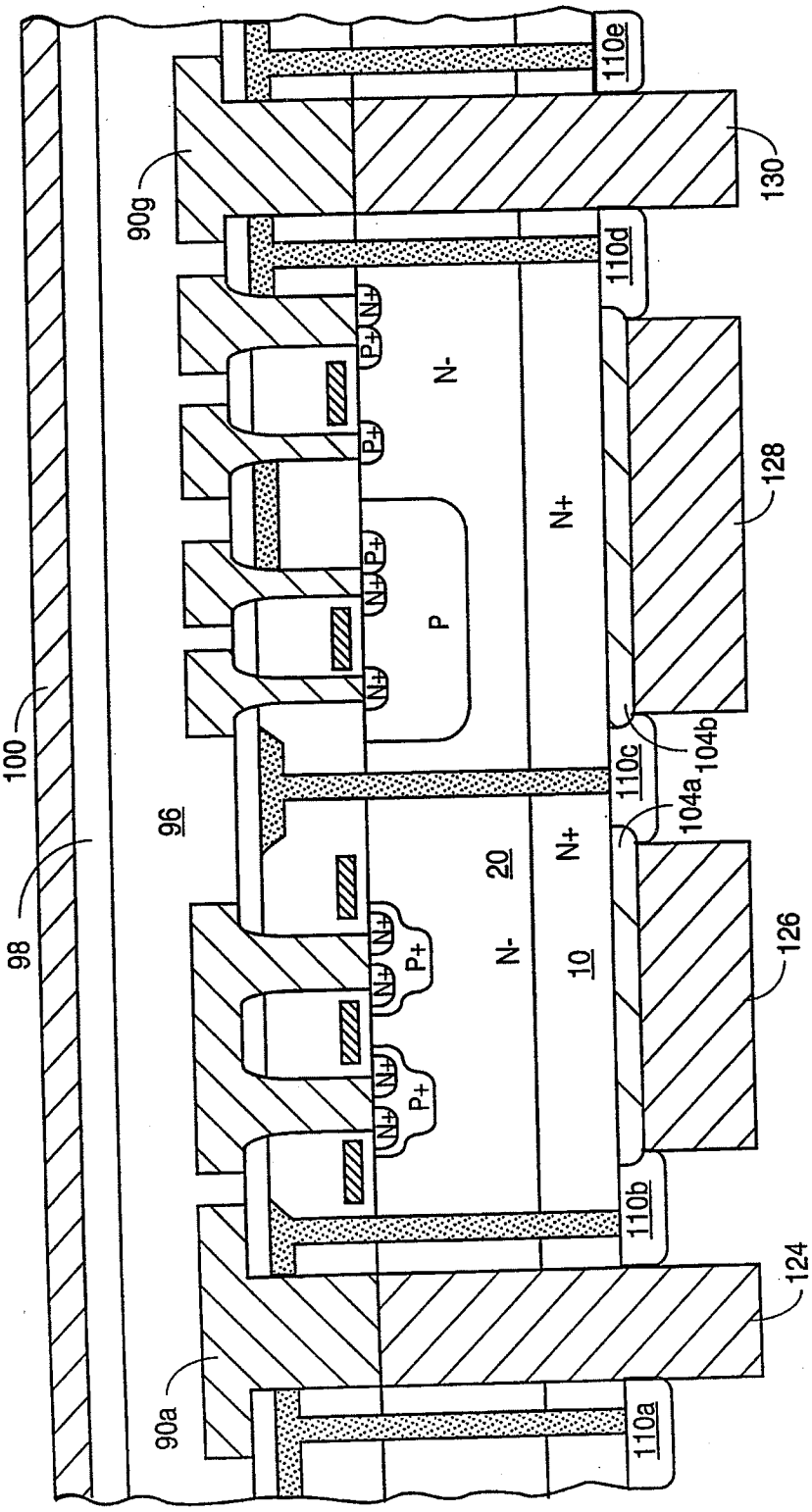

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124
90a
110a

Fig. 11

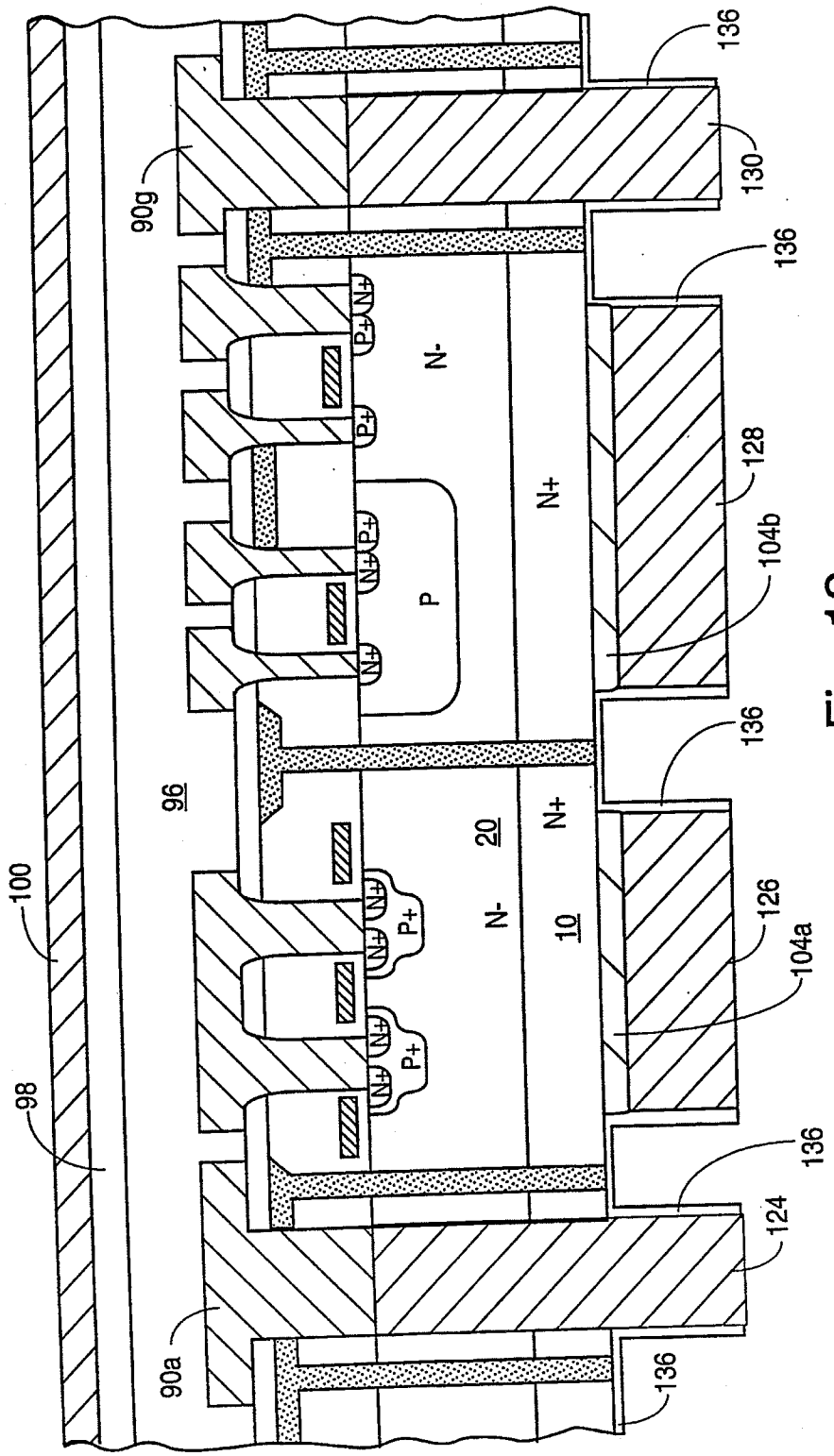

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Fig. 12

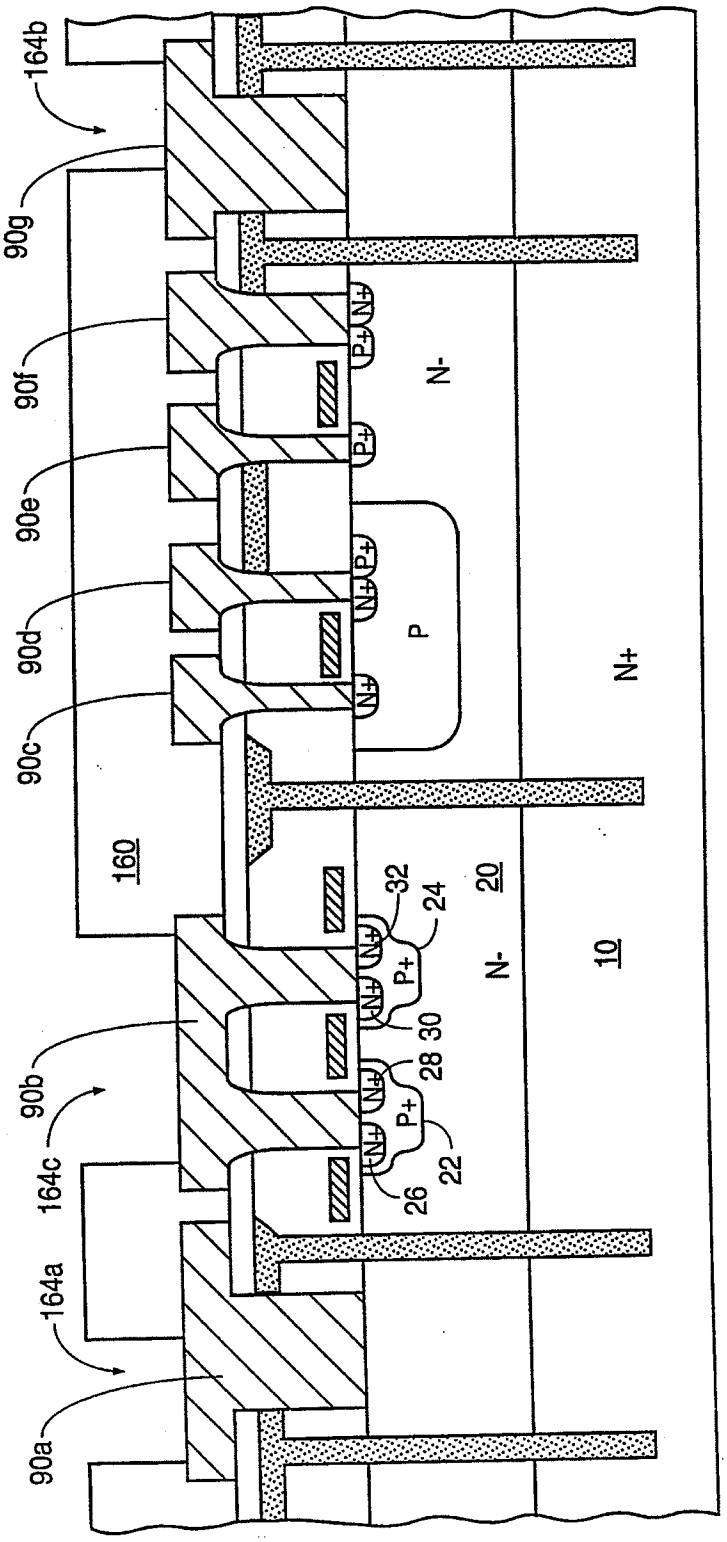

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90d
90c
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164c
164a
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Fig. 13

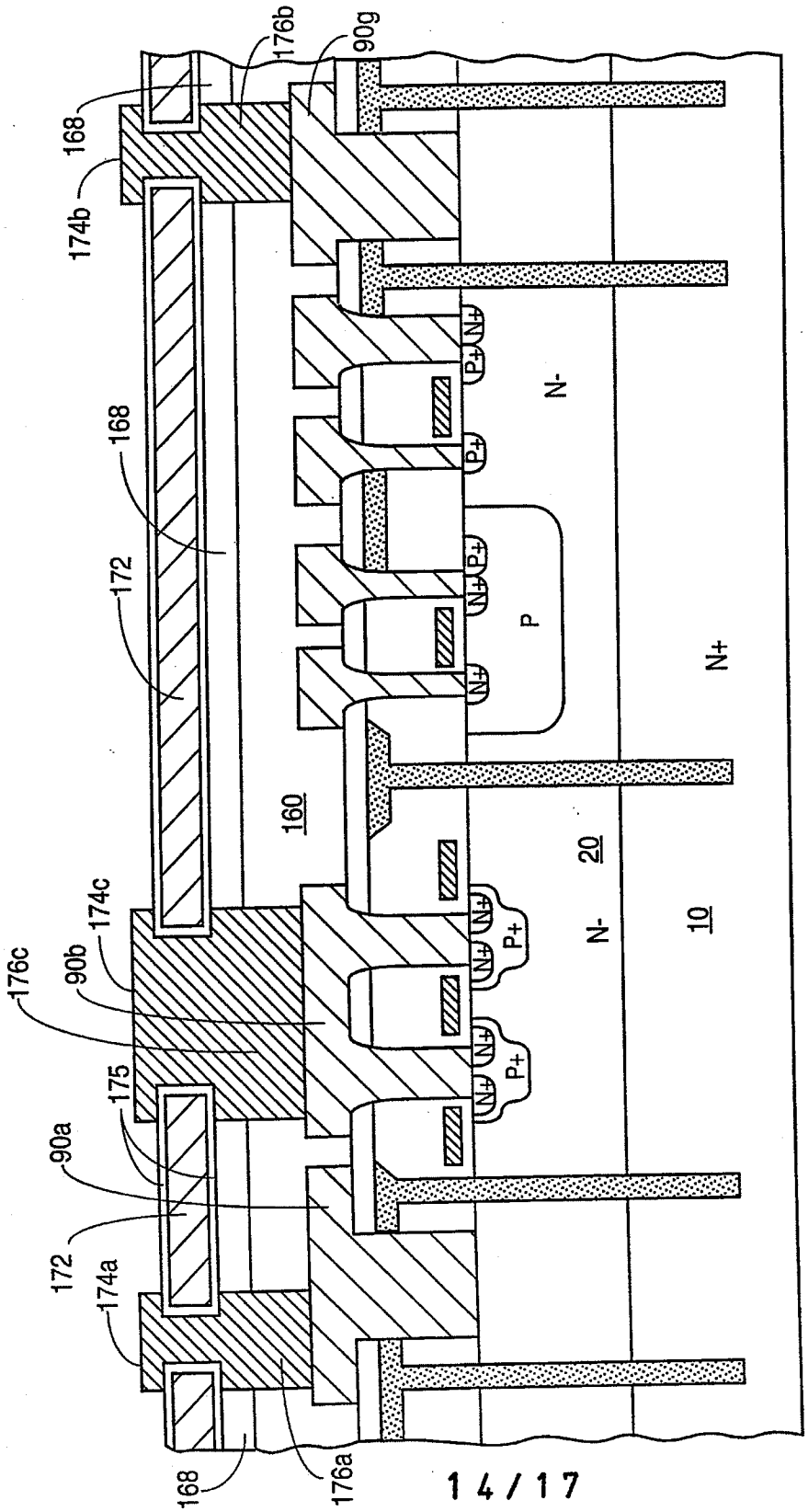

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174b
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174c
176c
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P+
N+
N-
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Fig. 14

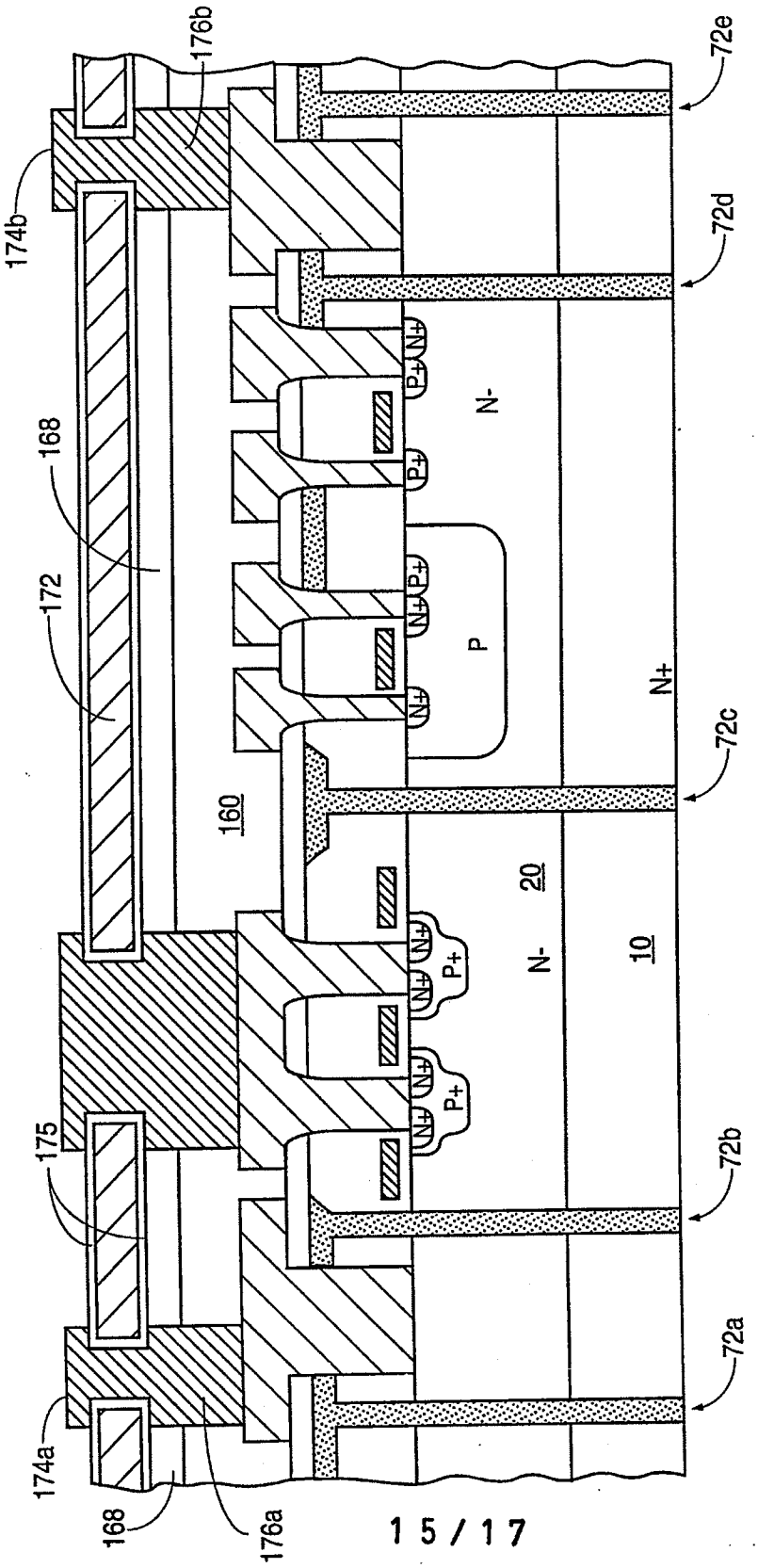

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Fig. 15

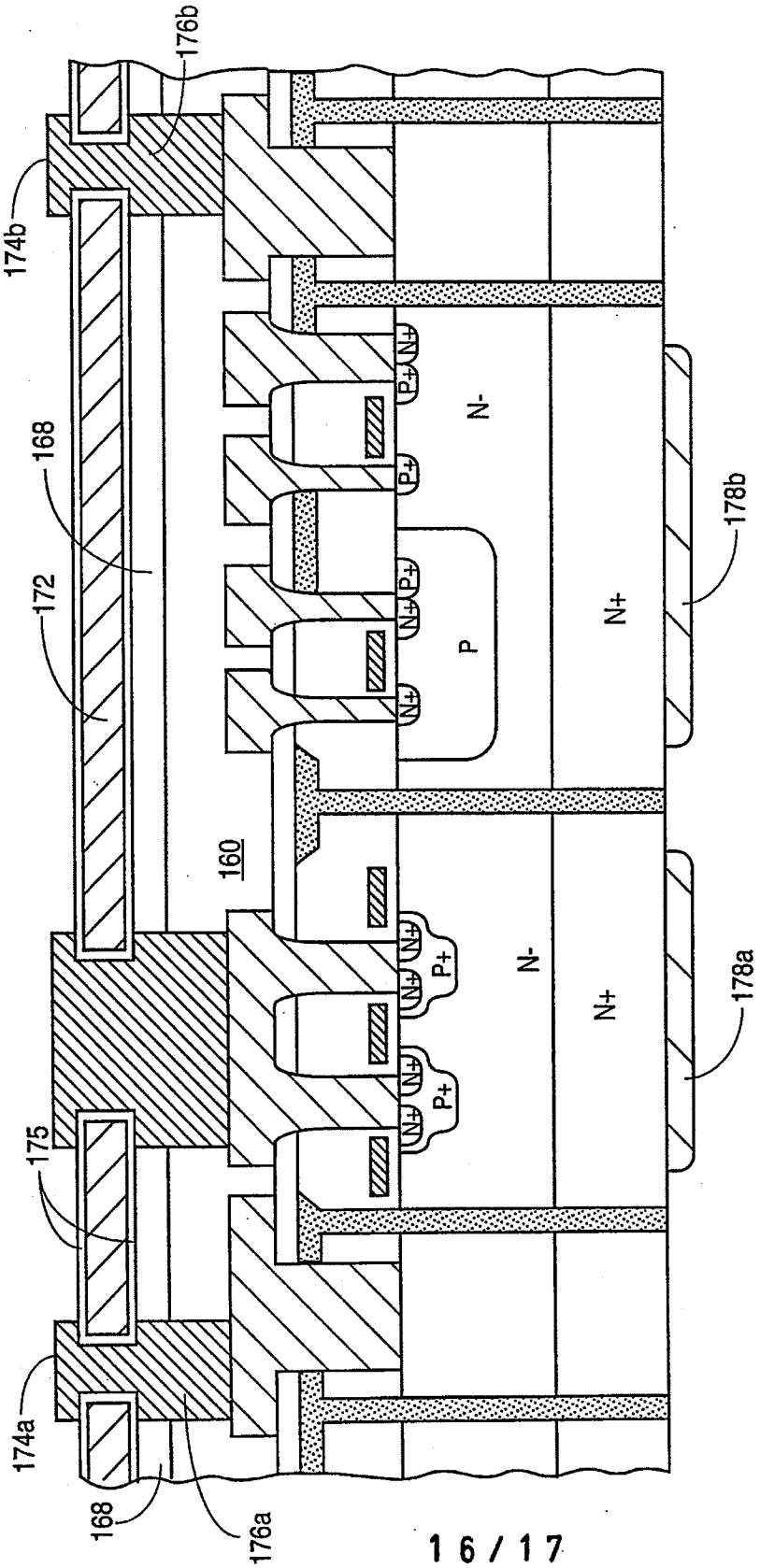


Fig. 16

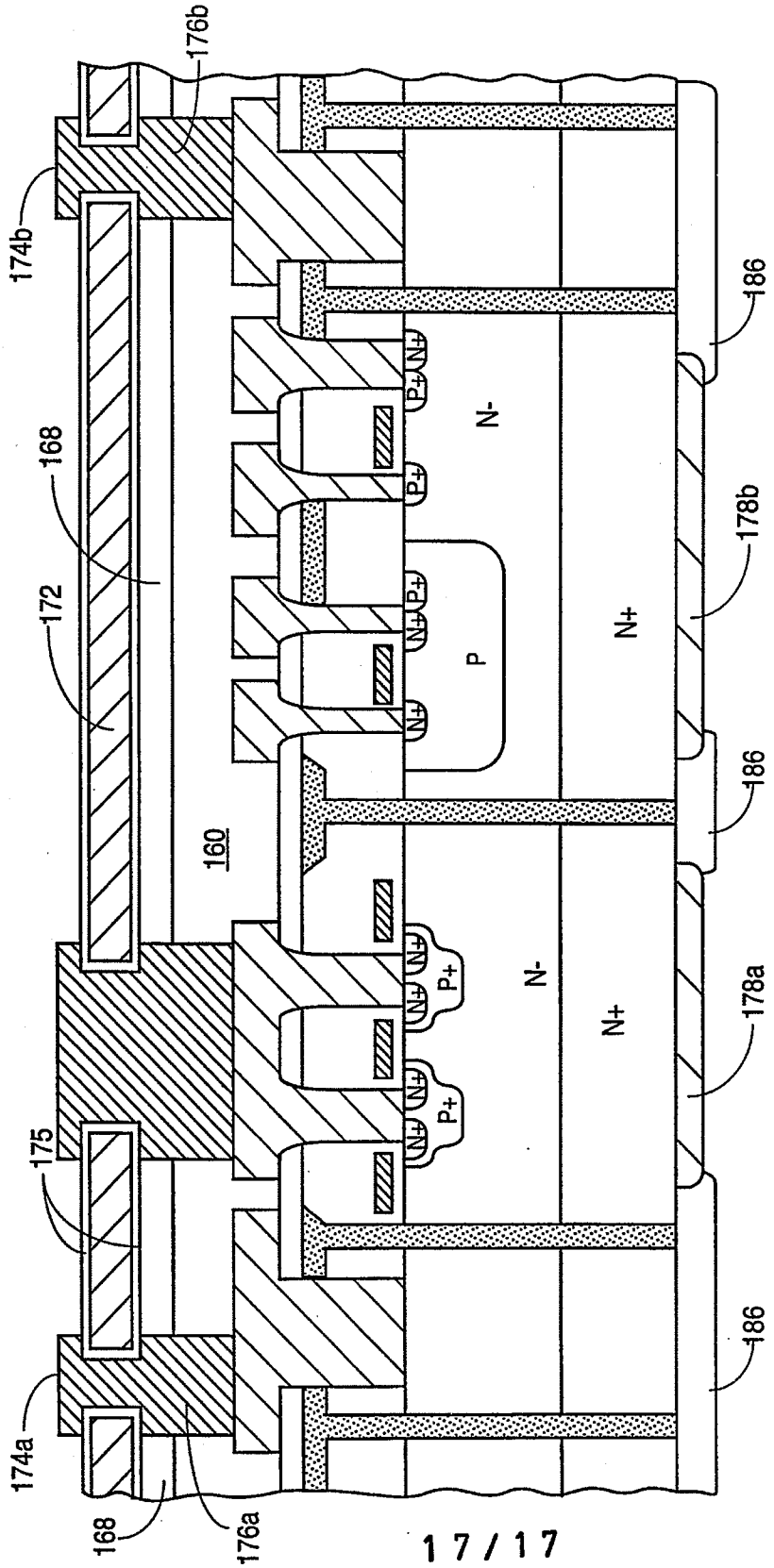


Fig. 17

INTERNATIONAL SEARCH REPORT

Int. ..national application No.
PCT/US95/05217

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H01L 23/48, 21/76
US CL :257/631,686,706,724; 437/62,63
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 257/631,686,706,724; 437/62,63

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USAPS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y, E	US,A 5,426,072 (FINNILA) 20 JUNE 1995, SEE FIGURE 6.	3,5,6, 11,14,15
Y	US,A 5,272,104 (SCHRANTZ ET AL.) 21 DECEMBER 1993, SEE FIGURE 1F.	1-16
Y	US,A 5,229,643 (OHTA ET AL.) 20 JULY 1993, SEE FIGURE 6,30,31.	1-16
Y	US,A 5,170,930 (DOLBEAR ET AL.) 15 DECEMBER 1992, SEE FIGURE 4.	8,13
Y	US,A 5,091,331 (DELGADO ET AL.) 25 FEBRUARY 1992, SEE FIGURE 1E,6,7.	1-16
Y	4,972,250 (OMORI ET AL.) 20 NOVEMBER 1990, SEE WHOLE DOCUMENT	1-16

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search	Date of mailing of the international search report
07 JULY 1995	19 JUL 1995
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer J. CARROLL Telephone No. (703) 308-4926

Form PCT/ISA/210 (second sheet)(July 1992)*

WO2009043058

Publication Title:

CMP PAD CONDITIONERS WITH MOSAIC ABRASIVE SEGMENTS AND ASSOCIATED METHODS

Abstract:

Abstract of WO 2009043058

(A2) A CMP pad conditioner comprises a plurality of abrasive segments. Each abrasive segment includes a segment blank and an abrasive layer attached to the segment blank, the abrasive layer including a superhard abrasive material, A pad conditioner substrate is also provided. Each of the plurality of abrasive segments is permanently affixed to the pad conditioner substrate in an orientation that enables removal of material from a CMP pad by the abrasive layer as the pad conditioner and the CMP pad are moved relative to one another.

Courtesy of http://v3.espacenet.com

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(21) International Application Number:
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29 September 2008 (29.09.2008)

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60/988,643	16 November 2007 (16.11.2007)	US
60/992,966	6 December 2007 (06.12.2007)	US
12/168,110	5 July 2008 (05.07.2008)	US

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(72) Inventors: **SUNG, Chien-min** [US/—]; 4, Lane 32, Chung-cheng Road, Tansui, Taipei County 251 (TW). **SUNG, Michael** [US/US]; 351 King Street, #813, San Francisco, CA 94158 (US).

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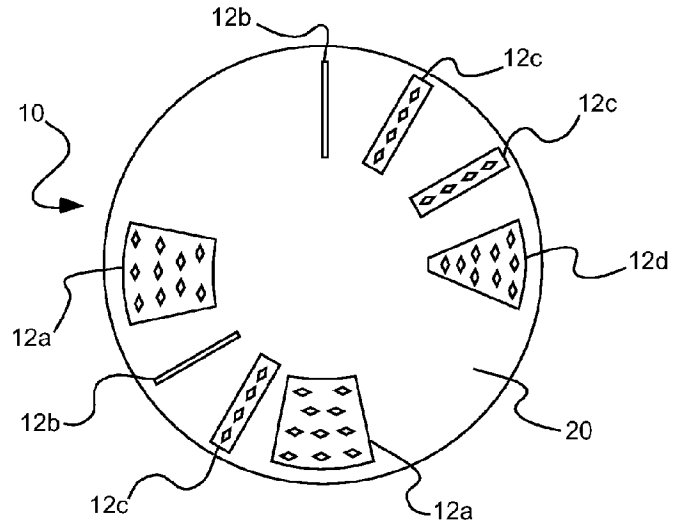


FIG. 1

(57) Abstract: A CMP pad conditioner comprises a plurality of abrasive segments. Each abrasive segment includes a segment blank and an abrasive layer attached to the segment blank, the abrasive layer including a superhard abrasive material, A pad conditioner substrate is also provided. Each of the plurality of abrasive segments is permanently affixed to the pad conditioner substrate in an orientation that enables removal of material from a CMP pad by the abrasive layer as the pad conditioner and the CMP pad are moved relative to one another.

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CMP PAD CONDITIONERS WITH MOSAIC ABRASIVE SEGMENTS AND ASSOCIATED METHODS

PRIORITY CLAIM:

This application claims the benefit of U.S. Provisional Patent Application Serial No. 60/976,198, filed September 28, 2007 and U.S. Non-Provisional Patent Application Serial No. 12/168,110, filed July 5, 2008, each of which are hereby incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates generally to CMP pad conditioners used to remove material from (e.g., smooth, polish, dress, etc.) CMP pads. Accordingly, the present invention involves the fields of chemistry, physics, and materials science.

BACKGROUND OF THE INVENTION

The semiconductor industry currently spends in excess of one billion U.S. Dollars each year manufacturing silicon wafers that must exhibit very flat and smooth surfaces. Known techniques to manufacture smooth and even-surfaced silicon wafers are plentiful. The most common of these involves the process known as Chemical Mechanical Polishing (CMP) which includes the use of a polishing pad in combination with an abrasive slurry. Of central importance in all CMP processes is the attainment of high performance levels in aspects such as uniformity of polished wafer, smoothness of the IC circuitry, removal rate for productivity, longevity of consumables for CMP economics, etc.

SUMMARY OF THE INVENTION

In accordance with one embodiment, the present invention provides a CMP pad conditioner, including a plurality of abrasive segments. Each abrasive segment can include a segment blank and an abrasive layer attached to the segment blank. The abrasive layer can include a superhard abrasive material. A pad conditioner substrate is also provided and each of the plurality of abrasive segments can be permanently affixed to the pad conditioner substrate in an orientation that enables removal of

material from a CMP pad by the abrasive layer as the pad conditioner and the CMP pad are moved relative to one another.

In accordance with another aspect of the invention, a CMP pad conditioner is provided, including a plurality of abrasive segments. Each abrasive segment can include a segment blank, an organic adhesive layer, and an abrasive layer attached to the segment blank by the organic adhesive layer. The abrasive layer can include a superhard abrasive material. A pad conditioner substrate is also provided, with each of the plurality of abrasive segments being permanently affixed to the pad conditioner substrate in an orientation that enables removal of material from a CMP pad by the abrasive layer as the pad conditioner and the CMP pad are moved relative to one another.

In accordance with another aspect of the invention, a CMP pad conditioner is provided, including a plurality of abrasive segments. Each abrasive segment can include a segment blank and an abrasive layer attached to the segment blank by a brazing alloy. The abrasive layer can include a superhard abrasive material. A pad conditioner substrate is also provided, with each of the plurality of abrasive segments being permanently affixed to the pad conditioner substrate in an orientation that enables removal of material from a CMP pad by the abrasive layer as the pad conditioner and the CMP pad are moved relative to one another.

In accordance with another aspect of the invention, a CMP pad conditioner is provided, including a plurality of abrasive segments. Each abrasive segment can include a segment blank and an abrasive layer attached to the segment blank. The abrasive layer can include a superhard abrasive blade. A pad conditioner substrate is also provided, with each of the plurality of abrasive segments being permanently affixed to the pad conditioner substrate in an orientation that enables removal of material from a CMP pad by the abrasive layer as the pad conditioner and the CMP pad are moved relative to one another.

In accordance with another aspect of the invention, a CMP pad conditioner is provided, including a plurality of abrasive segments. Each abrasive segment can include a segment blank and an abrasive layer attached to the segment blank. The abrasive layer can include a cutting face angled at 90 degrees or less relative to a

finished surface to be applied to the CMP pad. A pad conditioner substrate is also provided, with each of the plurality of abrasive segments being permanently affixed to the pad conditioner substrate in an orientation that enables removal of material from a CMP pad by the abrasive layer as the pad conditioner and the CMP pad are moved relative to one another.

In accordance with another aspect of the invention, a method of forming a CMP pad conditioner is provided, including: obtaining at least one abrasive segment, the abrasive segment including: a segment blank; and an abrasive layer attached to the segment blank, the abrasive layer including a superhard abrasive material. The method can include positioning the at least one abrasive segment on a face of a pad conditioner substrate in an orientation that enables removal of material from a CMP pad by the abrasive layer as the pad conditioner and the CMP pad are moved relative to one another; and permanently affixing the at least one abrasive segment to the pad conditioner substrate.

There has thus been outlined, rather broadly, various features of the invention so that the detailed description thereof that follows may be better understood, and so that the present contribution to the art may be better appreciated. Other features of the present invention will become clearer from the following detailed description of the invention, taken with any accompanying or following claims, or may be learned by the practice of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic, top plan view of an exemplary pad conditioner in accordance with an embodiment of the invention;

FIG. 1A is an enlarged, perspective schematic view of an exemplary abrasive segment that can be used in the pad conditioner of FIG. 1;

FIG. 1B is an end, schematic view of the abrasive segment of FIG. 1A, shown with one exemplary abrasive profile;

FIG. 1C is an end, schematic view of the abrasive segment of FIG. 1A, shown with another exemplary abrasive profile;

FIG. 2 is a schematic, top plan view of another pad conditioner in accordance with an embodiment of the invention;

FIG. 2A is an enlarged, perspective schematic view of an abrasive segment of the pad conditioner of FIG. 2;

FIG. 3A is a side, schematic view of an abrasive segment having a cutting face shown removing material from a section of a CMP pad;

FIG. 3B is a side, schematic view of an abrasive segment having a differently configured cutting face shown removing material from a section of a CMP pad;

FIG. 3C is a side, schematic view of an abrasive segment having a differently configured cutting face shown removing material from a section of a CMP pad;

FIG. 4A is a schematic, perspective view of an abrasive segment formed in a blade configuration in accordance with an embodiment of the invention;

FIG. 4B is a schematic, perspective view of another abrasive segment formed in a blade configuration in accordance with an embodiment of the invention; and

FIG. 5 is a schematic, side view of a portion of a CMP pad dresser having a series of abrasive segments arranged at varying elevations relative to one another.

It will be understood that the above figures are merely for illustrative purposes in furthering an understanding of the invention. Further, the figures may not be drawn to scale, thus dimensions, particle sizes, and other aspects may, and generally are, exaggerated to make illustrations thereof clearer. For example, an abrasive layer is illustrated in some of the figures as including a plurality of abrasive particles: however, many of the specific embodiments disclosed herein do not necessarily include abrasive particles. Therefore, it will be appreciated that departure can and likely will be made from the specific dimensions and aspects shown in the figures in order to produce the pad conditioners of the present invention.

DETAILED DESCRIPTION

Before the present invention is disclosed and described, it is to be understood that this invention is not limited to the particular structures, process steps, or materials disclosed herein, but is extended to equivalents thereof as would be recognized by those ordinarily skilled in the relevant arts. It should also be understood that

terminology employed herein is used for the purpose of describing particular embodiments only and is not intended to be limiting.

It must be noted that, as used in this specification and any appended or following claims, the singular forms "a," "an" and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "an abrasive segment" can include one or more of such segments.

Definitions

In describing and claiming the present invention, the following terminology will be used in accordance with the definitions set forth below.

All mesh sizes that may be referred to herein are U.S. mesh sizes unless otherwise indicated. Further, mesh sizes are generally understood to indicate an average mesh size of a given collection of particles since each particle within a particular "mesh size" may actually vary over a small distribution of sizes.

As used herein, the term "substantially" refers to the complete or nearly complete extent or degree of an action, characteristic, property, state, structure, item, or result. As an arbitrary example, when two or more objects are referred to as being spaced a "substantially" constant distance from one another, it is understood that the two or more objects are spaced a completely unchanging distance from one another, or so nearly an unchanging distance from one another that a typical person would be unable to appreciate the difference. The exact allowable degree of deviation from absolute completeness may in some cases depend upon the specific context. However, generally speaking the nearness of completion will be so as to have the same overall result as if absolute and total completion were obtained.

The use of "substantially" is equally applicable when used in a negative connotation to refer to the complete or near complete lack of an action, characteristic, property, state, structure, item, or result. As an arbitrary example, a cavity that is "substantially free of" foreign matter would either completely lack any foreign matter, or so nearly completely lack foreign matter that the effect would be the same as if it completely lacked foreign matter. In other words, a cavity that is "substantially free of" foreign matter may still actually contain minute portions of

foreign matter so long as there is no measurable effect upon the cavity as a result thereof.

As used herein, a pad conditioner "substrate" means a portion of a pad conditioner that supports abrasive materials, and to which abrasive materials and/or segment blanks that carry abrasive materials may be affixed. Substrates useful in the present invention may of a variety of shapes, thicknesses, or materials that are capable of supporting abrasive materials in a manner that is sufficient to provide a pad conditioner useful for its intended purpose. Substrates may be of a solid material, a powdered material that becomes solid when processed, or a flexible material. Examples of typical substrate materials include without limitation, metals, metal alloys, ceramics, relatively hard polymers or other organic materials, glasses, and mixtures thereof. Further, the substrate may include a material that aids in attaching abrasive materials to the substrate, including, without limitation, brazing alloy material, sintering aids and the like.

As used herein, "segment blank" refers to a structure similar in many respects to the pad conditioner substrates defined above. Segment blanks are utilized in the present invention to carry abrasive layers: attachment of the abrasive layers to the pad conditioner substrates is typically achieved by way of attaching the segment blanks to the pad conditioner substrates. It is important to note that a variety of manners of attaching the segment blanks to the substrates, and a variety of manners of attaching the abrasive layers to the segment blanks, are discussed herein. It is to be understood that all of these various attachment mechanisms can be used interchangeably herein: that is, if a method of attaching a segment blank to a substrate is discussed herein, the method of attachment discussed can also be used to attach an abrasive layer to a segment blank. For any particular CMP pad dresser being discussed, however, it is understood that attachment methods of the abrasive layers to the segment blanks can differ from, or can be the same as, the method used to attach the segment blanks to the pad conditioner substrate.

As used herein, "geometric configuration" refers to a shape that is capable of being described in readily understood and recognized mathematical terms. Examples of shapes qualifying as "geometric configurations" include, without limitation, cubic

shapes, polyhedral (including regular polyhedral) shapes, triangular shapes (including equilateral triangles, isosceles triangles and three-dimensional triangular shapes), pyramidal shapes, spheres, rectangles, "pie" shapes, wedge shapes, octagonal shapes, circles, etc.

As used herein, "vapor deposition" refers to a process of depositing materials on a substrate through the vapor phase. Vapor deposition processes can include any process such as, but not limited to, chemical vapor deposition (CVD) and physical vapor deposition (PVD). A wide variety of variations of each vapor deposition method can be performed by those skilled in the art. Examples of vapor deposition methods include hot filament CVD, rf-CVD, laser CVD (LCVD), metal-organic CVD (MOCVD), sputtering, thermal evaporation PVD, ionized metal PVD (IMPVD), electron beam PVD (EBPVD), reactive PVD, and the like.

As used herein, "abrasive profile" is to be understood to refer to a shape, configuration, or a space defined by abrasive materials that can be used to remove material from a CMP pad. Examples of abrasive profiles include, without limitation, rectangular shapes, tapering rectangular shapes, truncated wedge shapes, wedge shapes, a "saw tooth" profile and the like. In some embodiments, the abrasive profile exhibited by abrasive segments of the present invention will apparent when viewed through a plane in which the CMP pad will be oriented during removal of material from the CMP pad.

As used herein, an "abrading surface or point" may be used to refer to a surface, edge, face, point or peak of an abrasive segment that contacts and removes material from a CMP pad. Generally speaking, the abrading surface or point is the portion of the abrasive segment that first contacts the CMP pad as the abrasive segment and the CMP pad are brought into contact with one another.

As used herein, "superhard" may be used to refer to any crystalline, or polycrystalline material, or mixture of such materials which has a Mohr's hardness of about 8 or greater. In some aspects, the Mohr's hardness may be about 9.5 or greater. Such materials include but are not limited to diamond, polycrystalline diamond (PCD), cubic boron nitride (cBN), polycrystalline cubic boron nitride (PcBN), corundum and sapphire, as well as other superhard materials known to those skilled in

the art. Superhard materials may be incorporated into the present invention in a variety of forms including particles, grits, films, layers, pieces, segments, etc. In some cases, the superhard materials of the present invention are in the form of polycrystalline superhard materials, such as PCD and PcBN materials.

As used herein, "organic material" refers to a semisolid or solid complex or mix of organic compounds. As such, "organic material layer" and "organic material matrix" may be used interchangeably, refer to a layer or mass of a semisolid or solid complex amorphous mix of organic compounds, including resins, polymers, gums, etc. Preferably the organic material will be a polymer or copolymer formed from the polymerization of one or more monomers. In some cases, such organic material may be adhesive.

As used herein, the process of "brazing" is intended to refer to the creation of chemical bonds between the carbon atoms of the superabrasive particles/materials and the braze material. Further, "chemical bond" means a covalent bond, such as a carbide or boride bond, rather than mechanical or weaker inter-atom attractive forces. Thus, when "brazing" is used in connection with superabrasive particles a true chemical bond is being formed. However, when "brazing" is used in connection with metal to metal bonding the term is used in the more traditional sense of a metallurgical bond. Therefore, brazing of a superabrasive segment to a tool body does not necessarily require the presence of a carbide former.

As used herein, "particle" and "grit" may be used interchangeably.

As used herein, an "abrasive layer" describes a variety of structures capable of removing (e.g., cutting, polishing, scraping) material from a CMP pad. An abrasive layer can include a mass having several cutting points, ridges or mesas formed thereon or therein. It is notable that such cutting points, ridges or mesas may be from a multiplicity of protrusions or asperities included in the mass. Furthermore, an abrasive layer can include a plurality of individual abrasive particles that may have only one cutting point, ridge or mesa formed thereon or therein. An abrasive layer can also include composite masses, such as PCD pieces, segment or blanks, either individually comprising the abrasive layer or collectively comprising the abrasive layer.

As used herein, "metallic" includes any type of metal, metal alloy, or mixture thereof, and specifically includes but is not limited to steel, iron, and stainless steel.

As used herein, a plurality of items, structural elements, compositional elements, and/or materials may be presented in a common list for convenience. However, these lists should be construed as though each member of the list is individually identified as a separate and unique member. Thus, no individual member of such list should be construed as a de facto equivalent of any other member of the same list solely based on their presentation in a common group without indications to the contrary.

Concentrations, amounts, particle sizes, volumes, and other numerical data may be expressed or presented herein in a range format. It is to be understood that such a range format is used merely for convenience and brevity and thus should be interpreted flexibly to include not only the numerical values explicitly recited as the limits of the range, but also to include all the individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly recited.

As an illustration, a numerical range of "about 1 micrometer to about 5 micrometers" should be interpreted to include not only the explicitly recited values of about 1 micrometer to about 5 micrometers, but also include individual values and sub-ranges within the indicated range. Thus, included in this numerical range are individual values such as 2, 3, and 4 and sub-ranges such as from 1-3, from 2-4, and from 3-5, etc. This same principle applies to ranges reciting only one numerical value. Furthermore, such an interpretation should apply regardless of the breadth of the range or the characteristics being described.

The Invention

The present invention generally provides pad conditioners and associated methods that can be utilized in conditioning (e.g., smoothing, polishing, dressing) or otherwise affecting a CMP pad to remove material from the CMP pad in order to provide a finished, smooth and/or flat surface to the pad. Pad conditioners of the

present invention can be advantageously utilized, for example, in dressing CMP pads that are used in polishing, finishing or otherwise affecting silicon wafers.

In the embodiment of the invention illustrated in FIG. 1, a CMP pad conditioner 10 is provided. The pad conditioner can include at least one abrasive segment 12a, 12b, 12c and 12d (sometimes the varied and numerous abrasive segments discussed herein are collectively referred to as "12x"). As best appreciated from the example shown in FIG. 1A, each abrasive segment 12 can include a segment blank 14 and an abrasive layer 16 attached to the segment blank. The abrasive layer 16 can include a superhard abrasive material: in the exemplary embodiment of FIG. 1A, the superhard abrasive material includes a plurality of superhard particles 18. A pad conditioner substrate 20 (FIG. 1) can also be provided. The pad conditioner substrate can vary according to the applications for which the pad conditioner is designed, but generally includes a face on which the abrasive segments can be affixed to allow the pad conditioner to be used to grind, plane, cut or otherwise remove material from a CMP pad (not shown).

The at least one abrasive segment 12x can be permanently fixed to the pad conditioner 20 in an orientation that enables removal of material from the CMP pad by the abrasive layer as the pad conditioner and the pad are moved relative to one another. For example, in the embodiment shown in FIG. 1, the abrasive segments 12x are arranged radially along an edge of a substantially circular pad conditioner substrate. Such an arrangement has been found well suited to remove material from a CMP pad (while "dressing" the pad) by rotating the pad conditioner substrate relative to the pad.

The present invention provides a number of advantages over conventional devices. One such advantage lies in the ability to customize methods of attachment of the abrasive layer 16 to the segment blank 14 independently of methods of attachment of the segment blank or blanks to the pad conditioner substrate. For example, as various attachment methods may involve very high temperatures and/or pressures, very demanding environmental conditions, or simply are very labor intensive when attempted with pad conditioners of large or complex surface areas, performing the attachment method on distinct, easily handled segment blanks can improve costs,

efficiencies and integrities of the attachment process. Also, leveling of the components of the abrasive layer on each segment blank can be performed more easily when done in discrete, relatively small lots. The resulting plurality of abrasive segments can likewise be more easily positioned, leveled, spaced, oriented, etc., across the face of the pad conditioner substrate 20 after the abrasive layer is individually attached to each of the abrasive segments.

In addition, by obtaining a plurality of abrasive segments 12x, each with an abrasive layer 16 already attached thereto, an abrasive pattern across the face of the pad conditioner substrate 20 can be designed to optimize various conditioning procedures. For example, the spacing between adjacent abrasive segments can be carefully selected to aid in, or better control, the flow of various fluids (e.g., slurry) around and through the abrasive segments to increase the efficacy and efficiency of the material removing process. Also, as shown in FIG. 1, segment blanks having differing abrasive profiles (e.g., different sizes, shapes, abrasive aggressiveness, etc.) can be used on a single substrate, to enable customization of an abrading profile of the pad conditioner as a whole.

As will be discussed in further detail below, not only can the abrasive profile of each abrasive segment be customized, the type of, or composition of, the abrasive segment can vary from one segment 12x to another. For example, segment 12c may include a plurality of individual abrasive grits 18 attached to the segment blank 14 via an organic adhesive material layer 16. Segment 12a can include a substantially continuous piece of PCD compact attached to a segment blank via a differing attachment mechanism. Also, relative height or elevation of abrasive segments can be varied on any particular pad dresser. For example, the abrasive segment 12a of FIG. 1 can be elevated slightly higher than or lower than abrasive segment 12c of FIG. 1.

The various segment blanks 14 shown and discussed herein can be formed from a variety of materials, including, without limitation, metallic materials such as aluminum, copper, steel, metal alloys, etc., ceramic materials, glasses, polymers, composite materials, etc. Generally speaking, virtually any material to which an abrasive segment 12x can be attached will suffice.

In some embodiments, the material of the segment blank can be chosen to provide superior results during the process of attaching the abrasive layer thereto. As discussed above, the abrasive layer can be attached to the segment blank in a variety of manners, including epoxy bonding methods (e.g., organic bonding methods), metal brazing, sintering, electrodeposition, etc. The material of the segment blank can be chosen based upon the attachment process anticipated. For example, a segment blank formed partially or fully from nickel, or stainless steel, can be utilized in some processes involving brazing and/or sintering. Also, ceramic or metallic materials might be utilized in organic attachment methods.

Various embodiments of the invention employ various methods of attachment of the abrasive layer 16 to the segment blank 14. In one embodiment, an organic material layer can be deposited on the segment blank, and one or more abrasive particles, chips, segments, etc., can be fixed to the segment blank by way of the organic material layer. Examples of suitable organic materials include, without limitation, amino resins, acrylate resins, alkyd resins, polyester resins, polyamide resins, polyimide resins, polyurethane resins, phenolic resins, phenolic/latex resins, epoxy resins, isocyanate resins, isocyanurate resins, polysiloxane resins, reactive vinyl resins, polyethylene resins, polypropylene resins, polystyrene resins, phenoxy resins, perylene resins, polysulfone resins, acrylonitrile-butadiene-styrene resins, acrylic resins, polycarbonate resins, polyimide resins, and mixtures thereof.

So-called "reverse casting" methods can be used to accurately and controllably orient and attach the abrasive material on the segment blank (and to orient and attach the segment blanks to the pad conditioner substrate). Such methods can include initially securing a superabrasive material, e.g., a plurality of superabrasive grits, to a substrate using a "mask" material. The portions of the particles protruding from the mask material can then be attached to a pad conditioner substrate using the methods discussed herein, after which (or during which), the masking material can be removed. It has been found that these reverse casting techniques can increase the amount of abrasive particles (or other abrasive contact points) to as much as 10% and more of the total amount of abrasive particles or contact points.

Suitable reverse casting methods can be found in various patents and patent

applications to the present inventor, including U.S. Patent Application Serial No. 60/992,966, filed December 6, 2007; U.S. Patent Application Serial No. 11/804,221, filed May 16, 2007; and U.S. Patent Application Serial No. 11/805,549,filed May 22, 2007, each of which is hereby incorporated herein by reference. These techniques can be used when attaching the abrasive segments of the present invention to pad conditioner substrate: and when attaching the abrasive layers of the present invention to the segment blanks. Such techniques allow very precise control of lateral placement of the abrasive segments or abrasive layers, as well as very precise control of relative elevation of the abrasive segments or abrasive layers.

When an organic bonding material layer is utilized, methods of curing the organic material layer can be a variety of processes known to one skilled in the art that cause a phase transition in the organic material from at least a pliable state to at least a rigid state. Curing can occur, without limitation, by exposing the organic material to energy in the form of heat, electromagnetic radiation, such as ultraviolet, infrared, and microwave radiation, particle bombardment, such as an electron beam, organic catalysts, inorganic catalysts, or any other curing method known to one skilled in the art.

In one aspect of the present invention, the organic material layer may be a thermoplastic material. Thermoplastic materials can be reversibly hardened and softened by cooling and heating respectively. In another aspect, the organic material layer may be a thermosetting material. Thermosetting materials cannot be reversibly hardened and softened as with the thermoplastic materials. In other words, once curing has occurred, the process can be essentially irreversible, if desired.

Organic materials that may be useful in embodiments of the present invention include, but are not limited to: amino resins including alkylated urea-formaldehyde resins, melamine-formaldehyde resins, and alkylated benzoguanamine-formaldehyde resins; acrylate resins including vinyl acrylates, acrylated epoxies, acrylated urethanes, acrylated polyesters, acrylated acrylics, acrylated polyethers, vinyl ethers, acrylated oils, acrylated silicons, and associated methacrylates; alkyd resins such as urethane alkyd resins; polyester resins; polyamide resins; polyimide resins; reactive urethane resins; polyurethane resins; phenolic resins such as resole and novolac resins;

phenolic/latex resins; epoxy resins such as bisphenol epoxy resins; isocyanate resins; isocyanurate resins; polysiloxane resins including alkylalkoxysilane resins; reactive vinyl resins; resins marketed under the Bakelite™ trade name, including polyethylene resins, polypropylene resins, epoxy resins, phenolic resins, polystyrene resins, phenoxy resins, perylene resins, polysulfone resins, ethylene copolymer resins, acrylonitrile-butadiene-styrene (ABS) resins, acrylic resins, and vinyl resins; acrylic resins; polycarbonate resins; and mixtures and combinations thereof. In one aspect of the present invention, the organic material may be an epoxy resin. In another aspect, the organic material may be a polyimide resin. In yet another aspect, the organic material may be a polyurethane resin. In yet another aspect, the organic material may be a polyurethane resin.

Numerous additives may be included in the organic material to facilitate its use. For example, additional crosslinking agents and fillers may be used to improve the cured characteristics of the organic material layer. Additionally, solvents may be utilized to alter the characteristics of the organic material in the uncured state. Also, a reinforcing material may be disposed within at least a portion of the solidified organic material layer. Such reinforcing material may function to increase the strength of the organic material layer, and thus further improve the retention of the individual abrasive segments. In one aspect, the reinforcing material may include ceramics, metals, or combinations thereof. Examples of ceramics include alumina, aluminum carbide, silica, silicon carbide, zirconia, zirconium carbide, and mixtures thereof.

Additionally, in one aspect a coupling agent or an organometallic compound may be coated onto the surface of each superabrasive material to facilitate the retention of the superabrasive material in the organic material via chemical bonding. A wide variety of organic and organometallic compounds is known to those of ordinary skill in the art and may be used. Organometallic coupling agents can form chemicals bonds between the superabrasive materials and the organic material matrix, thus increasing the retention of the superabrasive materials therein. In this way, the organometallic coupling agent can serve as a bridge to form bonds between the organic material matrix and the surface of the superabrasive material. In one aspect of the present invention, the organometallic coupling agent can be a titanate, zirconate,

silane, or mixture thereof.

Specific non-limiting examples of silanes suitable for use in the present invention include: 3- glycidoxypropyltrimethoxy silane (available from Dow Corning as Z-6040); γ-methacryloxy propyltrimethoxy silane (available from Union Carbide Chemicals Company as A-174); β-(3,4-epoxycyclohexyl)ethyltrimethoxy silane, γ-aminopropyltriethoxy silane, N-(β-aminoethyl)-γ-aminopropylmethyldimethoxy silane (available from Union Carbide, Shin-etsu Kagaku Kogyo K.K., etc.).

Specific non-limiting examples of titanate coupling agents include: isopropyltriisostearoyl titanate, di(cumylphenylate)oxyacetate titanate, 4-aminobenzenesulfonyldodecylbenzenesulfonyl titanate, tetraoctylbis (ditridecylphosphite) titanate, isopropyltri(N-ethylamino-ethylamino) titanate (available from Kenrich Petrochemicals. Inc.), neoalkyoxy titanates such as LICA-01, LICA-09, LICA-28, LICA-44 and LICA-97 (also available from Kenrich), and the like.

Specific non-limiting examples of aluminum coupling agents include acetoalkoxy aluminum diisopropylate (available from Ajinomoto K.K.), and the like.

Specific non-limiting examples of zirconate coupling agents include: neoalkoxy zirconates, LZ-01, LZ-09, LZ- 12, LZ-38, LZ-44, LZ-97 (all available from Kenrich Petrochemicals, Inc.), and the like. Other known organometallic coupling agents, e.g., thiolate based compounds, can be used in the present invention and are considered within the scope of the present invention.

The amount of organometallic coupling agent used can depend upon the coupling agent and on the surface area of the superabrasive material. Oftentimes, 0.05% to 10% by weight of the organic material layer can be sufficient.

Metal brazing can also be utilized to attach the abrasive layer 16 to the segment blank 14. Metal brazing techniques are known in the art. For example, in fabricating a diamond saw blade, the process can include mixing diamond particles (e.g., 40/50 U.S. mesh saw grit) with a suitable metal support matrix (bond) powder (e.g., cobalt powder of 1.5 micrometer in size). The mixture is then compressed in a mold to form the right shape (e.g., a saw segment). This "green" form of the tool can then be consolidated by sintering at a temperature between 700-1200 degrees C to

form a single body with a plurality of abrasive particles disposed therein. Finally, the consolidated body can be attached (e.g., by brazing) to a tool body; such as the round blade of a saw, to form the final product. Many other exemplary uses of this technology are known to those having ordinary skill in the art.

Various sintering methods can also be utilized to attach the abrasive layer 16 to the segment blank 14. Suitable sintering methods will be easily appreciated by one of ordinary skill in the art having possession of this disclosure.

The abrasive layer 16 can also be attached to the segment blank 14 by way of known electroplating and/or electrodeposition processes. As an example (not shown in the figures) of a suitable method for positioning and retaining abrasive materials prior to and during the electrodeposition process, a mold can be used that includes an insulating material that can effectively prevent the accumulation of electrodeposited material on the molding surface. Abrasive particles can be held on the molding surface of the mold during electrodeposition. As such, the accumulation of electrodeposited material can be prevented from occurring on the particle tips and the working surface of the pad conditioner substrate. Such techniques are described in U.S. Patent Application Serial No. 11/292,938, filed December 2, 2005, which is hereby incorporated herein by reference.

One or more apertures can extend through the insulating material to allow for circulation of an electrolytic fluid from an area outside the mold through the mold and to the surface of the pad conditioner substrate in order to effect electrodeposition of the material used to secure the abrasive particles to the pad conditioner substrate. Such circulation can be advantageous as it is generally necessary to keep a sufficient concentration of the ions (not shown) in an electrolytic fluid at the location of electrodeposition. Other well known techniques can also be utilized, it being understood that the above-provided example is only one of many suitable techniques.

The segment blank can similarly be attached to the pad conditioner substrate in a variety of manners. Depending upon the material from which the segment blank is formed, various manners of fixing the segment blank to the pad conditioner substrate may be utilizing. Suitable attachment methods include, without limitation, organic binding, brazing, welding, etc.

The geometric configuration of the abrasive segment 12 can vary. In the embodiment illustrated in FIG. 1A and 1B, the abrasive segment includes a generally rectangular segment blank 14 with a layer 16 of abrasive material (that can include abrasive particles 18) attached to an upper portion thereof. The size of the segment blank can vary. In one aspect of the invention, segment size can be adjusted to achieve uniform distribution of diamond grits about an annular ring array. Each segment can contain up to about a thousand diamond grits with pitch set from 3X to 10X of the diamond size. Smaller segments can be better distributed to share the loading during dressings.

As will be appreciated, in the embodiment of FIG. 1B, the layer 16 of abrasive material extends partially onto (or "down") side edges of the segment blank 14. In the embodiment of FIG. 1C, the abrasive layer extends onto (or down) the side edges to a much lesser degree. The modular nature of the present systems allows a great deal of flexibility in attaching the abrasive layer 16 to the segment blanks 14. As the segment blanks can be prepared separately from the pad conditioner substrate, a variety of manufacturing advantages can be realized when applying the abrasive layer to the segment blank, without regard to the size, shape, mass, material, etc., of the pad conditioner substrate to which the segment blanks will eventually be attached.

While not so required, in one aspect of the invention, the plurality of abrasive segments can each include a substantially matching geometric configuration. In the embodiment illustrated in FIG. 2, each of the plurality of abrasive segments 12e presents a substantially wedge-shaped superabrasive profile (that can be truncated, if so desired). The abrasive layer 16e can be attached to segment blank 14e in a variety of manners, much the same as discussed above.

The plurality of abrasive segments 12x can be radially distributed about a face of the pad conditioner substrate 20, and can include a substantially uniform spacing between each segment. Also, a longitudinal axis of each of the plurality of abrasive segments can be aligned along a radius of the pad conditioner substrate. The abrasive segments 12e of the embodiment shown in FIGs. 2 and 2A can be arranged across the face of the pad conditioner substrate 20 in alternating or varying alignments: as

shown, the tapering portion of the segments can be aligned toward or away from a center of the pad conditioner substrate in alternating stages.

The abrasive segments arranged about the face of the conditioner substrate can each be substantially the same in size, shape, abrasive composition, height relative to one another, etc. In other embodiments, the size, shape, abrasive composition, height relative to one another, etc., can be purposefully varied, to achieve optimal design flexibility for any particular application. Also, each of the afore-mentioned qualities can be varied from segment to another: e.g., alternating segments can include PCD abrasive pieces, chips or slats, with adjacent segments including abrasive particles.

The retention of abrasive segments 12x on the pad conditioner substrate 20 can be improved by arranging the abrasive segments such that mechanical stress impinging on any individual abrasive segment is minimized. By reducing the stress impinging on each abrasive segment they can be more readily retained in place on the substrate, particularly for delicate tasks. Minimizing of stress variations between segments can be accomplished by spacing the segments evenly (or consistently) from one another, leveling to a uniform height (relative to the face of the pad conditioner substrate) an uppermost portion of each segment, radially aligning the segments about the face of the pad conditioner substrate, etc. Various other height and spacing techniques can be utilized to obtain a desired affect.

In one embodiment of the invention, the spacing of the abrasive segments can be adjusted to alter the contact pressure of the contact portion (e.g., the portion of the segment that engages and removes material from the CMP pad) of each segment. In general, the farther the segments are spaced from one another, the higher the contact pressure between the segment and the CMP pad. Thus, a higher density of abrasive segments across the face of the pad conditioner substrate can, in some cases, provide a more desirable abrasive interface between the pad conditioner substrate and the CMP pad. In other applications, a lower density of abrasive segments may be beneficial. In either case, the present invention provides a great deal of design flexibility to obtain the optimal abrading profile.

By forming the abrasive segments in individual units having defined geometric shapes, arrangement of the abrasive segments in a very precise manner becomes much

easier. As the defined geometric shapes can be replicated fairly precisely from one abrasive segment to another, the positioning of, and accordingly, the stress impinged upon, each abrasive segment can be accomplished fairly consistently across the face of the pad conditioner substrate in question. With prior art abrasive grits, for example, the overall shape and size of each a plurality of grits might change considerably from one grit to another, making precise placement of the grits difficult to accomplish. This problem is adequately addressed by the advantageous features of the present invention.

It has been found that diamond pad conditioners used commercially normally contain about ten thousand diamond grits. Due to the distortion of the substrate, particularly when the disk is manufactured by a high temperature process (e.g. by brazing), and also the distribution of grit sizes and diamond orientations, the cutting tips are located at different heights. When they are pressed against a polishing pad, only about 1% of the protruded diamond can be in engagement with a pad. This can increase the stress on the diamond cutting most deeply into the pad, and the diamond may break and cause catastrophic scratching of the expensive wafers.

By utilizing the present invention, the height difference of between particles can be greatly reduced. In one aspect of the invention, the segments are set on a flat metal (e.g. stainless steel) mold with designed spacing in a retainer ring. Epoxy with hardener fully mixed can be poured into the retainer ring to fill up and cover all segments. The diamond grits on the mold can be shielded by the penetration of the epoxy flow. After curing (with or without heating), the retainer ring and the mold can be removed. The diamond segments are thereby firmly embedded in the epoxy matrix. Due to the leveling of diamond by the flat mold, the tip height variations of the tallest diamond grits are minimized.

The mosaic disk thusly formed can be pressed against the polishing pad with the same fixed load. Resulting tests show that the engagement ratio can be over 50%. In other words, the number of working crystals can be increased many times so that the disk life can be greatly extended. In addition, due to the avoidance of deep cutting, the polishing pad can be used with a much longer life. Also, the dressed grooves can be made much more shallow and less dense. The slurry retention and

abrasive utility are both improved. The CMP's cost of consumable (CoC) and cost of ownership (CoO) are both reduced. The wafer polished is more uniform without scratching so the die yield can be higher.

Turning now to FIGs. 3A-5, a variety of differing embodiments of the invention are illustrated. In FIGs. 3A-3C, an embodiment is shown which aids in addressing issues relating to plastic deformation of a CMP pad (shown by example and in sectioned view at 24). This embodiment reduces the downward force required between the pad conditioner and the CMP pad. As a result, the CMP pad is left with a conditioned surface that is much more smooth and level than that obtained using conventional methods.

The conditioner shown in FIGs. 3A-3C can include abrasive layer 12f (only a section of which is shown). The abrasive layer can include a cutting face 26 angled at 90 degrees or less relative to a finished surface to be applied to the CMP pad (e.g., relative to movement of the cutting face away from the finished surface – sometimes referred to as a positive cutting angle). The face 26 of the abrasive layer 12f can be oriented such that relative movement of the pad conditioner (in the direction indicated at 23 in FIG. 3A) and the CMP pad 24 results in clean removal of material from the CMP pad with the cutting face to thereby condition the CMP pad.

By angling the cutting face 26 at 90 degrees or less, relative to a finished surface to be applied to the pad 24, the dressing process can cleanly shave a layer of pad material from the pad. The resultant surface applied to the pad can be safely used in the CMP process without damaging expensive silicon wafers. The present pad conditioners can be used to shave even a very shallow, thin layer of material from the pad and leave behind a clean, smooth and even finished surface on the pad. This technique can be used to remove thin layers of glaze that can be formed on the surface of the CMP pad.

The cutting face 26 is shown in FIGs. 3A and 3B oriented at an angle $\square_1$ of about 90 degrees relative to the finished surface to be applied to the CMP pad. Cutting face 26a of FIG. 3C is oriented at angle $\square_2$ that is less than 90 degrees relative to the finished surface to be applied to the CMP pad, on the order of about 60 degrees. The cutting faces can be oriented at a variety of angles, and in one embodiment vary from about 45 degrees to about 90 degrees relative to the finished surface of the CMP

pad. It has been found that reducing the angle creates an even sharper cutting interface between the cutting element and the pad.

The abrasive layers 12f, 12f' and 12f'' of FIGs. 3A-3C can be formed (along with their corresponding segment blank, not shown in these figures) as elongate cutting blades. These blades can include a significantly longer length than a width, similar to blade of a conventional kitchen knife. In this aspect of the invention, the blade can be used to cut, scrape or carve a relatively wide swath of material from the PCD pad (24 in FIGs. 3A-3C). As shown by example in FIGs. 4A and 4B, the abrasive layer, shown by example at 12f and 12f', can include either a substantially continuous cutting edge (as shown in FIG. 4A), or a series of cutting teeth can be formed in the blade (as shown in FIG. 4B). Examples of ways in which such cutting teeth can be formed are detailed in U.S. Provisional Patent Application Serial No. 60/987,687, filed November 13, 2007, which is hereby incorporated herein by reference.

Those embodiment illustrated in the figures that include angled cutting faces each include a cutting face that is formed having the corresponding angle. In some embodiments, however, it is to be understood that a relatively normal (e.g., 90 degree) cutting face can be utilized, except that the abrasive segment on which the cutting face is formed can be "tilted" when attached to the substrate. In other words, the cutting face is not angled relative to the abrasive segment, rather angling of the abrasive segment results in angling of the cutting face. In this manner, an angled cutting face is provided without requiring that the referenced angle be formed on (or in) the abrasive segment.

Additional and varying abrasive segments for use in the present invention are also contemplated. For example, use is contemplated of the various cutting elements/abrasive segments detailed in U.S. Patent Application No. 11/357,713, filed February 17, 2006, which is hereby incorporated herein by reference.

In addition, formation of the abrasive layer on the segment blanks can be accomplished by way of a variety of techniques, including but not limited to vapor deposition techniques similar to those outlined in U.S. Patent Application Serial No. 11/512,755, filed August 29, 2006, which is hereby incorporated herein by reference.

In addition, the abrasive segments can be formed utilizing ceramic components (as either or both the segment blank and/or the abrasive layer); electroplating techniques, etc.

In the embodiment illustrated in FIG. 5, a series of abrasive layers 14g, 14g' and 14g" is provided, each of which includes a cutting tip oriented at a different elevation. In this aspect of the invention, the leading abrasive segment (of which abrasive layer 14g forms a part) is generally at a relatively higher elevation than are trailing abrasive layers 14g' and 14g", as the trailing layers would not otherwise contact pad material remaining after the leading blade has passed. The abrasive segments having abrasive layers 14g, 14g' and 14g" can be formed in a variety of manners and in a variety of shapes, sizes and configurations, as detailed, for example, in U.S. Provisional Patent Application Serial 60/988,643, filed November 16, 2007, which is hereby incorporated herein by reference in its entirety. This embodiment can utilize intentionally cascaded cutting elements to achieve a desired abrading affect.

The following examples present various methods for making the pad conditioners of the present invention. Such examples are illustrative only, and no limitation on the present invention is to be thereby realized.

Examples:

Example 1:

A pad conditioner was formed by first arranging diamond grit (e.g. 50/60 mesh) on a stainless steel flat mold (also, a slightly convex or contoured mold can be utilized) having a layer of adhesive (e.g. acrylic). A hard rubber material was used to press individual diamond grits into the adhesive while tips of the grits were leveled by the flat mold. A mixture of epoxy and hardener was then poured onto the grit protruding outside the adhesive (a containment ring oriented outside the mold can retain the epoxy). After curing, the mold was then removed and the adhesive was peeled away. The remaining ODD contains diamond grit protruding outside a solidified epoxy substrate. The back of the epoxy can be machined and the disk adhered to a stainless steel (e.g. 316) plate with fastening holes for mounting on a CMP machine.

Example 2:

A pad conditioner was formed by radially arranging serrated PCD blades. As in the previous example, the teeth of the PCD blade were leveled with a mold that can be positioned either on the bottom or on the top of the pad conditioner. Epoxy was then cast as in the previous example. In the case that the mold is on the top, the blades are pressed slightly into the slot of a substrate and the slot is sealed by epoxy or silicone.

Example 3:

A composite design married the embodiments of Example 1 and Example 2 discussed above. This design leverages the many cutting tips of Example 1 with the cutting efficiency of Example 2. In this Example 3, smaller organic abrasive segments were formed by using a fiber reinforced polymer that is generally harder than epoxy. The organic segments were then radially arranged about a pad conditioner substrate with the blades of Example 2 interspersed therebetween. The cutting tips of the blades were leveled so as to be about 20 microns higher than were the tips of the organic abrasive segments. In this manner, the penetration depth of blade cutting teeth is controlled, while the organic cutting teeth play a secondary role in dressing the pad with the effect of removing glaze and also grooving the pad.

It is to be understood that the above-described arrangements are only illustrative of the application of the principles of the present invention. Numerous modifications and alternative arrangements may be devised by those skilled in the art without departing from the spirit and scope of the present invention and any appended or following claims are intended to cover such modifications and arrangements. Thus, while the present invention has been described above with particularity and detail in connection with what is presently deemed to be the most practical and preferred embodiments of the invention, it will be apparent to those of ordinary skill in the art that numerous modifications, including, but not limited to, variations in size, materials, shape, form, function and manner of operation, assembly and use may be made without departing from the principles and concepts set forth herein.

CLAIMS:

What is claimed is:

1. A CMP pad conditioner, comprising:

a plurality of abrasive segments, each abrasive segment including:

a segment blank; and

an abrasive layer attached to the segment blank, the abrasive layer including a superhard abrasive material; and

a pad conditioner substrate;

each of the plurality of abrasive segments being permanently affixed to the pad conditioner substrate in an orientation that enables removal of material from a CMP pad by the abrasive layer as the pad conditioner and the CMP pad are moved relative to one another.

2. The pad conditioner of claim 1, wherein at least some of the plurality of abrasive segments are radially distributed about a face of the pad conditioner substrate.

3. The pad conditioner of claim 1, wherein at least two of the plurality of abrasive segments differ in at least one of: a geometric configuration; an abrasive layer material; and an abrasive profile.

4. The pad conditioner of claim 1, wherein arrangement of the abrasive segments on the face of the pad conditioner substrate uniformly distributes drag forces across substantially each abrasive segment.

5. The pad conditioner of claim 1, wherein a longitudinal axis of each of the plurality of abrasive segments is aligned along a radius of the pad conditioner substrate.

6. The pad conditioner of claim 1, wherein each of the abrasive layers includes an abrading surface or point, and wherein the abrading surfaces or points are

leveled relative to one another such that no abrading surface or point protrudes above another abrading surface or point by more than about 30 microns.

7. The pad conditioner of claim 1, wherein each of the abrasive layers includes an abrading surface or point, and wherein at least one abrading surface or point is oriented at a greater elevation than is an abrading surface or point of an immediately adjacent abrasive layer.

8. The pad conditioner of claim 1, wherein the plurality of abrasive layers are attached to the segment blanks with an organic material layer including one or more of: amino resins, acrylate resins, alkyd resins, polyester resins, polyamide resins, polyimide resins, polyurethane resins, phenolic resins, phenolic/latex resins, epoxy resins, isocyanate resins, isocyanurate resins, polysiloxane resins, reactive vinyl resins, polyethylene resins, polypropylene resins, polystyrene resins, phenoxy resins, perylene resins, polysulfone resins, acrylonitrile-butadiene-styrene resins, acrylic resins, polycarbonate resins, polyimide resins, and mixtures thereof.

9. The pad conditioner of claim 1, wherein the abrasive layers are attached to the segments blanks by a brazing alloy.

10. The pad conditioner of claim 1, wherein the abrasive layers comprise PCD blades.

11. The pad conditioner of claim 1, wherein the abrasive layers include individual abrasive grits.

12. The pad conditioner of claim 1, wherein each of the abrasive layers includes a cutting face, and wherein each cutting face is angled at 90 degrees or less relative to a finished surface of the CMP pad.

13. A CMP pad conditioner, comprising:

a plurality of abrasive segments, each abrasive segment including:

a segment blank;

an organic adhesive layer; and

an abrasive layer attached to the segment blank by the organic adhesive layer, the abrasive layer including a superhard abrasive material; and

a pad conditioner substrate;

each of the plurality of abrasive segments being permanently affixed to the pad conditioner substrate in an orientation that enables removal of material from a CMP pad by the abrasive layer as the pad conditioner and the CMP pad are moved relative to one another.

14. The pad conditioner of claim 13, wherein at least some of the plurality of abrasive segments are radially distributed about a face of the pad conditioner substrate.

15. The pad conditioner of claim 13, wherein at least two of the plurality of abrasive segments differ in at least one of: a geometric configuration; an abrasive layer material; and an abrasive profile.

16. The pad conditioner of claim 13, wherein arrangement of the abrasive segments on the face of the pad conditioner substrate uniformly distributes drag forces across substantially each abrasive segment.

17. The pad conditioner of claim 13, wherein a longitudinal axis of each of the plurality of abrasive segments is aligned along a radius of the pad conditioner substrate.

18. The pad conditioner of claim 13, wherein each of the abrasive layers includes an abrading surface or point, and wherein the abrading surfaces or points are

leveled relative to one another such that no abrading surface or point protrudes above another abrading surface or point by more than about 30 microns.

19. The pad conditioner of claim 13, wherein each of the abrasive layers includes an abrading surface or point, and wherein at least one abrading surface or point is oriented at a greater elevation than is an abrading surface or point of an immediately adjacent abrasive layer.

20. A CMP pad conditioner, comprising:

a plurality of abrasive segments, each abrasive segment including:

a segment blank; and

an abrasive layer attached to the segment blank by a brazing alloy, the abrasive layer including a superhard abrasive material; and

a pad conditioner substrate;

each of the plurality of abrasive segments being permanently affixed to the pad conditioner substrate in an orientation that enables removal of material from a CMP pad by the abrasive layer as the pad conditioner and the CMP pad are moved relative to one another.

21. The pad conditioner of claim 20, wherein at least some of the plurality of abrasive segments are radially distributed about a face of the pad conditioner substrate.

22. The pad conditioner of claim 20, wherein at least two of the plurality of abrasive segments differ in at least one of: a geometric configuration; an abrasive layer material; and an abrasive profile.

23. The pad conditioner of claim 20, wherein arrangement of the abrasive segments on the face of the pad conditioner substrate uniformly distributes drag forces across substantially each abrasive segment.

24. The pad conditioner of claim 20, wherein a longitudinal axis of each of the plurality of abrasive segments is aligned along a radius of the pad conditioner substrate.

25. The pad conditioner of claim 20, wherein each of the abrasive layers includes an abrading surface or point, and wherein the abrading surfaces or points are leveled relative to one another such that no abrading surface or point protrudes above another abrading surface or point by more than about 30 microns.

26. The pad conditioner of claim 20, wherein each of the abrasive layers includes an abrading surface or point, and wherein at least one abrading surface or point is oriented at a greater elevation than is an abrading surface or point of an immediately adjacent abrasive layer.

27. A CMP pad conditioner, comprising:

a plurality of abrasive segments, each abrasive segment including:

a segment blank; and

an abrasive layer attached to the segment blank, the abrasive layer including a superhard abrasive blade; and

a pad conditioner substrate;

each of the plurality of abrasive segments being permanently affixed to the pad conditioner substrate in an orientation that enables removal of material from a CMP pad by the abrasive layer as the pad conditioner and the CMP pad are moved relative to one another.

28. The pad conditioner of claim 27, wherein at least some of the plurality of abrasive segments are radially distributed about a face of the pad conditioner substrate.

29. The pad conditioner of claim 27, wherein at least two of the plurality of abrasive segments differ in at least one of: a geometric configuration; an abrasive layer material; and an abrasive profile.

30. The pad conditioner of claim 27, wherein arrangement of the abrasive segments on the face of the pad conditioner substrate uniformly distributes drag forces across substantially each abrasive segment.

31. The pad conditioner of claim 27, wherein a longitudinal axis of each of the plurality of abrasive segments is aligned along a radius of the pad conditioner substrate.

32. The pad conditioner of claim 27, wherein each of the abrasive layers includes an abrading surface or point, and wherein the abrading surfaces or points are leveled relative to one another such that no abrading surface or point protrudes above another abrading surface or point by more than about 30 microns.

33. The pad conditioner of claim 27, wherein each of the abrasive layers includes an abrading surface or point, and wherein at least one abrading surface or point is oriented at a greater elevation than is an abrading surface or point of an immediately adjacent abrasive layer.

34. A CMP pad conditioner, comprising:

a plurality of abrasive segments, each abrasive segment including:

a segment blank; and

an abrasive layer attached to the segment blank, the abrasive layer including a cutting face angled at 90 degrees or less relative to a finished surface to be applied to the CMP pad; and

a pad conditioner substrate;

each of the plurality of abrasive segments being permanently affixed to the pad conditioner substrate in an orientation that enables removal of material from a CMP

pad by the abrasive layer as the pad conditioner and the CMP pad are moved relative to one another.

35. The pad conditioner of claim 34, wherein at least some of the plurality of abrasive segments are radially distributed about a face of the pad conditioner substrate.

36. The pad conditioner of claim 34, wherein at least two of the plurality of abrasive segments differ in at least one of: a geometric configuration; an abrasive layer material; and an abrasive profile.

37. The pad conditioner of claim 34, wherein arrangement of the abrasive segments on the face of the pad conditioner substrate uniformly distributes drag forces across substantially each abrasive segment.

38. The pad conditioner of claim 34, wherein a longitudinal axis of each of the plurality of abrasive segments is aligned along a radius of the pad conditioner substrate.

39. The pad conditioner of claim 34, wherein each of the abrasive layers includes an abrading surface or point, and wherein the abrading surfaces or points are leveled relative to one another such that no abrading surface or point protrudes above another abrading surface or point by more than about 30 microns.

40. The pad conditioner of claim 34, wherein each of the abrasive layers includes an abrading surface or point, and wherein at least one abrading surface or point is oriented at a greater elevation than is an abrading surface or point of an immediately adjacent abrasive layer.

41. A method of forming a CMP pad conditioner, comprising:
obtaining at least one abrasive segment, the abrasive segment including:

a segment blank; and

an abrasive layer attached to the segment blank, the abrasive layer including a superhard abrasive material;

positioning the at least one abrasive segment on a face of a pad conditioner substrate in an orientation that enables removal of material from a CMP pad by the abrasive layer as the pad conditioner and the CMP pad are moved relative to one another; and

permanently affixing the at least one abrasive segment to the pad conditioner substrate.

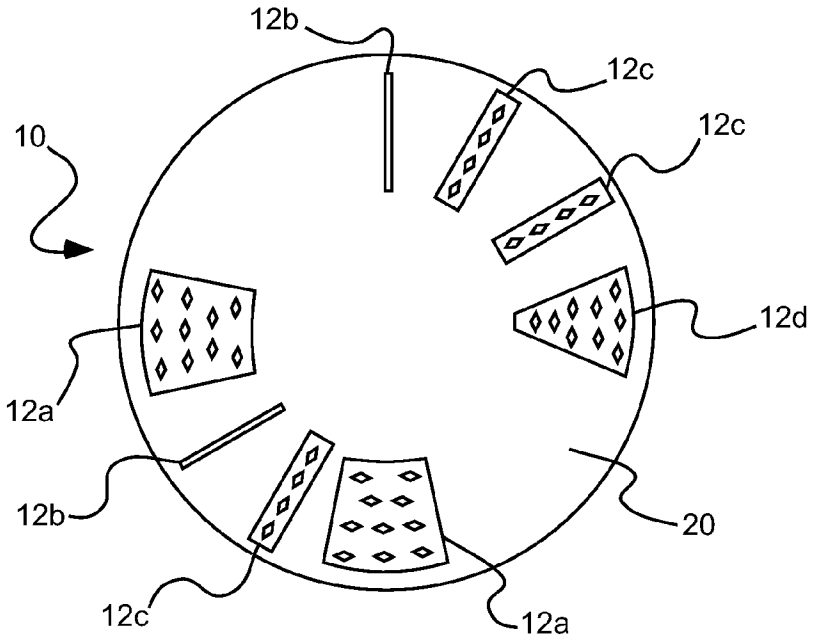


FIG. 1

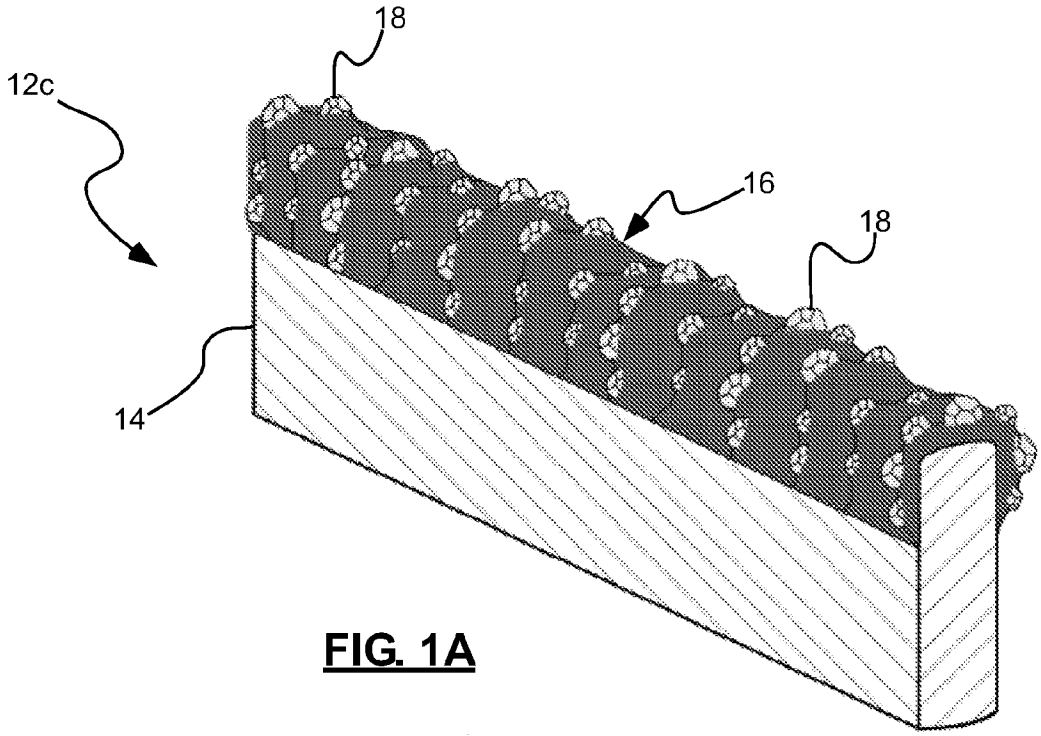


FIG. 1A

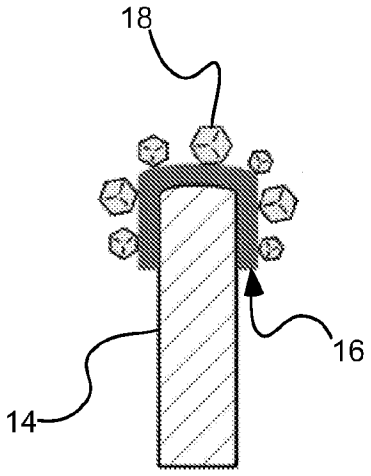


FIG. 1B

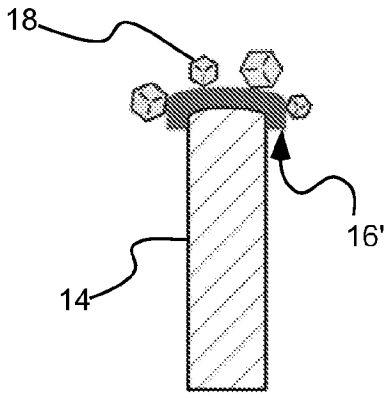


FIG. 1C

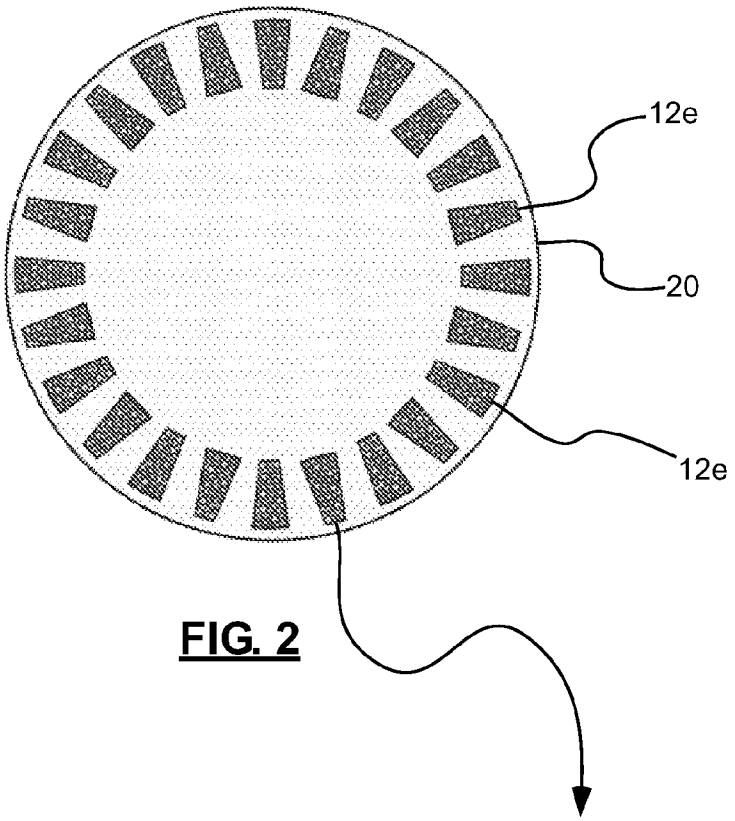


FIG. 2

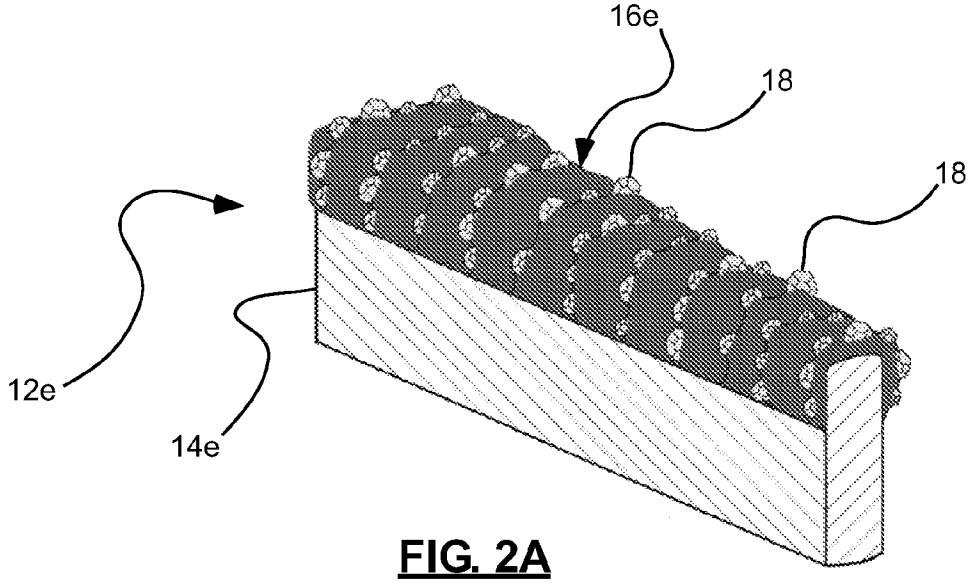


FIG. 2A

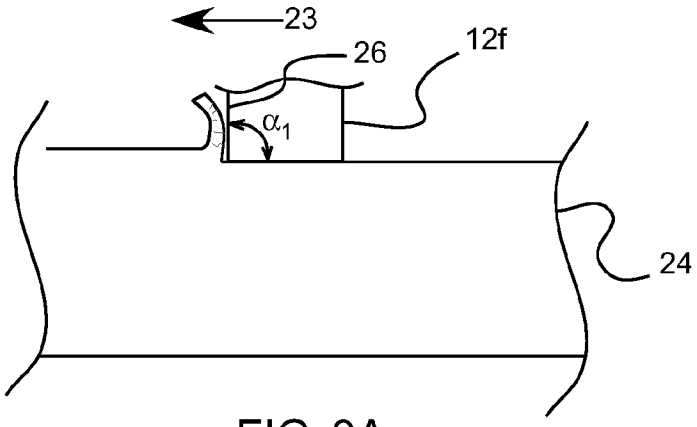


FIG. 3A

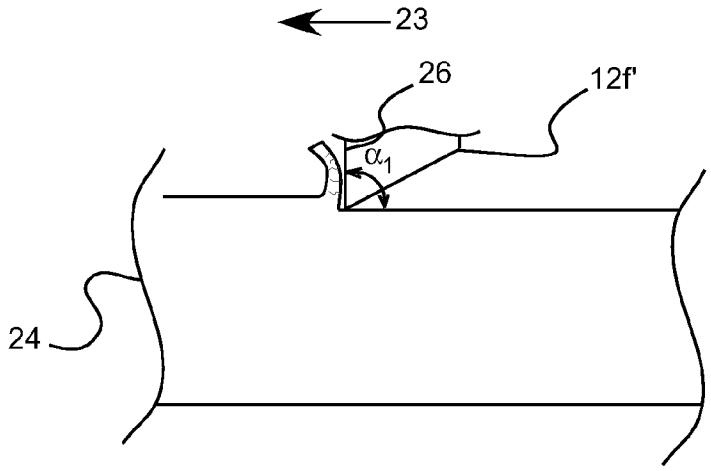


FIG. 3B

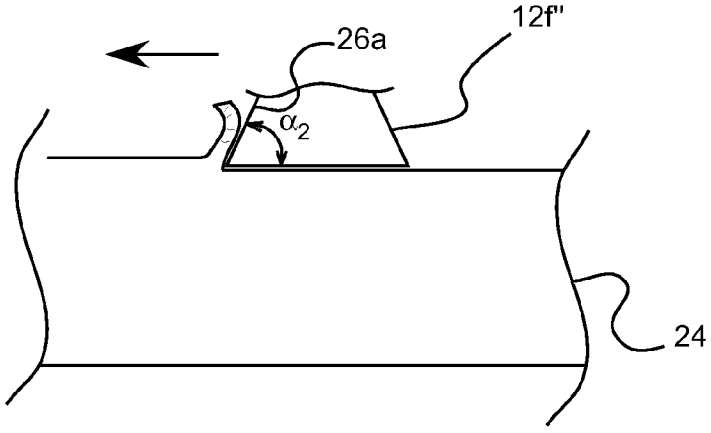


FIG. 3C

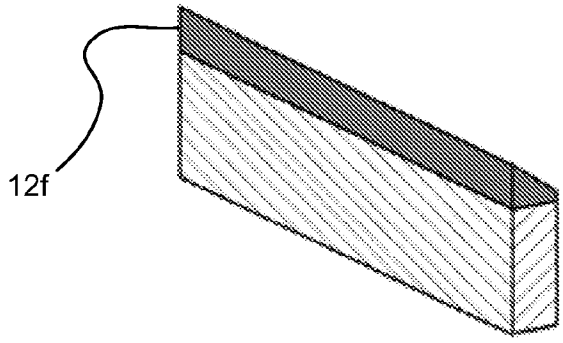


FIG. 4A

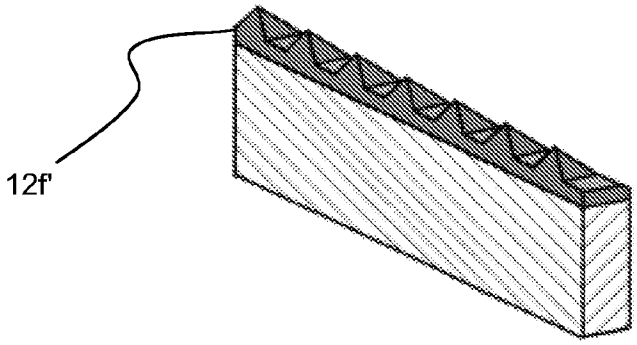


FIG. 4B

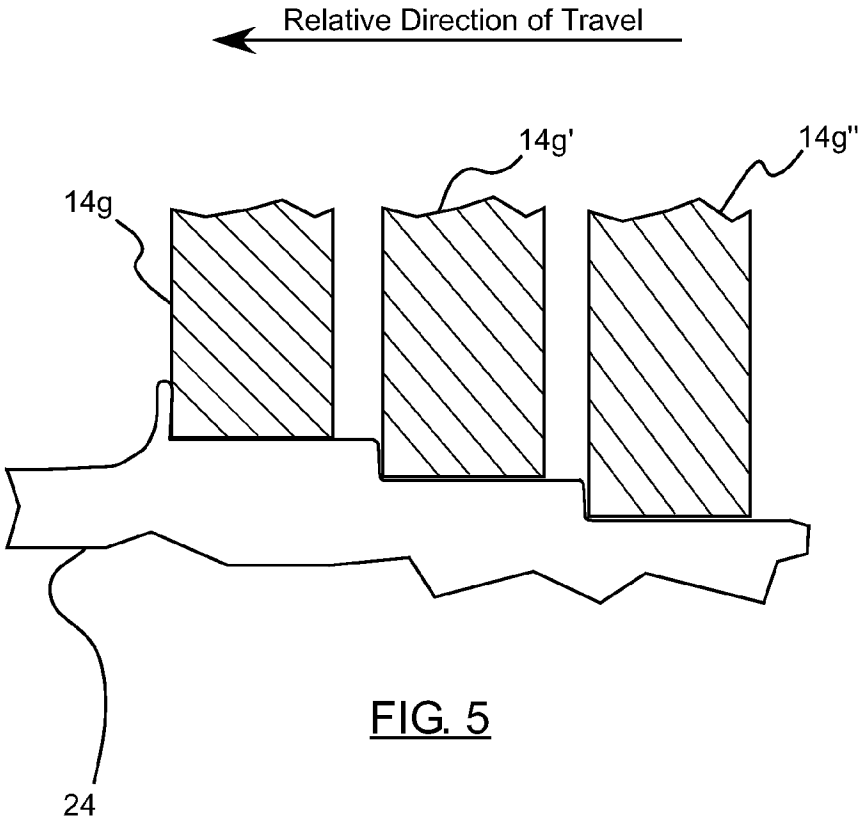


FIG. 5

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(54) Title: POLYCRYSTALLINE ABRASIVE GRIT

(57) Abstract: A method is provided for producing a plurality of polycrystalline ultra hard abrasive grit. The method includes the steps of providing a mass of ultra hard abrasive particles or a mass of a combination of a precursor for such particles and a suitable solvent/catalyst, forming the mass into a plurality of green state granules, placing the granules with a separating medium between adjacent granules in the reaction zone of a high pressure/high temperature apparatus, subjecting the contents of the reaction zone to elevated temperature and pressure conditions which the ultra-hard abrasive particle is crystallographically stable, recovering the thus sintered material from the reaction zone and removing the separating medium in the sintered material to produce a plurality of crystalline abrasive grit. The ultra-hard abrasive is generally diamond or cubic boron nitride.

POLYCRYSTALLINE ABRASIVE GRIT

BACKGROUND OF THE INVENTION

This invention relates to polycrystalline abrasive grit.

Ultra-hard abrasive bodies in the form of either abrasive compacts or individual crystals are well known in the art. The abrasive compact will generally be a diamond compact, also known as polycrystalline diamond or PCD, or a cubic boron nitride compact, also known as polycrystalline cubic boron nitride or PCBN. These abrasive compacts have wide application in cutting, drilling, boring, milling and other abrasive applications.

Such ultra-hard abrasive bodies are produced under conditions of elevated temperature and pressure at which the ultra-hard abrasive is crystallographically stable. Polycrystalline diamond or polycrystalline boron nitride can be produced with or without a second phase or bonding matrix. The second phase, when provided, may be in the case of diamond a solvent/catalyst such as cobalt, or it may be a carbide-forming element such as silicon. Similar sintering mechanisms are utilised in PCBN synthesis with various carbides, nitrides and borides being common second phases.

CONFIRMATION COPY

Abrasive compacts are generally produced in the form of a disc, either free-standing or bonded to a support, which may be cut into smaller segments for use.

Single crystal ultra-hard abrasives in the form of either diamond or cubic boron nitride crystals, also referred to as "grit", are used in loose or bonded form for a variety of abrasive applications such as lapping, drilling, grinding and sawing.

Examples of abrasive tools which utilise single crystal ultra-hard abrasives are grinding wheels and saw segments. Bond types for such abrasives can be a metal, resin or a ceramic.

Diamond or CBN grits are typically produced through a high pressure/high temperature process where graphite or hexagonal boron nitride is converted in the presence of a suitable catalyst to, respectively, diamond or cubic boron nitride. In some cases natural diamond crystals are also employed.

The concepts of abrasive compacts and grits have been combined and have led to the development of polycrystalline grit. For instance United States Patent 4,770,861 describes a process for generating polycrystalline grit containing ultra-hard material. This is achieved by leaching non-diamond material from polycrystalline diamond or cubic boron nitride compacts obtained through a high pressure/high temperature process and subsequently crushing the leached product.

The process of high pressure/high temperature sintering followed by subsequent crushing is not ideal as a high amount of energy is consumed in crushing sintered PCD and control over the shape and size of the final product is limited. Hence yield and quality tend to be low.

SUMMARY OF THE INVENTION

According to the present invention, a method of producing a plurality of polycrystalline ultra-hard abrasive grit includes the steps of providing a mass of ultra-hard abrasive particles or a mass of a combination of a precursor for such particles and a suitable solvent/catalyst, forming the mass into a plurality of green state granules, placing the granules with a separating medium between adjacent granules in the reaction zone of a high pressure/high temperature apparatus, subjecting the contents of the reaction zone to elevated temperature and pressure conditions at which the ultra-hard abrasive particle is crystallographically stable, recovering the thus sintered material from the reaction zone and removing the separating medium in the sintered material to produce a plurality of polycrystalline abrasive grit.

The method of the invention involves, as a first step, the forming of the mass of ultra-hard abrasive particles or of combination of a precursor for such particles and solvent/catalyst into a plurality of green state granules. The term "green state granules" means a coherent mass of any suitable shape or size and which is produced, for example, by known granulation or pelletising techniques.

The green state granules will generally be produced in the presence of a second (or binder) phase. The second phase may be provided by a material which participates in or contributes to the formation of the polycrystalline ultra-hard abrasive grit, e.g. a solvent/catalyst for the ultra-hard abrasive. The second phase may also be a binder, organic or inorganic, which may be removed prior to subjecting the granules to the high temperature/high pressure sintering conditions. The second phase can also consist of a combination of these two second phases.

If a precursor for the ultra-hard abrasive is used, then a solvent/catalyst for that ultra-hard abrasive must also be present. Examples of suitable solvent/catalysts for such particles, particularly when the particles are diamond or cubic boron nitride, are well known in the art. The solvent/catalysts may be precursors which can be converted to the solvent/catalyst, e.g. metal oxides which on heating are converted to the metal. Such precursors are included in the term "solvent/catalyst".

Examples of combinations, generally in the form of mixtures, of ultra-hard abrasive particles or precursor particles and second phases which are useful in the practice of the invention are:

1. Diamond and a diamond solvent/catalyst which may be a transition metal such as cobalt, nickel, iron or manganese or non-metallic solvent/catalyst such as a carbonate or sulphate to produce a sintered, intergrown polycrystalline diamond grit material.

2. Graphite and a diamond solvent/catalyst which may be a transition metal such as cobalt, nickel, iron or manganese or a non-metallic solvent/catalyst such as a carbonate or sulphate to produce a sintered, intergrown polycrystalline diamond grit. In producing the grit, the graphite is converted to diamond.

3. A combination of 1 and 2.

4. Diamond and a carbide forming metal such as silicon or titanium to produce a grit which is a sintered polycrystalline diamond/ SiC or TiC composite.

5. A combination of 1 and 4 or 2 and 4.

6. Cubic boron nitride together with a boride or nitride forming metal such as aluminium, titanium, zirconium, hafnium, tantalum, molybdenum, niobium, chromium or tungsten or mixtures thereof introduced either in metallic form or as a substoichiometric or stoichiometric carbide, boride or nitride. The polycrystalline cubic boron nitride grit produced consists of cubic boron nitride and metal nitrides or borides.

7. A combination of 6 and cobalt, nickel, iron or manganese.

8. A combination of cubic boron nitride and alumina or a combination of diamond and alumina.

9. Hexagonal boron nitride and a suitable solvent/catalyst for cubic boron nitride such as magnesium, lithium or calcium in either metallic form, as a nitride or in the form of a boronitride to produce a sintered, intergrown polycrystalline cubic boron nitride grit. In producing the grit, the hexagonal boron nitride is converted to cubic boron nitride.

The green state granules are placed in the reaction zone of a standard high pressure/high temperature apparatus for the high pressure/high temperature sintering. Generally, the granules will be placed in a capsule which itself is placed in the reaction zone.

A separating medium separates individual granules in the reaction zone. The separating medium is preferably provided as a coating on individual granules. A particularly suitable method of coating individual granules is spray coating in a fluidised medium.

The separating medium, in one form of the invention, may be a metal or alloy which does not interfere with the high pressure/high temperature sintering of the green state granules. For example, molybdenum is a suitable coating

where the ultra-hard abrasive is diamond or a precursor for diamond, e.g. graphite.

The separating medium may also be an inert medium which adequately transmits pressure, e.g. a salt such as a chloride or a carbonate, graphite, hexagonal boron nitride or an oxide.

A chemical barrier layer may be applied to the green state granules , generally to coat the granules completely, prior to the separation medium being interposed between adjacent granules. Examples of suitable chemical barrier layers are niobium, molybdenum, tantalum, titanium or other transition metal. The chemical barrier layer may be left on the polycrystalline abrasive grit produced from the green state granules.

The separating medium and chemical barrier layers may be applied to the green state granules by spraying in the form of an aqueous or non-aqueous suspension. The granules will generally be in a fluidised state during spraying. Alternatively, the granules may be dipped into a suspension of the separation medium and/or chemical barrier layer, or these layers may be coated mechanically on to the granules.

In one particular form of the invention, the green state granules are placed in a container, the separating medium in powdered or liquid form poured into the container and the granules and the separating medium mixed. If necessary, good dispersion and mixing can be assisted by some mechanical agitation or vibration to ensure that there are no gaps and the green state granules are all embedded in or enclosed by the separating medium.

Before subjecting the green state granules to the elevated temperature and pressure sintering, any removable binder, e.g. an organic binder which is present is preferably removed, for example, by a pressureless heat treatment.

The heat treatment conditions will vary according to the nature of the granules and its content. Typical heat treatment or outgassing conditions are 500°C in an argon atmosphere or 400°C in air or 1100°C in a vacuum. A slow heating cycle is preferred.

The green state granules may optionally be densified. Densification can be achieved by uniaxial compaction or cold isostatic pressing. Some deformation of the granules will take place during this compaction. When the green state granules contain a binder which is removed, the densification may take place before or after the binder is removed.

The elevated temperature and pressure sintering conditions to which the green state granules are subjected are known in the art. Typical pressures are 3 to 9 GPa and typical temperatures are 1000 to 2500°C.

The sintered material is removed from the reaction zone of the high temperature/high pressure apparatus using known techniques. The material which is recovered is sintered and coherent and consists of a plurality of sintered granules separated by the separating medium and a chemical barrier layer, when provided. The individual sintered granules or polycrystalline ultra-hard abrasive grit can be released by removing the separating medium. For example, if the separating medium is a metal such as molybdenum, the material may be placed in a hot boiling acid such as 3 parts of boiling hydrofluoric acid and one part nitric acid. This will dissolve the molybdenum leaving a plurality of polycrystalline diamond grit. When the separating medium is hexagonal boron nitride, removal of the separating medium may be achieved by placing the sintered material in an ultrasonic bath filled with water. Hexagonal boron nitride is hydrolysed by the water and the sonification breaks up or disintegrates the hexagonal boron nitride.

The polycrystalline ultra-hard abrasive grit produced by the method of the invention will typically have a particle size less than 5 mm and typically less than 2 mm. This grit may be used in a variety of abrasive applications, depending on the content and composition of the grit. The polycrystalline nature of the grit provides for a better bond retention in the bonding matrix of an abrasive tool when compared with single crystal grit. Further, controlled fracture of the grit can occur resulting in sharp edges or points being continuously produced, in use. The invention provides a particularly effective and economic method of producing polycrystalline abrasive grit. Further, the method is versatile in that polycrystalline abrasive grit may be produced with or without a second (binder) phase and contain more than one type of ultra-abrasive. The method allows for the production of polycrystalline abrasive grit of controlled shape and size.

EXAMPLE 1

A solvent based suspension with a 60 weight percent diamond (average particle diameter approximately 10 microns) and 20 weight percent of submicron cobalt powder was prepared and approximately 1 volume percent of organic binder added. The suspension was processed using a combination of spray drying and fluidised bed technology to produce strong green state spherical granules of approximately 1mm diameter and a porosity of approximately 42%. A solvent based suspension was formulated using submicron molybdenum powder. The diamond/cobalt granules were fluidised and a thin layer of molybdenum of approximately 100 microns thickness was spray dried on to the granules, using the molybdenum suspension.

The coated green state granules were placed into a die set and uniaxially compacted to yield a green compact of approximately 60% density. Binder removal from the green state granules was achieved by heat treatment at 1100°C for 2 hours in vacuum. The outgassed green state granules were then

loaded into a metal canister. The canister was loaded into the reaction capsule of a standard high pressure/high temperature apparatus and the loaded capsule placed into the reaction centre of this apparatus. The contents of the canister were exposed to a temperature of approximately 1450°C and a pressure of 5 GPa. These conditions were maintained for 10 minutes. After completion of the treatment a densely sintered compact was recovered from the canister. A polished cross-section showed sintered polycrystalline diamond grit separated by a honeycomb structure of thin molybdenum veins. The compact was placed into a beaker with 3 parts of boiling hydrofluoric acid and 1 part nitric acid. After a few minutes of treatment the compact separated into a plurality of roundish particles of approximately 0,5 to 0,7 mm diameter. Closer examination showed these particles to consist of hard sintered polycrystalline diamond with the cobalt leached out of the surface region of the particles.

EXAMPLE 2

An organic suspension of hexagonal boron nitride containing a small amount of dissolved organic binder was prepared. The molybdenum clad green state granules described in Example 1 were fluidised and spray coated with a second approximately 100 micron thick coating of hexagonal boron nitride, using the hexagonal boron nitride suspension. Repeating the same compaction, outgassing and high temperature/high pressure treatment as described in Example 1 resulted in a coherent sintered compact recovered from the canister. The compact was placed into an ultrasonic bath filled with water. After a few minutes of sonification the compact separated into a plurality of roundish particles of approximately 0,6 to 0,8 mm diameter. Closer examination revealed the particles to consist of sintered polycrystalline diamond grit clad with a thin sintered molybdenum metal coating.

EXAMPLE 3

The procedure in Example 2 was repeated replacing the hexagonal boron nitride layer with a spray deposited sodium chloride layer. The binder removal temperature was lowered to 500°C in argon so as to prevent volatilisation of the chloride. Repeating the same compaction, outgassing and high temperature/high pressure treatment as described in Example 1 resulted in a coherent sintered compact recovered from the canister. The compact was placed into an ultrasonic bath filled with water. After a few minutes of sonification the compact separated into a plurality of roundish particles of approximately 0,6 to 0,8 mm diameter. Closer examination revealed the particles to consist of sintered polycrystalline diamond grit clad with a thin sintered molybdenum metal coating.

CLAIMS

1 A method of producing a plurality of polycrystalline ultra-hard abrasive grit includes the steps of providing a mass of ultra-hard abrasive particles or a mass of a combination of a precursor for such particles and a suitable solvent/catalyst, forming the mass into a plurality of green state granules, placing the granules with a separating medium between adjacent granules in the reaction zone of a high pressure/high temperature apparatus, subjecting the contents of the reaction zone to elevated temperature and pressure conditions at which the ultra-hard abrasive particle is crystallographically stable, recovering the thus sintered material from the reaction zone and removing the separating medium in the sintered material to produce a plurality of polycrystalline abrasive grit.

2 A method according to claim 1 wherein the green state granules are produced by granulation or pelletising.

3 A method according to claim 1 or claim 2 wherein the green state granules contain a second phase which is an organic or inorganic binder, such binder being removed prior to subjecting the granules to the high temperature/high pressure conditions.

4 A method according to claim 1 or claim 2 wherein the green state granules contain a second phase which participates in or contributes to the formation of the polycrystalline ultra-hard abrasive grit.

5 A method according to claim 4 wherein the second phase is a solvent/catalyst for the ultra-hard abrasive.

8 A method according to any one of the preceding claims wherein the green state granules contain diamond and a metal solvent/catalyst.

7 A method according to any one of claims 1 to 5 wherein the green state granules contain graphite and a diamond solvent/catalyst.

8 A method according to any one of claims 1 to 5 wherein the green state granules contain diamond, graphite and a diamond solvent/catalyst.

9 A method according to any one of claims 1 to 5 wherein the green state granules contain diamond and a carbide forming metal.

10 A method according to any one of claims 1 to 5 wherein the green state granules contain diamond, a diamond solvent/catalyst and a carbide forming metal.

11 A method according to any one of claims 1 to 5 wherein the green state granules contain cubic boron nitride and a boride or nitride forming metal.

12 A method according to any one of claims 1 to 5 wherein the green state granules contain a combination of cubic boron nitride, a boride or nitride forming metal, and a metal selected from cobalt, nickel, iron and manganese.

13 A method according to any one of claims 1 to 5 wherein the green state granules contain cubic boron nitride and alumina.

14 A method according to any one of claims 1 to 5 wherein the green state granules contain diamond and alumina.

15 A method according to any one of claims 1 to 5 wherein the green state granules contain hexagonal boron nitride and a solvent/catalyst for cubic boron nitride.

16 A method according to any one of the preceding claims wherein the separating medium is provided as a coating on individual granules.

17 A method according to any one of the preceding claims wherein the ultra-hard abrasive for the green state granules is diamond or a precursor for diamond, and the separating medium is molybdenum.

18 A method according to any one of the preceding claims wherein the separating medium is selected from a salt, graphite, hexagonal boron nitride and an oxide.

19 A method according to any one of the claims 1 to 18 wherein a chemical barrier layer is applied to the green state granules prior to the separation medium being interposed between adjacent granules.

20 A method according to claim 19 wherein the chemical barrier layer coats the granules completely.

21 A method according to 19 or claim 20 wherein the chemical barrier layer is selected from niobium, molybdenum, tantalum, titanium or other transition metal.

22 A method according to any one of claims 19 to 21 wherein the chemical barrier layer is left on the polycrystalline abrasive grit produced from the green state granules.

23 A method according to any one of the preceding claims wherein the elevated temperature conditions are a pressure in the range 3 to 9 GPa and a temperature in the range 1000 to 2500°C.

24 A method according to claim 1 substantially as herein described with reference to any one of the examples.

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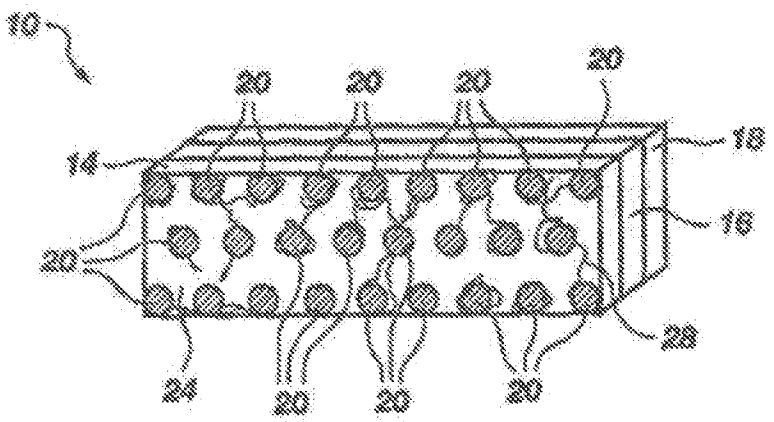
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(54) Title: BRAZED DIAMOND TOOLS BY INFILTRATION

(57) Abstract

The present invention describes a diamond tool with diamond bonded chemically by a braze that contains either Cr, Mn, Si, or Al or mixtures or alloys thereof. The diamond tool is made by infiltrating the braze into a matrix metal that contains diamond in either form of grits or polycrystalline bodies.



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BRAZED DIAMOND TOOLS BY INFILTRATION

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to tools having diamond particles formed thereon/therein, wherein the diamond particles are chemically bonded to matrix support material used to hold the diamond in place. More specifically, the diamond grit is bonded chemically in a matrix powder by a braze that can wet diamond. These tools are manufactured by the infiltration of the molten braze into a preform of matrix that contains diamond particles, thereby securing the diamond in place by a chemical bond.

2. State of the Art

Abrasive tools have long been used in numerous applications, including cutting, drilling, sawing, grinding, lapping and polishing materials. Because diamond is the hardest abrasive material, it is widely used as a superabrasive on saws, drills, and other devices which utilize the abrasive to cut, form or polish other hard materials. The total value of such tools consumed is believed to be over 5 billion U.S. dollars per year. More than half of the value of these tools is consumed in sawing applications such as cutting stones, concretes, asphalts, etc.

Diamond coated tools are particularly indispensable for applications where other tools lack the hardness and durability to be practical substitutes. For example, in the stone industry,

where rocks are cut, drilled, and sawed, diamond tools are about the only type which are sufficiently hard and durable to make the cutting, etc., economical. If diamond tools were not used, many such industries would be economically infeasible. Likewise, in the precision grinding industry, diamond tools, due to their superior wear resistance, are uniquely capable of developing the tight tolerances required, while simultaneously withstanding wear sufficiently to be practical.

Despite the prevailing use of diamond tools, these tools have suffered from several significant limitations which have placed unnecessary limits on the useful life of the tools. One such drawback is that the diamond grit is not attached to the matrix support material in a sufficiently strong attachment to maximize useful life of the cutting, drilling, polishing, etc., body. In fact, in most cases diamond grit is merely mechanically embedded in the matrix support material. As a result, diamond grit is often knocked out or pulled out prematurely during use. Moreover, the grit may receive inadequate mechanical support from the loosely bonded matrix under work conditions. Hence, the diamond particles could be shattered by the impact of the tool against the work piece to which the abrasive, etc., is applied.

It has been estimated that in a typical diamond tool, less than about one tenth of the grit is actually consumed in the intended application - i.e. during actual cutting, drilling, polishing, etc. The remainder of the diamond grit is either wasted by being leftover when the tool's useful life has expired, or is wasted by being pulled-out or broken during use due to poor attachment and inadequate support. Most of these diamond losses could be avoided if the diamond particles can be properly

positioned in and firmly attached to the surrounding matrix.

Furthermore, to ensure that the diamond grit is mechanically held sufficiently to remain in place, it must be buried deep in the matrix to prevent it falling out or being knocked free of the tool body during use. As a result, the protrusion of the diamond particle above the tool surface is insufficient. The low grit protrusion limits the cutting height for breaking the material to be cut. These limitations, in turn, limit the cutting speed of the cutting tool. If the diamond grit could be held more securely in the matrix, it could protrude higher from the matrix. The greater cutting depth would allow increased cutting speed and a greater useful life for the product. Moreover, due to the lower friction of the workpiece and tool matrix, the power required for cutting, drilling, etc., may also be reduced.

In order to anchor diamond grit firmly in the matrix, it is highly desirable for the matrix to form a carbide around the surface of the diamond. The chemical bond so formed is much stronger than the traditional mechanical attachment. The carbide may be formed by reacting diamond with a suitable carbide former such as a transition metal. Some examples of carbide forming transition metals are: titanium (Ti), vanadium (V), chromium (Cr), zirconium (Zr), molybdenum (Mo), and tungsten (W).

The formation of a carbide requires that the carbide former be deposited around the diamond and that the two subsequently be caused to react to form a carbide. Moreover, the non-reacted carbide former must also be consolidated by sintering or other means. All these steps require treatment at high temperatures. However, diamond may be degraded when exposed to a temperature above 1,000° C. The

degradation is due to either the reaction with the matrix material or the development of microcracks around metal inclusions inside the crystal. These inclusions are trapped catalysts used to synthesize the diamond.

Most carbide formers are refractory metals so they may not be consolidated below a temperature of about 1,200° C. Hence, refractory carbide formers are not suitable as the main constituent of the matrix support material.

There are, however, some carbide formers that may have a lower sintering temperature, such as manganese (Mn), iron (Fe), silicon (Si), and aluminum (Al). However, these carbide formers may have other undesirable properties that prohibit them from being used as the primary constituent of the matrix support material. For example, both manganese and iron are used as catalysts for synthesizing diamond at high pressure (above 50 Kb). Hence, they can catalyze diamond back to graphite during the sintering of the matrix powder at a lower pressure. The back conversion is the main cause of diamond degradation at high temperature.

Aluminum, on the other hand, has a low melting point (660° C), thus, making it easy to work with for securing the diamond particles. However, the melting point of aluminum can be approached when a diamond grit is cutting aggressively. Hence, aluminum may become too soft to support the diamond grit during the cutting operation. Moreover, aluminum tends to form the carbide Al_4C_3 at the interface with diamond. This carbide is easily hydrolyzed so it may be disintegrated when exposed to coolant. Hence, aluminum typically is not a suitable carbide former to bond diamond in a matrix.

To avoid the high temperature of sintering, carbide formers, such as tungsten, are often diluted

as minor constituents in the matrix that is made primarily, for example, of either cobalt or bronze. During the sintering process, there is a minimal amount, if any, of liquid phase formed. The diffusion of carbide former through a solid medium toward diamond is very slow. As a result, the formation of carbide on the surface of diamond is negligible. Therefore, by adding a carbide former as a minor matrix constituent, the improvement of diamond attachment is marginal at the best.

In order to ensure the formation of a carbide on the surface of diamond, the carbide former may be coated onto the diamond before mixing with the matrix powder. In this way, the carbide former, although it may be a minor ingredient in the matrix, can be concentrated around diamond to form the desired bonding.

The coating of diamond may be applied chemically or physically. In the former case, the coated metal is formed by a chemical reaction, generally at a relatively high temperature. For example, by mixing diamond with a carbide former such as titanium or chromium, and heated the mixture under a vacuum or in a protective atmosphere, a thin layer of the carbide former may be deposited onto the diamond. The thickness of the coating may be increased by increasing temperature. The deposition rate may also be accelerated by adding a suitable gas (e.g., HCl vapor) that assists the transport of the metal. For example, Chen and Sung (U.S. Patent No. 5,024,680) describes such a coating process.

Alternatively, the coating may be performed in a molten salt. For example, U.S. Patent No. 2,746,888 describes a method of coating a thin layer of titanium over diamond in a molten salt of chlorides.

A commonly used chemical method for coating diamond is chemical vapor deposition (CVD). In this

case, the deposited metal is produced by the reaction of gases at a high temperature. Thus, U.S. Patent No. 3,529,667 describes a technique to deposit a thin layer of silicon (Si) onto the surface of diamond. The temperature of this deposition is high enough so silicon carbide is formed instantaneously at the interface.

In order to prevent diamond from possible degradation by exposure to high temperatures, coating is produced at the lowest temperature possible. However, coating often becomes too thin when deposited at a low temperature. For example, the coating produced by a typical chemical method is about one micrometer thick. There are some commercial diamond grits that contain such thin coatings. For example, General Electric Company offers a saw grit that may be coated with a thin coating of either titanium or chromium.

However, when the thin coating is exposed to a high temperature, such as that which may be encountered during the sintering process, it can be easily oxidized in the atmosphere, or dissolved into the matrix metal. Thus, although a significant benefit is claimed for such commercially coated products, e.g., a one-third improvement in tool life, the ability for the thin coating to survive the manufacturing process is debatable.

In order to protect the thin metal coating, multiple layers of coating may be applied. Thus, U.S. Patent Nos. 5,232,469 and 5,250,086 described a second layer made of nickel, or another non-carbide former. The second layer may be deposited by an electroless process that is performed at a lower temperature. For more layers, Chen and Sung (U.S. Patent Nos. 5,024,680 or 5,062,865) describe a diamond grit with three layers of coating. In this case, the inner most layer is made of chromium, and it is overlaid by a secondary

metal layer such as titanium. The double layers are further wrapped in a third overcoat of a material such as tungsten. However, such a complicated coating system may be too costly to be economically feasible in the production of many cutting, drilling or polishing tools.

Alternatively, a chemical coating may be deposited relatively thick by a CVD method. For example, Sung, et al. (U.S. Patent Nos. 4,943,488 or 5,116,568) describes a fluidized bed system that can coat diamond with tungsten of a few tens of micrometers. But again, such a coating is expensive, and its application has not been widely used.

In contrast to chemical methods, a physical method may be inexpensive. Moreover, it may deposit a thick metal coating onto diamond at a very low temperature. For example, the author evaluated "Metal Coating of Saw Diamond Grit by Fluidized Bed" (see p267-273 of Fabrication and Characterization of Advanced Materials, edited by S. W. Kim and S. J. Park of The Materials Research Society of Korea 1995). The coating system is based on the method as described in U.S. Patent No. 4,770,907 (a similar concept is disclosed in U.S. Patent 5,143,523 or European Patent No. 0 533 443 A1). However, such a method, like many other similar processes, often produces coatings with different thickness. Moreover, only very fine (<5 micrometers) metal powders can be coated effectively onto the surface of diamond. Hence, although physical methods may be used to coat a diamond grit with an alloy that contains a carbide former, their benefits are limited.

When diamond is coated mechanically by a metal powder, as described in the above example, the powder is held loosely by an organic binder (e.g., PVA, or PEG). Such a coating may be easily rubbed off during the subsequent treatments, e.g., mixing or pressing.

Although heat treatment may increase the mechanical strength of the coating, it may not consolidate the coating to the full density. A porous coating lacks the mechanical strength necessary to support a diamond grit that is impacted repeatedly during the cutting operation.

Carbide formers may also be diluted in an alloy. If the alloy can melt below 1100° C, it may be used to braze the diamond without causing much degradation of the latter. Many diamond brazes are known in the art. Most are based on Group Ib solvents (copper, silver and gold) that contain one or more carbide formers, e.g., gold-tantalum (Au-Ta), or silver-copper-titanium (Ag-Cu-Ti). These brazes, however, are typically too expensive for commercial use. Moreover, they are soft and unsuitable as ingredients for the matrix support material of diamond tools.

There are some high temperature filler metals that may be used to braze diamond. Such brazes may be hard enough to hold a diamond grit in place during cutting. For example, U.S. Patent Nos. 3,894,673 and 4,018,576 describe diamond tools made by brazing a hard facing alloy that contains nickel-chromium (Ni-Cr) as the major constituent. However, these brazed diamond tools, although useful, are generally limited as surface set tools that contains only one layer of diamond. Such tools may not last when they are used to cut highly abrasive materials, e.g., granite. Moreover, the braze in these tools, in addition to holding the diamond, must also serve as the hard facing. The compromise of these dual-functions may not always be possible as the optimal wear resistance of the tool surface may need to be adjusted for specific applications.

Alternatively, a diamond bonding alloy may be used to infiltrate a high concentration (i.e greater than 40 % by volume) of diamond particles. Thus, Chen

and Sung (U.S. Patent Nos. 5,030,276 or 5,096,465) describe such a product and the process of making the same. However, the infiltration is very difficult due to the high concentration of diamond. Moreover, such products have limited applications, such as a drill bit. They are not applicable for most applications that require a lower concentration (i.e., less than 40 % by volume) of diamond, such as saw blades and grinding wheels.

The hard facing alloys may also be used as the matrix support material. For example, U.S. patent 4,378,975 describes a method to coat diamond with a very thin layer of chromium, and subsequently palletizing the coated grit with a nickel-chromium alloy. The palletized particles are then consolidated by sintering the alloy. However, as the consolidation process is taking place primarily in a solid phase, the bonding of matrix and diamond may not be sufficient.

In addition to sintering, infiltration is also a common technique for making diamond tools, in particular for drill bits and other specialty diamond tools that contain a large (i.e. greater than U.S. mesh 30/40) diamond grit. For example, U.S. Patent No. 4,668,522 describes a process to infiltrate a rotary drill bit with a copper alloy at a temperature lower than 850° C (preferably 750° C). Most commonly used infiltrants for these tools are copper based alloys. These infiltrants must flow and penetrate the small pores in the matrix powder. In order to avoid the diamond degradation at high temperature, the melting point of the infiltrant must be low. Hence, the infiltrant often contains a low melting point constituent, such as zinc (Zn). In addition to lowering the melting point of the infiltrant, the low melting point constituent also reduces the viscosity so the infiltrant can flow with ease. However, as

most carbide formers tend to increase the melting point of the infiltrant, they are excluded from most infiltrants. As a result, these infiltrants cannot improve the bonding of diamond.

Some infiltrants do contain a carbide former that may facilitate the bonding of diamond. U.S. Patent No. 5,000,273 describes an abrasive tool that is produced by infiltrating a matrix powder with an alloy that contains the major constituents of copper, manganese and zinc. However, as discussed above, zinc is added to increase the fluidity of the infiltrant, and it may not be suitable for making certain products that is produced under different environments. For example, if infiltration is performed under a vacuum, zinc may be vaporized. As a result the remaining alloy may become too viscous to infiltrate completely the matrix powder.

Thus, there is a need for an improved method of infiltrating the matrix powder to bond the diamond thereto. Such a method should be able to be accomplished at a sufficiently low temperature to avoid potential damage to the diamond. Additionally, such a method should be designed to improve the bonding of the diamond to the matrix support material.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an improved method for forming tools having diamond particles disposed therein/thereon.

It is another object of the present invention to provide such a method wherein the diamond particles are disposed in a matrix support material, and then the matrix support material infiltrated with a braze to bond the diamond particles to the matrix support materials.

It is yet another object of the present invention to provide such a method wherein the brazing occurs at

sufficiently low temperatures to prevent thermal damage to the diamond particles.

It is still another object of the present invention to provide such a method wherein the matrix support material is specifically selected to provide numerous pores through which the brazing material may flow and thereby facilitate chemical bonding of the diamond and matrix support material.

It is still yet another object of the present invention to provide such a method wherein the diamond particles are disposed in the matrix support material in some predetermined pattern, to thereby lengthen the useful life of the tool to which the diamond and matrix support material are attached.

The above and other objects of the invention are realized in specific illustrated embodiments of a novel method for forming brazed diamond tools, and for tools made by the novel method. The method includes forming a sheet of matrix support material, and then disposing a plurality of diamond particles in the matrix support material. Preferably, the amount of diamond particles to matrix support material is preferably less than 50 percent by volume, and most preferably less than 40 percent by volume. The diamond impregnated sheet is then infiltrated by a braze which is capable of wetting the diamond, so as to form a chemical bond with the diamond. The braze also bonds to the matrix support material, thereby creating a chemical bond connecting the diamond to the matrix support material, rather than relying on a simple mechanical attachment in accordance with the prior art. Although the technique is most suitable for making saw blades, its applications can extend to all diamond tools.

In accordance with one aspect of the present invention, the matrix support material may be made of common metal powder. Examples of such metal powder

are cobalt, nickel, iron, bronze or their alloys or mixtures (e.g., tungsten or its carbide). After formation of the matrix support material is then infiltrated by a diamond braze, such as Nicrobraz L. M. (made by Wall Colmonoy Company), either under a vacuum, typically about 10^{-3} torr, or in an inert atmosphere (e.g., argon (Ar) or nitrogen (N_2)) or a reducing atmosphere (e.g., hydrogen (H_2)). The braze, thus, facilitates bonding between the diamond particles and the matrix support material.

In accordance with another aspect of the present invention, the matrix support material is formed by coarse metal powder (i.e. greater 400 mesh U.S. or 34 microns). While conventional methods require the density of the green body be as high as possible so subsequent sintering can proceed rapidly, it has been found in accordance with the present invention, that it is preferable to use a precursor with a lower packing density to allow the easy flow of the diamond braze. In some situations, the porosity of the precursor body may be intentionally increased by using irregularly shaped matrix particles. This preference is again contrary to the conventional wisdom that requires the particles be as spherical as possible so the packing density can be increased.

In accordance with yet another aspect of the present invention, the diamond particles are placed in a predetermined pattern within the matrix support material, and the diamond impregnated matrix support material is then impregnated with the diamond braze to promote chemical bonding of the diamond material. The predetermined pattern may be substantially planar, i.e. the diamond placement may be controlled by the use of a template, or may be substantially vertical, with channels being formed in the matrix support material to receive diamond particles, which are then infiltrated with the diamond braze.

In accordance with still yet another aspect of the present invention, the matrix support material may contain minor ingredients to enhance certain properties. For example, hard materials such as tungsten, tungsten carbide and silicon carbine may be added to increase wear resistance. Soft materials, such as molybdenum sulfide, copper, and silver, may also be added as solid lubricants.

The supportive material may be prepared by a conventional method. For example, the powder may be mixed with diamond grit thoroughly. An organic binder (e.g., PVA or PVB) may be added to hold the mixture. The mixture is then cold pressed to form the desirable shape (e.g., a saw blade). The precursor is then ready to be infiltrated by a suitable diamond braze.

As discussed, a fine matrix powder used for conventional tools may hinder the infiltration of the diamond braze. Moreover, it would react excessively with the braze so the melting temperature of the braze is raised. As a result, the infiltration may not be complete.

Alternatively, the mixture may be processed following the teaching of applicant's other, copending patent application (U.S. Patent Application, Serial No. 08/832,852 (identified as attorney docket no. TS100), filed April 4, 1997). For example, the powder blend of the supportive material may be cold rolled to form a sheet. The sheet can them be punched out with a desirable shape (e.g., a saw segment) (See Fig. 1). Several such punched segments may be assembled to form the precursor (see Fig. 2,3,4) for infiltration. As described in the pending patent application, by assembling substantially two-dimensional segments to form a three-dimensional body, the distribution of diamond grit in a tool can be positively controlled. Thus, diamond concentration in different parts of the same tool may be adjusted (see FIGS. 1A through 4).

Such a control of diamond distribution is highly desirable to improve the wear characteristics of the tool. For example, the sides of a diamond saw blade are often worn faster then the center, so it is advantageous to add more diamond grit on to the sides (see FIG. 1B).

Current applications require the matrix support material to serve dual functions: to provide the mechanical support of the tool, and to hold the diamond grit in the matrix. These two functions often demand contradictory properties. For example, as the mechanical support, the matrix support material must be strong and wear resistant (e.g., cobalt, or bronze mixed with tungsten carbide). However, the material with good mechanical support is often ineffective to adhere the inert diamond. On the other hand, a braze alloy (e.g., silver-copper-titanum alloys) may hold diamond firm, but are too soft to provide the mechanical support for the tool body. Thus it is desirable to separate these two functions of the matrix support material by using a composite material. In this case, the framework of the composite material is optimized for mechanical support, yet the filler material is designed to hold the diamond.

The composite material may be made by using coated diamond as discussed above. In this case, a diamond braze may be used to coat the diamond grit first and the coated grit is subsequently mixed in the matrix powder. However, the coating incurs an additional cost. Moreover, most diamond brazes are not in a powder form. Even if they were, it is very difficult to coat these brazes uniformly onto the diamond grit. As a result, coated diamond grit is seldom used today in making diamond tools.

The present invention makes the composite matrix support material by infiltrating a diamond braze into a supporting material that contains diamond grit. The

braze includes carbide formers such as chromium, manganese, silicon and aluminum, while avoiding volatile metals such as zinc, lead and tin.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the invention will become apparent from a consideration of the following detailed description presented in connection with the accompanying drawings in which:

FIG. 1A shows a segment from a superabrasive tool formed by a plurality of linear, longitudinal layers disposed adjacent one another to form a three-dimensional superabrasive member;

FIG. 1B shows a cross-sectional view of one typical configuration of the tool segment shown in FIG. 1A, wherein a layer formed by a matrix support material and a relatively large superabrasive is sandwiched between two layers of matrix support materials which have smaller grit and higher concentration of the abrasive;

FIG. 2A shows a segment from a superabrasive tool formed by a plurality of arcuate, longitudinal layers which are attached to one another to form a three-dimensional superabrasive member;

FIG. 2B shows a cross-sectional view of a plurality of layers matrix support material as may be used with the segment shown in FIG. 2A;

FIG. 3 shows another possible layout of a segment of a cutting tool with transverse layers configured with a denser concentration of abrasive material disposed at a forward, cutting end of the three-dimensional superabrasive member;

FIG. 4 shows yet another layout of a segment wherein a three-dimensional superabrasive member is formed with progressively denser abrasive distribution

toward the upper surface of a tool with horizontal layers;

FIGs. 5A through 5D show one possible method for forming layers with controlled superabrasive distribution within the layer;

FIGs. 6A through 6C show an alternate method for forming one or more layers with controlled superabrasive distribution;

FIG. 7A shows a side view of a matrix support material formed in accordance with one aspect of the present invention, wherein a plurality of slots are formed in the matrix support material;

FIG. 7B shows a side view of the matrix support material of FIG. 7A, wherein a plurality of diamond particles are disposed in the slots and brazed to bond with the matrix support material and thereby form a plurality of abrasive fins in the matrix support material; and

FIG. 8 shows a perspective view of the matrix support material similar to that shown in FIGs. 7A and 7b, but with a plurality of abrasive needle structures.

DETAILED DESCRIPTION

Reference will now be made to the drawings in which the various elements of the present invention will be given numeral designations and in which the invention will be discussed so as to enable one skilled in the art to make and use the invention. It is to be understood that the following description is only exemplary of the principles of the present invention, and should not be viewed as narrowing the pending claims.

Referring to FIG. 1A, there is shown a perspective view of a segment, generally indicated at 10, formed by a plurality of layers, 14, 16 and 18. Each of the layers 14, 16 and 18 is formed by matrix

support material 24 impregnated with diamond particles, indicated by the circles 20, and has been infiltrated with a braze 28 selected to bond to the diamond particles and the matrix support material. Preferably, the diamond particles 20 constitute less than 50 percent by volume of the matrix support material - diamond mixture, and more preferably less than 40 percent by volume. Keeping the amount of diamond particles to the minimum helps to minimize cost while optimizing the useful life of the product.

Preferably, the diamond braze contains at least 3% by weight of a member selected from the group consisting of chromium, manganese, silicon and aluminum, and alloys and mixtures thereof. Additionally, the diamond braze should have a liquidus temperature of less than 1,100° C to avoid damage to the diamond during the brazing process.

As discussed in U.S. Patent No. _____ (U.S. Patent Application, Serial No. 08/832,852 (Attorney Docket No. TS100)), which is expressly incorporated herein, forming the segment 10 in a plurality of thin layers provides remarkably improved control over the distribution of the diamond particles 20. By controlling the distribution of the diamond particles 20 within each layer and then combining layers, a three-dimensional segment can be formed in which distribution of the diamond particles is controlled in each dimension. This, in turn, enables the formation of segments which are particularly adapted to the likely use of the segment, be it for polishing, cutting, grinding, etc. By tailoring the distribution and concentration of the superabrasive particles within the segment 10, more precise control is given over performance of the tool under actual working conditions.

The present invention further improves the above technique by infiltrating the matrix support material

24 with a braze 28 which is selected to chemically bond to the diamond particles and to the matrix support material. Thus, while the placement of the diamond particles shown in FIG. 1A is a marked improvement over the prior art, an additional increase in the segment's 10 useful life is obtained by utilizing a braze to form a chemical bond, rather than merely relying on mechanical retention of the diamond particles.

Likewise, the selective placement of differing sizes of diamond particles can used to form a cutting segment formed to resist premature wear to the sides of the segment, thereby extending the cutting segment's useful life. Referring specifically to FIG. 1B, there is shown a cross-sectional view of the cutting segment 10 of FIG. 1A. Unlike the cutting segments of the prior art, the cutting segment 10 is formed of three layers, 14, 16 and 18 respectively. The middle layer 16 has a plurality of superabrasive particles 20a which are of a first size (e.g. 40/50 mesh) and a first concentration. The outer layers 14 and 18, in contrast, have a plurality of superabrasive particles 20b, which are of a second size (e.g. 50/60 mesh) smaller than the first size, and in a second concentration greater than that present in the middle layer 16. The smaller, more densely distributed superabrasive particles 20b provide the outer layers 14 and 18 with a greater resistance to wear as they cut through concrete, rock, asphalt, etc. Because the outer layers 14 and 18 are more resistant to wear, the cutting segment 10 resists formation of a convex outer surface, as has traditionally occurred with cutting elements. By maintaining a more planar cutting surface, the cutting segment is able to maintain a straight cutting path so it can cut more efficiently with a longer useful life.

Furthermore, an additional increase in useful life is obtained by infiltrating the matrix support material 24 with a braze 28 formed from chromium, manganese, silicon, and/or aluminum, or an alloy or mixture thereof. While a wide variety of quantities of these materials may be used, it has been found that it is preferable if the chromium, manganese, silicon or aluminum or alloy or mixture in the diamond braze constitutes at least 3 percent of the braze by weight (and more preferably 5 percent). The braze 28 fills the pores in the matrix support material 24, which is typically powder selected from the group including iron, cobalt, nickel or alloys or mixtures thereof.

Another advantage to the use of multiple layers of matrix with diamond or some other superabrasive particle disposed therein is that the layers are easily formed into other desirable shapes for the cutting, drilling, grinding, etc., segment. For example, FIG. 2A shows a perspective view of a segment, generally indicate at 30, of a superabrasive tool formed by a plurality of arcuate, longitudinal layers which are attached to one another to form a three-dimensional superabrasive member which has been infiltrated with the braze 28 to thereby hold the diamond within the member. The segment 30 is formed from first, second and third layers, 34, 36 and 38, which are each arcuate. When the three are joined together, an arcuate segment 30 is created. Such a segment, of course, may be used on cutting tools which are non linear, e.g. a circular saw blade, and on other types of tools for which a nonlinear superabrasive segment is desired. Because the layers 34, 36 and 38 are initially formed independent of one another, they are much easier to conform to a desired shape, and are able to do so while the brazed diamond particles 20 disposed therein are held in their predetermined positions.

Referring now to FIG. 2B, there is shown a cross-sectional view of a plurality of the layers 34, 36 and 38 of the segment 30. Of course, the configuration of the diamond particles may be used with the segment shown in FIG. 1A or that shown in FIG. 2A. Unlike the embodiment of FIG. 1B, the layers are each provided with the same size and concentration of the diamond particles 20. However, because the spacing is substantially uniform, there is no underspacing or overspacing between the superabrasive particles, and the segment 30 wears more evenly than the segments of the prior art with randomly spaced particles. The more even wear prevents premature failure of the segment 30, and thus extends the life of the tool while keeping the amount of superabrasive used to a minimum. Furthermore, the braze 28 which bonds to the diamond particles and the matrix 24 further strengthens each layer and prevents loss of the diamond particles 20.

FIG. 3 shows another possible embodiment of a segment 50 made in accordance with the teachings of the present invention. The layered structure in a diamond segment may also be assembled transversely or horizontally, and the braze 28 may be applied to every layer, or to select layers as shown in FIG. 3. Thus, the segment 50 in FIG. 3 is formed from a plurality of transverse layers. A first plurality of the layers (i.e. the first four layers), indicated at 56, are provided with a first concentration of diamond particles 20 which are brazed to bond to the matrix support material 24. A second plurality of layers (i.e. the remaining 9 layers), indicated at 58, are provided with a second concentration, less than the first concentration and are also brazed to bond to the matrix support material 24.

Many cutting tools are configured such that the cutting segment 50 is provided with a lead edge which

performs a majority of the cutting and which receives most of the impact force when contacting the surface to be cut. For example, a circular saw blade will usually have a plurality of teeth or segments, each tooth having a leading edge which takes the force of the cutting. Because the leading edge performs a significant portion of the cutting, it is much more susceptible to wear than are rearward portions of the tooth. When formed in accordance with the prior art, the teeth, however, often had relatively consistent concentrations of abrasive disposed thereon. Over time the leading edge wears significantly, but the other portions coated with diamond particles are subjected to minimal wear. Eventually, the abrasive is worn off the leading edge, while significant amounts remain on the other portions of each tooth. Thus, a considerable amount of superabrasive is wasted when the blade is discarded. The embodiment of FIG. 3 is specifically configured to overcome such concerns. The layers 56 and 58 are configured to provide substantially even wear across the cutting segment 50 by placing a larger percentage of the diamond particles 20 near the leading edge, than on the rear portions. Additionally, brazing the diamond particles 20 in layers 56 and 58 further extends tool life.

FIG. 4 shows yet another layout of a segment wherein a three-dimensional superabrasive member is formed with progressively denser abrasive distribution toward the upper surface of a tool with horizontal layers. As with the embodiment of FIG. 3, the controlled distribution of the diamond particles 20 forms an improved abrasive segment 70, while at the same time decreasing the cost of abrasive tools by decreasing the unnecessary consumption of diamond particles. Additionally, brazing may be used on some of the layers, while being omitted from other layers, to thereby customize the abrasive segment 70.

With routine experimentation and the teachings of the method of the present invention, those skilled in the art will be able to customize cutting, drilling, grinding, polishing and other types of abrasive segments which are specifically formed to maximize their abrasive ability (i.e. cutting, drilling, grinding, etc.) over an extended useful life, while simultaneously decreasing the amount of superabrasive which is used to form the tool.

Referring now to FIGs. 5A through 5D, there is shown one method for forming layers in accordance with the principles of the present invention. The first step of the method is to form a sheet 100 of matrix support material 104 which will be bonded to the superabrasive particles 20. The sheet 100 of matrix support material 104 can be formed from conventional powders such as cobalt, nickel, iron, copper or bronze. Additionally, for reasons which are discussed in detail below, it is highly advantageous to use coarse powders, such as those above 34 microns in diameter. While the use of course powders is inconsistent with the prior art teachings that it is desirable to use the finest powder available, considerable benefits may be achieved by combining course powder and braze to secure diamond particles in place.

There are many ways that a matrix powder can be made into the sheets 100. For example, the powder can first be mixed with a suitable binder (typically organic) and a solvent that can dissolve the binder. This mixture is then blended to form a slurry with a proper viscosity. In order to prevent the powder from agglomeration during the processing, a suitable wetting agent (e.g., menhaden oil, phosphate ester) may also be added. The slurry can then be poured onto a plastic tape and pulled underneath a blade or leveling device. By adjusting the gap between the

blade and the tape, the slurry can be cast into a plate with the right thickness. The tape casting method is a well known method for making thin sheets out of powdered materials and it works well with the method of the present invention.

Alternatively, the powder can be mixed with a suitable binder and its solvent to form a deformable cake. The cake can then be extruded through a die with a slit opening. The gap in the opening determines the thickness of the extruded plate. Alternatively, the material can also be drawn between two rollers with adjustable gap to form sheets with the right thickness.

It is desirable to make the sheets pliable for subsequent treatments (e.g., bending over the tool substrate). Therefore, a suitable organic plasticizer can also be added to provide the desired characteristics.

The use of organic agents for powder (metal, plastics, or ceramics) processing is documented in many text books and it is well known by those skilled in the art. Typical binders include polyvinyl alcohol (PVA), polyvinyl butyral (PVB), polyethylene glycol (PEG), pariffin, phenolic resin, wax emulsions, and acrylic resins. Typical binder solvents include methanol, ethanol, acetone, trichlorethylene, toluene, etc. Typical plasticizers are polyethylene glycol, diethyl oxalate, triethylene glycol dihydroabietate, glycerin, octyl phthalate. The organic agents so introduced are to facilitate the fabrication of metal layers. They must be removed before the consolidation of metal powders. The binder removal process (e.g., by heating in a furnace with atmospheric control) is also well known to those skilled in the art.

Once the sheet 100 of matrix support material 104 is formed, a template 110 is laid on the top of the sheet. The template 110 contains apertures 114 that

are larger than one abrasive particle 20, but smaller than two abrasive particles, thereby allowing a single particle of the abrasive to be disposed at each specific location.

The thickness of the template is preferably between 1/3 to 2/3 of the height of the average abrasive particle 20. However, other thicknesses may be used if appropriate accommodations are made for seating the abrasive particles in the desired locations.

After the template 110 is properly positioned, a layer of abrasive particles 20 is then spread over the template so that each aperture 114 receives an abrasive particle. Those particles not falling into the apertures 114 in the template 110 are removed by tilting the substrate, sweeping the template with a broom, or some other methods.

As shown in FIG. 5B, a generally flat surface 120, such as a steel plate, is then laid over the particles 20 which rest in the apertures 114 in the template 110. The flat surface 120 presses the abrasive particles 20 at least partially into the pliable sheet 100 of matrix support material 104 to seat the particles.

After removing the template 110, the flat surface 120 is used again to press the abrasive particles 120 firmly into the sheet 100 of matrix support material 104 as shown in FIG. 5C. While the flat surface 120 is preferable, those skilled in the art will appreciate that there may be occasions when it is desirable to have some of the abrasive particles 20 extend outwardly from the sheet 100 of matrix support material more that other abrasive particles. In such situations, a contoured or otherwise shaped surface could be used to seat some of the abrasive particles 20 deeper into the sheet 100 of matrix support material 104, than other particles.

If desired, the process shown in FIGs. 5A through 5C can be repeated on the other side of the sheet 100 of matrix support material 104 (as shown in FIG. 5D), to form an impregnated layer having diamond particles 20 distributed throughout the layer in some predetermined, desired pattern. The process is typically repeated several times to obtain multiple thin layers or sheets 100 which are impregnated with the diamond particles 20. Of course, each sheet 100 need not have the same distribution pattern for the diamond particles 20, nor need the concentration of the abrasive particles be the same in each sheet.

The abrasive impregnated sheets 100 are then infiltrated with a braze which is formed with chromium, manganese, silicon, aluminum or alloys or mixtures thereof. While prior art brazes typically includes metals which were designed to facilitate flow of the braze material, such as zinc, lead and tin, it has been found in accordance with the present invention that such materials actually impair the brazing process. The materials are generally more volatile, and have a tendency to contaminate the vacuum or inert atmosphere used in infiltration. While very small amounts of the volatile metals will not significantly interfere with brazing, amounts over about 1 or 2 percent can be undesirable. As used herein, substantially free of volatile metals, or substantially free of zinc, etc. is used to characterize such a situation in which the volatile metal is present in sufficiently small amounts as to not provide any impediment to the process of vacuum infiltration.

It is important that the infiltration temperature be kept lower than the melting point of the matrix powder so the tool body can maintain the shape during the infiltration of the diamond braze. Moreover, the brazing temperature must also be low enough to not

cause diamond to degrade. In addition to control the brazing temperature, the brazing time should also be kept short so the braze will not react excessively with diamond and the matrix powder. In the former case, diamond may also be degraded. In the later case, the alloying with the matrix powder may raise the melting point of the diamond braze. As a result, the diamond braze may solidify gradually and eventually stop to flow.

The environment for infiltration also may be controlled to provide superior performance. For example, if the braze material contains a strong getter of oxygen or nitrogen, such as titanium, a high degree of vacuum (e.g., 10^{-5} torr maximum) must be maintained during the infiltration of the braze. On the other hand, if the braze material contains a less sensitive getter, such as chromium and manganese, a lower degree of vacuum (e.g., 10^{-4} torr minimum) or a hydrogen atmosphere may be adequate for the infiltration.

After the infiltration, the produced part (e.g., a saw segment) may be trimmed (e.g., by grinding) to the finished dimension. It can then be mounted (e.g., by brazing) onto a tool body (e.g., a round steel blade) to make a finished product.

As discussed above, this invention uses a diamond braze as the infiltrant that penetrates the matrix powder of a diamond tool. Most diamond brazes can wet easily common matrix powders with major constituents of cobalt, nickel, iron, copper or bronze, so the infiltration may proceed smoothly.

In contrast to a sintering process that eliminates pores in the matrix powder by consolidation, the infiltration allows the diamond braze to fill up these pores. Sintering is achieved by diffusion of atoms mainly along surfaces. In order to facilitate the sintering process the matrix powder

must have large surface areas. Hence, in sintering, it is preferable to use fine powders. The fine powder can allow the sintering to proceed at a lower temperature.

The most widely used matrix powder for making diamond tools (e.g., saw segments) is cobalt powder. The standard sizes of cobalt powder for making conventional diamond tools are less than 2 micrometers. In the last decade, the diamond tool manufacturers have demanded finer and finer matrix powders. The commercial suppliers (e.g., Eurotungsten Co.) are therefore, moving toward making ultrafine (one micrometer), and even ultra-ultrafine (submicron) powders. With such a trend, the sintering temperature is continuously decreasing. A lower sintering temperature can not only reduce the degradation of diamond, it also reduces the cost of manufacturing. For example, the electrical power consumption for heating is lower. Moreover, the oxidation loss of graphite mold is also minimized.

The present invention, however, uses a diamond braze to fill up the pores of the matrix powder. Hence, contrary to a conventional sintering process, coarse-sized powders, i.e. greater than 400 U.S. mesh or 34 microns, are preferred. Moreover, while conventional methods require the packing density be as high as possible so sintering can proceed rapidly, the present invention prefers to use a precursor with a lower packing density to allow the easy flow of the diamond braze. In fact, sometimes, the porosity of the precursor body may be intentionally increased by using irregularly shaped matrix particles. This preference, again, is contrary to the conventional wisdom that requires the particles be as spherical as possible so the packing density can be increased.

As discussed, a fine matrix powder used for conventional tools may hinder the infiltration of the

diamond braze. Moreover, it would react excessively with the braze so the melting temperature of the braze is raised. As a result, the infiltration may not be complete.

The use of a coarse matrix powder has other benefits. For example, a coarse powder can mix better with different compositions. Hence, the diamond grit may distribute more uniformly in the matrix. Moreover, a coarse powder has a smaller surface area, and hence, a lower frictional force for infiltration. Therefore, it can flow easier in the mold. Of course, a coarse matrix powder is also much less expensive, so the production cost may be reduced.

It is important to note that this invention utilizes the matrix merely as the network for holding the diamond grit in place. Hence, the matrix may not have to be made of powder. For example, the matrix body may be made of a piece of steel with openings that contain diamond grits of PCD bodies, such as that which is discussed below with respect to FIGs. 7A and 7B.

The most critical part of this invention is in the selection of a diamond braze. Although there are numerous kinds of diamond brazes, only those that meet the following requirements are applicable. Firstly, the infiltration temperature of the braze must not be so high as to cause significant diamond degradation. The temperature limit is, in general, about 1100° C. The infiltration temperature can be 50° C above the liquidus of the braze. A course matrix powder and a shorter infiltration path requires a lower excess temperature beyond the melting point of the braze.

The diamond braze must wet the diamond and chemically bond with the diamond. As discussed above, a carbide former dissolved in a suitable solvent alloy can meet this requirement. However, the reactivity of the carbide former must be balanced between diamond

and oxygen or other gases such as nitrogen or hydrogen. It is a dilemma that a strong carbide former, such as titanium or zirconium that bonds diamond well are also gas scavengers. They would react quickly with harmful gases in the ambient atmosphere before forming the carbide with diamond.

Most diamond tools are manufactured in a graphite mold often in air or in an inert gas. The minute amount of oxygen or moisture in the atmosphere may oxidize the carbide former so the latter may not bond to diamond. This is true even if the brazing is performed in a vacuum or in a hydrogen atmosphere, unless the vacuum is kept lower than 10^{-6} torr, or the dew point of the gas is kept below - 60° C. Such a stringent requirement of vacuum or dew point often adds unnecessary cost to manufacturing.

On the other hand, if the reactivity is low, such as that of cobalt or nickel, the metal can be processed in graphite mold without being oxidized. However, it cannot bond to diamond either. Hence, there is a compromise for the carbide former between its ability to bond with diamond and its tendency to be oxidized.

In accordance with the present invention, it has been found that the preferred carbide former for the diamond braze is either chromium, manganese, silicon, aluminum or their alloys. The preferred total content of such carbide former is at least 3 percent, and more preferably at least 5 percent by weight. Examples of these brazes are NICROBRAZ LM (Ni-CR-B-Si-Fe), manufactured by Wall Colmonoy Company (U.S.A.), with a melting range of 970-1000° C, and 21/80 (Cu-Mn-Ni), manufactured by Degussa (Germany), with a melting range of 970-990° C. Other possible brazes include: Cu-Mn alloy near the eutectic composition (about 25 wt% Mn) with a melting point of about 880° C; Ni-Si alloy near the eutectic composition (about 50 wt% Si)

with a melting point of about 970° C; Cu-Si alloy near the eutectic composition (about 30 wt% Si) with a melting point of about 810° C; Al-Si alloy near the eutectic composition (about 15 wt% Si) with a melting point of about 600° C.

The above examples of infiltratable diamond brazes cover a wide range of mechanical properties and infiltration temperatures (e.g. about 50° C above the liquidus). The alloys of them may also be used for further adjustments of infiltration temperature and mechanical properties. The selection of diamond braze depends on the intended application. In general, more severe applications, such as sawing granite, concrete, or asphalt) would require a stronger diamond grit that may tolerate a higher temperature of brazing. Brazes which melt at higher temperatures are, in general, more wear resistant. On the other hand, less demanding applications, such as sawing limestone or marble, require lower strength diamond grit. Such a diamond is degraded easily at high temperature so it must be brazed at a lower temperature. Brazes of this type are typically less wear resistant.

The sheets 100 may be first assembled to form the precursor of the tool segment and then infiltrated with diamond braze, or they can be infiltrated by the braze and later assembled to form the tool segment or the entire tool body where appropriate. While the method described in FIGs. 5A through 5D is preferred for many applications, there are instances where it is desirable to have the abrasive particles 20 extend outwardly from the sheet 100 of matrix support material. For example, some tools may only have one layer of abrasive. This can be accomplished simply by leaving the template 110 in place when performing the steps shown in FIG. 5A and 5B, and not further

pressing the particles 20 into the matrix support material once the template has been removed.

In the alternative, FIGs. 6A through 6C show a side view of an alternate to the method discussed in FIGs. 5A through 5D. The sheet 130 of matrix support material in FIGs. 6A through 6C is formed to be of a lesser thickness than the cross-sectional thickness or diameter or the superabrasive particles 20. When the particles or pressed into the sheet 130, the thickness of the sheet forces the particles 20 to protrude from the matrix support material 134. The sheet 130 is then infiltrated with diamond braze in the manner discussed above.

While the use of the diamond braze 28 has been discussed with respect to the patterned distribution of diamond particles, it is equally applicable to the random distribution of diamond particles in a matrix support material. Once the diamonds have been placed in the matrix support material, a diamond braze comprising chromium, manganese, aluminum or silicon, and being substantially free of volatile metals, is melted and poured onto the matrix support material. The liquidous braze infiltrates the matrix support material and bonds the diamond particles to the matrix support material.

In addition to its use with conventional matrix support materials, such as metal powders, the diamond braze also facilitates the use of novel support materials, such as that shown in FIGs. 7A and 7B. Referring specifically to FIG. 7A, there is shown the matrix support material 200 of a saw segment, generally indicated at 210. The matrix support material 200 includes a plurality of slots 214 which are cut in specific intervals.

To form a finished cutting segment, the matrix support material 200 is placed in a mold (e.g. graphite or metal) made of refractory material (e.g.,

graphite). Diamond particles 20 (FIG. 7B) is poured into the slots 214 to fill the open slots. Diamond braze is added on top of these slots. After infiltration, the braze will fill in these slots and bond with the diamond particles 20, and with the matrix support material 200 to form a completed saw segment 210. In this geometry, the diamond particles form blades in the saw segment (FIG. 7B) instead of distributing throughout the matrix body as in the case of a conventional tool. Those skilled in the art will appreciate that such a configuration would be nearly impossible in accordance with the teachings of the prior art, because the matrix support material 200 was required to hold the diamond particles in place mechanically. In contrast, the use of the diamond braze enables the positioning of columns of diamond particles in a slot, hole, etc., because the braze bonds to the diamond and to the support material, the diamonds are secured in place. While the embodiment shown in FIGs. 7A and 7B forms diamond "fins", needle like columns of diamond also can be formed (FIG. 8). Furthermore, the slots, hole, etc, can be formed to provide such columns which are linear, or which curve in any desired direction. Thus, with routine experimentation, those skilled in the art can customise cutting, drilling, polishing, etc., segments which are customized to particular uses. The diamond particles used may be either diamond grit or thermally stable polycrystalline diamond (PCD). The infiltration will not only consolidate the matrix powder, but also bond the diamond firmly, so an integrated diamond tool is formed.

Example 1

40/50 mesh diamond grit (SDA-85+ made by De Beers Company) was mixed with iron powders coarser than 200 U.S. mesh, and an organic binder to form a mixture with diamond concentration of 20 (5% of total volume).

The mixture was cold pressed in a steel mold to form the shape of a saw segment. The precursor was placed in a graphite mold and overlaid with a powder of Nicrobraz LM. The mold was heated under vacuum to about 1,050° C for 20 minutes. The infiltrated braze had bonded diamond and matrix powder together to form a segment. Twenty-four of such segments were manufactured and they were trimmed to desirable tolerances. These segments were brazed onto a 14 inch round steel circular saw blade. The blade was used to cut granite at a faster cutting rate than was possible with conventional diamond saw blades. Additionally, the brazed saw blades had a longer useful life than a conventional diamond saw blade.

A distinct advantage cutting tools of the present invention have over the prior art cutting tools lies in the manner in which the tool may be used. Diamond saws are typically made in the form of a circular blade that cuts the workpiece by rotation in the same direction with each rotation. This one directional movement causes a "tail" to be formed, wherein the matrix material rotationally forward of the diamond particle is worn away, but the matrix material behind the diamond particle is protected by the diamond particle itself. Thus, the matrix material behind the diamond continues to hold the diamond particle in place. If the saw rotation were to be reversed, the diamond particle could easily be knocked free of the matrix.

Round saws, however, can only cut the work piece to a depth of less than one-half the diameter of the saw. In order to cut thicker work pieces, a frame or gang saw is typically used. Because these saws move reciprocally, the diamond particles must be securely held on each side. As a result, tails of diamond matrix cannot be maintained to hold the diamond particles in place. It is for this reason that

reciprocating diamond saws have not been used to saw hard rock such as granite. Rather, they are used to cut only soft materials such as marble.

This invention allows diamond to be held chemically by a braze. Hence, matrix tails are not needed to support the diamond. As a result, tools made according to the present invention can be used on reciprocating saws to cut hard materials. This breakthrough can expand diamond applications to markets which were previously unavailable due to limitations of the prior art.

Thus, there is disclosed an improved method for making diamond saw blades. The above description and examples are intended only to illustrate certain potential uses of this invention. It will be readily understood by those person skilled in the art that the present invention is susceptible of a broad utility and applications. Many embodiments and adaptations of the present invention other than those herein described, as well as many variations, modifications and equivalent arrangements will be apparent from or reasonably suggested by the present invention and the forgoing description thereof without departing from the substance for scope of the present invention. Accordingly, while the present invention has been described herein in detail in relation to its preferred embodiment, it is to be understood that this disclosure is only illustrative and exemplary of the present invention and is made merely for purpose of providing a full and enabling disclosure of the invention. The forgoing disclosure is not intended or to e construed to limit the present invention or otherwise to exclude any such other embodiment, adaptations, variations, modifications and equivalent arrangements, the present invention being limited only by the claims appended hereto and the equivalents thereof.

CLAIMS

What is claimed is:

1. An abrasive tool comprising:

a matrix support material configured for holding diamond particles to be used as abrasives;

a plurality of diamond particles disposed in the matrix support material; and

an alloy infiltrated through the matrix support material and the diamond particles, the alloy being bonded to the diamond particles and the matrix support materials, the alloy comprising a metal alloy that contains 2 to 50 percent of an element selected from the group consisting of chromium, manganese, silicon and aluminum, and being substantially free of zinc.

2. The abrasive tool according to claim 1, wherein the matrix support material contains more than 50 percent by weight of material selected from the group consisting of cobalt, nickel, iron, copper and bronze and mixtures and alloys thereof.

3. The abrasive tool according to claim 1, wherein the matrix support material occupies more volume than the diamond particles.

4. The abrasive tool according to claim 1, wherein the diamond particles are less than 40 percent of the volume of the matrix support material and diamond particles combined.

5. The abrasive tool according to claim 1, wherein the matrix support material is formed of coarse-sized powders greater than 400 U.S. mesh.

6. The abrasive tool according to claim 1, wherein the diamond particles are disposed in the matrix support material in a predetermined pattern.

7. The abrasive tool according to claim 1, wherein the matrix support material is formed by a plurality of diamond impregnated sheets.

8. The abrasive tool according to claim 7, wherein the diamond impregnated sheets are made by rolling, extruding, or tape casting a mixture of metal powder and diamond grits.

9. The abrasive tool according to claim 7, wherein the diamond impregnated sheets are made by mechanically planing diamond grits into the metal sheet.

10. The abrasive tool according to claim 9, wherein the metal sheet is formed by the group consisting of rolling from an ingot and prepared from a metal powder.

11. The abrasive tool according to claim 7, wherein at least one of the diamond impregnated sheets has been infiltrated with the alloy.

12. The abrasive tool according to claim 1, wherein the alloy is substantially free of interfering metals selected from the group consisting of zinc, lead and tin.

13. The abrasive tool of claim 1, wherein the alloy comprises at least 3 percent by weight of a material selected from the group consisting essentially of chromium, manganese, silicon, and aluminum and mixtures and alloys thereof.

14. The abrasive tool according to claim 1 and characterized further in that the alloy is selected from the group consisting essentially of MICROBRAZ LM,

copper-manganese alloy, copper-silicon alloy, and aluminum-silicon alloy.

15. The abrasive tool of claim 1, wherein the alloy has a liquidus temperature of less than 1,100° C.

16. The abrasive tool of claim 1, wherein the matrix support materials has a plurality of slots formed therein, and wherein the diamond particles are disposed within the slots.

17. The abrasive tool of claim 16, wherein the slots are filled with an alloy to bond the diamonds disposed within the slots to the matrix support material defining the slots.

18. The abrasive tool of claim 1, wherein the diamond particles are disposed in columns extending into the matrix support material, and wherein the diamonds are held in place by the alloy.

19. The abrasive tool of claim 18, wherein the column is substantially linear.

20. The abrasive tool of claim 18, wherein the column is curved.

21. The abrasive tool of claim 1, wherein the tool is a circular saw blade.

22. The abrasive tool of claim 1, wherein the tool is a linear saw blade.

23. A method for forming a diamond impregnated tool comprising:

(a) forming a matrix support material configured for holding diamond particles to be used as abrasives;

(b) distributing diamond particles in the matrix supportive material; and

(c) infiltrating the matrix support material with an alloy that contains between 2 and 50 percent of an element selected from the group consisting essentially of chromium, manganese, silicon and aluminum, and being substantially free of zinc.

24. The method according to claim 23, wherein step (a) comprises, more specifically, forming the matrix support material from powder larger than 400 mesh.

25. The method according to claim 23, wherein step (a) comprises, more specifically, forming the matrix support material from irregularly shaped particles.

26. The method according to claim 23, wherein the method comprises, more specifically, distributing the diamond particles in the matrix support material in a predetermined pattern.

27. The method according to claim 23, wherein the method comprises, more specifically, infiltrating the matrix support material with an alloy substantially free of interfering metals selected from the group consisting of zinc, lead and tin.

28. The method according to claim 23, wherein the method comprises, more specifically, forming a plurality of slots in the matrix support material, and distributing diamond particles into the slots.

29. The method according to claim 23, wherein the method further comprises infiltrating the slots with alloy braze to bond the diamond to the matrix support material.

30. The method according to claim 23, wherein the method further comprises subjecting the matrix support material and diamond particles to a vacuum of at least 10^{-3} torr during infiltration.

31. The method according to claim 23, wherein the method comprises, more specifically, infiltrating the matrix support material and diamond particles with an alloy having at least 5 percent by weight of a carbide former selected from the group consisting essentially of chromium, manganese, aluminum and silicon and mixtures and alloys thereof.

32. The method according to claim 23, wherein the alloy is selected from the group consisting of Nicrobraz LM; an alloy including copper and manganese; an alloy including copper and silicon; an alloy including aluminum and silicon and an alloy including nickel and silicon.

33. The abrasive tool according to claim 1, wherein the tool is a wire saw.

34. The abrasive tool according to claim 33, wherein the tool is a diamond wire saw.

35. the abrasive tool according to claim 34, wherein the tool is a diamond wire saw that contains beads fitted over a steel cable.

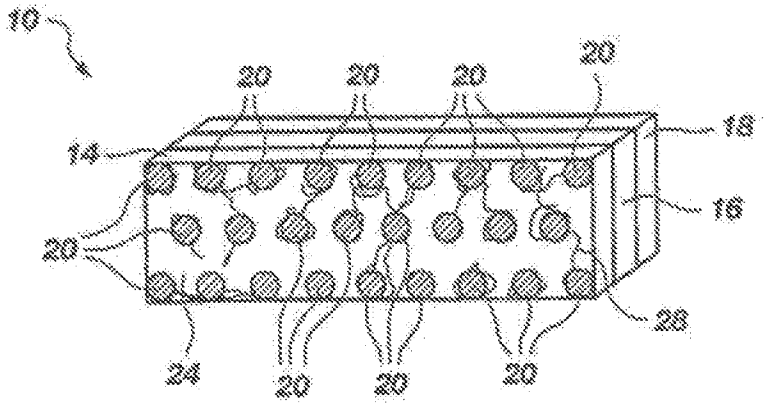


Fig. 1A

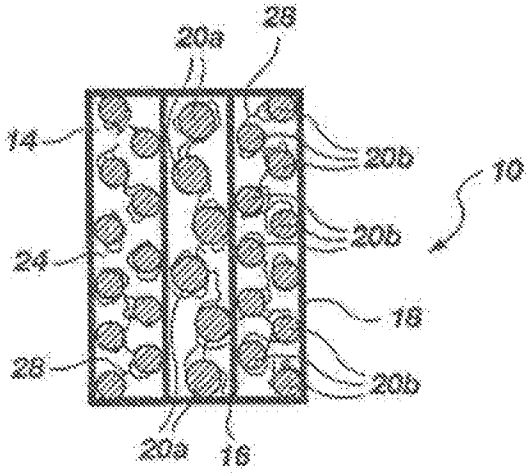


Fig. 1B

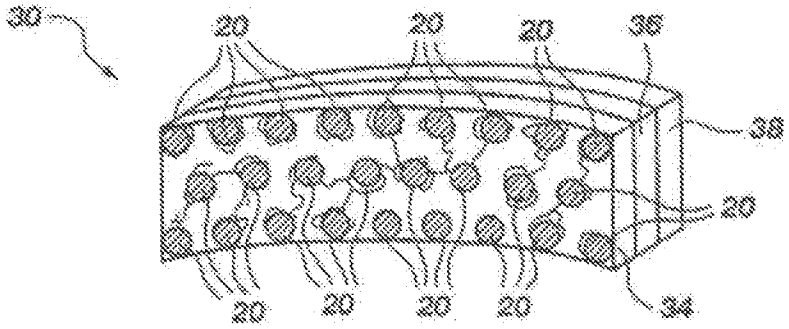


Fig. 2A

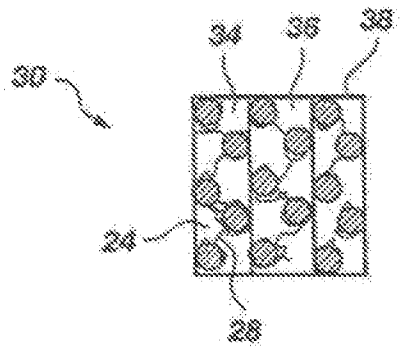


Fig. 2B

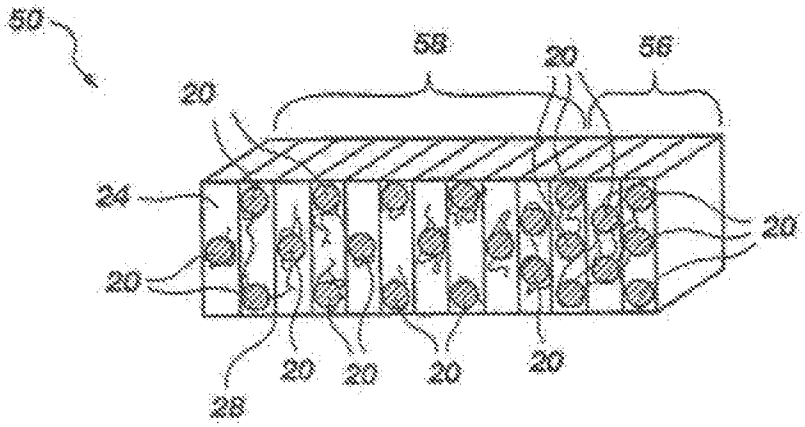


Fig. 3

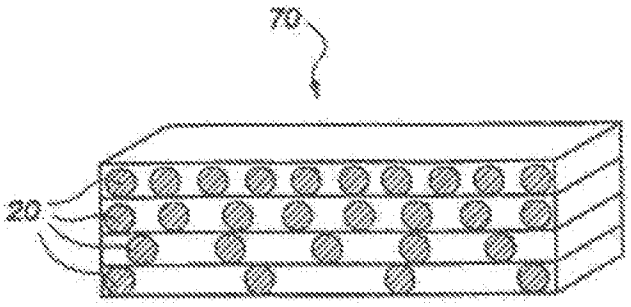


Fig. 4

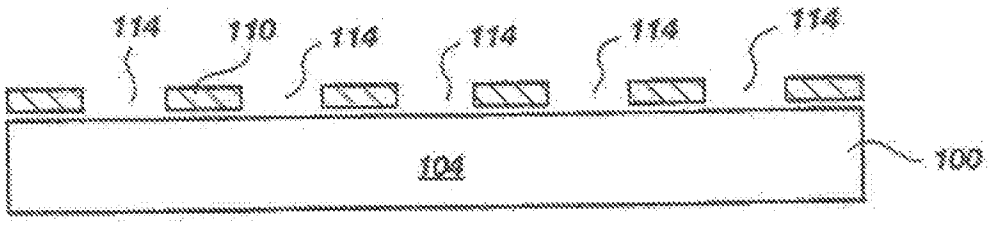


Fig. 5A

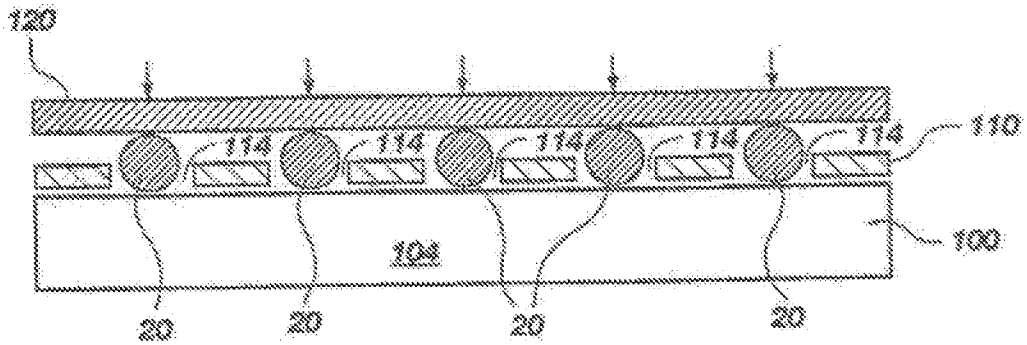


Fig. 5B

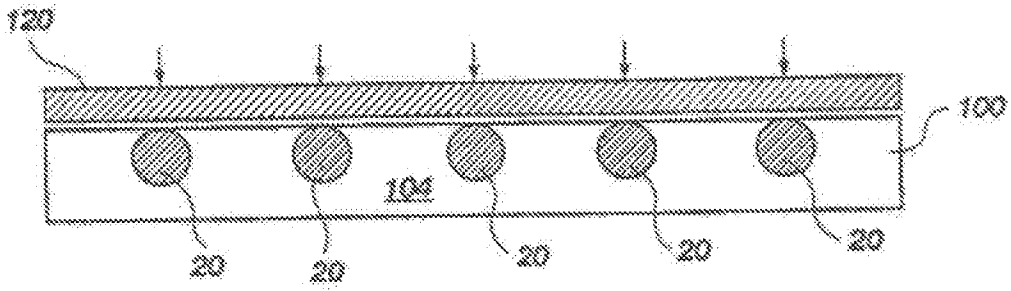


Fig. 5C

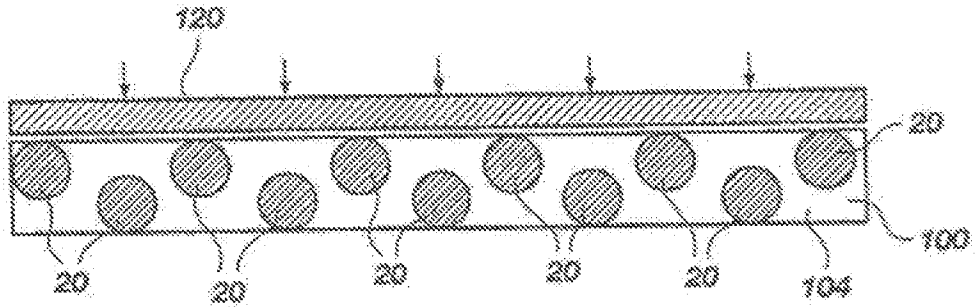


Fig. 5D

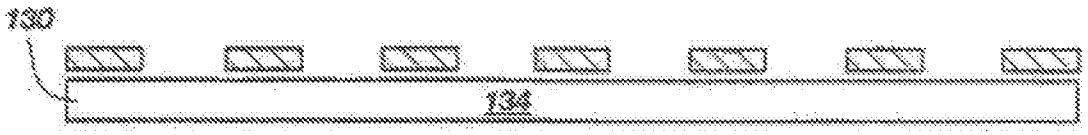


Fig. 6A

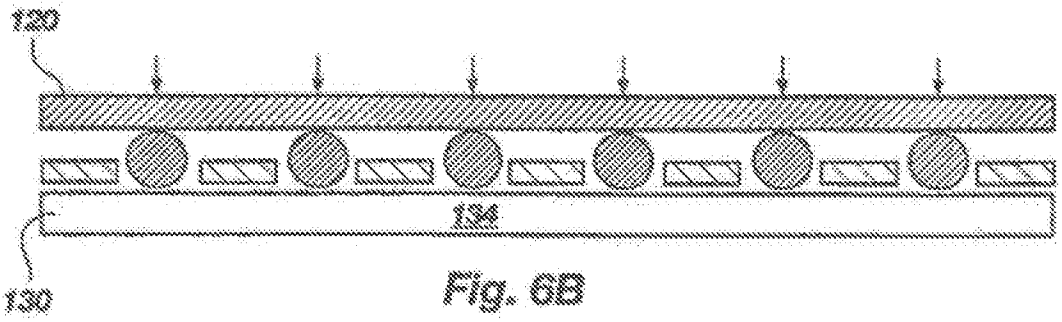


Fig. 6B

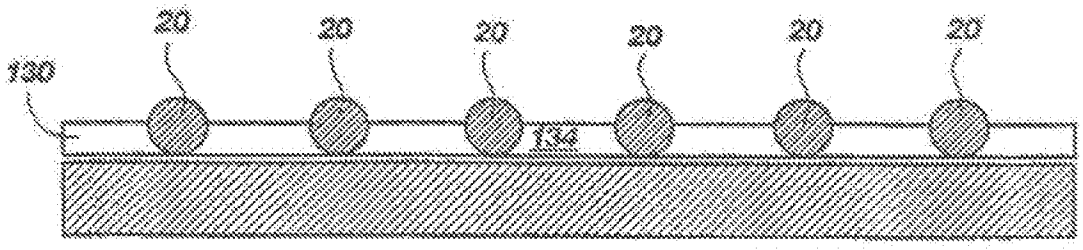


Fig. 6C

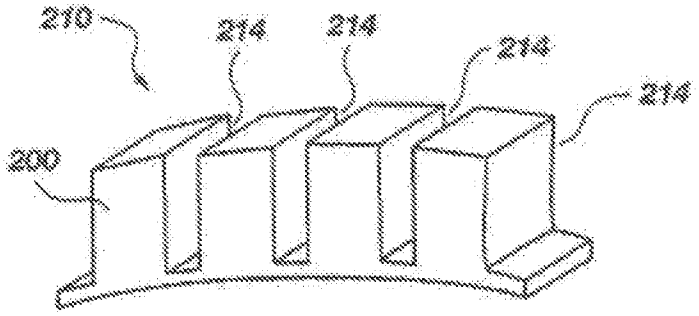


Fig. 7A

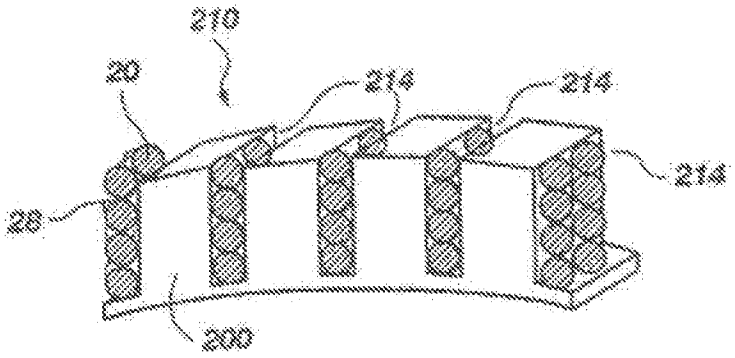


Fig. 7B

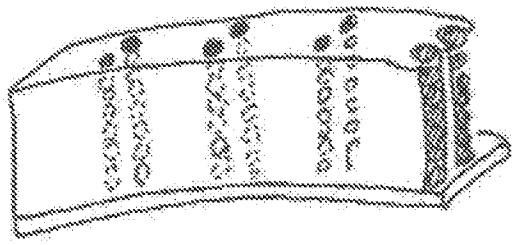


Fig. 8

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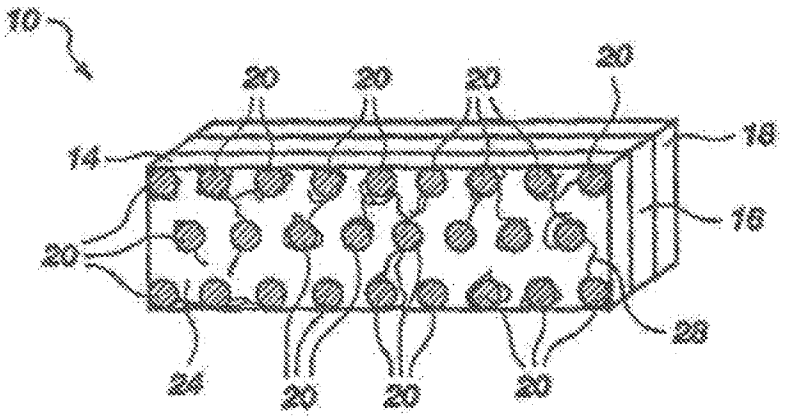
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(57)Abstract

The present invention describes a diamond tool (10) with diamond bonded chemically by a braze (28) that contains either Cr, Mn, Si, or Al or mixtures or alloys thereof. The diamond tool (10) is made by infiltrating the braze (28) into a matrix metal (24) that contains diamond (20) in either form of grits or polycrystalline bodies.

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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APS
search terms: infiltration, alloy, diamond, matrix, braze, compact,

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 5,000,273 A (HORTON ET AL) 19 MARCH 1991, SEE ENTIRE DOCUMENT	1-2, 12-15, 23, 25, 27, 31-32 --- 3-4, 21-22, 30, 33-35
A	US 4,669,522 A (GRIFFIN) 02 JUNE 1987	1, 23
A	US 4,780,274 A (BARR) 25 OCTOBER 1988	1, 23
A	US 5,518,443 A (FISHER) 21 MAY 1996	7, 21

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
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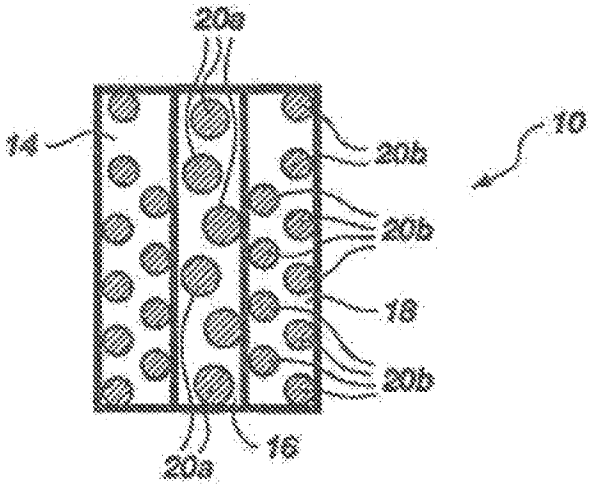
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(54) Title: ABRASIVE TOOLS WITH PATTERNED GRIT DISTRIBUTION AND METHOD OF MANUFACTURE

(57) Abstract

An abrasive tool (10) that contains abrasive particles (20) distributed in a predetermined pattern. Such a pattern is produced by fabricating two-dimensional slices (14, 16, 18) and assembling them. Abrasive particles (20) may be incorporated during the process of making these slices, or they may be planted afterwards into these slices which contain matrix powder. The planting may be guided by a template with openings laid in a specific pattern.



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ABRASIVE TOOLS WITH PATTERNED GRIT DISTRIBUTION AND METHOD OF MANUFACTURE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to improved abrasive tools used for cutting, grinding and the like. More particularly, the present invention relates to improved abrasive tools wherein abrasive particles are distributed in a predetermined pattern in a matrix powder in order to decrease cost and/or increase the useful life of the tool.

2. State of the Art

Abrasive tools have long been used in numerous applications, including cutting, drilling, sawing, grinding, lapping and polishing materials. Because diamond is the hardest abrasive material and cubic boron nitride is the second hardest, the two materials have been widely used as superabrasives on saws, drills, and other tools which utilize the abrasive to cut, form or polish other hard materials. It is estimated that the total value of superabrasive tools now consumed world wide is over is over 5 billion U.S. dollars per year. More than half of the superabrasive tools are believed to be consumed in sawing and

drilling application such as cutting stones, concretes, asphalts, etc.

Superabrasive tools are particularly indispensable for applications where other tools lack the strength and durability to be practical substitutes. For example, in the stone industry where rocks are cut, drilled, or sawed, diamond tools are the type which are sufficiently hard and durable to make the cutting, etc., economical. If superabrasives were not used, many such industries would be economically infeasible. Likewise, in the precision grinding industry, superabrasive tools, due to their superior wear resistance, are uniquely capable of developing the tight tolerances required, while simultaneously withstanding wear sufficiently to be practical.

Despite the tremendous improvements which diamond and cubic boron nitride have provided for cutting, drilling and grinding tools, there are still several disadvantages which, if overcome, would greatly improve performance of the tools, and/or reduce their cost. For example, the abrasive diamond or cubic boron nitride particles are not distributed uniformly in the matrix that holds them in place. As a result, the abrasive particles are not positioned to maximize efficiency for cutting, drilling, etc., and for production costs of the tools. In some instances, the abrasive particles are disposed too close together.

In other instances, the abrasive particles are disposed to far apart from one another.

In all applications, the separation between abrasive particles determines the work load each particle will perform. Improper spacing of the abrasive particles typically leads to premature failure of the abrasive surface or structure. Thus, if the abrasive particles are too close to one another, some of the particles are redundant. The particles are present, but provide little or no assistance in the cutting, grinding, etc., application. Of course, excess particles add to the expense of the abrasive, due the high cost of diamond and boron nitride. Moreover, these non-performing particles can block the passage of debris, thereby reducing the cutting efficiency. Thus, having abrasive particles disposed too close to one another adds to the cost, while decreasing the cutting efficiency of the tool.

On the other hand, if abrasive particles are separated too far, the work load (e.g., the impact force exerted by the work piece) for each particle becomes excessive. The sparsely distributed particles may be crushed, or even dislodged from the matrix into which they are disposed. The damaged or missing abrasive particles are unable to fully assist in the work load. Thus, the work load is transferred to the surviving abrasive particles. The failure of each

abrasive particle causes a chain reaction which soon renders the tool ineffective to cut, drill, grind, etc.

A typical superabrasive tool, such as a diamond saw blade, is manufactured by mixing diamond particles (e.g., 40/50 U.S. mesh saw grit) with a suitable matrix (bond) powder (e.g., cobalt powder of 1.5 micrometer in size). The mixture is then compressed in a mold to form the right shape (e.g., a saw segment). The "green" form is then consolidated by sintering at a temperature between 700-1200 °C to form a single body with a plurality of abrasive particles disposed therein. Finally, the consolidated body is attached (e.g., by brazing) to a tool body, such a round blade of a saw, to form the final product.

Different applications, however, require different combinations of diamond (or cubic boron nitride) and matrix powder. For example, for drilling and sawing applications, a large sized (anywhere from 20 to 60 U.S. mesh) diamond grit is mixed with a metal powder. The metal powder is typically selected from cobalt, nickel, iron, copper, bronze, alloys thereof, and/or mixtures thereof. For grinding applications, a small sized (anywhere from 60 to 400 U.S. mesh) diamond grit (or cubic boron nitride) is mixed with either metal (typically bronze), ceramic/glass (typically a mixture of oxides of sodium, potassium, silicon, and aluminum) or resin (typically phenolic),

Because diamond or cubic boron nitride is much larger than the matrix powder (300 times in the above example for making saw segments), and it is much lighter than the latter (about 1/3 in density for making saw segments), it is very difficult to mix the two to achieve uniformity. Moreover, even when the mixing is thorough, diamond can still segregate from metal in the subsequent treatments such as pouring the mixture into a mold, or when the mixture is subjected to vibrations. This diamond distribution problem is particularly troublesome for metal matrix tools. Metal matrix tools may account for more than 60% of the total value of all diamond tools. Within metal matrix tools, diamond saws (circular saws, straight blades, wire saws, etc.) comprise about 80% of the value. Thus, finding a method for increasing life of the abrasive material, and/or decreasing the amount of abrasive which is needed is highly desirable. Such has been accomplished by the invention set forth herein. The invention is applicable to all superabrasive tools, and is particularly effective for diamond saws, the largest value category of all diamond tools.

Over the decades, there have been numerous attempts to solve the diamond distribution problem. Unfortunately, none of the attempted methods have proven effective and, as of today, the distribution of diamond particles in diamond tools is still random and

irregular, except for some special cases such as drillers or dressers, where large diamond particles are individually set by hand in the surface to provide a single layer.

One method used in an attempt to make the diamond distribution uniform is to wrap diamond particles with a thick coating of matrix powder. The concentration of diamond particles in each diamond tool is tailored for a particular application. The concentration determines the average distance between diamond particles. For example, the concentration of a typical saw segment is 25 (100 means 25% by volume) or 6.25% by volume. Such a concentration makes the average diamond to diamond distance about 2.5 times of the particle size. Thus, if one coats the diamond to 0.75 times of its diameter and mix the coated particle together, the distribution of diamond would be controlled by the thickness of coating and may become relatively uniform. Additional metal powder may be added as interstitial filler between these coated particles to increase the packing efficiency so the consolidation of the matrix powder in subsequent sintering would be easier.

Although the above described coating method has certain merit, in practice, the uniformity of coating is very difficult to achieve. There are many chemical methods to coat diamond grit and its aggregates (polycrystalline diamond). For example, Chen and Sung

(U.S. Patent Nos. 5,024,680 or 5,062,865) described a CVD method for coating diamond grit using a fluidized bed. Sung et al (U.S. Patent Nos. 4,943,488 or 5,116,568) described another CVD method for coating polycrystalline diamond by fluidized bed. However, most of these methods can only produce thin coatings (e.g. a few micrometers) that do not affect the diamond distribution. Moreover, chemical coating methods typically require treatment at high temperatures (e.g. greater than 900 °C) that may cause damage to diamond. It is well known that synthetic diamond grit tends to form microcracks above this temperature. These microcracks are formed by the back-conversion of diamond to graphite at high temperature. The back-conversion is induced by the catalytic action of metal inclusions that diamond incorporated during its synthesis. CVD treatments cannot readily make thick coatings, and those which are formulated are often cost prohibitive. Thus, CVD treatments are not practical methods to make diamond distribution uniform in the tool.

There are, however, less expensive mechanical methods (e.g., by tumbling diamond particles with metal powder) that can build up a thick coating on diamond grit, typically at a low temperature that would not cause the degradation of diamond. However, it is very difficult to achieve a thick coating with uniform thickness using such methods.

For example, in attempts to practice the invention described in U.S. Patent No. 4,770,907 C.M. Sung performed "Metal Coating of Saw Diamond Grit by Fluidized Bed" (see p 267-273 of Fabrication and Characterization of Advanced Materials, edited by S. W. Kim and S. J. Park of The Materials Research Society of Korea 1995). It was found that the thickness of coated diamond particles varied considerably. Moreover, only extremely fine (i.e. less than 5 micrometers) metal powders can be coated on diamond effectively. Furthermore, the reproducibility of this method is poor. Hence, although such coating may improve the diamond distribution in the tool, its effect is limited.

Furthermore, in mechanical coating, metal powder is held loosely by an organic binder (e.g., PVA, PEG). The coating may be easily rubbed off during the subsequent mixing process, and thereby losing its intended benefit. Although heat treatment may increase the mechanical strength of the coating, nonetheless, it is an additional step with cost.

There is yet another limitation associated with the current methods of coating diamond particles. Many times a diamond tool requires different sizes of diamond grit and/or different diamond concentrations to be disposed at different parts of the same diamond tool. For example, saw segments tend to wear faster on the edge or front than the middle. Therefore,

higher concentrations and smaller diamond grit are preferred in these locations to prevent uneven wear, and thus premature failure of the saw segment. These segments with different concentration/size combinations (known as "sandwich" segments) are difficult to fabricate by mixing coated diamond with metal powder to achieve a controlled distribution of the abrasive particles in the segment. Thus, despite the known advantages of having varied diamond grit sizes and concentration levels, such configurations are seldom used because of the lack of a practical method.

In summary, current arts are incapable of efficiently controlling the uniformity of diamond distribution in the tool. Likewise, the current methods are inadequate to provide effective control of size variations and/or concentration variations on different parts of the same tool. Moreover, even when the distribution is made relatively uniform, current arts cannot tailor the pattern of the distribution to overcome or compensate for typical wear patterns for the abrasive material, when used for a particular purpose. By resolving these problems, the performance of a diamond and other superabrasive tools can be effectively optimized.

It is estimated that less than 10% of abrasives are actually consumed at work. Most of remainder is wasted due to the low efficiency of using these tools.

Among the various causes of this low efficiency, the inability to place every abrasive at the desired location is a major factor. This invention is aimed to make a revolutionary improvement to overcome the deficiency by eliminating random distribution of abrasive particles. The result would be an abrasive tool with every abrasive particle positively planted at desired positions to achieve the maximum utility. Hence, the performance of the abrasive tool can be optimized.

By making the distribution of abrasive particles uniform or tailored to the particular applications of the tool, then the work load can be evenly distributed to each particle. As a result, the abrasive tool will cut faster and its working life be extended a considerable amount of time. Moreover, by eliminating the redundancy, less abrasive may be needed, thereby reducing the cost of the tool manufacture. Additionally, if the distribution can be controlled, abrasive tools utilizing diamond or cubic boron nitride can be configured to provide the most efficient wear profile possible.

The present invention resolves these problems and provides the advantages set forth above by providing a method for forming such tools wherein the abrasive particle distribution can be controlled to provide either uniform grit placement, or to provide grit placement which is tailored to the particular wear

characteristics of the tool. Because the distribution of the diamond particles is controlled, the particles can be disposed in patterns which provide for relatively even wear of the abrasive surface, rather than having portions of the surface wear prematurely. As each particle is more fully utilized, there is no need for redundant particles as a back up. Therefore, the cost of making the abrasive tools can be reduced by decreasing the overall amount of superabrasive which is used. For example, the cost of superabrasives (diamond or cubic boron nitride) is so high that it often accounts for about half of the total manufacturing cost of the tool. By maintaining the performance of a superabrasive tool with a substantially lower concentration used in a controlled distribution, significant cost saving may be realized due to the decreased use of the expensive abrasive.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method for forming superabrasive tools, wherein the distribution of the superabrasive grit is controlled to provide improved cutting, grinding, etc., characteristics without requiring an increase in the amount of superabrasive grit used to form the tool.

It is another object of the invention to provide such a method wherein the distribution of the

superabrasive grit is controlled to promote more even wear of the abrasive surface, and thereby lengthen the useful life of the tool.

It is yet another object of the present invention to provide tools with minimal amount of superabrasive required to perform the task for which the tool is designed, thereby reducing the cost of making the tool.

The above and other objects of the invention are achieved by the use of a novel method of forming the superabrasive surface. While the distribution of the diamond or cubic boron nitride particles has always been viewed as a complex, three dimensional problem, the present invention reduces the distribution of the superabrasive to a substantially two-dimensional process that is easy to manipulate and control, and which can be repeated with a high degree of accuracy. More specifically, the desired distribution of abrasive particles in a matrix body is achieved by assembling layers of matrix material that contain a controlled, preset pattern of abrasive particles. Each layer is formed by distributing the superabrasive grit into a layer of bonding matrix in a predetermined pattern. Each layer which is assembled to form a superabrasive impregnated segment can be of the same distribution pattern and concentration, or the distribution pattern and/or concentration may vary from layer to layer.

In accordance with one aspect of the present invention, each layer is assembled by disposing a layer of matrix material so that it may be used as a precursor. The superabrasive grit is then disposed in the matrix material in a desire pattern. After the diamond particles are planted into the matrix material layer in a predetermined pattern, the process is repeated until a desired number of layers have been formed. These layers are then assembled to form the desired three-dimensional body. Subsequently, the diamond tool is consolidated (e.g., by sintering or infiltration as described above) to form the final product.

By reducing the three-dimensional problem to a two-dimensional solution through the use of the layers, the present invention can not only achieve the desirable diamond distribution pattern in the tool body, but can also provide the flexibility for possible manipulation of diamond concentration at different parts of the same tool body. Thus, for example, diamond particles can be disposed in denser concentrations in some layers than others, and the layers with the greater diamond concentrations can be disposed within the three-dimensional structure created in such a manner to prevent the uneven wear patterns that are typical in many prior art abrasive tools.

In accordance with another aspect of the present invention, each superabrasive layer is created by first forming a thin layer of bonding matrix. A template is then disposed on the bonding matrix. The template has a plurality of apertures formed therein which are sized to receive superabrasive grit of a particular size, with one particle being disposed in each aperture. As the superabrasive grit fills the apertures, it may subjected to pressure or otherwise moved into the bonding matrix. Because of the template, the superabrasive grit which enters the bonding matrix is disposed in a predetermined pattern. A plurality of such superabrasive layers can then be bonded together and attached to the tool by brazing, or some other process, to provide a three-dimensional superabrasive cutting or grinding member on the tool.

In accordance with another aspect of the present invention, the pattern in which the superabrasive grit is disposed may be uniform, or may be calculated to provide superabrasive members with particular cutting abilities. For example, the superabrasive particles may be disposed in varied concentrations to compensate for uneven wear patterns. Thus, the diamond distribution for the cutting edge of a saw may have a greater distribution of diamond particles on the lead edge and sides than on the middle portion which is generally subjected to less wear. Likewise, the sizes of the superabrasive particles can be

controlled to provide a cutting, grinding, etc., surface which is tailored to the particular purpose, such as to prevent chipping of the workpiece.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the invention will become apparent from a consideration of the following detailed description presented in connection with the accompanying drawings in which:

FIG. 1A shows a segment from a superabrasive tool formed by a plurality of linear, longitudinal layers disposed adjacent one another to form a three-dimensional superabrasive member;

FIG. 1B shows a cross-sectional view of one likely configuration of the tool segment shown in FIG. 1A, wherein a layer formed by a matrix material and a relatively large superabrasive is sandwiched between two layers of matrix materials which have smaller grit and higher concentration of the abrasive;

FIG. 2A shows a segment from a superabrasive tool formed by a plurality of arcuate, longitudinal layers which are attached to one another to form a three-dimensional superabrasive member;

FIG. 2B shows a cross-sectional view of a plurality of layers matrix material as may be used with the segment shown in FIG. 2A;

FIG. 3 shows another possible layout of a segment of a cutting tool with transverse layers configured with a denser concentration of abrasive material disposed, e.g., at a forward, cutting end of the three-dimensional superabrasive member;

FIG. 4 shows yet another layout of a segment wherein a three-dimensional superabrasive member is formed with progressively denser abrasive distribution toward, e.g., the upper surface of a tool with horizontal layers;

FIGs. 5A through 5D show one possible method for forming layers with controlled superabrasive distribution within the layer;

FIGs. 6A through 6C show an alternate method for forming one or more layers with controlled superabrasive distribution.

DETAILED DESCRIPTION

Reference will now be made to the drawings in which the various elements of the present invention will be given numeral designations and in which the invention will be discussed so as to enable one skilled in the art to make and use the invention. It is to be understood that the following description is only exemplary of the principles of the present invention, and should not be viewed as narrowing the pending claims.

Referring to FIG. 1A, there is shown a perspective view of a segment, generally indicated at 10, from a superabrasive tool (the remainder of which is not shown). The segment 10 is formed by a plurality of layers, 14, 16 and 18, which are impregnated with superabrasive particles, indicated by the circles 20. The plurality of layers 14, 16 and 18 are disposed adjacent to one another in a linear, longitudinal array so that the layers form the three-dimensional superabrasive segment 10.

As will be discussed in additional detail below, forming the segment 10 in a plurality of thin layers provides remarkably improved control over the distribution of the superabrasive particles. By controlling the distribution of the superabrasive particles within each layer and then combining layers, a three-dimensional segment can be formed in which distribution of the superabrasive particles is controlled in each dimension. This, in turn, enables the formation of segments which are particularly adapted to the likely use of the segment, be it for cutting, sawing, grinding, etc. By tailoring the distribution and concentration of the superabrasive particles within the segment 10, more precise control is given over performance of the tool under actual working conditions.

For example, when using a diamond saw blade to cut a rock (e.g., granite), the two sides of diamond

saw segments are cutting more materials than the center. As a result of the uneven wear, the cross section of the saw segment becomes convex in shape with the center bulging above both sides. This configuration typically slows the cutting rate of the saw blade. Moreover, the protruding profile may also cause the saw blade to deflect sideways in the cut slot. In order to maintain a straight cutting path, it is sometimes desirable to make a "sandwiched diamond segment" to reinforce both sides of the segment with layers impregnated with more superabrasive particles. Such a "sandwich segment" is difficult to manufacture by mixing diamond grit with metal powder by conventional means, but it can be easily accomplished by first planting diamond particles with desirable patterns in layered metal matrix and then assembling these layers together to form the sandwich segment.

In accordance with the present invention, a cutting segment can be formed to resist premature wear to the sides of the segment, thereby extending the cutting segment's useful life. Referring specifically to FIG. 1B, there is shown a cross-sectional view of the cutting segment 10 of FIG. 1A. Unlike the cutting segments of the prior art, the cutting segment 10 is formed of, for example, three layers, 14, 16 and 18 respectively. The middle layer 16 has a plurality of superabrasive particles 20a

which are of a first size (typically 40/50 U.S. mesh) and a first concentration (e.g. 20). The outer layers 14 and 18, in contrast, have a plurality of superabrasive particles 20b, which are of a second size (typically 50/60 mesh), smaller than the first size, and in a second concentration greater than that present in the middle layer 16 (e.g. 23). The smaller, more densely distributed superabrasive particles 20b provide the outer layers 14 and 18 with a greater resistance to wear as they cut through concrete, rock, asphalt, etc. Because the outer layers 14 and 18 are more resistant to wear, the cutting segment 10 resists formation of a convex outer surface, as has traditionally occurred with conventional tools. By maintaining a more planar cutting surface or even a concave profile, the cutting segment can maintain a straighter cutting path with a longer useful life. Moreover, by using a smaller grit on the flank of the saw, the finish of cut surface is more smooth. Furthermore, the chipping of the workpiece can be avoided.

Another advantage to the use of multiple layers of matrix with diamond or cubic boron nitride disposed therein is that the layers are easily formed into other desirable shapes for cutting, drilling, grinding, etc. For example, FIG. 2A shows a perspective view of a saw segment, generally indicate at 30, of a superabrasive tool formed by a plurality

(e.g., 3) of arcuate, longitudinal layers which are attached to one another to form a three-dimensional tool member. In this example, the segment 30 is formed from first, second and third layers, 34, 36 and 38, which are each arcuate. When the three are joined together, an arcuate segment 30 is created. Such a segment, of course, may be used on cutting tools which are non linear (e.g, circular saw blades), and on other types of tools for which a nonlinear superabrasive segment is desired. Because the layers 34, 36 and 38 are initially formed independent of one another, they are much easier to conform to a desired shape, and are able to do so while the superabrasive particles 20 disposed therein are held in their predetermined positions.

Each of the layers is impregnated with a plurality of superabrasive particles 20, typically diamond or cubic boron nitride. Because each layer is formed as a substantially two-dimensional unit (i.e., the matrix will usually be no more than two times the thickness of the diameter of the particles) superior control is provided over placement of the superabrasive particles. As discussed above, the random placement of the prior art often led to ineffective use of superabrasive particles. However, the controlled distribution of the present invention enables either even distribution designed to prevent under or over spacing, or controlled distribution so

that different portions of the segment have different sizes and concentrations which are matched to prevent traditional wear patterns.

Referring now to FIG. 2B, there is shown a cross-sectional view of a plurality of the layers 34, 36 and 38 of the segment 30. Of course, the superabrasive particle as may be used with the segment shown in FIG. 1A or that shown in FIG. 2A. Unlike the embodiment of FIG. 1B, the layers are each provided with the same size and concentration of the superabrasive particles 20. However, because the spacing is substantially uniform, there is no underspacing or overspacing between the superabrasive particles, and the segment 30 wears more evenly than the segments of the prior art with randomly spaced particles. The more even wear prevents premature failure of the segment 30, and thus extends the life of the tool while keeping the amount of superabrasive used to a minimum.

FIG. 3 shows another possible embodiment of a segment 50 made in accordance with the teachings of the present invention. The layered structure in a diamond segment may also be assembled transversely or horizontally. Thus, the segment 50 in FIG. 3 is formed from a plurality of transverse layers. A first plurality of layers, indicated at 56 are provided with a first concentration of superabrasive particles 20 (represented by four layers, that contain superabrasive particles 20 distributed within an

offset pattern). A second plurality of layers, indicated at 58, are provided with a second concentration, less than the first concentration (represented by nine layers with an offset pattern of superabrasive particles 20).

Many cutting tools are configured such that the cutting segment 50 is provided with a lead edge which performs a majority of the cutting and which receives most of the impact force when contacting the workpiece to be cut. For example, a circular saw blade will usually have a plurality of teeth (saw segments), each tooth having a leading edge which takes the force of the cutting. Because the leading edge preforms a significant portion of the cutting, it is much more susceptible to wear than are rotationally trailing portions of the tooth. When formed in accordance with the prior art, the teeth, however, often had similar concentrations of abrasive particles disposed therein. Over time the leading edge wears significantly, but the trailing layers 58 remain with minimal wear. Eventually, the abrasive of the saw tooth is worn off the leading edge, while significant amounts remain on the tail end. Thus, a considerable amount of superabrasive is wasted when the blade is discarded.

The embodiment of FIG. 3 is specifically configured to overcome such concerns. The layers 56 and 58 are configured to provide substantially even wear across the cutting segment 50 by placing a larger

percentage of the superabrasive particles 20 near the leading edge, than on rotationally distal portions. Thus, by the time the leading edge has reached the end of its useful life, the remaining portions of the cutting segment 50 have also been worn out. Such controlled distribution of the superabrasive particles 20 decreases the use of the expensive material and lowers the cost for making the cutting segment 50 without hurting performance. Additionally, by providing more even wear, the cutting segment 50 will often be able to maintain most of its cutting speed until shortly before ending its useful life.

FIG. 4 shows yet another layout of a segment wherein a three-dimensional superabrasive member is formed with progressively denser abrasive distribution toward the upper surface of a tool with horizontal layers. It is often found that the speed of cutting tends to decrease with the wear of the tool. Thus, with a reduced concentration of superabrasive particles, the tool can maintain its current cutting speed at a constant power of the machine. Thus, as with the embodiment of FIG. 3, the controlled distribution of the superabrasive particles 20 forms an improved abrasive segment 70, while at the same time decreasing the cost of abrasive tools by saving those superabrasive particles which are not needed.

With routine experimentation and the teachings of the method of the present invention, those skilled in

the art will be able to customize cutting, drilling, grinding, polishing and other types of abrasive segments which are specifically formed to maximize their performance (i.e. cutting, drilling, grinding, etc.) over an extended useful life, while simultaneously decreasing the amount of expensive superabrasive which is used to form the tool.

Referring now to FIGs. 5A through 5D, there is shown one method for forming layers in accordance with the principles of the present invention. The first step of the method is to form a sheet 100 of matrix material 104 which will be bonded to the superabrasive particles 20. The sheet 100 of matrix material 104 can be formed from conventional metal powders as discussed above, or other bonding agents which have yet to be discovered.

There are many ways that a matrix powder can be made into the sheets 100. For example, the powder can first be mixed with a suitable binder (typically organic) and a solvent that can dissolve the binder. This mixture is then blended to form a slurry with a proper viscosity. In order to prevent the powder from agglomeration during the processing, a suitable wetting agent (e.g., menhaden oil, phosphate ester) may also be added. The slurry can then be poured onto a plastic tape and pulled underneath a blade or leveling device. By adjusting the gap between the blade and the tape, the slurry can be cast into a

sheet with the right thickness. The tape casting method is a well known method for making thin sheets out of powdered materials and it works well with the method of the present invention.

Alternatively, the powder can be mixed with a suitable binder and its solvent to form a deformable cake. The cake can then be extruded through a die with a slit opening. The gap in the opening determines the thickness of the extruded plate. Alternatively, the material can also be drawn between two rollers with adjustable gap to form sheets with the right thickness.

It is desirable to make the sheets pliable for subsequent treatments (e.g., bending over a tool substrate which has a curvature). Therefore, a suitable organic plasticizer may also be added to provide the desired characteristics.

The use of organic agents for powder (metal, plastics, or ceramics) processing is documented in many text books and it is well known by those skilled in the art. Typical binders include polyvinyl alcohol (PVA), polyvinyl butyral (PVB), polyethylene glycol (PEG), paraffin, phenolic resin, wax emulsions, and acrylic resins. Typical binder solvents include methanol, ethanol, acetone, trichlorethylene, toluene, etc. Typical plasticizers are polyethylene glycol, diethyl oxalate, triethylene glycol dihydroabietate, glycerine, octyl phthalate. The organic agents so

introduced are to facilitate the fabrication of metal layers. They must be removed before the consolidation of metal powders. The binder removal process (e.g., by heating in a furnace with atmospheric control) is also well known to those skilled in the art.

Once the sheet 100 of matrix material 104 is formed, a template 110 is laid on the top of the sheet. The template 110 contains apertures 114 that are larger than one abrasive particle 20, but smaller than two abrasive particles, thereby allowing a single particle of the abrasive to be disposed at each specific location.

In this example, the thickness of the template is preferably between 1/3 to 2/3 of the height of the average abrasive particle 20. However, other thicknesses may be used if appropriate accommodations are made for seating the abrasive particles in the desired locations.

After the template 110 is properly positioned, a layer of abrasive particles 20 is then spread over the template so that each aperture 114 receives an abrasive particle. Those particles not falling into the apertures 114 in the template 110 are removed by tilting the substrate, sweeping the template with a broom, or some other similar method.

As shown in FIG. 5B, a generally flat surface 130, such as a steel plate) is then laid over the particles 20 which rest in the apertures 114 in the

template 110. The flat surface 120 presses the abrasive particles 20 at least partially into the pliable sheet 100 of matrix material 104 to seat the particles.

After removing the template 110, the flat surface 120 is used again to press the abrasive particles 120 firmly into the sheet 100 of matrix material 104 as shown in FIG. 5C. While the flat surface 120 is preferable, those skilled in the art will appreciate that there may be occasions when it is desirable to have abrasive particles protruding above the metal sheet 100 with equal height. Alternatively, some of the abrasive particles 20 may be wanted to extend outwardly from the sheet 100 of matrix material more than that of other abrasive particles. In such situations, a contoured or otherwise shaped surface could be used to seat some of the abrasive particles 20 deeper into the sheet 100 of matrix material 104, than other particles.

If desired, the process shown in FIGs. 5A through 5C can be repeated on the other side of the sheet 100 of matrix material 104 (as shown in FIG. 5D), to form an impregnated layer having abrasive particles 20 distributed throughout the layer in some predetermined, desired pattern. The process is typically repeated several times to obtain multiple thin layers or sheets 100 which are impregnated with the abrasive particles 20. Of course, each sheet 100

needs not have the same distribution pattern for the abrasive particles 20, nor does it need the concentration of the abrasive particles be the same.

The abrasive impregnated sheets 100 are next cut to any desired size and shape. The sheets 100 are then assembled to form the tool segment or the entire tool body where appropriate. Typically, the assembly of the sheets 100 is accomplished by a known method such as cold compaction with a press. The "green" body so formed can then be consolidated to form a final tool product by conventional method of sintering or infiltration as described by following the examples.

While the method described in FIGs. 5A through 5D is preferred for many applications, there are instances where it is desirable to have the abrasive particles 20 extend outwardly from the sheet 100 of matrix material. For example, some tools may only have one layer of abrasive. This can be accomplished simply by leaving the template 110 in place when performing the steps shown in FIG. 5A and 5B, and not further pressing the particles 20 into the matrix material once the template has been removed.

In the alternative, FIGs. 6A through 6C show a side view of an alternate to the method discussed in FIGs. 5A through 5D. The sheet 130 of matrix material in FIGs. 6A through 6C is thinner than the height of the superabrasive particles 20. Thus, in this

procedure, when the particles are pressed into the sheet 130, the particles 20 would protrude above the matrix material 134.

Although the present invention is intended for making three-dimensional abrasive tools, the teachings contained in the present application can readily be applied to two-dimensional tools as well. For example, U.S. Patent Nos. 3,894,673 and 4,100,576 describe certain brazed diamond tools that contain a single layer of diamond particles. These particles are brazed onto a tool shank by a chromium containing alloy. Such diamond tools are widely marketed (e.g., by Abrasives Technology of U.S.A.) for cutting and grinding non-ferrous materials (e.g., stones or glass).

However, the distribution of diamond particles on these tools are typically random and non-uniform. The methods illustrated in FIGs. 5A through 6C can readily be applied to such tools to improve the diamond distribution. In this case, the method offers several advantages over the conventional technology as described by these patents. For example, by making diamond particles distributed in a desirable pattern, the load of cutting can be evenly distributed to all diamond particles. As a result, the tool can cut faster with a longer life.

The performance may be further improved by having a braze layer of uniform thickness. This uniformity

can allow a better diamond retention and easier debris removal. Moreover, by fully utilizing each diamond particle for cutting, the concentration of diamond can be reduced. As discussed, diamond cost often accounts for about half of the total manufacturing cost of a diamond tool. Hence, by practicing this invention, manufacturing cost can be reduced substantially.

Also shown in FIG. 6A through 6C is the principle that the spacings of the apertures in the template 130 need not be uniform. Rather, variations in spacing can be provided to facilitate different concentrations on various portions of the sheet 130 of matrix material 134. Likewise, by controlling the size of the apertures 138 and the order in which the diamond particles are placed in the apertures, a single layer could be provided with particles of different sizes.

In addition to being able to improve the performance of the tool and to reduce the cost of the manufacturing, this invention also provides a easier method for making thin bladed tools. For example, the electronic industry requires using larger and larger silicon wafers (now 12 inches in diameter). Hence, thinner saw blades for slicing silicon crystals with lower kurf loss, and thinner dicing wheels for grooving silicon chips with tighter partitions have been in demand.

Prior to the present invention, it has been extremely difficult to make very thin tools that

contain evenly distributed diamond particles. The present invention provides an alternative method for making such tools. For example, it has been discovered that by mixing micron powders of diamond, a blend of metal powders (e.g., bronze and cobalt) and a suitable binder, the material can be rolled to a thickness thinner than 0.1 mm. By firing this thin sheet and mounting it on a tool holder, a thin dicing wheel can be made.

In the alternative to the above, it has been found in accordance with the present invention that some of the advantages of the controlled distribution, multilayered superabrasive configurations described above can be achieved without the use of a template. More specifically, the abrasive particles can also be mixed in with the matrix powder and made as an ingredient of the layered sheet. In this case, the distributions of abrasive particles are still somewhat random. Even so, their distribution is typically more uniform than that in a conventional abrasive body. The segregation of abrasive particles and matrix powders discussed in the background section is less extensive in a substantially two-dimensional sheet than in a three-dimensional body. This is particularly true for sheets made by a deforming process (e.g., by rolling). In this case, abrasive particles are further spread out in the matrix by the shearing action of the rollers.

This invention may also be applicable to other applications not related to making abrasive tools. For example, graphite or metal sheets planted with diamond particles may be used as seeds for diamond growth under high pressure and temperature. Industrial diamonds are typically produced by compressing alternative layers of graphite and metal catalyst (e.g., Fe, Co, or Ni alloy) to high pressure and heated above the melting point of the catalyst. Diamond will then nucleate randomly on the interface of these layers. The quality of the diamond crystal formed often suffers by the impingement of growing crystals that are distributed unevenly. Hence, the yield and cost of diamond synthesis can be substantially improved by making the nuclei distributed uniformly. This invention can provide layers of either graphite or metal catalyst with a pre-determined pattern of diamond seeds. If organic binders are introduced during the fabrication of these layers, they can be removed by heating in a furnace before loading into the press.

Example 1

40/50 mesh diamond grit (SDA-85' made by De Beers Company) were mixed with metal powder to form a mixture with diamond concentration of 20 (5% of total volume). Five different proportion of cobalt (about 1.5 micrometer in size) and bronze (about 20

micrometers in size) were used for the matrix powder. An acrylic binder was added (8% by weight) to the mixture and the charge was blended to form a cake. The cake was then rolled between two stainless steel rollers to form sheets with a thickness of 1 mm. These sheets were cut in the shape of saw segments with a length of 40 mm and width of 15 mm. Three each of such segments were assembled and placed into a typical graphite mold for making conventional diamond saw segments. The assembled segments were pressed and heated by passing electric current through the graphite mold. After sintering for three minutes, the segments were consolidated to a height of 9 mm with less than 1% porosity. Twenty-four segments for each composition were fabricated. They were brazed onto a circular saw of 14 inches in diameter. These five blades were used for cutting granites and found to perform equal or better than those with higher diamond concentrations (e.g. 23) made by conventional methods. Microscopic examination of the worn segment indicated that although diamond particles were not planted into the layered matrix, they were distributed more evenly than segments prepared by the traditional method. The segregation of particles in layered matrix was considerably less than that in a thick body of conventional segments.

Example 2

The same procedures were followed as Example 1, but with 8 thinner layers (0.4 mm) for each segment. The diamond concentration was reduced to 15 and particles were planted according to the illustration as shown in FIGs. 5A through 5D. The diamond distribution was much improved. As a result, the performance of these blades were equal or better than those made by conventional methods with diamond concentration of 20.

Example 3

Iron powders of about 100 mesh were mixed with an S-binder made by Wall Colmonoy Company to form a cake. The cake was then rolled to form sheets of 0.4 mm in thickness. 40/50 mesh SDA-100' diamond grit was planted into these sheets to attain a concentration of 15. These diamond containing sheets were cut in the shape of saw segments with a length of 40 mm and width of 9 mm. Eight of such segments were assembled as a group and placed in a graphite mold. Twenty-four groups were placed horizontally, and another twenty-four groups were placed vertically in the graphite mold. Nicrobraz LM powder (-140 mesh) (made by Wall Colmonoy Company) was added on the top of these segments. These samples were heated in a vacuum furnace (10^{-5} torr) to 1050 °C for 20 minutes for horizontally placed segments, and 30 minutes for

vertically placed segments. The melted LM alloy (Ni-Cr-B-Si with a liquidus point at 1000 °C) infiltrated into these segments and filled the porosity. The excess LM braze on these segments were ground by electrode discharge (EDG). Each of the 24 segments so fabricated were brazed onto a 14 inch (diameter) circular saw blade. These blades were used to cut granite and showed marked improvement over conventional saw blades.

Example 4

Microbrax LM powder was mixed with an acrylic binder and rolled to form layers of about 0.25 mm. 40/50 mesh MBS-960 diamond grit manufactured by General Electric Company was planted into these metal layers according to the method as illustrated in Figure 5. These diamond planted metal layers were cut in proper size and wrapped around 2,000 beads (pearls) of wire saw. The beads preferably have a taper angle between 3 and 5 degrees. These beads (10 mm in diameter by 10 mm long) were divided into two groups, one contains 280 crystals (about 0.2 carat) per bead; and the other, 400 crystals (about 0.3 carat). These beads were heated in a vacuum furnace to a temperature of 1,000 °C for 8 minutes. These beads were mounted on several wire saws and used to cut marble, serpentine and granite. The performance of these beads was found to be superior to conventional beads.

The latter beads were typically made by either hot pressing or electroplating. These conventional beads may contain a much higher amount of diamond (up to 1 carat) per bead.

Example 5

The same method as described by Example 4, but applied to other products, e.g., circular saws, thin-wall core bits, and curvature grounder. Each of these products shows superior performance over conventional electro-plated diamond tools having a similar or higher superabrasive concentrations.

The above description and examples are intended only to illustrate certain potential uses of this invention. It will be readily understood by those persons skilled in the art that the present invention is susceptible of a broad utility and applications. Many embodiments and adaptations of the present invention other than those herein described, as well as many variations, modifications and equivalent arrangements will be apparent from or reasonably suggested by the present invention and the forgoing description thereof without departing from the substance for scope of the present invention. Accordingly, while the present invention has been described herein in detail in relation to its preferred embodiment, it is to be understood that this disclosure is only illustrative and exemplary of the present invention and is made merely for the purpose

of providing a full and enabling disclosure of the invention. The forgoing disclosure is not intended to be construed to limit the present invention or otherwise to exclude any such other embodiment, adaptations, variations, modifications and equivalent arrangements, the present invention being limited only by the claims appended hereto and the equivalents thereof.

CLAIMS

What is claimed is:

1. An abrasive tool having an abrasive impregnated segment comprising:

a matrix material configured for bonding abrasive particles; and

a plurality of abrasive particles distributed in the matrix material in a predetermined pattern.

2. The abtasive tool according to claim 1, wherein the plurality of abrasive particles are selected from the group consisting essentially of diamond, cubic boron nitride, alumina and silicon carbide.

3. The abrasive tool according to claim 1, wherein the abrasive impregnated segment is formed by a plurality of matrix material layers, each layer being impregnated with abrasive particles, and wherein the plurality of layers are disposed adjacent one another.

4. The abrasive tool according to claim 3, wherein the abrasive particles in one of the layers are larger than the abrasive particles in at least one of the other layers.

5. The abrasive tool according to claim 4, wherein the plurality of layers includes at least one outer layer and at least one inner layer, and wherein the abrasive particles of the at least one inner layer

are larger than the abrasive particles of the at least one outer layer.

6. The abrasive tool according to claim 5, wherein the abrasive segment is configured with two outer layers and at least one inner layer disposed between the outer layers, wherein each of the outer layers and the at least one inner layer has abrasive particles disposed therein, and wherein the abrasive particles disposed in the at least one inner layer are larger than those disposed in the outer layers.

7. The abrasive tool according to claim 3, wherein at least one of the layers has a greater concentration of abrasive particles than at least one of the other layers.

8. The abrasive tool according to claim 7, wherein the plurality of layers includes at least one outer layer and at least one inner layer, and wherein the at least one outer layer has a greater concentration of abrasive particles than the at least one inner layer.

9. The abrasive tool according to claim 8, wherein the abrasive segment is configured with two outer layers and at least one inner layer disposed between the outer layers, wherein each of the outer layers and the at least one inner layer has abrasive particles disposed therein, and wherein the abrasive particles disposed in the outer layers are disposed in

greater concentration than the abrasive particles in the at least one inner layer.

10. The abrasive tool according to claim 7, wherein the plurality of layers includes at least one first layer having a first concentration of abrasive particles, at least one second layer having a second concentration less than the first concentration, and at least one third layer having a third concentration less than the second concentration.

11. The abrasive tool according to claim 7, wherein the abrasive impregnated segment has a leading edge configured to initially impact a surface to be cut, wherein the segment is formed by a plurality of layers and wherein the layers adjacent the leading edge having a higher concentration of abrasive particles than layers remote from the leading edge.

12. The abrasive tool according to claim 1, wherein the abrasive particles are distributed in a uniform pattern throughout the impregnated segment.

13. The abrasive tool according to claim 12, wherein the abrasive particles are uniformly distributed throughout the tool.

14. The abrasive tool according to claim 1, wherein the tool has abrasive particles distributed therethrough, and wherein the tool has an outer

portion having a higher concentration of abrasive particles disposed therein.

15. The abrasive tool according to claim 1, wherein the segment has an impacting surface formed thereon and wherein the abrasive particles are distributed in higher concentration adjacent the impacting surface.

16. The abrasive tool according to claim 1, wherein the segment is formed by a plurality of two-dimensional layers assembled together to form a three-dimensional segment.

17. An abrasive tool comprising a plurality of layers formed from a matrix material for holding abrasive particles, and a plurality of abrasive particles distributed in the layers of matrix material, the layers being attached to one another to form a three-dimensional tool abrasive segment.

18. The abrasive tool of claim 17, wherein at least one of the layers is 1 millimeter thick or less.

19. The abrasive tool of claim 17, wherein the layers have been consolidated together by a method selected from the group consisting of brazing, sintering or infiltration.

20. The abrasive tool of claim 17, wherein the abrasive particles are distributed within the layers in predetermined patterns.

21. The abrasive tool of claim 20, wherein the distribution of the abrasive particles if uniform in at least one of the layers.

22. An abrasive tool comprising at least one layer of matrix material with abrasive particles formed therein, the layer being 1 millimeter or less in thickness and formed by rolling the matrix material and abrasive particles between rollers to improve uniformity in the distribution of the abrasive particles.

23. A method for forming an abrasive tool body, the method comprising:

(a) forming a sheet of matrix material configured for bonding to abrasive particles; and

(b) disposing a plurality of abrasive particles in the sheet of matrix material in a predetermined pattern.

24. The method according to claim 23, wherein the method comprises, more specifically, placing a template with a plurality of apertures formed therein on the sheet of matrix material prior to disposition of the plurality of abrasive particles so that placement of the abrasive particles is controlled by the position of the apertures, thereby selectively limiting placement of the abrasive particles in the sheet of matrix material to the positions of the apertures.

25. The method according to claim 24, wherein the method comprises, more specifically, using a template formed from a sieve.

26. The method according to claim 24, wherein the template is formed by a plate having a plurality of apertures formed therein, the apertures being configured in a predetermined pattern.

27. The method according to claim 26, wherein each aperture has a diameter which is greater than a diameter of the abrasive particles to be positioned thereby, but less than twice the diameter of the abrasive particles.

28. The method according to claim 23, wherein the method comprises, more specifically, forming the sheet of matrix material by tape casting.

29. The method according to claim 23, wherein the method comprises, more specifically, forming the sheet of matrix material by rolling.

30. The method according to claim 23, wherein the method comprises, more specifically, forming the sheet of matrix material by extrusion.

31. The method according to claim 23, wherein the method comprises, more specifically, forming a plurality of layers of matrix material having abrasive particles disposed therein, and attaching the layers together to form a three-dimensional abrasive segment.

32. A method for forming a layer of abrasive impregnated matrix material having improved abrasive distribution, the method comprising:

(a) forming a layer having a mixture of matrix material and abrasive particles; and

(b) rolling the layer of mixture to form a layer no greater than 1 millimeter thick.

33. A method of making layers catalyst for diamond synthesis, the method comprising:

(a) forming at least one layer of a catalyst; and

(b) planting a plurality of diamond particles in the catalyst in a predetermined pattern.

34. The method according to claim 33, therein the method further comprises disposing organic binders in the catalyst prior to planting the plurality of diamond particles, and removing the heating in a furnace before pressing the catalyst and diamond particles.

35. A method of making a source material for diamond synthesis, the method comprising:

(a) providing a layer of graphite; and

(b) planting a plurality of diamond particles in the layer of graphite in a predetermined pattern.

36. The abrasive tool according to claim 1, wherein the abrasive impregnated segment is formed by at least one layer of matrix material.

37. The abrasive tool according to claim 36, wherein the at least one layer of matrix material contains at least one layer of abrasive particles.

38. The abrasive tool according to claim 37, wherein the tool is a wire saw that it at least partially surrounded by the matrix material that contains the abrasive particles.

39. The abrasive tool according to claim 38, wherein the tool is a wire saw that contains diamond beads overcoated with diamond.

40. The abrasive tool according to claim 39, wherein the diamond bead has a taper angle of 3 to 5 degrees.

41. The abrasive tool according to claim 36, wherein the matrix material is consolidated by a method selected from the group consisting of brazing, sintering and infiltration.

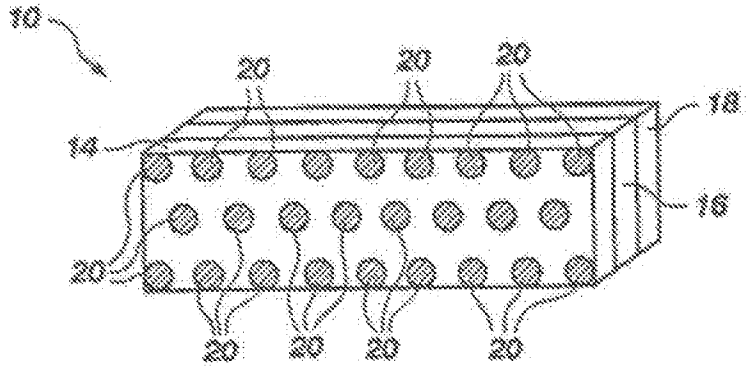


Fig. 1A

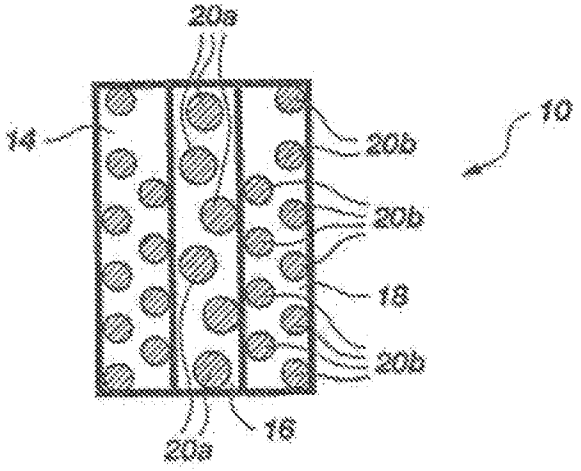


Fig. 1B

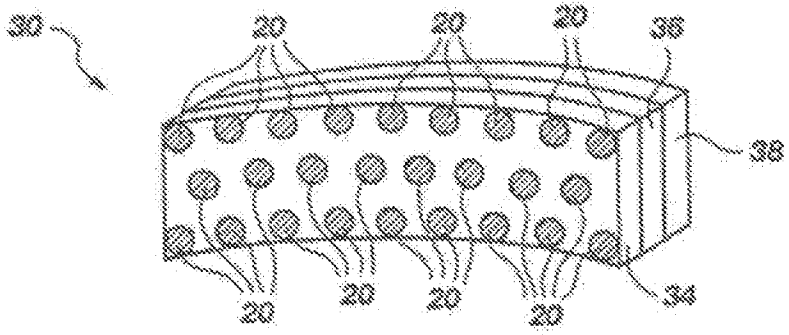


Fig. 2A

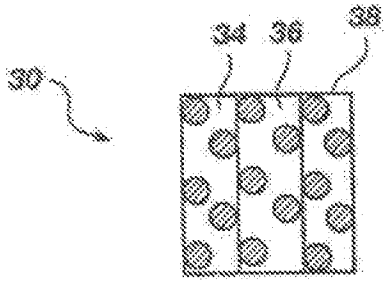


Fig. 2B

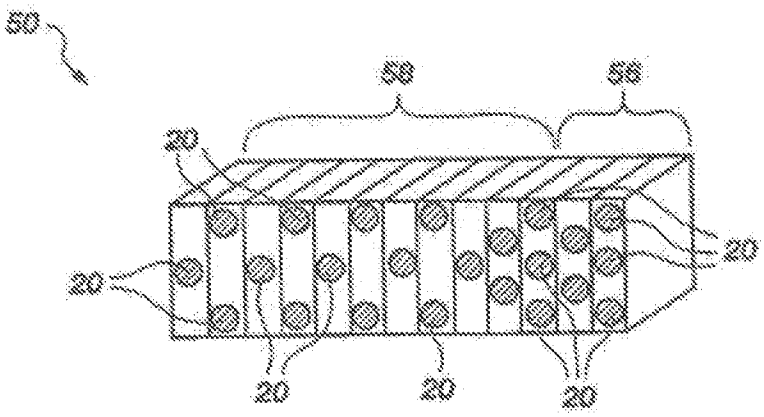


Fig. 3

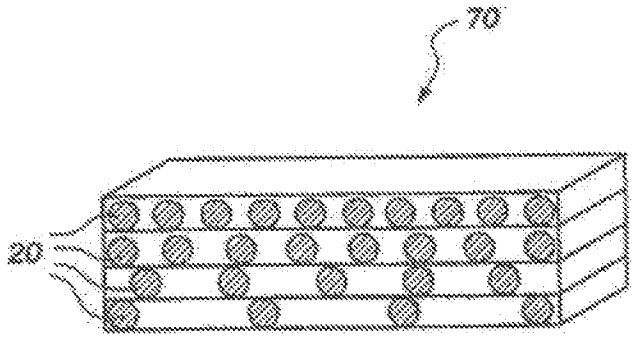


Fig. 4

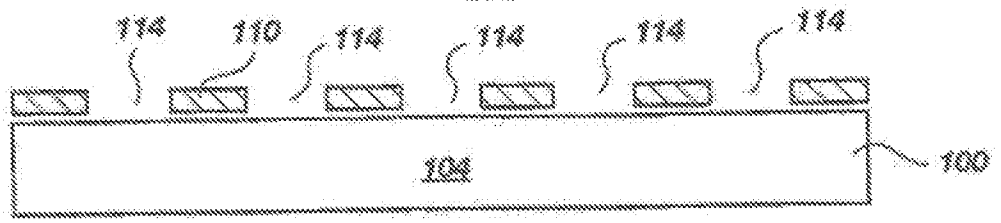


Fig. 5A

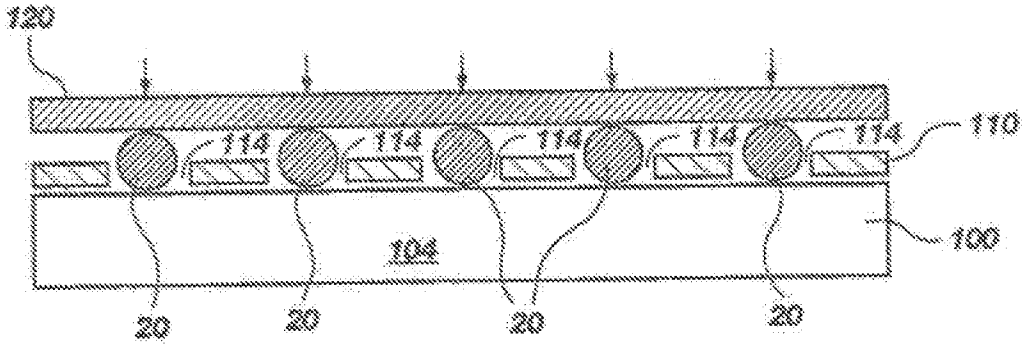


Fig. 5B

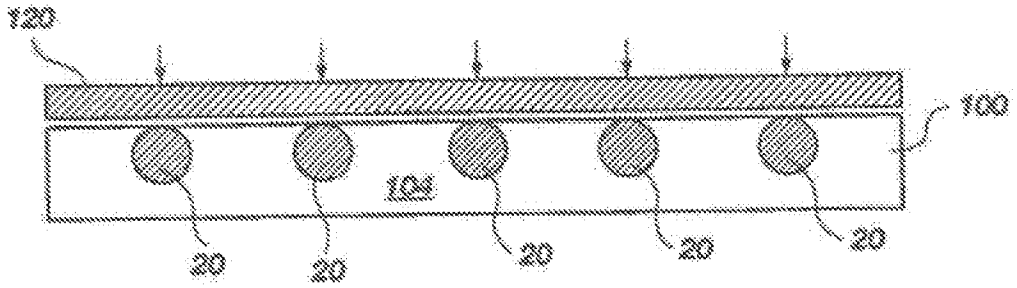


Fig. 5C

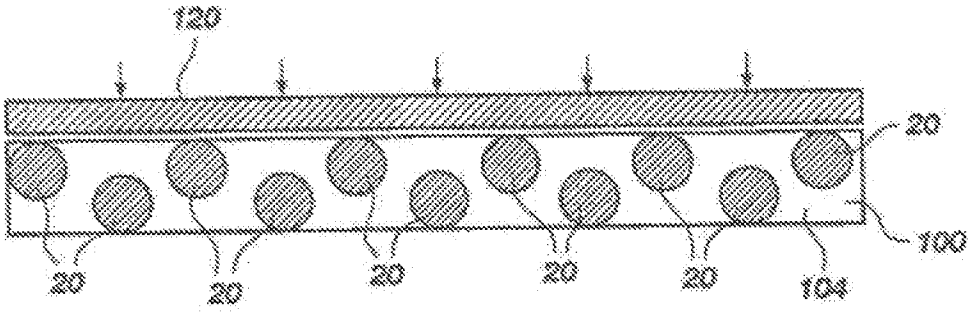


Fig. 5D

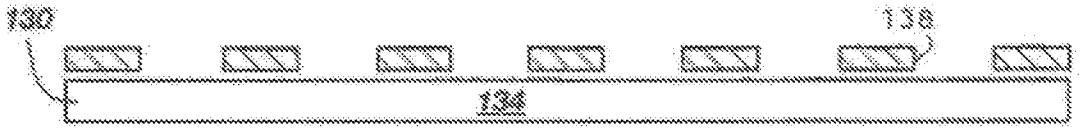


Fig. 6A

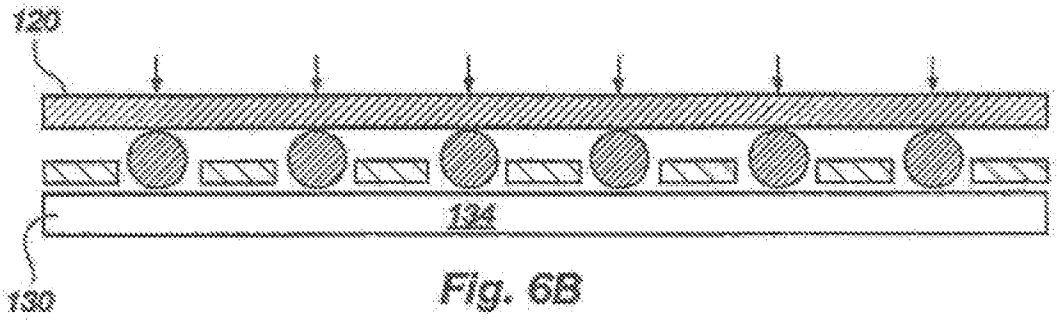


Fig. 6B

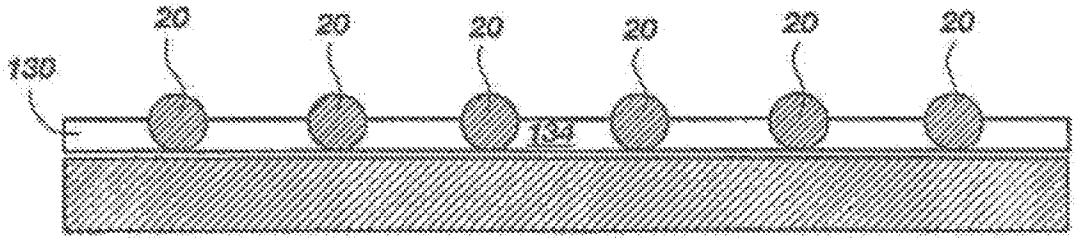


Fig. 6C

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/05931

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B24D 11/00
US CL :451/540

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 451/527,529,533,540; 51/297; 125/16.02,21,22

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, 2,725,693 A (SMITH) 06 December 1955	1-41
Y	US, 2,952,951 A (SIMPSON) 20 September 1960, see entire document, specifically figure 2	1-41
Y	US, 3,146,560 A (HURST) 01 September 1964, see entire document.	1-41
Y	US 4,712,552 A (PANGBURN) 15 December 1987, see entire document, specifically figures 9 and 10.	1-41
A	US, 4,866,888 A (MURAI et al) 19 September 1989.	1-41
A	US 5,176,155 A (RUDOLPH, JR.) 05 January 1993.	1-41.

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
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"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 19 JUNE 1998	Date of mailing of the international search report 16 JUL 1998
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer Timothy V. Eley Telephone No. (703) 308-1824

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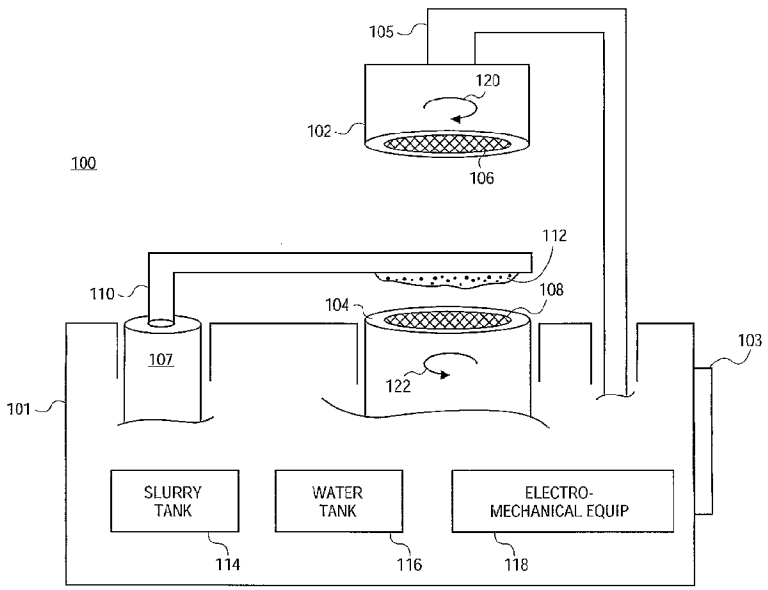
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (BW, GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: DIAMOND CONDITIONING OF SOFT CHEMICAL MECHANICAL PLANARIZATION/POLISHING (CMP) POLISHING PADS



(57) Abstract: Conditioning of chemical mechanical planarization (CMP) using conventional diamond-embedded abrasive strips are well suited to condition conventional "hard" polishing but not soft polishing pads because the diamonds not only remove waste material, but they also damage the polishing surface of the pad. Embodiments of the present invention condition soft polishing pads using diamond strips without damaging the soft polishing pad (108).

WO 2004/094106 A1

DIAMOND CONDITIONING OF SOFT CHEMICAL MECHANICAL PLANARIZATION/POLISHING (CMP) POLISHING PADS

BACKGROUND

1. Field

[0001] Embodiments of the present invention relate to chemical mechanical planarization/polishing (CMP) and, in particular, to conditioning of CMP polishing pads.

2. Discussion of Related Art

[0002] Chemical mechanical planarization/polishing (CMP) is a process technology first developed in the mid-1980s to enable production of integrated circuits on substrates or wafers. CMP processes are used prepare wafers and to fabricate semiconductor devices or structures on the wafers. A CMP process may be used to planarize (*i.e.*, make flat) a semiconductor layer on a wafer, an insulating layer on the semiconductor layer, and a conductive layer on the insulating layer in predetermined patterns.

[0003] A typical CMP system includes a wafer carrier and a platen mounted in a housing. A polishing pad is secured to the platen and the wafer to be polished is secured in the wafer carrier. A typical CMP process operates as follows. The wafer carrier rotates the wafer and/or the platen rotates the polishing pad. Chemical slurry is applied to the surface of the polishing pad and the wafer is brought into contact with the polishing pad and is polished (or planarized). The combination of applying the chemical slurry and the mechanical rotation leads to the term "chemical-mechanical planarization."

[0004] As the wafer is polished, the chemical slurry and materials removed from the wafer tend to glaze the surface of the polishing pad, making the polishing pad slick and reducing the polishing rate and efficiency. It is thus important that the polishing pad surface be clean and free of surface irregularities. The process of cleaning the polishing pad is sometimes referred to a "conditioning" or "refreshing."

[0005] One method of conditioning polishing pads is to abrade them with a conventional diamond-embedded abrasive disk or strip. Although conventional diamond-embedded abrasive strips are well suited to condition "hard" polishing pads used for rough polishing,

they are not well suited to condition "soft" polishing pads used for fine polishing. When a soft polishing pad is conditioned with a diamond-embedded abrasive disk, the diamonds not only remove waste material, but they also damage the polishing surface of the pad.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] In the drawings, like reference numbers generally indicate identical, functionally similar, and/or structurally equivalent elements. The drawing in which an element first appears is indicated by the leftmost digit(s) in the reference number, in which:

[0007] Figure 1 is schematic diagram of a chemical mechanical planarization/polishing (CMP) polishing system according to an embodiment of the present invention;

[0008] Figure 2 is a flowchart illustrating a process performed by a CMP polishing system in according to embodiments of the present invention;

[0009] Figure 3 illustrates an example soft polishing pad according to an embodiment of the present invention;

[0010] Figure 4 illustrates operation of a conditioning arm according to an embodiment of the present invention; and

[0011] Figure 5 illustrates a diamond conditioner according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

[0012] Figure 1 is schematic diagram of a chemical mechanical planarization (CMP) polishing system 100 according to an embodiment of the present invention. The CMP polishing system 100 includes a housing 101, a polishing head 102, a control panel 103, a platen 104, a spindle 105, a wafer 106, a base 107, a soft polishing pad 108, a conditioning arm 110, a diamond (or artificial diamond) conditioner 112, a slurry tank 114, a spindle 115, a water tank 116, and electromechanical equipment 118. The slurry tank 114 and/or the water tank 116 may be located in or separate from the housing 101. The electromechanical equipment 118 may include vertical drivers, rotational drivers,

controllers, or other equipment generally used to operate arms, motors, and other devices in CMP polishing systems.

[0013] The platen 104 is mounted in the housing 101 and may be rotated by a motor (not shown) in the electromechanical equipment 118. The polishing head 102 is mounted on the spindle 105 and may be rotated by a motor (not shown) in the electromechanical equipment 118. The wafer 106 is mounted with the surface to be polished face down and away from the polishing head 102. The soft polishing pad 108 mounted to the platen using an adhesive. During polishing of the wafer 106, the polishing head 102 may be rotated in a direction opposite to the rotation of the polishing pad 108 may be, as shown by arrows 120 and 122. Alternatively, the polishing head 102 may rotate while the platen 104 remains stationary. Alternatively still, the polishing head 102 may be stationary while the platen 104 rotates. The slurry tank 114 delivers slurry to the surface of the soft polishing pad 108 during wafer 106 polishing.

[0014] The conditioning arm 110 pivots in its base 107 when conditioning the soft polishing pad 108. A motor (not shown) in the electromechanical equipment 118 may move the conditioning arm 110. The water tank 116 may dispense a rinsing solution, such as potable water or de-ionized (DI) water, to the surface of the soft polishing pad 108 during conditioning of the soft polishing pad 108.

[0015] Figure 2 is a flowchart illustrating a process 200 performed by the CMP polishing system 100 according to embodiments of the present invention. A machine-readable medium with machine-readable instructions thereon may be used to cause a processor to perform the process 200. Of course, the process 200 is only an example process and other processes may be used. The example process 200 may be used to remove metal, oxides, glass, silicon, etc. Although the example process 200 is described with reference to wafers, the example process 200 may be used for semiconductors, memory disks, or other suitable objects requiring smoothness, planarity, fine polishing, etc., such as lenses and mirrors.

[0016] In a block 202 the head 102 holds the wafer 106 and rotates the wafer 106 against the soft polishing pad 108 as slurry from the slurry tank 114 is applied to the surface of the

soft polishing pad 108 and the platen 104 applies a force to the wafer 106. In a block 204, the head 102 disengages the wafer 106 from contact with the soft polishing pad 108 and the slurry stops flowing to the surface of the soft polishing pad 108.

[0017] In a block 206, the soft polishing pad 108 is conditioned using the diamond conditioner 112. In one embodiment of the present invention, the platen 104 rotates the soft polishing pad 108, rising solution from the water tank 116 rinses the soft polishing pad 108, e.g., by supplying DI water to the surface of the soft polishing pad 108, and the conditioning arm 110 with the diamond conditioner 112 sweeps across (e.g., back and forth) the soft polishing pad 108. Although polishing of the soft polishing pad 108 may be described in some embodiments as being performed *ex situ* (between wafer 106 polishings), polishing of the soft pat 108 in other embodiments may be performed *in situ* (while wafers 106 are being polished), or some combination of both. Of course, the soft polishing pad 108 may be conditioned according to embodiments of the present invention prior to polishing any wafers 106.

[0018] One or a combination of the following process parameters may be modified to improve the process for soft pad 108 conditioning using the diamond conditioner 112 to ensure that the conditioning arm 110 with the diamond conditioner 112 do not destroy or significantly reduce the lifetime of the soft polishing pad 108. In fact, according to embodiments of the present invention, the lifetime of the soft polishing pad 108 is significantly increased. Increased soft polishing pad 108 lifetime results in reduced labor costs and costs of parts, as well as improved processes, (*e.g.*, soft polishing pads 108 do not have to be changed as often).

[0019] In one embodiment, the conditioning arm 110 applies approximately 0.25 psi to the soft polishing pad 108 through the diamond conditioner 112 as opposed to approximately three psi applied using conventional hard polishing pad techniques..

[0020] In known soft polishing pad conditioning methods, the platen and thus the soft polishing pad does not rotate. In embodiments of the present invention, the rotational speed of the platen 104 and thus the soft polishing pad 108 may be approximately one hundred revolutions per minute 100 (rpm)

[0021] In known soft polishing pad conditioning methods, there may be no DI water flowing to the soft conditioning pad. In one embodiment of the present invention, the volumetric flow rate of DI water from the DI water tank 116 may may be one gallon per minute (gpm). Alternatively, the volumetric flow rate may be anywhere from zero to approximately seven gallons per minute.

[0022] In known soft polishing pad conditioning methods, there is no diamond conditioner used, thus no down force applied to a soft polishing pad In one embodiment, the down force applied to the soft polishing pad by the diamond conditioner 112 may be 0.25 psi.

[0023] In known soft polishing pad conditioning methods, no diamond conditioner is used. n known hard polishing pad conditioning methods, the diamond conditioner makes at least ten sweeps. In one embodiment, the diamond conditioner 112 makes one sweep across the soft polishing pad.

[0024] Figure 3 illustrates the example soft polishing pad 108 according to an embodiment of the present invention. The example soft polishing pad 108 includes several pores 302 and may be made from napped poromerics-porous urethane layers on a mylar or compressible urethane substrate. In an alternative embodiment, the example soft polishing pad 108 may be a soft pad made with tangled polyester fibers coated with polyurethane. In another embodiment, the example soft polishing pad 108 may be a felt sheet of fibers impregnated with micro porous elastomer. Alternatively still, the example soft polishing pad 108 may be a porous thermoplastic resin matrix, typically polyurethane, reinforced with a fibrous network such as a felted mat of polyester fibers. An example of a suitable soft pad includes any of the Politex® Series polishing pads available from Rodel Holdings in Wilmington, Delaware.

[0025] The soft polishing pads 108 according to embodiments of the present invention are to be distinguished from known hard polishing pads, which include micro porous polyurethane polishing pads that are relatively hard and not as compressible when compared to other types of polishing pads and polyurethane impregnated felt polishing

pads. Examples of hard pads include the SUBA 1000 Series polishing pads and the SUBA® Pads available from Rodel in Phoenix, Arizona.

[0026] Figure 4 illustrates operation of the conditioning arm 110 according to an embodiment of the present invention. When the soft polishing pad 108 is moving and a wafer 106 is being polished, the conditioning arm 110 (and the diamond conditioner 112) remain in the position 402 situated adjacent to the perimeter of the soft polishing pad 108. After a predetermined number of wafers have been polished by the soft polishing pad 108, or when the polishing rate has been decreased due to build up of slurry and other debris, the conditioning arm 110 is pivoted at one end by the base 107, lowered onto the soft polishing pad 108, and swept along an arc indicated by the arrows 408 from the position 402 across the surface of the soft polishing pad 108 (as shown by phantom lines) to a second position 406 adjacent to the other side of the perimeter of the soft polishing pad 108 (also shown by phantom lines).

[0027] Figure 5 illustrates the diamond conditioner 112 according to an embodiment of the present invention. The diamond conditioner 112 includes a base 502 having diamonds 504. The base 502 may be any suitable rigid substrate. The diamonds 504 may be synthetic diamonds, natural diamonds, etc.

[0028] The diamonds 504 may be placed on the base 502 using chemical vapor deposition (CVD). Alternatively, the diamonds 404 may be embedded in the base 502. For example, the diamond conditioner 112 may be formed by embedding diamond particles in nickel coated on the surface of a rigid substrate according to well-known or proprietary techniques.

[0029] Embodiments of the invention can be implemented using hardware, software, firmware, or a combination of hardware and software. In implementations using software, the software may be stored on a computer program product (such as an optical disk, a magnetic disk, a floppy disk, etc.) or a program storage device (such as an optical disk drive, a magnetic disk drive, a floppy disk drive, etc.).

[0030] The above description of illustrated embodiments of the invention is not intended

to be exhaustive or to limit the invention to the precise forms disclosed. While specific embodiments of, and examples for, the invention are described herein for illustrative purposes, various equivalent modifications are possible within the scope of the invention, as those skilled in the relevant art will recognize. These modifications can be made to the invention in light of the above detailed description.

[0031] In the above description, numerous specific details, such as particular processes, materials, devices, and so forth, are presented to provide a thorough understanding of embodiments of the invention. One skilled in the relevant art will recognize, however, that the embodiments of the present invention can be practiced without one or more of the specific details, or with other methods, components, etc. In other instances, well-known structures or operations are not shown or described in detail to avoid obscuring the understanding of this description.

[0032] Various operations have been described as multiple discrete operations performed in turn in a manner that is most helpful in understanding embodiments of the invention. However, the order in which they are described should not be construed to imply that these operations are necessarily order dependent or that the operations be performed in the order in which the operations are presented.

[0033] Reference throughout this specification to "one embodiment" or "an embodiment" means that a particular feature, structure, process, block, or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, the appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more embodiments.

[0034] The terms used in the following claims should not be construed to limit the invention to the specific embodiments disclosed in the specification and the claims. Rather, the scope of embodiments of the invention is to be determined entirely by the following claims, which are to be construed in accordance with established doctrines of claim interpretation.

CLAIMS

What is claimed is:

1. A method of conditioning a chemical mechanical planarization (CMP) polishing pad, comprising:

conditioning a soft polishing pad using diamond conditioner.

2. The method of claim 1, further comprising:

rotating a soft polishing pad on a platen;

rinsing the soft polishing pad; and

passing a diamond conditioner over the soft polishing pad.

3. The method of claim 2, further comprising:

applying zero pounds per square inch (psi) to the soft polishing pad from the platen.

4. The method of claim 1, wherein passing the conditioning arm having the diamond conditioner thereon over the soft polishing pad comprises passing the diamond conditioner over the soft polishing pad during wafer polishing.

5. The method of claim 1, wherein passing the conditioning arm having the diamond conditioner thereon over the soft polishing pad comprises passing the diamond conditioner over the soft polishing pad between wafer polishings.

6. The method of claim 1, further comprising rotating a wafer against the soft polishing pad.

7. The method of claim 6, further comprising applying a slurry to the surface of the soft polishing pad.

8. A chemical mechanical planarization (CMP) system, comprising:

a head mounted in a housing;

a wafer mounted to the head;

a platen mounted in the housing;

a soft polishing pad mounted to the platen;

a pad conditioning arm mounted in the housing; and

a diamond conditioner mounted to the pad conditioning arm.

9. The system of claim 8, further comprising a slurry tank mounted in the housing.

10. The system of claim 9, further comprising a water tank mounted in the housing.

11. The system of claim 8, further comprising electromechanical equipment mounted in the housing.

12. A chemical mechanical planarization (CMP) apparatus, comprising:

a soft polishing pad adhered to a platen in a housing; and

a pad conditioning arm mounted in the housing, the pad conditioning arm having a diamond conditioner attached thereto.

13. The CMP apparatus of claim 12, wherein the soft polishing pad comprises napped poromerics-porous urethane layers on a substantially compressible substrate.

14. The CMP apparatus of claim 13, wherein the soft polishing pad comprises napped poromerics-porous urethane layers on a mylar substrate.

15. The CMP apparatus of claim 12, wherein the soft polishing pad comprises napped poromerics-porous urethane layers on a substantially compressible urethane substrate.

16. The CMP apparatus of claim 12, wherein the diamond conditioner comprises a diamond strip.

17. The CMP apparatus of claim 12, wherein the diamond strip comprises synthetic diamonds embedded in a base.

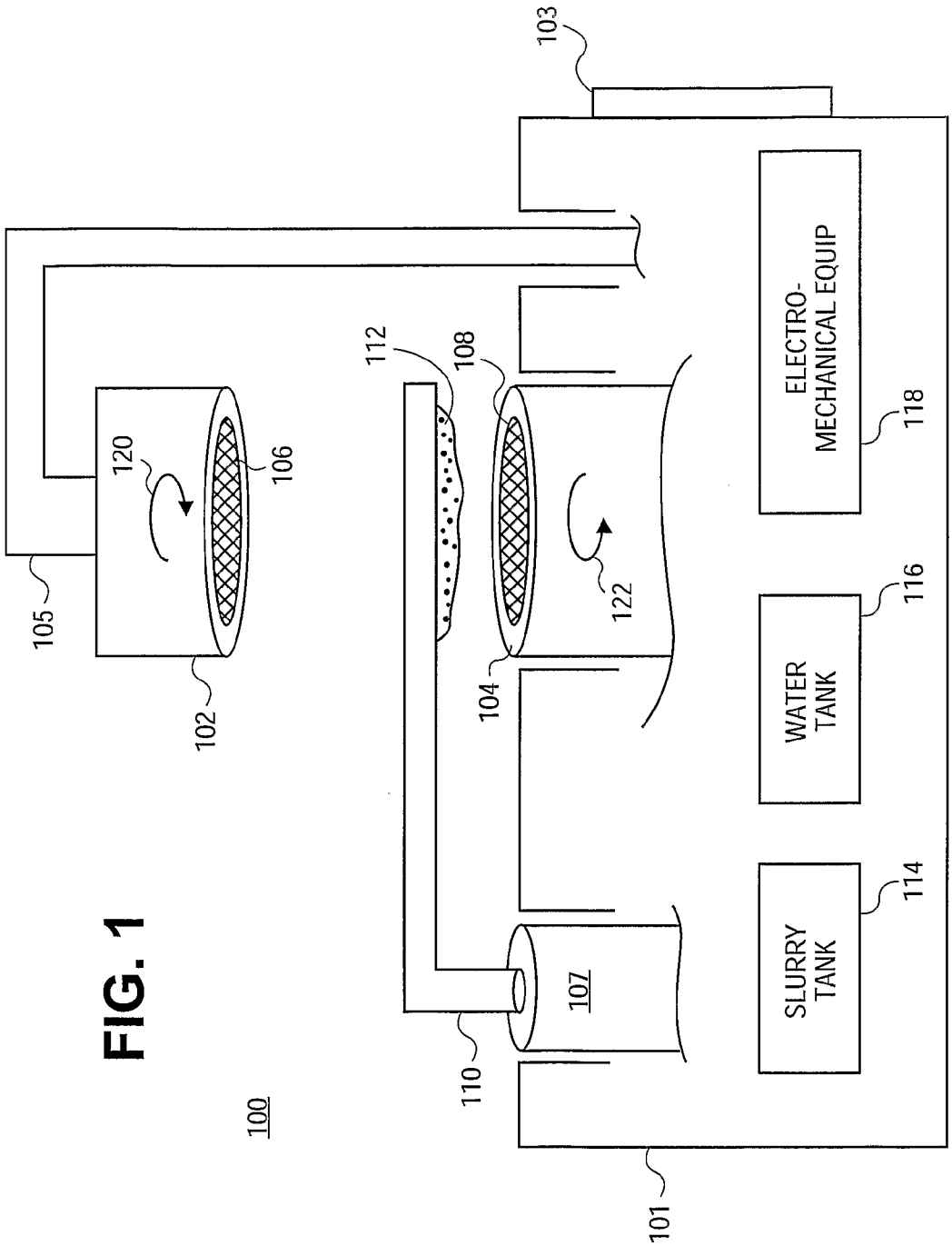

103
ELECTRO-
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118
112
108
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FIG. 1

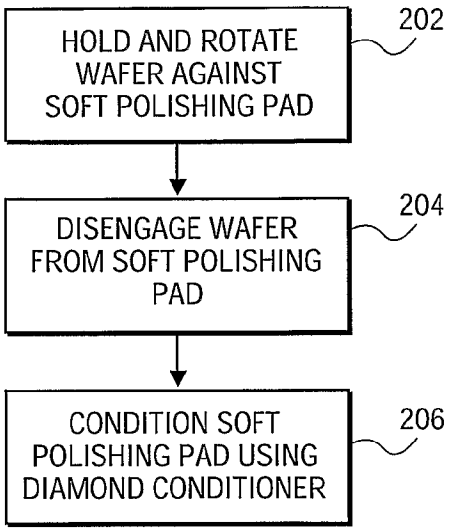

HOLD AND ROTATE WAFER AGAINST SOFT POLISHING PAD
202
DISENGAGE WAFER FROM SOFT POLISHING PAD
204
CONDITION SOFT POLISHING PAD USING DIAMOND CONDITIONER
206

FIG. 2

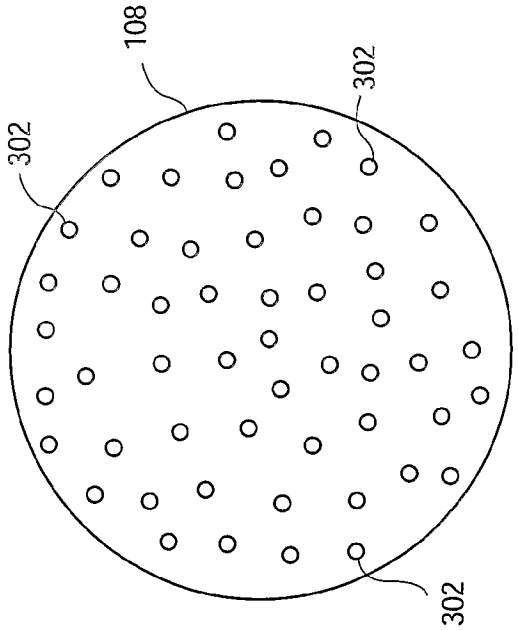


FIG. 3

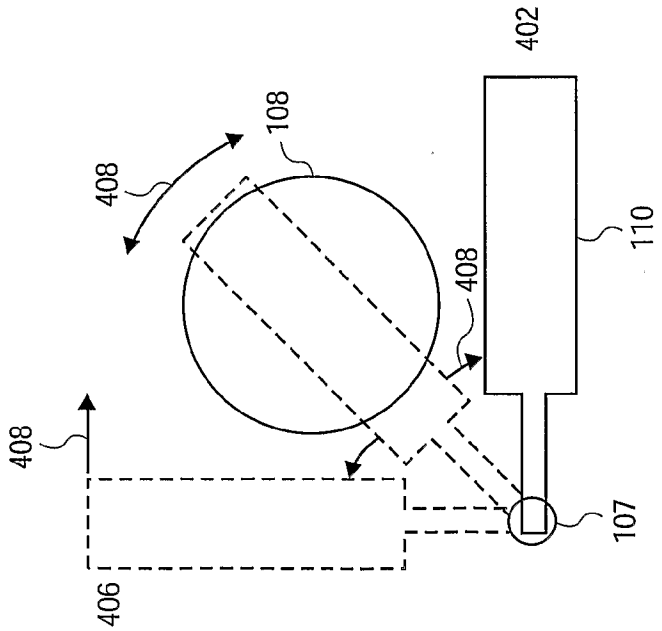


FIG. 4

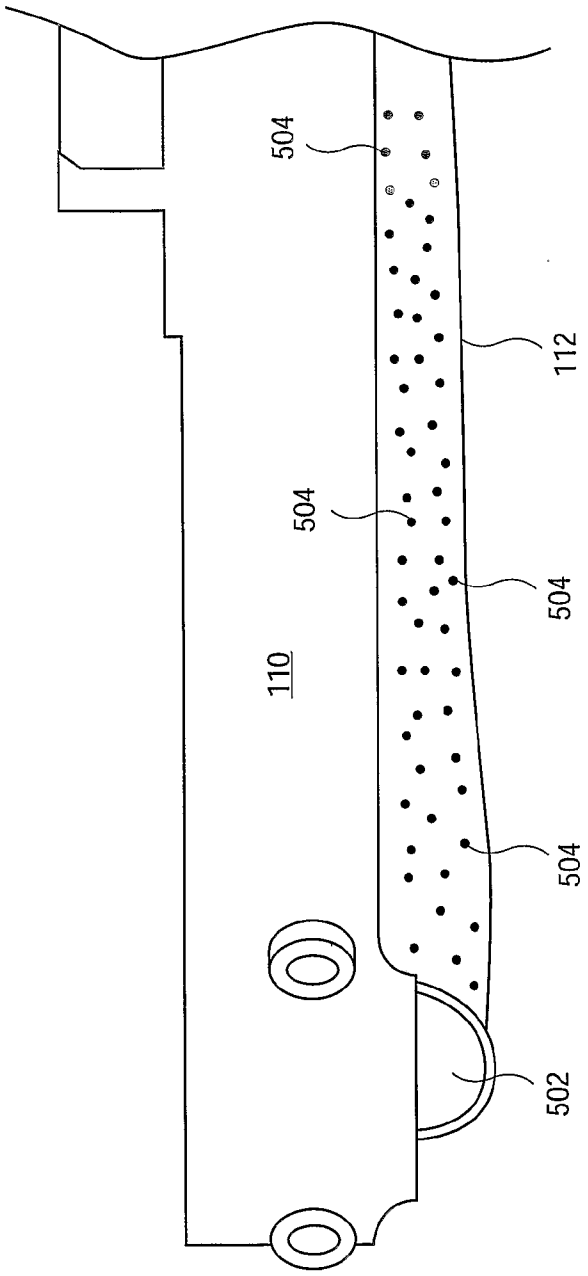


FIG. 5

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 03/39969

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B24B37/04 B24B53/007

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B24B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2001/029155 A1 (LI JUI-LUNG ET AL) 11 October 2001 (2001-10-11) paragraphs '0034!,'0035!,'0043!; claim 1; figure 3	1-17
A	US 2002/137436 A1 (GOTKIS YEHIEL ET AL) 26 September 2002 (2002-09-26) paragraph '0024!; figure 5C	16,17

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 May 2004	25/05/2004

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Do Huu Duc, J

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 03/39969

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2001029155 A1	11-10-2001	NONE	
US 2002137436 A1	26-09-2002	US 6340326 B1	22-01-2002
		AU 2940301 A	07-08-2001
		EP 1250215 A1	23-10-2002
		JP 2003521117 T	08-07-2003
		TW 471994 B	11-01-2002
		WO 0154862 A1	02-08-2001
		US 2001012751 A1	09-08-2001

PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

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(30) Priority Data:
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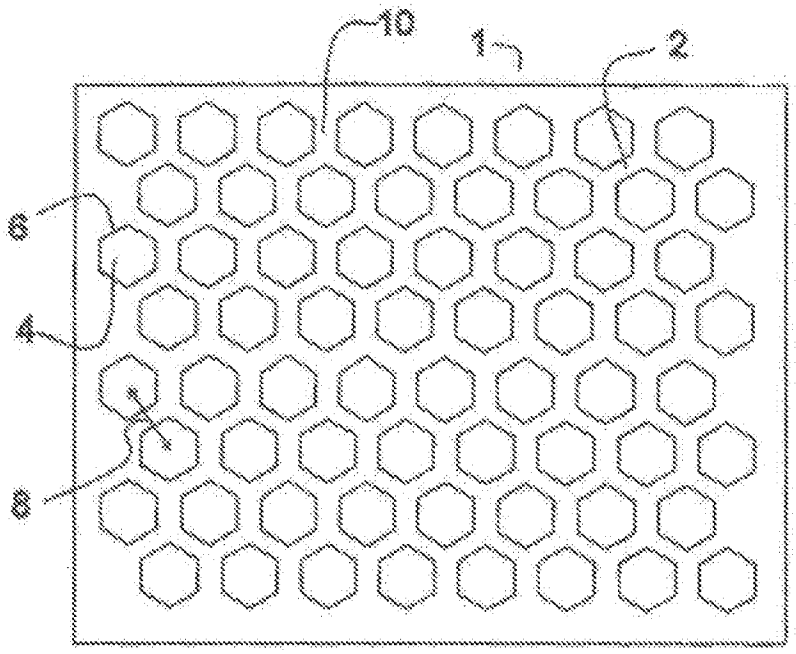
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(54) Title: PATTERNED ABRASIVE TOOLS

(57) Abstract

A method of making a metal bonded, abrasive tool uses a perforated stencil to place abrasive parcels in a pattern on the cutting surface of the tool. The stencil is placed against the tool preform so that the perforations define cavities. Metal brazing composition in the form of a paste is packed into the cavities and the stencil is removed to leave discrete parcels of brazing paste tacked to the cutting surface. Abrasive grains are deposited onto the paste particles and fixed in place by firing the preform at brazing conditions. The abrasive grains thus are precisely positioned and spaced apart on the cutting surface by abrasive free channels which are defined by the web of the stencil. The abrasive free channels provide paths to facilitate flow of coolant material and swarf particles at the cutting zone. The method can include initially placing the brazing paste parcels onto a resilient, transfer medium and subsequently transferring the parcels onto the preform cutting surface. This method is particularly useful for depositing an abrasive pattern on a non-planar or highly curved tool surface. In another contemplated variation of the invention, the abrasive grains are premixed with the brazing paste prior to filling the cavities.



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Patterned Abrasive Tools

This invention relates to the manufacture of abrasive tools. More specifically, it relates to making tools with abrasive grains disposed in discrete parcels separated from neighboring parcels on the cutting surface by open channels. The invention further relates to self-sharpening abrasive tools in which the abrasive parcels are formed from multiple, ultrafine abrasive grains embedded therein.

In certain abrasive tools for industrial applications abrasive grains are affixed to a metal preform. The grains are attached to the preform by brazing a metal bonding composition at temperatures above about 600°C.

Removing swarf from the cutting zone during grinding improves performance. Among other things, swarf removal reduces wear of the brazed bonding composition and premature dulling of the abrasive grains. Cooling the work piece is another way abrasive tool users obtain improved grinding performance. Often cooling is accomplished by bathing the work piece in a cool, liquid lubricant. By providing open spaces on the abrasive tool, manufacturers can enhance swarf removal and cooling efficiency. These open spaces provide paths for swarf to leave the cutting zone and conduct coolant to and from the work piece.

A typical method of creating swarf removal and coolant spaces involves cutting grooves or drilling holes through the preform. This technique is widely used in abrasive wheel manufacture. In segmented abrasive tool fabrication, channels can be created by placing gaps between abrasive segments. Normally, such segments are molded from mixtures of abrasive grains and bonding composition and then attached as units to the tool. These methods add to the complexity of the manufacturing operation, are time consuming, and add to product cost.

It is desirable to provide an efficient method of making an abrasive tool with swarf removal and cooling space. Some methods for placing abrasive grains in discrete locations separated by open space on an abrasive tool have been suggested.

U.S. 5,389,119 (Ferronato et al.) discloses a method of making a nonwoven fabric with discrete islands of abrasive bound to a porous fabric layer. The islands are created by

masking portions of a conductive fabric layer and electro-depositing or electroplating a metal structure which contains abrasive material in isolated, unmasked spots.

U.S. 4,826,508 (Schwartz et al.) teaches a method of forming a flexible abrasive member which includes applying a flexible mask of non-electrically conductive material having a multitude of discrete openings therein to one side of a flexible fabric, placing the fabric with the mask applied in a metal deposition bath, and depositing metal directly in the discrete openings in the presence of particulate abrasive material such that the metal adheres directly to the fabric and the abrasive material becomes embedded in the metal deposits.

U.S. 4,047,902 (Wiand) discloses a method of manufacturing a metal-plated abrasive product which entails providing a conductive or metallic backing member, masking off predetermined desired surface portions thereof to leave exposed, spaced-apart portions on the backing, and bonding abrasive grit particles to the exposed portions. The bonding is carried out by a metal plating process.

U.S. 4,863,573 (Moore et al.) teaches a method of making an abrasive article by screen printing a non-conductive mesh with non-electrically conductive ink. The mesh is passed through an electroplating bath while in contact with an electrically conductive cylinder or metal band. A first, nearly complete thickness of metal is electrodeposited onto the non-printed areas of the mesh. Then abrasive particles are deposited on the metal and a second, outer layer of metal is electrodeposited onto the first thickness of metal. The abrasive particles thus are captured by the outer layer of metal and lie at the surface of the metal.

U.S. 4,874,478 (Ishak et al.) provides a method of making an abrasive member comprising attaching a metal film to one surface of a flexible sheet, applying a mask of plating resistant material having a multitude of discrete openings to the exposed surface of the film and depositing metal directly through the openings into the metal film in the presence of particulate abrasive so that the metal adheres to the film and embeds the abrasive in the metal deposits.

Each of the foregoing references relates to manufacture of flexible abrasive fabric or film. Although these abrasive articles might be laminated to supporting substrates to form coated abrasive products, they generally cannot be used by themselves in many industrial grinding applications. Fabric or film-borne abrasive tools will not hold up in aggressive

grinding of construction materials, such as steel and concrete. Additionally, each referenced method employs electro-deposition or electroplating to attach the abrasive to the fabric. Such methods of attachment do not usually provide sufficient thickness of bond material to endure in demanding, industrial grinding applications.

Other approaches to incorporating open space in an abrasive matrix have been disclosed. U.S. 4,882,878 (Benner) describes a grinding wheel having a rigid, continuous abrasive-bearing matrix. The matrix has a plurality of spaced apertures extending into the wheel from the grinding surface. Preferably the matrix is of an organic binding material.

International Patent Application WO 96/26811 (Ferronato) discloses a flexible abrasive member having a backing layer on one side and deposits of abrasive particles and bonding material on the other side. The article further includes a permanent one way mold substantially encircling the deposits and extending along at least part of the height of the deposits. The deposits are placed in holes of the flexible abrasive member.

U.S. 5,152,917 (Pieper et al.) teaches the method of making a structured, coated abrasive article comprising a backing bearing a plurality of abrasive composites having precise shape and disposed in a non-random array. The method includes introducing a slurry of binder precursor and abrasive grains into cavities on the outer surface of a production tool. A backing is placed over the outer surface such that the slurry wets one major surface of the backing to form an intermediate article. The binder precursor is then cured before the intermediate article departs from the outer surface of the production tool. The binder precursor is a quick setting, curable or thermoplastic organic resin.

The prior art does not satisfy the need for a metal preform abrasive tool for aggressive grinding applications in which discretely spaced apart abrasive elements are strongly attached to the preform with a brazeable metal bonding composition. Accordingly, there is provided a process for making an abrasive tool comprising the steps of:

(A) providing a stencil having a plurality of perforations of selected shape;

(B) contacting a cutting surface on the abrasive tool with the stencil whereby the perforations define cavities adjacent the cutting surface;

(C) providing a brazing paste including a metal braze composition and a binder component;

(D) filling the cavities with brazing paste;

(E) removing the stencil to form parcels of brazing paste on the cutting surface, each parcel being separated from neighboring parcels by paste-free channels;

(F) depositing abrasive grains onto the parcels; and

(G) thermally processing the abrasive tool to braze the abrasive grains to the cutting surface.

In another aspect, the present invention provides a process for making a metal preform abrasive tool in which selectively shaped and spaced apart parcels of brazing paste are first formed on a transfer medium. The brazing paste parcels are then transferred to the cutting surface of a metal preform where abrasive grains are added and brazing is accomplished. This method facilitates the manufacture of riddly-shaped and curved cutting surface abrasive tools. There is thus provided a process for making an abrasive tool comprising the steps of:

(A) providing a stencil having a plurality of perforations of selected shape;

(B) contacting a transfer medium with the stencil whereby the perforations define cavities adjacent the transfer medium;

(C) providing a brazing paste including a braze composition and a binder component;

(D) filling the cavities with brazing paste;

(E) removing the stencil to form a patterned face of parcels of brazing paste on the transfer medium, each parcel being separated from neighboring parcels by paste-free channels;

(F) forcing the patterned face against a cutting surface of the abrasive tool;

(G) peeling the transfer medium away to leave the parcels on the cutting surface;

(H) depositing abrasive grains onto the parcels; and

(I) thermally processing the abrasive tool to braze the abrasive grains to the cutting surface.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a plan view of a mask for creating a stencil useful in the practice of the present invention.

DETAILED DESCRIPTION

The present invention is useful for fabricating abrasive tools in which abrasive grains are metal-bonded onto metal, primarily ferrous metal, preforms. The method can be used with a diverse variety of preform shapes. Representative preforms include flat disks, drill bit cores, abrasive wheel rims, saw blades and many specialty tool bodies, such as spherical, conical, and frustoconical-shaped preforms. The abrasive tools made according to this invention thus will be rugged and suitable for demanding industrial and construction material grinding and cutting applications.

The abrasive grains will be of a substance that is harder than the substance being cut. Very hard abrasive substances generally known as superabrasives, such as diamond, cubic boron nitride and mixtures of them can be used. Among these, diamond is preferred, primarily for cutting nonferrous materials. Many non-superabrasive substances also can be employed. Representative non-superabrasives which can be used in this invention include aluminum oxide, silicon carbide, tungsten carbide, and the like. Aluminum oxide encompasses standard alumina abrasive as well as seeded and unseeded sol-gel microcrystalline alumina, described in greater detail, below.

A preferred non-superabrasive is a microcrystalline alumina. Also preferred are the sol-gel alumina filamentary abrasive particles described in U.S. Pat. Nos. 5,194,072 and 5,201,916, incorporated herein by reference. "Microcrystalline alumina" means sintered sol-gel alumina in which the crystals of alpha alumina are of a basically uniform size which is generally smaller than about 10 μm, and more preferably less than about 5 μm, and most preferably less than about 1 μm in diameter. Crystals are areas of essentially uniform crystallographic orientation separated from contiguous crystals by high angle grain boundaries.

Sol-gel alumina abrasives are conventionally produced by drying a sol or gel of an alpha alumina precursor which is usually but not essentially, boehmite; forming the dried gel into particles of the desired size and shape; then firing the pieces to a temperature sufficiently high to convert them to the alpha alumina form. Simple sol-gel processes for making grain suitable for use in accordance with the present invention are described, for example, in U.S. Patent Nos. 4,314,827; 4,518,397 and 5,132,789 ; and British Patent Application 2,099,012, the disclosures of which are incorporated herein by reference.

In one form of sol-gel process, the alpha alumina precursor is "seeded" with a material having the same crystal structure as, and lattice parameters as close as possible to, those of alpha alumina itself. The "seed" is added in as finely divided form as possible and is dispersed uniformly throughout the sol or gel. It can be added *ab initio* or it can be formed *in situ*. The function of the seed is to cause the transformation to the alpha form to occur uniformly throughout the precursor at a much lower temperature than is needed in the absence of the seed. This process produces a crystalline structure in which the individual crystals of alpha alumina are very uniform in size and are essentially all sub-micron in diameter. Suitable seeds include alpha alumina itself but also other compounds such as alpha ferric oxide, chromium suboxide, nickel titanate and a plurality of other compounds that have lattice parameters sufficiently similar to those of alpha alumina to be effective to cause the generation of alpha alumina from a precursor at a temperature below that at which the conversion normally occurs in the absence of such seed. Examples of such seeded sol-gel processes are described in U.S. Patent Nos. 4,623,364; 4,744,802; 4,788,167; 4,881,971; 4,954,462; 4,964,883; 5,192,339; 5,215,551; 5,219,806; and 5,453,104, the disclosures of which are incorporated herein by reference, and many others.

Preferably the abrasive grains are attached to the metal preform by a bond containing metal. The bond is formed from a metal braze composition which is thermally treated according to a conventional, high temperature brazing process. Metal braze compositions for uniting abrasive to a metal tool preform are well known. Illustrative metal braze compositions include silver, nickel, zinc, lead, copper, tin and mixtures of these metals alloyed with other metals, such as phosphorous, cadmium, vanadium and the like. Generally minor amounts of additional components can be included in the braze composition to modify the properties of the bond during and after brazing, such as to modify melting temperature, melt viscosity, abrasive surface wetting and bond strength. Copper/tin bronze-based alloys are preferred for bonding abrasives, especially superabrasives to metal. Certain so-called "active metals" or "reactive metals" including titanium, tantalum, chromium,
and zirconium, for example, can be added to the braze composition particularly for bonding diamond. These metals react with the carbon to form carbides and thereby improve the wetting of the braze composition on the superabrasive particle. Hybrid bond

material such as a metal filled resinoid braze composition containing a major fraction of metal can also be used with the present invention.

Brazing is performed at elevated temperatures selected with consideration to numerous system parameters such as solidus-liquidus temperature range of the metal brazing composition, geometry and material of construction of the preform and physical properties of the abrasive. For example, diamond can graphitize at temperatures above about 1000°C in air and above about 1200°C under vacuum or inert atmosphere. Hence, it is often desirable to braze at the lowest possible temperatures. The metal brazing composition should be selected to braze preferably at about 800-1025°C, and more preferably, at about 850-950°C.

The metal braze composition is usually employed in fine particulate form. The components of the metal braze composition can be present as prealloyed particles, as a mixture of separate component powders or a combination of both forms. The metal braze composition can be conveniently delivered to the braze site in paste form by mixing a liquid binder with the dry particulate components. The liquid binder facilitates blending of the dry particulate components to uniform composition and provides a vehicle for dispensing precise amounts of metal braze composition.

The liquid binder should be sufficiently volatile to evaporate or pyrolize below the melting temperature of the metal braze composition so as not to interfere with the formation of a secure bond between abrasive and preform. However, the volatility should not be so great that the paste dries too quickly. The paste should remain fluid for a reasonable time to permit assembly of the abrasive tool. Preferably, the paste should be fluid for at least several minutes and up to about an hour at ambient temperature and humidity conditions. Liquid binders are well known in the industry. Representative paste-forming binders suitable for use in the present invention include Braz™-Binder Gel from Vitta Company; "S" binder from Wall Colmonoy Corporation, Madison Heights, Michigan; and Cusil-ABA, Cusin-ABA, and Incusil-ABA pastes from Wesgo, Belmont, California. Active metal braze composition pastes including binder premixed with metal braze composition components can be obtained from Lucas-Milhaupt Company, Cudahy, Wisconsin under the Lucanex ™ tradename, such as Lucanex 721.

The present invention uses a stencil to place abrasive parcels in a pattern on the abrasive tool. Generally, the stencil is a flat sheet structure. The sheet can be flexible

which permits it to conform to a curved cutting surface and to be rolled up for storage or for deployment in an endless belt configuration.

The stencil material should be capable of being perforated with a plurality of precisely positioned, selectively shaped holes. Perforating can be done by any well known technique, such as stamping with a die, photoetching, drilling and cutting. Stainless steel sheet can be reused repeatedly, is wear resistant, is generally not affected by a wide range of chemicals, and therefore, is a preferred stencil material. For one-time or limited reuse stencils, disposable material, such as plastic film and fiberboard sheeting, also is contemplated to fall within the scope of this invention.

The perforations will extend completely through the stencil. Shape and placement of the perforations determine the size and location of abrasive parcels on the tool. Any regular or non-regular geometric, area-enclosing shape can be employed. Uncut regions of the stencil correspond to open channels on the tool between abrasive parcels.

In use, one side of the stencil is brought in contact with the tool preform adjacent the cutting surface. The other side of the stencil remains exposed. The interior walls of the perforations and the cutting surface within the perimeters of the perforations define vacant cavities. On the exposed side of the stencils, the cavities are open.

The cavities are filled with brazing paste. Filling preferably is accomplished by forcing the paste into the cavities with a squeegee-like tool. That is, a thick bead of brazing paste is dispensed on the exposed side of the stencil, generally at one end of the cutting surface. The bead length extends slightly beyond the width of the cutting surface. A straight edged blade longer than the bead length is drawn with slight pressure from behind the bead across the exposed side of the stencil. The blade forces the paste into the cavities and removes the excess paste above the cavities flush with the exposed side of the stencil. The blade also wipes away excess paste from the exposed side of the stencil for reuse or disposal.

It is seen that the thickness of the stencil sheet will determine the height of the abrasive parcels on the tool. The thickness can vary widely to suit the needs of a particular grinding application. Generally, the thickness will be about equal to the maximum cross section dimension of the abrasive particles, although a different thickness can be used, especially if the binder concentration of the brazing paste varies outside the range of about 20-25 wt%. One can also appreciate that the size of the metal braze

composition particles should be small enough to form a smooth paste that will flow into the cavities. Particle size of 325 U.S. standard mesh or smaller, *i.e.*, at most 44 μm, is generally suitable.

The stencil is peeled away from the cutting surface. The parcels of brazing paste remain stuck to the cutting surface. Thus the brazing paste is disposed on the cutting surface in discrete islands separated from neighboring parcels by paste-free channels.

In one aspect, abrasive grains are deposited onto the still soft parcels of abrasive paste. Grains can be placed individually or dusted over the whole surface. In an embodiment, abrasive grains are at least about 100 μm and only one abrasive grain is deposited onto each of most parcels. A feeding apparatus can be used to facilitate individual placement of a single abrasive grain in each parcel of paste. Such feeding apparatus also advantageously may orient grain placement to optimize exposure of each grain's cutting facet relative to the workpiece. The fabricator thus can control the tool at the individual grain level to provide maximum cutting speed, minimum energy consumption, minimum grain fracture, or combinations of these parameters. The metal brazing composition will liquefy during brazing. Consequently, it may be necessary to provide means to preserve the orientation of individually placed grains until a permanent bond is formed at the conclusion of brazing. For example, this may be achieved by utilizing a stencil or feeding apparatus of a thermally stable composition, such as graphite or ceramic. The thermally stable stencil or feeding apparatus may be left in place during all or part of the brazing step.

In another embodiment the abrasive grains have a particle size of at most 10 μm. Preferably, the small grains are dusted onto the cutting surface to embed the grains in the parcels. Excess grains which dust into the paste-free channels are not embedded in the parcels. They can be removed by inverting the preform, by vacuum, by blowing with gas jets or like procedures. After removing excess grains, loosely embedded grains can be further buried in the parcels of paste. The grains can be deeply planted by placing a flexible release film over the parcel-populated cutting surface and applying pressure with a manual or automated roller, for example.

In yet another embodiment, the abrasive grains are premixed with the brazing paste prior to filling the cavities. The premixed grains should be smaller than the cross section

dimension of the perforations to permit the grains to enter the cavities. Preferably the premixed grains should be smaller than 75% of the stencil thickness.

Premixing of small grains with the paste can provide a uniform concentration throughout the paste. This technique will embed grains over the complete depth of the parcel. Moreover, the small grains can impart self-sharpening behavior to the premixed parcels. That is, each parcel on the tool will constitute a plurality of abrasive grains bonded within a matrix of metallic braze. Such parcels tend to wear by dislodging the most exposed abrasive grains. This will expose underlying fresh, sharp grains to continue grinding. Consequently, tools fabricated in this manner generally provide consistent, superior grinding performance as the parcels wear away over time in service.

Once the abrasive grains are embedded in the parcels of brazing paste, the preform can be fired by traditional methods. A brazing treatment causes the residual liquid binder to dissipate or burn off at intermediate temperature. At high temperature the metal braze composition components permanently unite the abrasive grains to the preform. Control of the thermal cycle variables permits the braze composition components to sinter without significantly changing the shape or placement of the parcels. One of ordinary skill in the art can select appropriate brazing time and temperature parameter to optimize parcel shape retention.

It is sometimes desirable to create a patterned abrasive on a tool exhibiting non-planar or extreme surface curvature. Deployment of a stencil directly against such a cutting surface may be problematic. In another aspect of this invention, this problem is solved by forming parcels of brazing paste on a transfer medium, and subsequently transferring the parcels to the cutting surface of a metal preform. The transfer medium can be a resilient, rubbery pad that is capable of conforming to the shape of the preform cutting surface. The operative face of the transfer medium preferably has a closed cell, smooth surface structure to facilitate transfer of paste parcels.

According to this variation of the invention, a stencil is provided with a plurality of perforations. Each perforation has a precise shape and is placed apart from neighboring perforations. One side of the stencil is brought in contact with a generally flat sheet of transfer medium while the other side of the stencil remains exposed. The interior walls of the perforations and the transfer medium within the perimeters of the perforations define vacant cavities. On the exposed side of the stencils, the cavities are open.

The cavities are filled with brazing paste. Filling preferably is accomplished by forcing the paste into the cavities, as explained above. The stencil is peeled away leaving the parcels of brazing paste stuck to the transfer medium. The parcel-bearing side of the transfer medium is pressed against the cutting surface of a tool preform. This can be accomplished to some advantage by first placing the parcel-free side of the transfer medium on a stable working surface, such as a table top or similar holding structure. The parcel-bearing side of the medium is held stationary and exposed. Then the cutting surface of the preform is forced against the stationary transfer medium. The parcels transfer to the cutting surface. Thereafter, abrasive particles can be added and the tool can be fired to permanently attach the abrasives.

EXAMPLES

EXAMPLE 1

The example can be better understood with reference to Fig. 1. Mask the surface of a 15 inch long by 15 inch wide by 0.010 inch thick stainless steel sheet with a U.V. impenetrable coating. The mask 1 is a continuous network 2 with exposed regular hexagonal areas 4 of 0.115 inches length on each side 6 and center-to-center distance 8 of 0.32 inches. The gap 10 between neighboring hexagons is 0.12 inches. Photoetch the sheet to open hexagonal perforations at the exposed areas and remove the mask.

Mount the perforated stainless steel stencil to a sturdy, rigid rectangular frame to maintain flatness. Place a 0.030 inch thick, 9.875 inch diameter, flat, circular steel preform for an abrasive disk on a table with the cutting surface facing up. Align the stencil centrally over the disk and clamp the frame to the preform so that the face of the disk contacts one side of the stencil. Maintain the exposed side of the stencil facing up in a horizontal plane.

Dispense an approximately 0.5 inch diameter, 12 inch long bead of Lucanex™ 721 braze paste just inside one edge of the rectangular frame. Use a 14 inch long, hard rubber squeegee, to draw the bead in a steady speed stroke across the exposed face of the stencil with slight downward pressure and to force the braze paste into the hexagonal cross-section cavities to a depth flush with the exposed surface of the stencil, i.e., approximately 0.010 inch. Use only a single pass to prevent braze paste from bleeding under the stencil between perforations.

Unclamp the frame from the preform and lift the stencil vertically away from the disk face. Sprinkle 120/140 U.S. mesh type PDA 989 diamond abrasive grains from DAC Company, New York, New York to evenly dust grains over the disk face. Lift the preform from the table and invert to drop excess abrasive grains into a collection pan. Place the abrasive bearing preform cutting surface side up on a horizontal work surface. Align a 0.25 inch thick, 14 inch diameter circular rigid acrylic plastic sheet to overlay the preform and push down evenly to embed the abrasive grains into the braze paste parcels.

Remove the acrylic sheet and fire the preform in a vacuum furnace at about 15°C per minute to a maximum temperature of about 900°C, while maintaining pressure within the furnace below 10^{-4} Torr. Hold the preform at 900°C for 10 minutes and allow to cool to room temperature. This example demonstrates the manufacture of a flat, single diamond layer metal abrasive disk.

EXAMPLE 2

Drill 2.0 mm diameter circular holes on 5 mm centers in a 60° isometric pattern through a 0.2 inch thick by 12 inch wide by 12 inch long stainless steel sheet to form a stencil. Mount the stencil in a sturdy, rigid frame to maintain stencil flatness. Align the stencil over a 1 inch thick by 12 inch wide by 12 inch long pad of smooth-faced urethane rubber. Bring the stencil and rubber pad in laminating contact. Maintain the exposed side of the stencil facing up in a horizontal plane.

Dispense an approximately 0.5 inch diameter, 12 inch long bead of Incusil™ ABA braze paste along one edge of
the stencil. Use a 14 inch long, hard rubber squeegee, to draw the bead in a steady speed stroke across the exposed face of the stencil with slight downward pressure and to force the braze paste into the cylindrical cavities to a depth flush with the exposed surface of the stencil, *i.e.*, approximately 0.2 inch. Use only a single pass to prevent braze paste from bleeding under the stencil between perforations.

Lift the stencil vertically away from the face of the rubber pad. Sprinkle a 50/50 vol/vol mixture of 60/80 U.S. mesh diamond and cubic boron nitride abrasive grains from General Electric Company, Columbus, Ohio to evenly dust grains over the rubber pad. Lift the pad from the table and invert to drop excess abrasive grains into a collection pan. Replace the pad with abrasive/paste side up on a horizontal work surface.

Place a spherical steel preform firmly in a manual jig to expose the convex cutting surface of the preform. Press the preform vertically downward against the pad. Apply a slight rolling motion to the sphere to evenly transfer the parcels of abrasive laden brazing paste onto the cutting surface of the preform. Remove the manual jig and fire the preform as in Example 1. This example demonstrates the manufacture of an abrasive tool with a transfer medium according to the present invention. The abrasive tool is useful for grinding concave ball joints.

What is claimed is

1.A process for making an abrasive tool comprising the steps of:

(A) providing a stencil having a plurality of perforations of selected shape;

(B) contacting a cutting surface on the abrasive tool with the stencil whereby the perforations define cavities adjacent the cutting surface;

(C) providing a brazing paste including a metal braze composition and a binder component;

(D) filling the cavities with brazing paste;

(E) removing the stencil to form parcels of brazing paste on the cutting surface, each parcel being separated from neighboring parcels by paste-free channels;

(F) depositing abrasive grains onto the parcels; and

(G) thermally processing the abrasive tool to braze the abrasive grains to the cutting surface.

2. The invention of claim 1 wherein the filling step includes forcing the brazing paste into the cavities with a straight-edged blade.

3. The invention of claim 2 wherein the abrasive grains are mixed with the brazing paste prior to filling the cavities.

4. The invention of claim 3 wherein the abrasive grains have a particle size of at most 10 μm.

5. The invention of claim 2 wherein the depositing step includes:

(i) dusting grains onto the cutting surface to embed grains into the parcels; and

(ii) removing non-embedded grains.

6. The invention of claim 5 wherein the depositing step further includes pressing the embedded grains into the parcels.

7. The invention of claim 1 wherein the abrasive grains have a particle size of at least about 100 μm and only one abrasive grain is deposited onto each of most parcels.

8. A process for making an abrasive tool comprising the steps of:

(A) providing a stencil having a plurality of perforations of selected shape;

(B) contacting a transfer medium with the stencil whereby the perforations define cavities adjacent the transfer medium;

(C) providing a brazing paste including a braze composition and a binder component;

(D) filling the cavities with brazing paste;

(E) removing the stencil to form a patterned face of parcels of brazing paste on the transfer medium, each parcel being separated from neighboring parcels by paste-free channels;

(F) forcing the patterned face against a cutting surface of the abrasive tool;

(G) peeling the transfer medium away to leave the parcels on the cutting surface;

(H) depositing abrasive grains onto the parcels; and

(I) thermally processing the abrasive tool to braze the abrasive grains to the cutting surface.

9. The invention of claim 8 wherein the filling step includes forcing the brazing paste into the cavities with a straight-edged blade.

10. The invention of claim 9 wherein the abrasive grains are mixed with the brazing paste prior to filling the cavities.

11. The invention of claim 10 wherein the abrasive grains have a particle size of at most 10 μm.

12. The invention of claim 9 wherein the depositing step includes:

(i) dusting grains onto the cutting surface to embed grains into the parcels; and

(ii) removing non-embedded grains.

13. The invention of claim 12 wherein the depositing step further includes pressing the embedded grains into the parcels.

14. The invention of claim 8 wherein the abrasive grains have a particle size of at least about 100 μm and only one abrasive grain is deposited onto each of most parcels.

15. The invention of claim 8 wherein the cutting surface is a three dimensional, curvilinear surface and the transfer medium is a flexible, resilient pad.

16. An abrasive tool fabricated by a process comprising the steps of:

(A) providing a stencil having a plurality of perforations of selected shape;

(B) contacting a cutting surface on the abrasive tool with the stencil whereby the perforations define cavities adjacent the cutting surface;

(C) providing a brazing paste including a braze composition and a binder component;

(D) filling the cavities with brazing paste;

(E) removing the stencil to form parcels of brazing paste on the cutting surface, each parcel being separated from neighboring parcels by paste-free channels;

(F) depositing abrasive grains onto the parcels; and

(G) thermally processing the abrasive tool to braze the abrasive grains to the cutting surface.

17. An abrasive tool fabricated by a process comprising the steps of:

(A) providing a stencil having a plurality of perforations of selected shape;

(B) contacting a transfer medium with the stencil whereby the perforations define cavities adjacent the transfer medium;

(C) providing a brazing paste including a braze composition and a binder component;

(D) filling the cavities with brazing paste;

(E) removing the stencil to form a patterned face of parcels of brazing paste on the transfer medium, each parcel being separated from neighboring parcels by paste-free channels;

(F) forcing the patterned face against a cutting surface of the abrasive tool;

(G) peeling the transfer medium away to leave the parcels on the cutting surface;

(H) depositing abrasive grains onto the parcels; and

(I) thermally processing the abrasive tool to braze the abrasive grains to the cutting surface.

18. The invention of claim 17 wherein the cutting surface includes a convex, spherical portion.

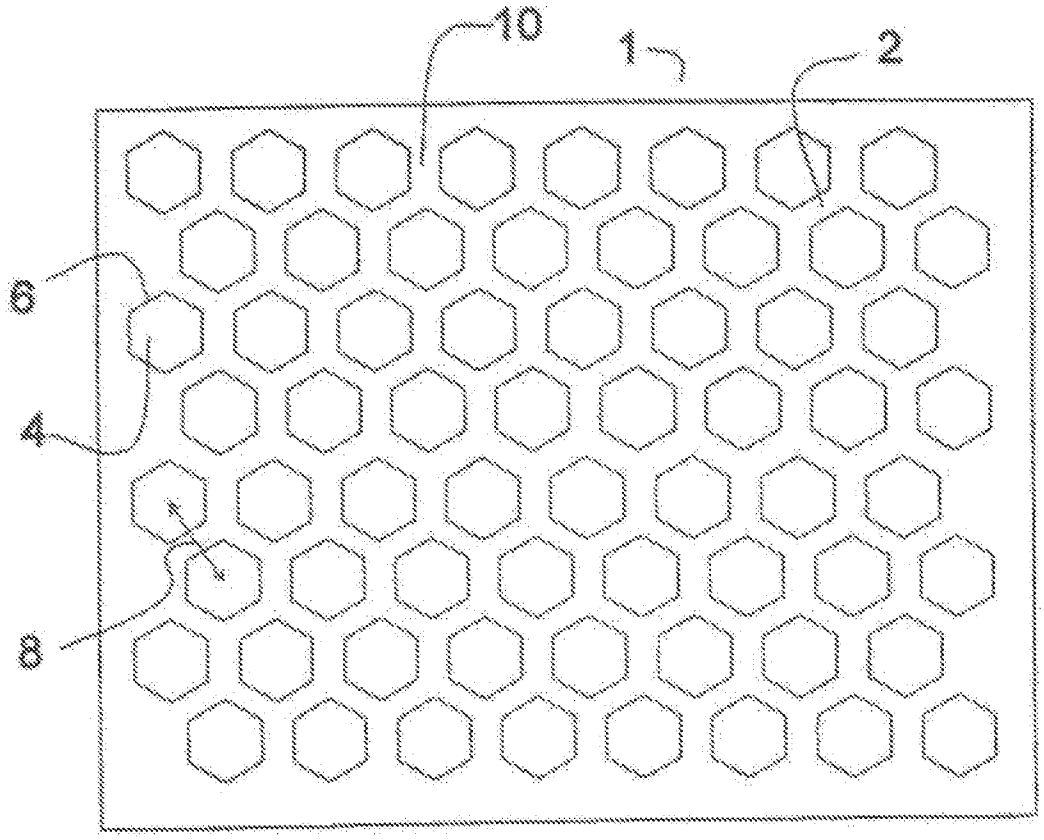


FIG. 1

INTERNATIONAL SEARCH REPORT

Inter national Application No
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A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B24D11/00 B24D18/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

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IPC 6 B24D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 380 390 A (TSELESIN NAUM H) 10 January 1995	1,16
A	see column 3, line 13 - column 5, line 6; figures 1-4	8,17
A	US 3 774 355 A (DAWSON C ET AL) 27 November 1973 see column 2, line 32 - line 58; figures 1-6,11	1,8,16, 17
A	US 4 010 583 A (HIGHBERG CARLE W) 8 March 1977 see column 8, line 38 - line 63; figures 4-6	1,16
A	US 5 219 462 A (BRUXVOORT WESLEY J ET AL) 15 June 1993 see column 3, line 62 - line 68; figure 2	2,3,9,10

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
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Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

Inter national Application No
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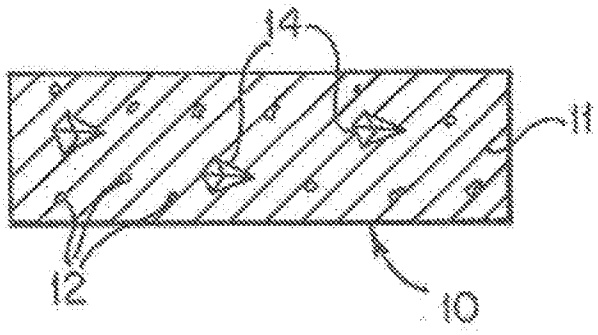
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(54) Title: METHOD FOR MAKING POWDER PREFORM AND ABRASIVE ARTICLES MADE THEREFROM

(57) Abstract

A method for making abrasive articles uses a soft, easily deformable and flexible preform having a high binder content. The binder gives the preform its integrity, and is present in greater quantity than the retaining powder. The preform can have superabrasive particles mixed therein, or added later. The preform allows even distribution of a small quantity of retaining powder for thin superabrasive articles. A porous layer may be added to the assembly for making an abrasive article, the porous layer absorbing the liquid binder, supporting the retaining powder and superabrasive particles to prevent lateral movement, and perhaps giving strength to the preform. The final assembly is to be heated or sintered (preferably under pressure) for making the abrasive article, which may include any number of layers of superabrasive particles, porous layers and preforms.



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Description

METHOD FOR MAKING POWDER PREFORM AND ABRASIVE ARTICLES MADE THEREFROM

Technical Field

This invention relates generally to the making of abrasive articles and the like, and is more particularly concerned with the use of soft, flexible and easily deformable powdered pieces as preforms for the manufacture of abrasive articles having superabrasive particles therein.

Background Art

Powdered preforms are widely used in the manufacture of abrasive articles that include a plurality of superabrasive particles such as diamond, cubic boron nitride and the like. Such powdered preforms are conventionally manufactured by compacting powder mixtures of retaining compositions and superabrasives particles in cold presses or roll compactors. Compacting pressure ranges from 300 to 10,000 kg/sq. cm, resulting in 20-50% relative density of the green compacts. Such green compacts are hard, stiff and brittle. The green compacts are sintered, either with or without pressure, and with or without impregnation.

There is a method of making abrasive articles wherein a non-compacted mixture of the powdered retaining composition, with the plurality of superabrasive particles therein, is placed directly into a sinter mold, then compacted and sintered in the sinter mold. This method requires a lot of adjustments in attempts to spread the powder evenly within the sinter mold. The required adjustments slow the manufacturing process, so the method does not fit well with mass production requirements.

In all the above mentioned methods, the powdered mixture can contain some binders, but the conventional green compacts are held together, not by the binder, but primarily by interaction among the particles of the powder, e.g. by mechanical interlocking of the particles. The above mentioned methods are widely used to produce traditional

cutting, drilling, and grinding abrasive tools and elements of abrasive tool, such as segments for saws and the like.

There are powdered preforms formed by spraying powder onto a substrate, and fixing the powder to itself and to the substrate by an adhesive, for example by an adhesive spray. Such preforms are flexible, but may experience loss of some powder when flexed. Also, such a method must deal with air borne particles and aerosol sprays that, because of environmental concerns, put serious limitations on the implementation of the method. This method has been used by the present inventor to make articles disclosed in U.S. Patents Nos. 4,925,457, 5,049,165, 5,092,910 and 5,190,568, as well as in U.S. patent Application Ser. No. 08/066,475 titled "patterned Abrasive Material and Method" and Ser. No. 08/024,649 titled "Abrasive Cutting Tool".

Soft and flexible preforms of powders and/or fibers, including both metallic and non-metallic materials, are also known; but, to the knowledge of the present inventor, such preforms are not known in the art of manufacturing articles that include superabrasive particles. Presently, the soft and flexible preforms are made by casting, or extruding a composition of brazing filler metal, or ceramic components, or hard facing compositions including metallic components and non-metallic abrasive components such as tungsten carbide particles. Such soft and flexible preforms can be bent more than 90°, and can be cut by scissors or the like.

The earlier known soft and flexible preforms comprise a high content of various binders, up to 95% by volume, and up to 20% by weight. It is the binder that makes such preforms soft and flexible; but, even with the high content of binders, the preforms are flimsy and must be handled with care. This is especially true for the very thin preforms, around .005--.010", or 0.10--0.25 mm.

It is important to distinguish between the soft and flexible preforms and the products of roll compacting of powders, even in the presence of a binder. When a roll compacted product includes a binder, the binder is in a much

smaller quantity than in a flexible preform. The roll compacted product is held together, not by the binder, but by the mechanical interlocking of particles, which makes the roll compacted product much less flexible than the soft and flexible preforms.

Soft and flexible preforms made of brazing filler metal compositions are used to put some parts together through brazing, mostly through furnace brazing. Soft and flexible preforms made for hard facing compositions are used to repair worn parts. For this purpose, the preforms are applied to a worn spot on the part.

The brazing process using the soft and flexible preforms made of brazing filler metal has a significant time duration because of the necessity for removal of the substantial quantity of binder. The time for removal of the binder is called the "dewaxing" cycle, and it allows the binder to melt, evaporate, or run out from the preform. It has been found that, if the dewaxing time is shortened or omitted, the powder of the soft and flexible preform can be literally washed out by the liquefied binder.

In attempting to use the known soft and flexible preform to hold a plurality of superabrasive particles in order to produce abrasive articles, it will be recognized that:

1. Compositions of the brazing filler preform do not correspond to the desired matrix compositions to hold superabrasive particles;

2. Soft and flexible preforms are not produced with superabrasive particles on, or within, the preforms;

3. Soft and flexible preforms are quite flimsy and not as strong as desired for production of abrasive articles, especially for mass production requirements of abrasive articles requiring thin (.005--.020", or 0.1-- 0.5 mm) flexible preforms;

4. De-waxing time must be severely reduced to meet production rates, especially for mass production; and,

5. Heating and/or brazing processes alone do not provide the most reliable matrix for retaining superabrasive particles.

Disclosure of the Invention

The present invention provides a method for manufacturing abrasive articles and wear resistant parts, such articles or parts comprising a plurality of superabrasive particles such as diamond, cubic boron nitride or the like randomly or systematically distributed in a retaining matrix. Specifically, the method of the present invention includes the preparation and utilization of powdered preforms in the form of soft, easily deformable flexible (SEDF) bodies that may include a plurality of superabrasive particles.

In making the SEDF preforms, the powdered compositions will be chosen based on criteria related to the holding necessary for the superabrasive particles to be included. Any number of matrix materials, or powdered compositions may be used, with any number of binders. The binder will be selected to provide the desired integrity of the product, while maintaining the flexibility and processability. In any case it must be remembered that the concentration of powdered composition and abrasive particles (if included) is low, and the volume of the binder is high. The volume of the binder phase substantially exceeds the volume of the powdered composition and the abrasive particles within the SEDF preform.

In one preferred form of the present invention, a porous layer will be placed against the SEDF preform. The purpose of the porous layer is to hold the abrasive particles in place during subsequent processing of the material. Successful material can be made without the porous layer, but the porous layer provides a better quality product than is obtained without the porous layer.

Final processing of the SEDF preform of the present invention includes sintering or other heat treating. The result is a high quality abrasive material, with or without a

porous layer therein, which can be used for numerous cutting or abrasive tools and the like.

Brief Description of the Drawings

These and other features and advantages of the present invention will become apparent form consideration of the following specification when taken in conjunction with the accompanying drawings in which:

Fig. 1 is a cross-sectional view showing one form of preform made in accordance with the present invention, the preform having some superabrasive particles therein;

Fig. 2 is a cross-sectional view of another preform made in accordance with the present invention, the preform being formed on a substrate which may be a porous material;

Fig. 3 is a view similar to Fig. 1 but showing the superabrasive particles on the surface of the preform;

Fig. 4 is a view similar to Fig. 3 wherein the superabrasive particles are held by a carrier which is placed against the preform;

Fig. 5 is a cross-sectional view illustrating a continuous process for forming the preform, and placing superabrasive particles on one surface of the preform;

Fig. 6 is a view similar to Fig. 5, but showing the preform being formed on a substrate having superabrasive particles thereon;

Fig. 7 is a view similar to Fig. 1 and showing a comparison between the thickness of the preform and the size of the superabrasive particles;

Fig. 8 is a view similar to Fig. 7, but showing the preform after sintering;

Fig. 9 is a cross-sectional view illustrating a method and apparatus for casting preforms according to the present invention;

Fig. 10 is a cross-sectional view showing a process of sintering under pressure;

Fig. 10A is a view similar to Fig. 10 but showing a plurality of preforms within the mold;

Fig. 11 is a cross-sectional view illustrating an assembly of a preform with porous layers in accordance with the present invention;

Figs. 12--17 are similar to Fig. 11 and show various modifications thereof;

Fig. 18 is a cross-sectional view illustrating extrusion of the preform into openings of a porous layer;

Fig. 19 is a cross-sectional view showing a continuous process for assembling a preform in accordance with the present invention using rolls;

Fig. 19A is a cross-sectional view illustrating the casting of a profiled preform on a substrate;

Fig. 19B is a view similar to Fig. 19A but showing a preform being cast between two substrates;

Fig. 19C is a cross-sectional view showing the deformation of a flat preform;

Fig. 20 is an exploded, cross-sectional view showing an be mixed assembly for producing an abrasive article;

Fig. 20A is a view similar to Fig. 20 but showing a modification thereof;

Fig. 21 is a cross-sectional view showing the assembly of Fig. 20 after assembly and sintering;

Figs. 22 and 23 are similar to Figs 20 and 21 but showing a modification thereof;

Figs. 24 and 25 and Figs. 26 and 27 are similar to Figs 20 and 21 but showing additional modifications thereof; and,

Fig. 28 is a side elevational view showing the assembly of a cutting tool in accordance with the present invention.

Best Mode for Carrying Out the Invention

Referring now more particularly to the drawings, and to those embodiments of the invention here presented by way of illustration, the invention has two major parts: preparation of soft, easily deformed flexible (SEDF) preforms; and, utilization of SEDF preforms for making abrasive articles.

Preparation of Preform

The preform is prepared by mixing a binder with a powder composition in the required proportions. The mixture may or may not include a plurality of superabrasive particles. Thus, depending on the particular portions chosen, one may produce the binder-powder mixture in the form of a slurry, granulated powder, or a paste.

If the granulated powder is used, a plurality of superabrasive particles can be placed onto the granules by a supplementary process. The granules may be mixed with a plurality of superabrasive particles, and the superabrasive particles may stick to the granules either because of the binder in the granules, or because of an additional binder covering the granules and/or the superabrasive particles.

Mixing the binder with the retaining powder can be performed on a variety of standard equipment, including virtually any equipment suitable for mixing powder and liquid together. Thus, no detail discussion of the equipment is necessary herein.

There is a variety of materials that can be used as the binder for the preform. The binder may be organic or inorganic, but should be selected to carry the particles of the powder, keep the particles suspended, and provide integrity and flexibility to the final preform. It is preferable to choose a binder that allows air, a low vacuum, heat, or a combination of these, to evaporate at least some of the volatile components of the binder for at least partial curing of the binder. Such binders include water soluble binders.

It is well recognized that the prior art powder technology requires that a person mix powders and superabrasive particles. Such powders and superabrasive particles become air borne, and are deleterious to the health of workers. Safety masks and the like are available, but are uncomfortable to wear, and of course are not totally effective. The present invention overcomes this difficulty with the prior art in that the powders and superabrasive

particles can be handled by machines, appropriately covered to minimize the escape of particles. The material is available to be manipulated by people only after mixing powdered components with the binder, so there is no longer a hazard of air borne particles.

Those skilled in the art will understand that many materials will be acceptable as binders, depending on the precise characteristics desired. However, by way of example, the following have been found to be suitable binders: Sanford's Rubber Cement (commercially available from Sanford Corporation, Bellwood IL) in a combination with Carter's Rubber Cement Thinner (commercially available from Dennison Carter's Division, Dennison Manufacturing Company, Framington, MA); Microcoat Cements (available from Wall Colmanoy Company, Madison Heights, MI) in a combination with Exosen No. 40 (available from Smithkline Beckman Company, Lewistown, PA).

In the binder-powder composition, the binder is usually 3 to 20% by weight of the composition, but the ratio can be extended. By volume, the percentage of the powder within the binder-powder composition is usually from 1 to 5%, but it can be extended to a range of 0.3 to 10%. One successful preform has from 5.0 to 8.5% by weight of rubber cement and thinner. The retaining powder is dispersed in the binder and held thereby. Superabrasive particles may also be dispersed within the binder, and also held therein.

Referring to Fig. 1 of the drawings, it will be seen that the SEDF preform 10, comprises mostly binder 11. There is a plurality of particles 12 of a retaining powder distributed in the binder 11, and there are superabrasive particles 14 also distributed in the binder. From the above discussion it will be understood that the superabrasive particles 14 may or may not be included. This will also be discussed in more detail below.

Looking at Fig. 2, it will be seen that the SEDF preform 10 includes the binder 11 and retaining powder 12. Superabrasive particles 15 are here shown as fixed to a

substrate 16, the substrate 16 then being placed against the SEDF preform 10. The substrate 16 may take many forms, including a film having a low melting point or the like, but it is preferably a porous material, which will be discussed in more detail hereinafter.

Fig. 3 shows a modification of Fig. 2, the SEDF preform 10 being substantially the same. The superabrasive particles 18 in Fig. 3, however, are placed on the upper surface of the preform 10. The superabrasive particles may be pressed into the preform 10, or may be held by an adhesive. The adhesive may be the binder 11, or may be a separately applied adhesive. Similarly, Fig. 4 shows the arrangement of Fig. 3, but with a carrier 19 having the abrasive particles 20 adhered thereto. The particles 20 on the carrier 19 can therefore be brought into contact with the preform 10 when desired.

In accordance with the present invention, SEDF preforms can be formed by spreading a binder-powder composition on a substrate. The composition may be powdered slurry, granules, or a paste. The composition is then cured, e.g. dried, on the substrate, and one may use applied heat or pressure if desired.

When dealing with granules, an external pressure in the range of 50 to 200 kg/cm^2 is helpful to apply a binder to the granules while the granules are on the substrate. The binder, which may be spread on the substrate, may penetrate between the granules and assists in integrating the granules into a preform.

In some cases, especially when the superabrasive particles are substantially larger than the particles of the retaining powder, or the viscosity of the liquid is not balanced to suspend the superabrasive particles, some measure must be taken to prevent separation or sedimentation of the superabrasive particles after mixing has stopped. One might therefore pour immediately after mixing, or combine continuous mixing with simultaneous pouring or coating.

The superabrasive particles in the SEDF preforms are not surrounded by closely packed particles of a retaining powder as in the traditional green compacts. Rather, the superabrasive particles in the SEDF preform are suspended predominantly by the binder, and in contact with a very few particles of the retaining powder. This is illustrated in Figs. 1--4 of the drawings.

Superabrasive particles can be added to the SEDF preform during the process of forming or curing the preform. By way of example, attention is directed to Fig. 5 of the drawings. A binder- powder composition 21 is dispensed onto a substrate 22, and doctored to a uniform thickness by a doctor blade 24. After the doctor blade 24,, superabrasive particles 25 are dispensed onto the surface of the preform 26. It will be understood that the composition 21 is not cured at the time the superabrasive particles 25 are placed onto the preform 26, so the particles will be adhered thereto. If desired, or necessary due to the viscosity of the preform and the weight of the particles 25, pressure can be applied to assist in urging the superabrasive particles 25 at least partially into the preform 26. Also, additional adhesives or the like can be applied as needed.

Fig. 6 illustrates a modification of the arrangement shown in Fig. 5. In Fig. 5, the binder-powder composition 21 is dispensed onto the substrate 22 and doctored to the desired thickness by doctor blade 24. In Fig. 6, however, the substrate 22 carries a plurality of superabrasive particles 28, and the binder-powder composition is dispensed onto the particles 28. The superabrasive particles 28 may be completely covered, or only partially covered by the binder-powder composition as desired.

The difference between the thickness of the SEDF preform and the size of the superabrasive particles can vary considerably; but, it will be realized that the difference will change significantly in sintering. Fig. 7 shows an SEDF preform 10 having superabrasive particles 14 therein. At this stage, the thickness t of the SEDF preform may be equal

to 3d to 10d, where d is the dimension of the superabrasive particles in the direction of the thickness of the SEDF preform. After sintering, the same preform is shown in Fig. 8. It will of course be realized that the superabrasive particles 14 will not change in size during sintering, but the preform 10 will be significantly condensed. After sintering, the preferable ratio is that the thickness t is approximately equal to the dimension d, the desirable range being t = 0.3--2d. It should be mentioned that superabrasive particles of all sizes are suitable for use with the technology disclosed herein, but the preferable sizes are from 18 to 324 mesh (about 1.0 mm to about 0.035 mm).

The weight of the dry retaining powder per unit volume of the SEDF preform (grams of powder per cubic centimeter of preform) determines the thickness of the sintered abrasive material, it being realized that the binder will run off, or evaporate, during sintering or other heat processing. For example, the density of cobalt is 8.9 g/cm^3, and a cobalt preform contains 0.8 g/cm^2 of the dry cobalt powder; therefore, the thickness of the fully densified, sintered product will be about 0.9 mm, which is found by dividing 0.8 g/cm^2 by 8.9 g/cm^3. It will be noted that the thickness of the SEDF preform is not in the calculation, this being irrelevant. The important consideration is the quantity of the dry powder per unit area of the preform.

One technique for production of SEDF preforms of the present invention is illustrated in Fig. 9. Essentially, a plurality of trays 29 is moved under a hopper 30 which dispenses the binder-powder composition. Each tray 29 will receive a predetermined quantity of the composition to provide SEDF preforms of predetermined weight. As shown in Fig. 9, the trays 29 can be placed on a conveyor 31, or may be part of a conveyor 31 which can move continuously, or intermittently, and timed so the binder in the composition will be cured before the preforms are removed from the trays 29. In the system illustrated, the preforms are received by another conveyor 32 which will carry the preforms to the next

processing step. It should be understood that the conveyor 31 can take various geometrical arrangements, including a zig-zag shape in the horizontal plane and a stepped shape in vertical plane.

In using the system shown in Fig. 9, if a substrate is desired on the preform, the substrate, with or without superabrasive particles thereon, can be placed in the bottom of the trays 29. Also, superabrasive particles, with or without a substrate, can be placed on top of the preform after the tray 29 is filled to the desired extent.

It will therefore be realized that the SEDF preform may be made in the form of discrete plates as shown in Fig. 9, or may be made in the form of continuous tapes as shown in Figs. 5 and 6. Either form can then be cut easily with scissors, paper cutter, die cutting or the like.

Preparation of Abrasive Articles

Fig. 10 of the drawings shows the preferred means and method for heating an SEDF preform and condensing the preform. Fig. 10 illustrates a generally conventional sinter fixture for sintering under pressure. It will be seen that there is a bottom punch 34 and a top punch 35, the space between the punches 34 and 35 being closed by the side plates 36. Within the cavity so defined, there is an SEDF preform 38, here shown as having superabrasive particles 39 distributed therein, and a plurality of superabrasive particles 40 on the top side of the preform 38.

Those skilled in the art will understand that the punches 34 and 35 will be urged towards each other as indicated by the arrows, and an electric current will be passed through the sinter fixture and/or the preform to heat the preform. An important feature of the present method is that the side plates 36 will tend to restrain lateral movement of the SEDF preform during sintering, even though there may be a flow of liquid as the binder and/or retaining matrix melt and run.

A further advantage of the SEDF preform in a sintering fixture as shown in Fig. 10 is that the softness of the preform makes redistribution of material quite easy. As a result, variations in thickness and stress can be made uniform simply through the usual pressure on the preform during sintering. The preform therefore has less sensitivity to various non- uniformities, and tends to reduce damage to the sinter molds. The inventor has experienced a 50-fold reduction in consumption of graphite mold parts since using the technique disclosed herein. It should be noted that, because of the softness and deformability of the SEDF preform, abrasive articles with a corrugated shape can be mass produced without significant consumption of corrugated (hence expensive) punches, e.g. graphite or metal punches.

It should be understood that the sinter mold can be loaded with several assemblies of SEDF preforms, the assemblies being separated from one another by punches and/or separators as disclosed in U. S. Patent No. 5,203,880, "Method and Apparatus for Making Abrasive Tools", by the present inventor. Such sintering "in stock" is illustrated in Fig. 10A. The unique uniformity, softness and deformability of the SEDF preform make sintering in stock acceptable for mass production technology.

While the heating of the SEDF preforms under pressure has many advantages, there is one severe disadvantage: the heating melts and vaporizes the binder, which runs; and, the liquid or vaporized binder, intensified by the applied pressure, tends to carry the retaining powder and superabrasive particles out of the mold. If most of the retaining powder is washed out of the mold, there will of course be practically no matrix material to hold the left over superabrasive particles in place. Also, melted binder and/or melted or moved retaining matrix of SEDF preform will catch the superabrasive particles, which can be washed out of the mold.

To solve the problem of the loss of retaining powder and superabrasive particles, it has been found that a porous

layer can be placed against the SEDF preform to prevent lateral movement of the particles. The porous layer may take many forms, but will not be held together by a binder as used in the SEDF preform. Rather, the porous layer may be screen wire, a conventional compacted preform, egg-crate or reticulated metal structures or the like.

Looking at Fig. 11, it will be noticed that the superabrasive particles 41 are larger than the openings in the porous layer 42. Under pressure, the particles 41 may cut into the porous layer 42. The particles 44 of the retaining powder are smaller than the opening in the layer 42, so these particles will pass easily into the openings of the layer 42.

As shown in Fig. 11, there is a second porous layer 45 on the opposite side of the SEDF preform; and, the assembly shown in Fig. 11 will be urged together and heated under pressure. The porous layers 42 and 45 will support the superabrasive particles and prevent lateral movement (perpendicular to the direction of the applied compaction force), and will provide additional volume to receive the SEDF preform, and restrain lateral motion of the particles of retaining powder in the SEDF preform. The porous layers will also temporarily absorb liquid binder to reduce the flow of binder and thereby help prevent washout of retaining powder and superabrasive particles.

The porous layer, or layers, can be placed in various positions relative to the SEDF preform and other layers of an assembly to be sintered. By way of example, and not by way of limitation, Fig. 12 shows the SEDF preform 46 having a porous layer 48 on one side, and a layer of abrasive particles 49 on the opposite side of the porous layer 48, a substrate, or carrier 50 holding the particles 49 in place. Fig. 13 shows the same arrangement, but the substrate 50 is between the particles 49 and the porous layer 48.

Fig. 14 shows the SEDF preform 46 in the middle with the porous layer 48 on one side, and the superabrasive particles 49 and substrate 50 on the opposite side. Fig. 15 shows the

superabrasive particles 49 and substrate in the middle, with the SEDF preform 46 on one side, and the porous layer 48 on the opposite side. Fig. 16 is like Fig. 15, except that the positions of the superabrasive particles 49 and the substrate 50 are reversed.

Fig. 17 shows two SEDF preforms 46 and 46'. A porous layer 48 is between the preforms, and the superabrasive particles 49 with the substrate 50 are on the opposite side of one of the preforms.

The porous layer may take the form of a woven mesh, a nonwoven material, expanded foil, knitted materials and textile fabrics. Also, a material that is roll-compacted, extruded, sintered or the like can be used. Virtually any material can be used so long as the material is highly porous (about 30% to 99.5% porosity), having pores open to the surface and interconnected, with sufficient integrity to support the superabrasive particles and to restrain motion of the retaining powder in the process of sintering.

Presently, the best material known for use as porous layers are metallic non-woven materials, and particularly a nickel fiber powder non-woven mat, manufactured by National Standard, Woven production Division, Corbin KY, and sold under the trademark "Fibrex". The porosity of this mat is 85-98%; the fiber is 20 microns in diameter and is about 80 weight percent of the mat, while the powder is about 20 weight percent.

It has also been found that copper wire mesh, in the range of 20 to 200 mesh, works well as the porous layer. Some expanded metals (manufactured by Delker Corporation) have been used, for the same purpose.

Fig. 18 of the drawings illustrate an SEDF preform 51 after the preform 51 has been urged against a porous layer 52. The porous layer 52 is here shown as having some substantial thickness, and being made up of a plurality of cells 54 so the porous layer 52 comprises a cellular type of material. It will be seen, then, that the material of the preform 51 has been urged into the cells 54. It has been

found desirable in some cases to compress the preform 51 with the porous layer 52 prior to applying heat and pressure during sintering. The material of the preform 51, being received in the openings, or cells, 54 of the porous layer 42, tends to stay within the openings and not to move laterally.

It should be understood that the role of the porous layer 52 can be limited to the restriction of flow of the material of the SEDF preform 51. Thus, a porous layer 52 may be made of a material having a melting point below the sintering temperatures. In this case, after at least a portion of the binder has been removed from the preform in the process of heating, and the retaining powder is at least partially solidified, the porous layer will melt onto the preform, and thereby modify the retaining composition. For example, a cobalt-nickel SEDF preform may utilize a porous layer made of copper, bronze, brass, zinc, aluminum, or various combinations of these, as well as other porous layers.

Another function of a porous layer 52 may be conduction of heat and/or electricity during heating of the preform. For example, a mesh or expanded foil of copper will readily conduct heat or electricity to facilitate uniform heating. Further, the porous layer may include superabrasive particles within the cells 54. A preform as shown in Fig. 18 may be placed against a porous layer 52 having superabrasive particles therein, or the porous layer may be used as a substrate in an arrangement such as that shown in Fig. 6 of the drawings.

In any arrangement, it must be realized that, if the porous layer is filled with superabrasive particles, the ability of the porous layer to absorb binder during heating is reduced. Thus, if one wish to provide a full, or nearly full, layer of superabrasive particles through the use of a porous layer, an additional porous layer may be needed, or desired, to absorb the binder and prevent displacement of the retaining powder.

Looking at Fig. 19 of the drawings, it will be seen that the SEDF preform of the present invention is admirably suited to mass production techniques. The arrangement shown in Fig. 19 includes rolls 55 and 56 for assembling a plurality of layers to be sintered. There is a roll of preform 58 to form one side of the assembly, and a roll of substrate 59 to form the opposite side of the assembly. Optionally, a roll of a porous layer 60 is placed between the preform 58 and the substrate 59.

The substrate 59 may have a plurality of superabrasive particles 61 previously placed thereon; or, as here illustrated, a dispenser 62 may place superabrasive particles on the substrate 59 during the assembling process. In either case it is contemplated that the substrate, or carrier, 59 will have an adhesive to hold the superabrasive particles 61 temporarily.

The SEDF preform 58 may take many forms as discussed above. The preform 58 may include a plurality of superabrasive and abrasive particles, or may not. Further, the preform may be placed on a substrate in order to give the preform greater integrity.

The porous layer 60 may or may not be included in the assembly. As is mentioned above, the preform 58 may utilize a porous layer as a substrate, or carrier, and this may be sufficient for some products. However, if one or more additional porous layers are desired, they may be fed to the assembly as shown in Fig. 19. Fig. 19 also shows separators 66 and 67. Such separators are disclosed in U. S. patent No. 5,203,880, "Method and Apparatus for Making Abrasive Tools", by the present inventor. In accordance with the disclosure in that patent, these separators assist in protrusion of the superabrasive particles through the retaining matrix, and in distribution of the temperature within the sinter mold during the sintering process. These separators 66 and 67 may or may not be attached to the SEDF preform assembly. When attached to the preform, the separators will be part of the assembly itself.

It should be understood that, in all techniques disclosed in the present application, separators such as the separators 66 and 67 may or may not be used. If separators are used, they may also be utilized as the substrate for SEDF preform (see numeral 22 in Figs. 5 and 6). It should be understood that, in the majority of the figures in the drawings, separators are not shown for the sake of simplification of the illustration.

Those skilled in the art will understand that the rolls 55 and 56 will urge the layers 58, 59 and 60, and separators 66 and 67 together into a single assembly 64. It is contemplated that the assembly 64 will then be cut into discrete pieces, or plates, 65 by a cutter 66. The individual plates 65 can be received by a conveyer 68 for transport to means for sintering.

Examples

Figs. 20 and 21 of the drawings show one assembly and one resulting sintered abrasive material respectively in accordance with the present invention. There is an SEDF preform 70 having superabrasive particles 71 distributed therein. The opposite side of the assembly is an SEDF preform 72 without abrasive particles. Between these two outside layers, there are two additional preforms 74 and 75, both having superabrasive particles distributed therein. Then, between the preforms 70 and 74 there is a porous layer 76; and between the preforms 74 and 75 there is a porous layer 78.

In Fig. 21 it can be seen that the superabrasive particles remain in layers; and, on one side, the superabrasive particles 71 are at the surface of the sintered assembly, while on the opposite side the preform 72 provides a backing without superabrasive particles. This sintered abrasive material can now be used to manufacture cutting and grinding tools.

The SEDF preform may have a profiled shape, which may or may not correspond to the shape of a compacting means, e.g. punches used for providing pressure during sintering. The

profiled SEDF preform, along with the non-profiled, or flat ones, are utilized by the present inventor for manufacturing abrasive articles according to U. S. patent No. 5,190,568 titled "Abrasive Tool with Contoured Surface".

Fig. 19A illustrates a one-sided profiled SEDF preform. One-way to manufacture the one-sided profiled SEDF preform includes the use of a profiled substrate 111, a binder-powder composition 112 being poured onto the substrate 111.

Fig. 19B illustrates the formation of a two-sided profiled SEDF preform. Fig. 19B shows two substrates, or walls, 114 and 115 and a binder-powder composition 116 between the walls 114 and 115. According to the method illustrated in Fig. 19B, the two-sided profiled SEDF preform is manufactured by pouring a binder-powder slurry between the two profiled walls 114 and 115, resulting in the formation of the two-sided profiled SEDF preform 116.

It should be understood that wall 114 and wall 115 may have different profiles, and each side of the SEDF preform has a profile corresponding to the profile (relief) of the respective wall. It also should be understood that the walls can be positioned vertically or horizontally; and, application of pressure and/or changing the distance between the walls in the process of solidification of the binder-powder composition 116 are optional.

A non-profiled, or flat, SEDF preform can be converted prior to sintering into a profiled one. The flat profile 118 can be shaped between profiled compacting means. Fig. 19C illustrates one of the processes for shaping a flat SEDF preform 118 into a profiled SEDF preform 119 by two profiled rolls or gears 120 and 121. The preferable arrangement does not require change of the thickness of the SEDF preform as a result of the shaping. This type of shaping does not require very great pressure because of the easy deformability of the SEDF preform.

Fig. 20 also shows separators 66a and 67a placed against SEDF preforms 70 and 72 as a part of the assembly itself. Fig. 21 does not show these separators, indicating that at

least some of the separators have been removed from the sintered abrasive material in the process of after-sintering cleaning, or in the process of dressing the abrasive tool.

One method for utilization of the separators in combination with the SEDF preform is shown in Fig. 20A. The separator 100 is placed on one side of the assembly 103 that includes an SEDF preform 101, a layer of porous material 102 and a layer of superabrasive particles 104 on a substrate 105. A mesh type material 106 having openings 108 is applied against the separator 100; and, the preferable mesh type material 106 has orderly distributed openings 108. Under pressure provided by one or both of the punches 35a and 35b, the assembly 103 extrudes at least partially into openings 108 of the mesh type material 106, de forming the separator 100 and leaving imprints on the surface of the assembly 103. The whole assembly 103 is put into the sintering mold as is shown in Figs. 10 and 10A, and then sintered, providing that sintering under pressure is preferable. The pressure to extrude the assembly 103 into the openings 108 can be applied prior to sintering, outside of the sinter mold and/or within this sinter mold, and/or in the process of sintering. After sintering the mesh type material 106 is removed from the mold, as well as the separator 100. The removal of the mesh type material 106 from the sintered abrasive article is not a problem because the separator 100 prevents diffusion between the assembly 103 and the mesh type material 106. The resulting abrasive article will comprise a profile corresponding to the design of the mesh type material 106.

It should be understood that there are additional options (some being shown in Fig. 20A) that may or may not be implemented: the mesh type material 106 can be placed against both sides of the SEDF preform 101 for making two-sided profiled abrasive article (see separator 109 in Fig. 20A); another separator 110 can be used to separate mesh type material 106 from the punch 35a, and separator 118 can be used to separate another side of the assembly 103 from the punch 35b. It also should be understood that several

assemblies comprising SEDF preforms and the mesh material for extrusion can be sintered in stock as is shown in Fig. 10A. Furthermore, separators of different thicknesses and different types can be used for opposite sides of the SEDF preform 101. The mesh type material 106 for extrusion can be made from different materials, e.g. steel woven mesh, expanded metal, machined crags, honeycomb or the like. It is also preferable that openings in the mesh 106 be big enough to allow at least one superabrasive particle 104 to go therethrough. For example, diamonds have sizes of 0.015 to 0.200 mm (80-100 mesh) while the mesh type material for extrusion comprises openings of 1.00 to 0.850 mm (18 to 20 mesh). It is also preferable that the mesh type material 106 for extrusion does not melt under, sintering temperatures, and have a minimum deformability under the pressure that makes this mesh multiusable.

Figs. 22 and 23 of the drawings show an assembly and a sintered single layer cutting tool respectively. Fig. 22 illustrates the layers to be assembled, and includes a central porous layer 79 having a plurality of superabrasive particles 80 in the openings thereof. It should be noticed that the particles 80 are at least as wide as the layer 79, so the particles 80 extend completely through the porous layer 79.

Each side of the central layer 79 includes two SEDF preforms 81, 82 and 81', 82', separated by porous layers 84, 84'.

When the assembly is heated under pressure, the material shown in Fig. 23 results. The present inventor has used this method to produce abrasive articles with one layer of diamonds as shown. It should be understood, however, that the abrasive article can include as many layers as desired, in accordance with other disclosures herein.

Figs. 24 and 25 show the production of a no-diamond foot on a conventional diamond segment. Current methods are difficult to use because the foot 85 is quite thin, requiring that powder be distributed very thinly, yet very uniformly,

in a sinter mold. Using the methods and apparatus of the present invention, however, an SEDF preform 86 can be placed against the segment 88, and the retaining powder is readily distributed uniformly. As is discussed in detail above, the final thickness of the foot 85 can be easily calculated.

Figs. 26 and 27 show the use of a conventional green compact having randomly distributed abrasive and/or superabrasive particles in combination with preforms of the present invention, and porous layers having orderly arranged superabrasive particles. The central green compact 89 has a porous layer 90, 90' on each side thereof, then an SEDF preform 91, 91'. The outside comprises a porous, or cellular, layer 92, 92' having a plurality of superabrasive particles 94, 94' distributed therein in an orderly fashion.

The assembly of Fig. 26 can be compressed in the direction indicated by the arrows 95, or in the direction indicated by the arrows 96. The inventor has used this technique, with pressure in the direction of the arrows 95, to manufacture diamond segments for saw blades, and a resm saw blade.

Fig. 28 illustrates the making of a cut-off disk. Individual pieces 98, or a complete ring, of the SEDF preform can be prepared of the proper shape, and placed around the periphery of a core 99. From the foregoing discussion it will be understood that the pieces 98 may include any number of layers, may or may not include porous layers, and may have as many or as few superabrasive particles as desired.

After the pieces 98, or the ring, is assembled on the core 99, the assembly will be sintered (preferably under pressure) so the sintering of the preform and fixing the preform to the core 99 are performed in one step.

Following are some specific examples of use of the technology of the present invention:

1. a) Make an SEDF preform in the form of a plate or a tape from a diamond retaining composition, e.g., from Wall Colmonoy's setting powder 50, or from Kennametal's powder N50, or from any other powdered composition suitable for an

application of the superabrasive articles. Do not mix these retaining powders with diamonds in the process of making SEDF preform.

b) Cut the preform with paper cutter or scissors into the shape suitable for the sintering mold and design of the abrasive articles.

c) Put diamonds into openings of the mesh type material and temporarily retain them with an adhesive carrier. As an option, the mesh type material can be then removed.

d) Apply SEDF preform against the carrier that includes superabrasive particles. As an option, pressure and/or adhesive can be applied to hold the assembly together. As another option, separators can be placed on at least one side of the assembly as disclosed in U.S. patent 5,203,880, "Method and Apparatus for Making Abrasive Tools".

e) Place the assembly into a heating device e.g., between heating plates or into a sintering mold. It can be several assemblies per one device.

f) Heat the assembly under a pressure, e.g., up to 1040°C and 300 kg/cm^2, so called "hot compacting".

g) Remove the sintered assembly from the device, clean and cut, if necessary, into pieces required by the design, then mount the pieces on a carrier, if necessary, to make the final product.

2. a) Make an SEDF preform in the form of a plate or a tape from a slurry mixture of the diamond particles and a diamond retaining composition, e.g., from Wall Colmonoy's setting powder 50, or from Kennametal's powder N50, or from any other powdered composition suitable for an application of the abrasive articles.

b) Cut the preform with paper cutter or scissors into the shape suitable for the sintering mold and design of the abrasive articles.

c) As an option, separators can be placed on at least one side of the preform as disclosed in U.S. patent

5,203,880, "Method and Apparatus for Making Abrasive Tools", forming an assembly.

d) Place the assembly into a heating device, e.g. between heating plates or into a sintering mold. It can be several assemblies per one device.

e) Heat the assembly under pressure, e.g. up to 1040°C and 300 kg/cm^2, so called "hot compacting".

f) Remove the sintered assembly from the device, clean and cut, if necessary, into pieces required by the design, then mount the pieces on a carrier, if necessary, to make the final product.

3. a) Make an SEDF preform in the form of a plate or a tape from a slurry mixture of a first plurality of diamonds and a diamond retaining composition, e.g. from Wall Colmonoy's setting powder 50, or from Kennametal's powder N50, or from any other powdered composition suitable for an application of the abrasive articles.

b) Cut the preform with paper cutter or scissors into the shape suitable for the sintering mold and design of the abrasive articles.

c) Put a second plurality of diamonds into openings of the mesh type material and temporarily retain them with an adhesive carrier. As an option, the mesh type material can be then removed.

d) Apply SEDF preform, including the first plurality of diamonds against the carrier including the second plurality of diamonds. As an option, pressure and/or adhesive can be applied to hold the assembly together. As another option, separators can be placed on at least one side of the assembly as disclosed in U.S. patent 5,203,880, "Method and Apparatus for Making Abrasive Tools".

e) Place the assembly into a heating device, e.g. between heating plates or into a sintering mold. It can be several assemblies per one device.

f) Heat the assembly under a pressure, e.g. up to 1040°C and 300 kg/cm^2, so called "hot compacting".

g) Remove the sintered assembly from the device, clean and cut, if necessary, into pieces required by the design, then mount the pieces on a carrier, if necessary, to make the final product.

It should be understood that the first and second pluralities of diamonds, and generally, any superabrasive particles, can be of the same or different origin, size, shape and physical-mechanical parameters.

6. a) Make an SEDF preform in the form of a tape from a diamond retaining composition, e.g. from Wall Colmonoy's setting powder 50, or from Kennametal's powder N50, or from any other powdered composition suitable for an application of the abrasive articles. Do not mix these retaining powders with diamonds in the process of making SEDF preform.

b) Cut the preform with paper cutter or scissors into the shape suitable for the sintering mold and design of the abrasive articles.

c) Take the nickel non-woven mat of National Standard, cut it into the proper pieces.

d) Assemble a sandwich "SEDF preform--the nickel mat--SEDF preform". As an option, apply pressure and/or an adhesive to improve the integrity of this assembly.

e) Put diamonds into openings of the mesh type material and temporarily retain with an adhesive carrier. As an option, the mesh type material can be then removed.

f) Apply this carrier including the superabrasive particles against the sandwich "SEDF preform--the nickel mat--SEDF preform". As an option, pressure and/or adhesive can be applied to hold the assembly together. As another option, separators can be placed on at least one side of the assembly as disclosed in U.S. patent 5,203,880, "Method and Apparatus for Making Abrasive Tools".

g) Place the assembly into a heating device, e.g. between heating plates or into a sintering mold. It can be several assemblies per one device.

f) Heat the assembly under a pressure, e.g. up to 1040°C and 300 kg/cm^2, so called "hot compacting".

g) Remove the sintered assembly from the device, clean and cut, if necessary, into pieces required by the design, then mount the pieces on a carrier, if necessary, to make the final product.

5. a) Make an SEDF preform in the form of a plate or a tape from a slurry mixture of the superabrasive particles and a diamond retaining composition, e.g. from Wall Colmonoy's setting powder 50, or from Kennametal's powder N50, or from any other powdered composition suitable for an application of the abrasive articles.

b) Cut the preform with paper cutter or scissors into the shape suitable for the sintering mold and design of the abrasive articles.

c) Take the nickel non-woven mat of National Standard, cut it into the proper pieces.

d) Assemble a sandwich "SEDF preform--the nickel mat--SEDF preform". As an option, apply pressure and/or an adhesive to improve the integrity of this assembly. As another option separators can be placed on at least one side of the assembly as disclosed in U.S. patent 5,203,880, "Method and Apparatus for Making Abrasive Tools".

e) Place the assembly into a heating device, e.g. between heating plates or into a sintering mold. It can be several assemblies per one device.

f) Heat the assembly under a pressure, e.g., up to 1040°C and 300 kg/cm^2, so called "hot compacting".

g) Remove the sintered assembly from the device, clean and cut, if necessary, into pieces required by the design, then mount the pieces on a carrier, if necessary, to make the final product.

6. a) Make an SEDF preform in the form of a plate or a tape from a slurry mixture of the superabrasive particles and a diamond retaining composition, e.g. from Wall Colmonoy's setting powder 50, or from Kennametal's powder

N50, or from any other powdered composition suitable for an application of the abrasive articles.

b) Cut the preform with paper cutter or scissors into the shape suitable for the sintering mold and design of the abrasive articles.

c) Take the nickel non-woven mat of National Standard, cut it into the proper pieces.

d) Assemble a sandwich "SEDF preform--the nickel mat--SEDF preform". As an option, apply pressure and/or an adhesive to improve the integrity of this assembly.

e) Put diamonds into openings of the mesh type material and temporarily retain with an adhesive carrier. As an option, the mesh type material can be then removed.

f) Apply this carrier including the superabrasive particles against the sandwich "SEDF preform--the nickel mat--SEDF preform". As an option, pressure and/or adhesive can be applied to hold the assembly together. As another option, separators can be placed on at least one side of the assembly as disclosed in U.S. patent 5,203,880, "Method and Apparatus for Making Abrasive Tools".

g) Place the assembly into a heating device, e.g. between heating plates or into a sintering mold. It can be several assemblies per one device.

f) Heat the assembly under a pressure, e.g. up to 1040°C and 300 kg/cm^2, so called "hot compacting".

g) Remove the sintered assembly from the device, clean and cut, if necessary, into pieces required by the design, then mount the pieces on a carrier, if necessary, to make the final product.

It should be understood that the preferred embodiments of the invention here presented comprise assemblies of superabrasive particles such as diamonds, cubic boron nitride or the like, distributed in an orderly fashion on a substrate, or a carrier, and a pre-made SEDF preform formed from metals, ceramics, epoxy materials with binders or other plastics. The assemblies of the above components are heated or sintered, preferably under an external pressure. The SEDF

preform may or may not include randomly distributed superabrasive particles therein; and, and a separator can be a part of the assembly itself to prevent contacting and/or diffusion between the SEDF preforms and the molding parts.

It will of course be understood by those skilled in the art that the particular embodiments of the invention here presented are by way of illustration only, and are meant to be in no way restrictive; therefore, numerous changes and modifications may be made, and the full use of equivalents resorted to, without departing from the spirit or scope of the invention as outlined in the appended claims.

Claims

1. In a method for making abrasive articles, wherein said abrasive articles comprise a quantity of a retaining powder and at least one plurality of superabrasive particles, said method including the steps of making a preform of said retaining powder, placing said plurality of superabrasive particles into said preform, and heating said preform, the improvement comprising the steps of making said preform of a binder and said quantity of retaining powder wherein the volume of said binder is greater than the volume of said quantity of retaining powder, so that said preform is soft, easily deformable and flexible.

2. In a method as claimed in claim 1, the further improvement wherein the said step of heating said preform includes the steps of heating said preform while exerting pressure on said preform.

3. In a method as claimed in claim 1, the improvement including the step of adding said superabrasive particles to said binder and retaining powder before the said step of making said preform.

4. In a method as claimed in claim 1, wherein the said step of placing said plurality of superabrasive particles into said preform comprises the step of placing said plurality of superabrasive particles on one side of said preform.

5. In a method as claimed in claim 1, the improvement wherein said step of placing said plurality of superabrasive particles into said preform comprises the step of randomly distributing said superabrasive particles.

6. In a method as claimed in claim 1, the improvement wherein said step of placing said plurality of superabrasive particles into said preform comprises the step of distributing said superabrasive particles in an orderly fashion.

7. In a method as claimed in claim 1, the further improvement wherein the said step of making said preform comprises the step of forming said preform on a substrate.

8. In a method as claimed in claim 7, the improvement including the step of placing said plurality of superabrasive particles on said substrate prior to the said step of forming said preform.

9. In a method as claimed in claim 8, the improvement wherein said superabrasive particles are randomly distributed on said substrate.

10. In a method as claimed in claim 8, the improvement wherein said superabrasive particles are distributed on said substrate in an orderly fashion.

11. In a method as claimed in claim 8, the improvement wherein said substrate includes a plurality of openings extending to the surface of said substrate, and including the step of placing said superabrasive particles in said openings of said substrate.

12. In a method as claimed in claim 1, the further improvement comprising the step of placing a porous layer against said preform for making an assembly prior to the said step of heating said preform, said porous layer having a plurality of openings extending to the surface thereof for restraining movement of said retaining powder and said superabrasive particles.

13. In a method as claimed in claim 12, the improvement including the step of placing said porous layer between said superabrasive particles and said preform.

14. In a method as claimed in claim 12, the improvement including the step of placing another preform against said porous layer prior to the said step of heating said preform.

15. In a method as claimed in claim 12, the further improvement wherein the said step of making a preform is carried out by making said preform on a substrate, said substrate having openings therein and acting as said porous layer.

16. In a method as claimed in claim 15, the improvement including the step of placing said superabrasive particles on said substrate prior to the step of making said preform.

17. In a method as claimed in claim 12, wherein the porous layer is selected to have a lower melting point than the retaining powder, and further including the step of heating the assembly sufficiently to melt said porous layer.

18. The product made in accordance with claim 13.

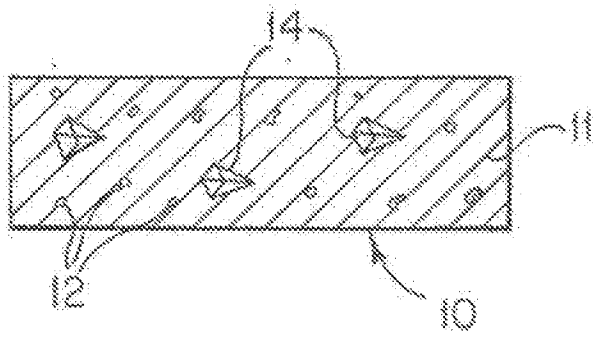


FIG. 1

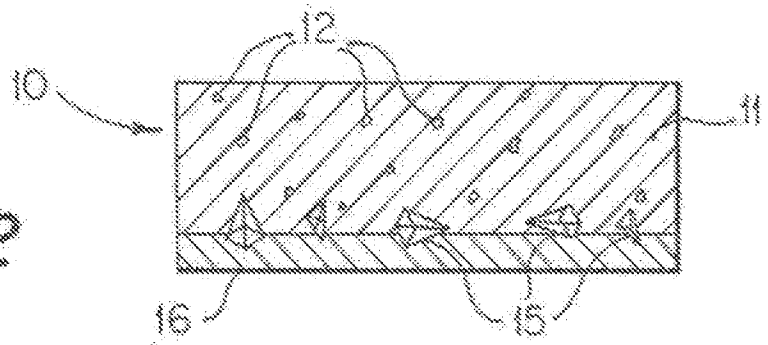


FIG. 2

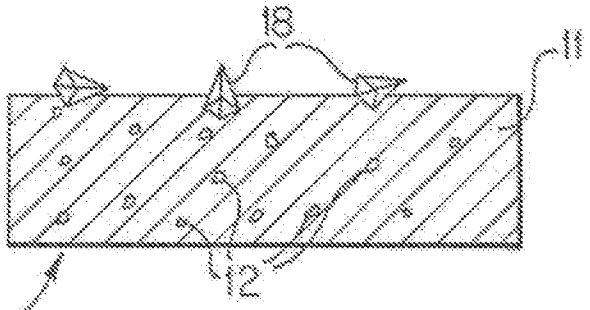


FIG. 3

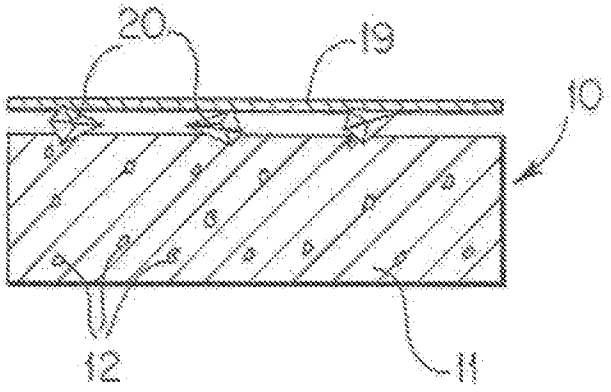


FIG. 4

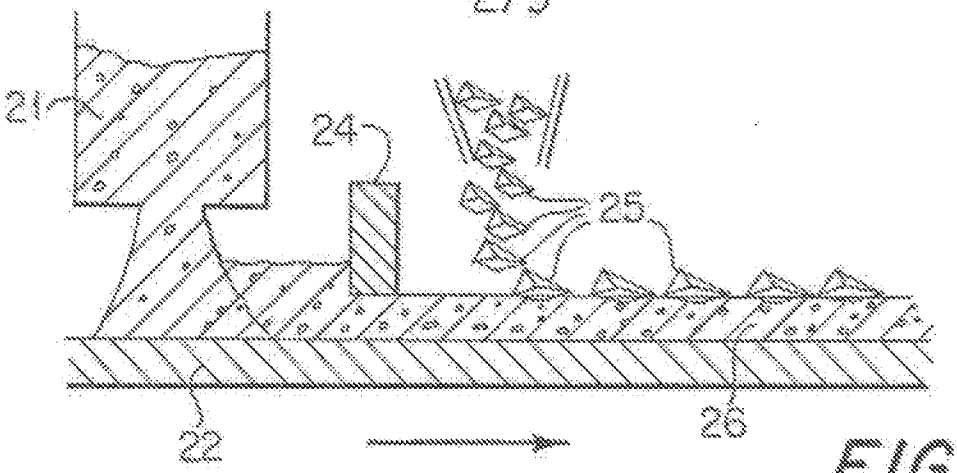


FIG. 5

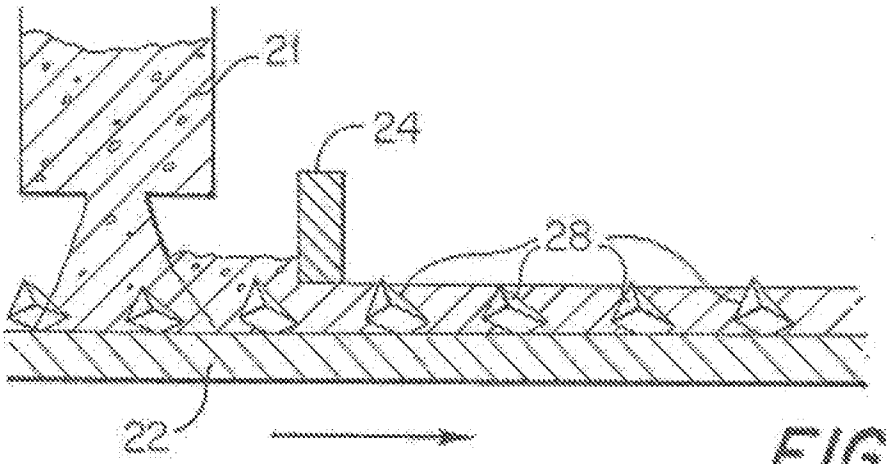


FIG. 6

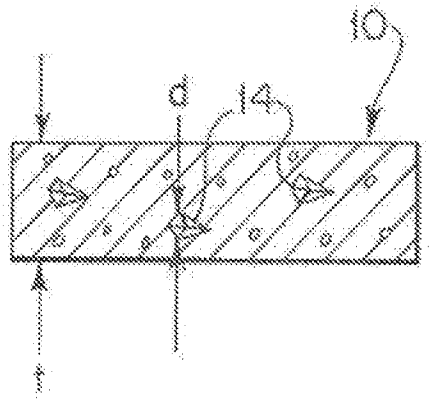


FIG. 7

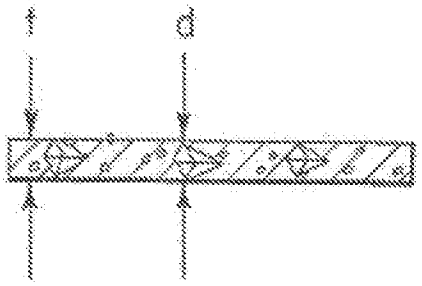


FIG. 8

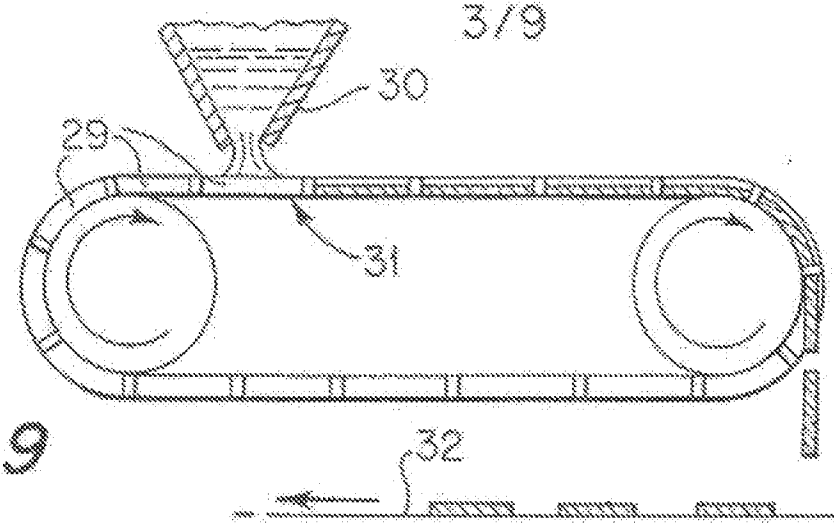


FIG. 9

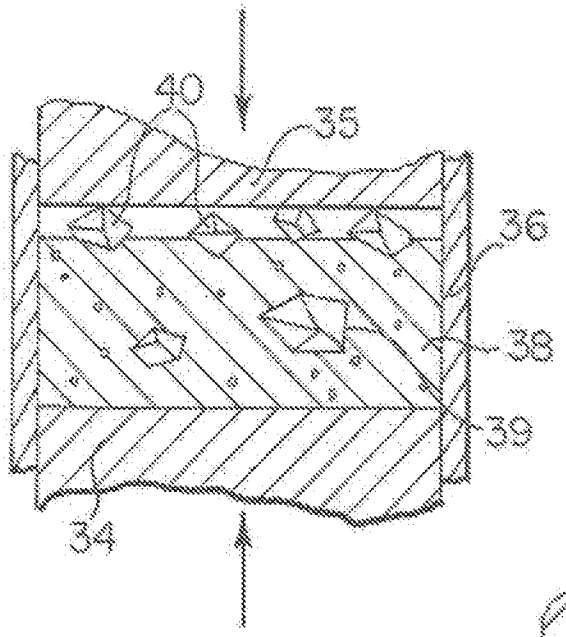


FIG. 10

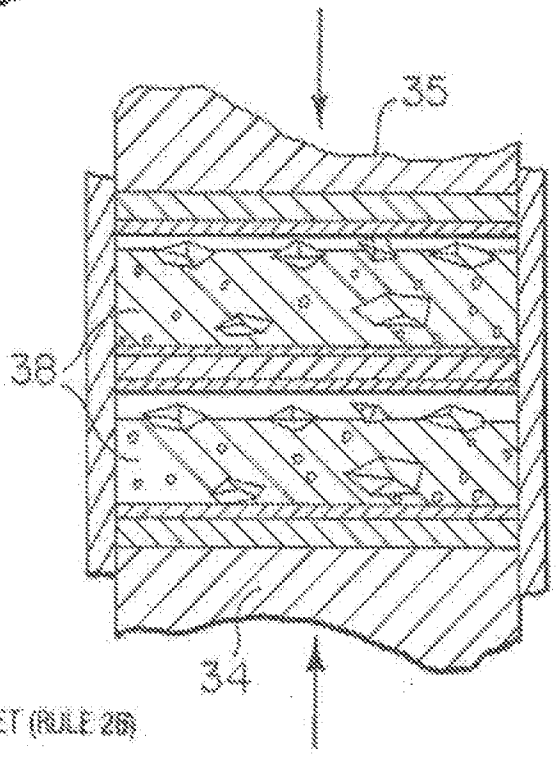


FIG. 10A

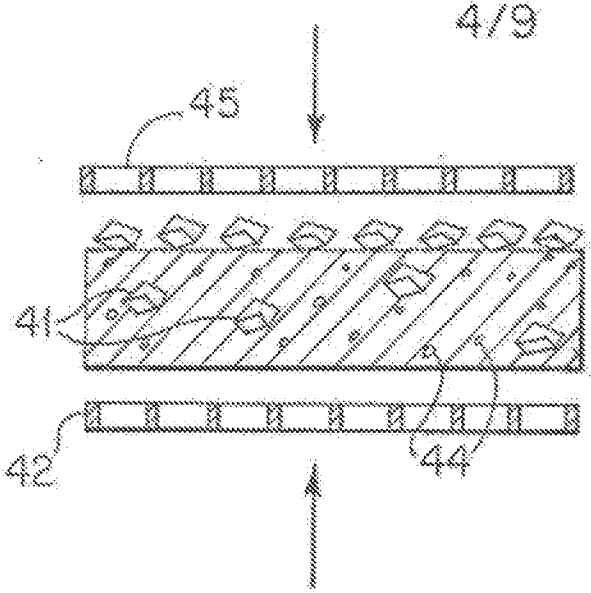


FIG. 11

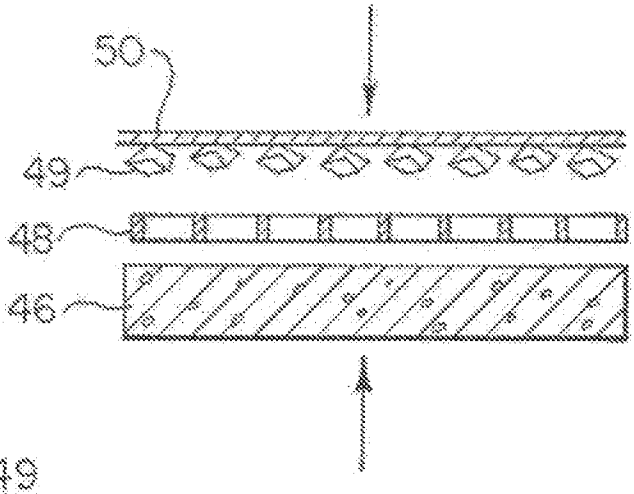


FIG. 12

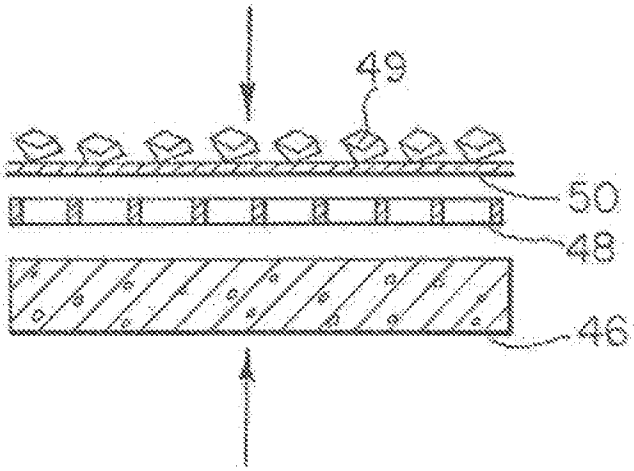


FIG. 13

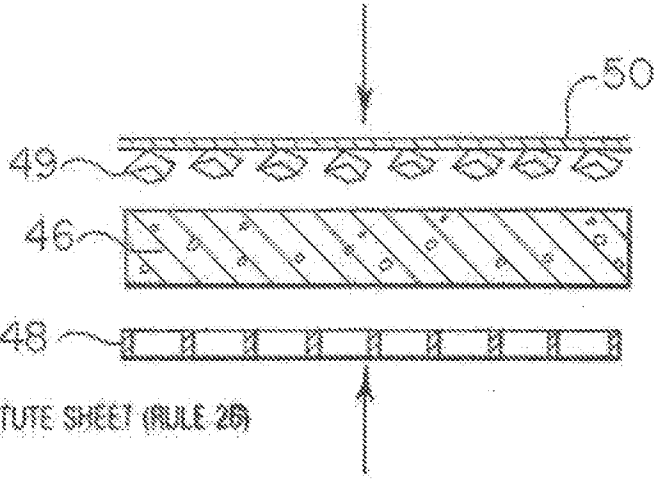


FIG. 14

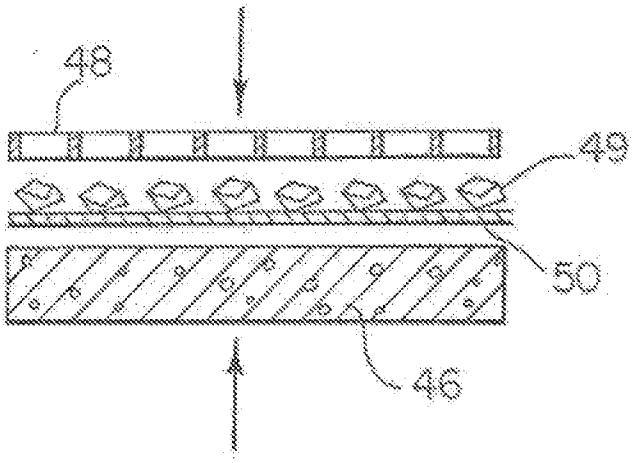


FIG. 15

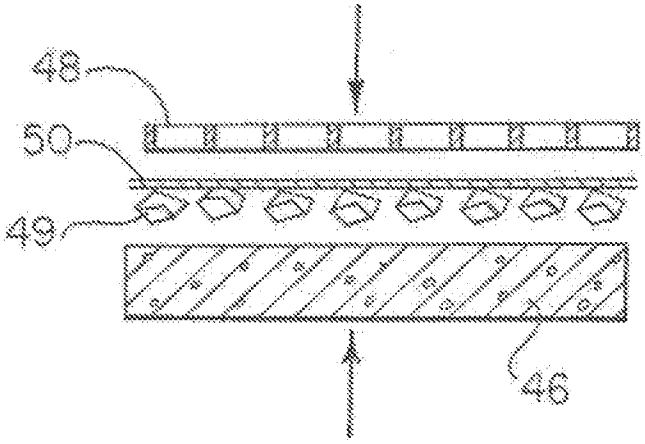


FIG. 16

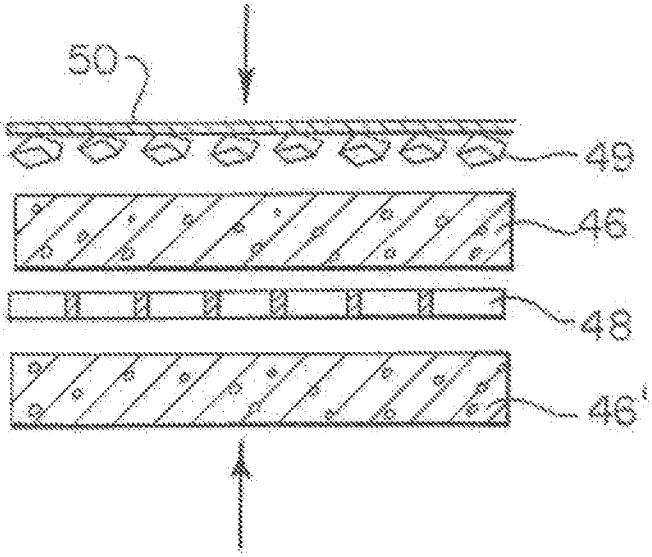


FIG. 17

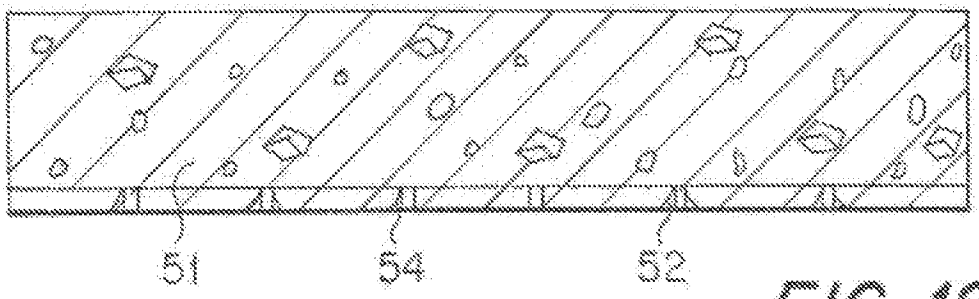


FIG. 18

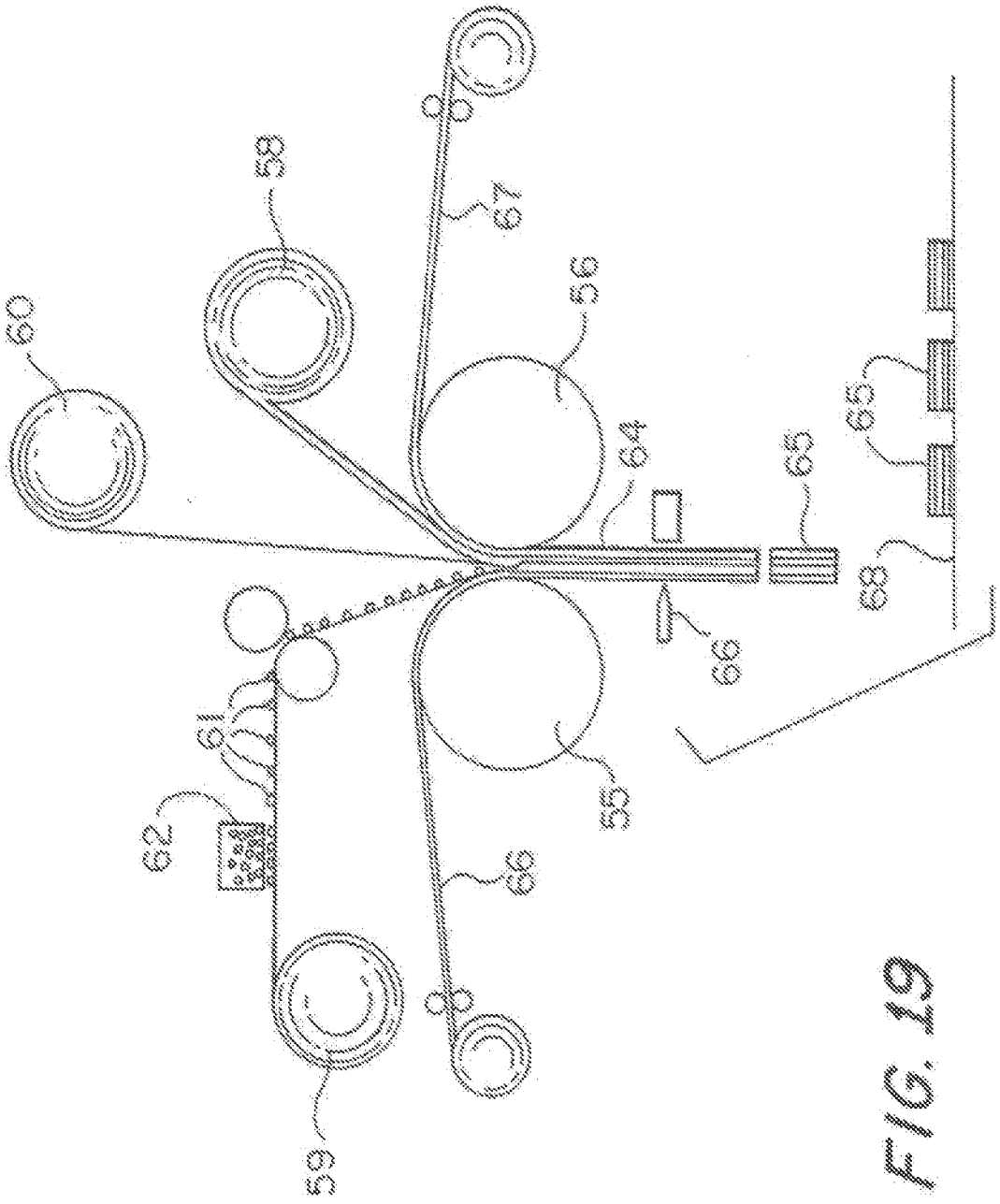


FIG. 19

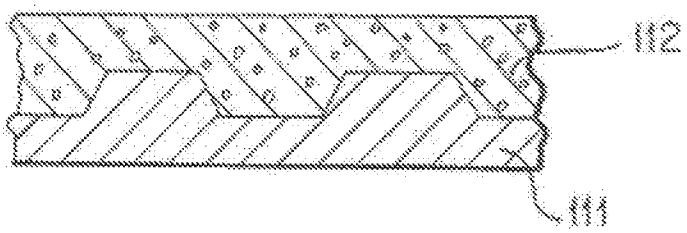


FIG. 19A

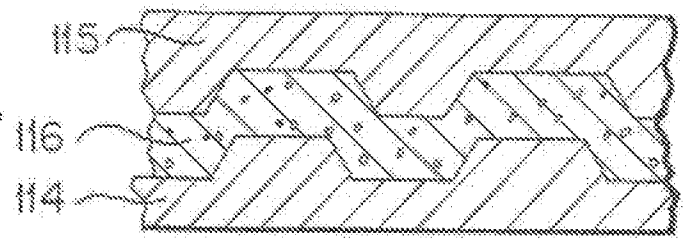


FIG. 19B

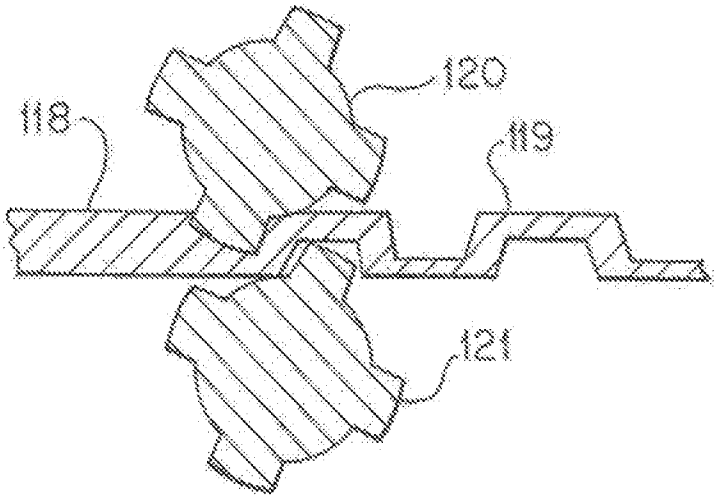


FIG. 19C

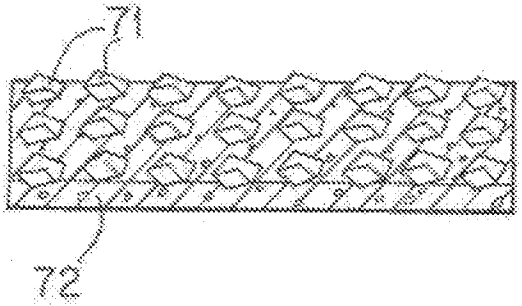


FIG. 21

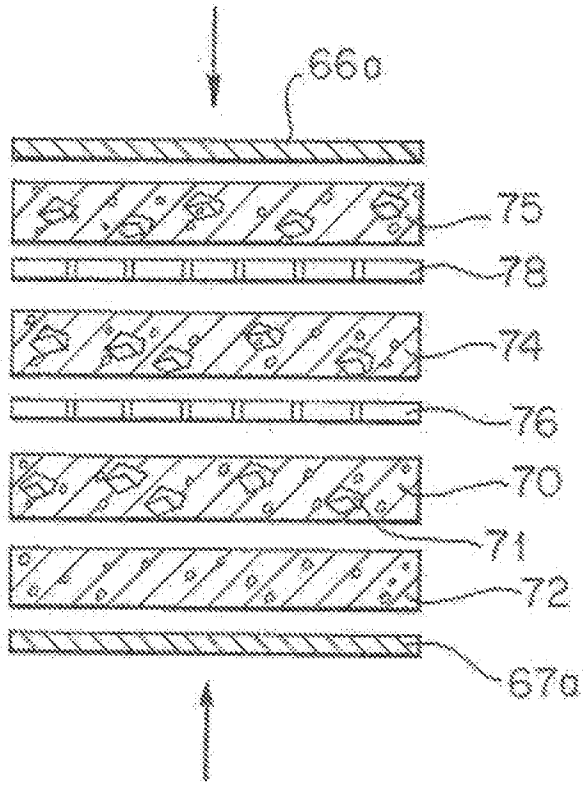


FIG. 20



FIG. 23

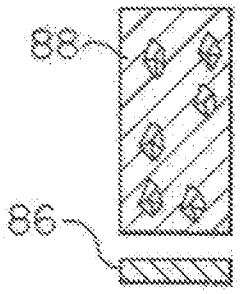


FIG. 24

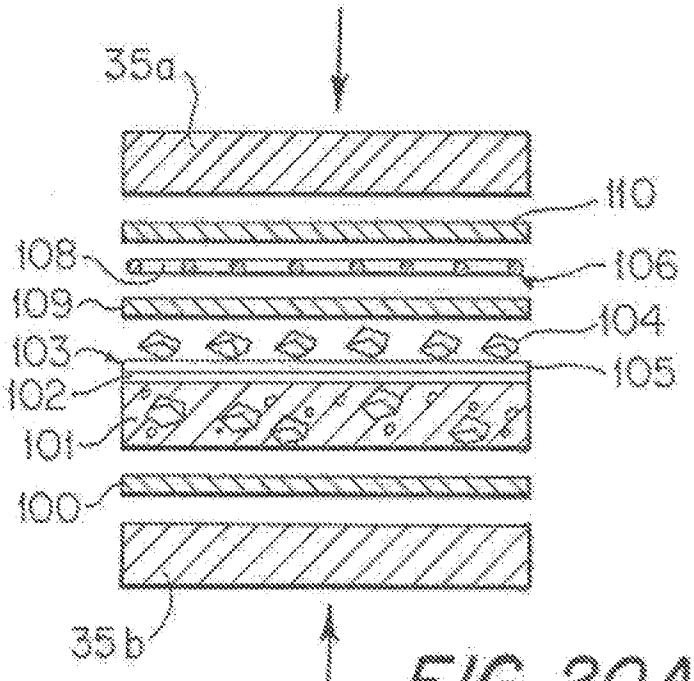


FIG. 20A

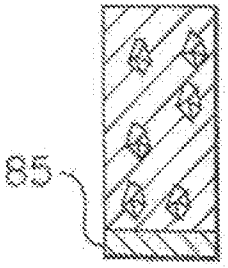


FIG. 25

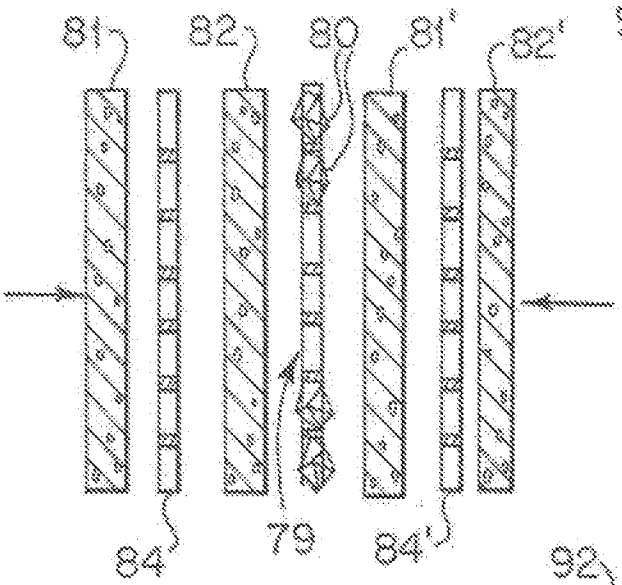


FIG. 22

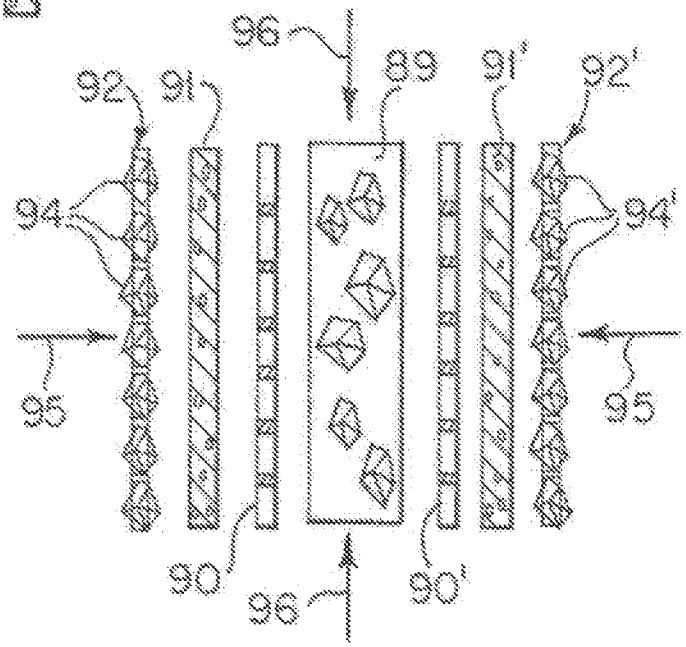


FIG. 26

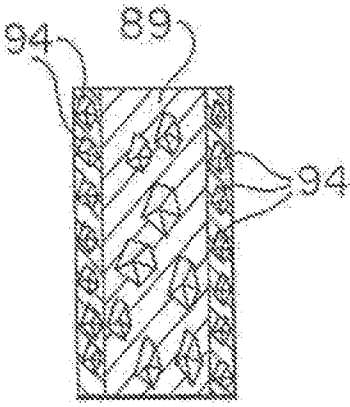


FIG. 27

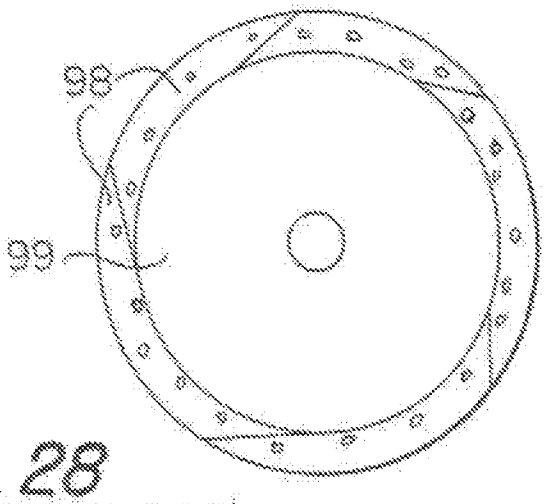


FIG. 28

INTERNATIONAL SEARCH REPORT

Inter ional Application No
PCT/US 95/01503

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B24D18/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 B24D B22F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US,A,5 264 011 (BROWN LAWRENCE E ET AL) 23 November 1993 see column 6, line 57 - column 7, line 32; figure 1	1
A	US,A,5 203 880 (TSELESIN NAUM H) 20 April 1993 cited in the application see claims	1
A	US,A,5 092 910 (DEKOK PETER T ET AL) 3 March 1992 cited in the application see claims	1
A	US,A,4 409 058 (RYAN EDWARD J) 11 October 1983 see claims	1

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[X] Further documents are listed in the continuation of box C. [X] Patent family members are listed in annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
1 June 1995	20.06.95

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl, Fax (+ 31-70) 340-3016	Eschbach, D

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 95/01503

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP,A,0 242 955 (DRESSER IND) 28 October 1987 see page 4, line 28 - line 37	1
A	EP,A,0 533 443 (GEN ELECTRIC) 24 March 1993 see page 3, column 3, line 30 - column 4, line 21	1
A	EP,A,0 407 069 (UNICORN IND PLC) 9 January 1991 see abstract; figure 3	1
A	EP,A,0 204 195 (NORTON CO) 10 December 1986 see abstract; figure 1	1
A	US,A,5 221 294 (CARMAN LEE A ET AL) 22 June 1993 see column 4, line 39 - line 43	1

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

...formation on patent family members

Inter... al Application No
PCT/US 95/01503

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US-A-5264011	23-11-93	NONE		
US-A-5203880	20-04-93	NONE		
US-A-5092910	03-03-92	US-A-	4925457	15-05-90
		AU-A-	5080090	05-09-90
		CA-A-	2025567	31-07-90
		EP-A-	0407568	16-01-91
		JP-T-	3505849	19-12-91
		WO-A-	9009260	23-08-90
		US-A-	5049165	17-09-91
		US-A-	5190568	02-03-93
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US-A-5221294	22-06-93	US-A-	5160509	03-11-92

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(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
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(43) International Publication Date
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(51) International Patent Classification: Not classified

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PCT/US2007/024165

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16 November 2007 (16.11.2007)

(25) Filing Language: English

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(30) Priority Data:
11/560,817 16 November 2006 (16.11.2006) US
11/786,426 10 April 2007 (10.04.2007) US

(71) Applicant and
(72) Inventor: **SUNG, Chien-Min** [US/—]; 4, Lane 32, Chung-Cheng Road, Tansui, Taipei County 251 (TW).

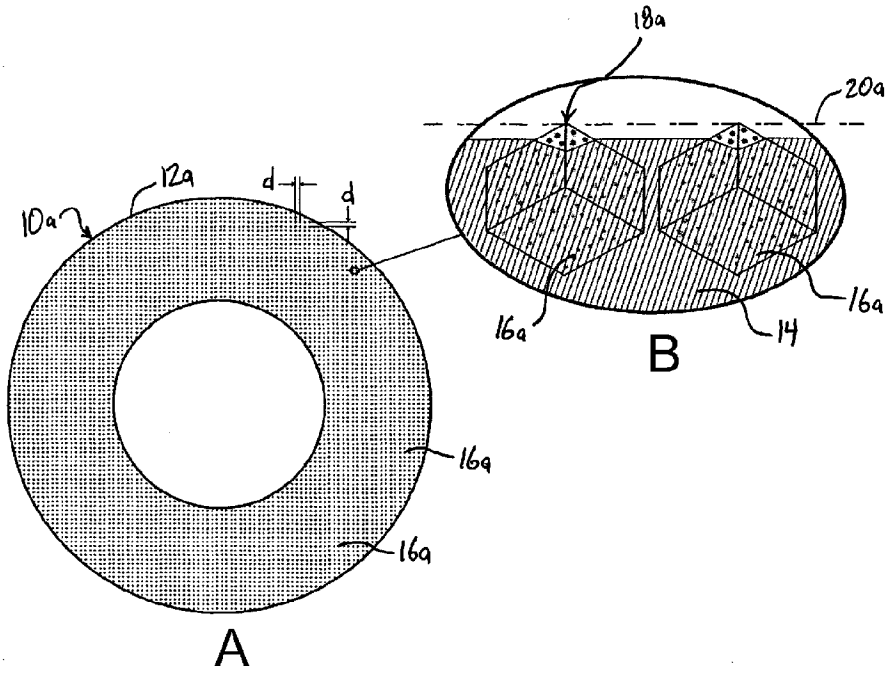
(74) Agents: **OSBORNE, David, W.** et al.; Thorpe North & Western, LLP, PO Box 1219, Sandy, UT 84091-1219 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

(54) Title: SUPERHARD CUTTERS AND ASSOCIATED METHODS



(57) Abstract: A cutting device comprises a base having a solidified organic material layer disposed thereon. A plurality of individual polycrystalline cutting elements are secured in the solidified organic material layer. Each of the plurality of individual polycrystalline cutting elements has a substantially matching geometric configuration.

WO 2008/063599 A2

SUPERHARD CUTTERS AND ASSOCIATED METHODS

FIELD OF THE INVENTION

The present invention relates generally to cutting devices used to remove material from (e.g., plane, smooth, polish, dress, etc.) workpieces formed of various materials. Accordingly, the present invention involves the fields of chemistry, physics, and materials science.

BACKGROUND OF THE INVENTION

It is estimated that the semiconductor industry currently spends more than one billion U.S. Dollars each year manufacturing silicon wafers that exhibit very flat and smooth surfaces. Typically, chemical mechanical polishing ("CMP") is used in the manufacturing process of semiconductor devices to obtain smooth and even-surfaced wafers. In a conventional process, a wafer to be polished is generally held by a carrier positioned on a polishing pad attached above a rotating platen. As slurry is applied to the pad and pressure is applied to the carrier, the wafer is polished by relative movement of the platen and the carrier.

While this well-known process has been used successfully for many years, it suffers from a number of problems. For example, this conventional process is relatively expensive and is not always effective, as the silicon wafers may not be uniform in thickness, nor may they be sufficiently smooth, after completion of the process. In addition to becoming overly "wavy" when etched by a solvent, the surface of the silicon wafers may become chipped by individual abrasive grits used in the process. Moreover, if the removal rate is to be accelerated to achieve a higher productivity, the grit size used on the polishing pad must be increased, resulting in a corresponding increase in the risk of scratching or gouging expensive wafers. Furthermore, because surface chipping can be discontinuous, the process throughput can be very low. Consequently, the wafer surface preparation of current state-of-the-art processes is generally expensive and slow.

In addition to these considerations, the line width (e.g., nodes) of the circuitry on semiconductors is now approaching the virus domain (e.g., 10-100 nm). In addition, more layers of circuitry are now being laid down to meet the increasing demands of advanced logic designs. In order to deposit layers for making nanometer sized features,

each layer must be extremely flat and smooth during the semiconductor fabrication. While diamond grid pad conditioners have been effectively used in dressing CMP pads for polishing previous designs of integrated circuitry, they have not been found suitable for making cutting-edge devices with nodes smaller than 65 nm. This is because, with the decreasing size of the copper wires, non-uniform thickness due to rough- or over-polishing will change the electrical conductivity dramatically. Moreover, due to the use of coral-like dielectric layers, the fragile structure must be polished very gently to avoid disintegration. Hence, the pressure used in CMP processes must be reduced significantly.

In response, new CMP processes, such as those utilizing electrolysis (e.g. Applied Materials ECMP) of copper or those utilizing air film cushion support of wafer (e.g. Tokyo Semitsu), are being pursued to reduce the polishing pressure on the contact points between wafer and pad. However, as a consequence of gentler polishing action, the polishing rate of the wafer will decrease. To compensate for the loss of productivity, polishing must occur simultaneously over the entire surface of the wafer. In order to do so, the contact points between the wafer and the pad must be smaller in area, but more numerous in frequency. This is in contrast to current CMP practice in which the contacted areas are relatively large but relatively few in number.

Thus, in order to polish fragile wafers more and more gently, the CMP pad asperities must be reduced. However, to prevent the polishing rate from declining, more contact points must be created. Consequently, the pad asperities need to be finer in size but more in number. However, the more delicate the polishing process becomes, the higher the risk of scratching the surface of the wafer becomes. In order to avoid this risk, the highest tips of all asperities must be fully leveled. Otherwise, the protrusion of a few "killer asperities" can ruin the polished wafer.

SUMMARY OF THE INVENTION

The present invention provides a cutting device, including a base having a plurality of individual polycrystalline cutting elements secured in a solidified organic material layer. Each of the plurality of individual polycrystalline cutting elements can have a matching geometric configuration.

In accordance with another aspect of the invention, a cutting device is provided, including a base having a solidified organic material layer attached thereto, and a plurality

of individual polycrystalline cutting elements secured in a solidified organic material layer, wherein each of the plurality of individual polycrystalline cutting elements can include at least one cutting tip. The cutting tips of the cutting elements can be aligned in a common plane.

In accordance with another aspect of the invention, a method of forming a cutting device is provided, including: obtaining a substrate; arranging on the substrate a plurality of individual polycrystalline cutting elements in an uncured organic material, each of the plurality of individual polycrystalline cutting elements having a substantially matching geometric configuration, and curing the organic material to form a solidified organic material layer, such that each of the plurality of individual polycrystalline cutting elements are secured therein.

There has thus been outlined, rather broadly, various features of the invention so that the detailed description thereof that follows may be better understood, and so that the present contribution to the art may be better appreciated. Other features of the present invention will become clearer from the following detailed description of the invention, taken with the accompanying exemplary claims, or may be learned by the practice of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a schematic, top plan view of a cutting device in accordance with an embodiment of the invention;

FIG. 1B is an enlarged view of a portion of the cutting device of FIG. 1A;

FIG. 2A is a schematic, top plan view of a cutting device in accordance with another embodiment of the invention;

FIG. 2B is an enlarged view of a portion of the cutting device of FIG. 2A;

FIG. 3A is a schematic, top plan view of a polycrystalline blank, and a cutting device including individual polycrystalline cutting elements formed from the blank, in accordance with an embodiment of the invention;

FIG. 3B is an enlarged view of a portion of one cutting element of FIG. 3A, taken along section B-B of FIG. 3A;

FIG. 4 is a schematic, top plan view of a polycrystalline blank, and a cutting device including individual polycrystalline cutting elements formed from the blank, in accordance with another embodiment of the invention;

FIG. 5 is a schematic, top plan view of another polycrystalline blank in accordance with an embodiment of the invention, shown with the blank divided into a series of individual cutting elements;

FIG. 6 is a schematic, top plan view of a cutting device including individual polycrystalline cutting elements formed from the blank of FIG. 5 in accordance with another embodiment of the invention;

FIG. 7 is a schematic, top plan view of another cutting device, including the individual polycrystalline cutting elements formed from the blank of FIG. 5 in accordance with another embodiment of the invention;

FIG. 8 is a schematic, top plan view of another polycrystalline blank in accordance with an embodiment of the invention, shown with the blank divided into a series of individual cutting elements;

FIG. 9 is a schematic, top plan view of a cutting device, including the individual polycrystalline cutting elements formed from the blank of FIG. 8 in accordance with another embodiment of the invention;

FIG. 10 is a schematic, top plan view of another cutting device, including the individual polycrystalline cutting elements formed from the blank of FIG. 8 in accordance with another embodiment of the invention;

FIG. 11 is a schematic, top plan view of another polycrystalline blank in accordance with an embodiment of the invention, shown with the blank divided into a pair of individual cutting elements; and

FIG. 12 is a schematic, top plan view of a cutting device including the individual polycrystalline cutting elements formed from the blank of FIG. 11 in accordance with another embodiment of the invention.

It will be understood that the above figures are merely for illustrative purposes in furthering an understanding of the invention. Further, the figures may not be drawn to scale, thus dimensions, particle sizes, and other aspects may, and generally are, exaggerated to make illustrations thereof clearer. Therefore, departure can be made from

the specific dimensions and aspects shown in the figures in order to produce the cutting devices of the present invention.

DETAILED DESCRIPTION

Before the present invention is disclosed and described, it is to be understood that this invention is not limited to the particular structures, process steps, or materials disclosed herein, but is extended to equivalents thereof as would be recognized by those ordinarily skilled in the relevant arts. It should also be understood that terminology employed herein is used for the purpose of describing particular embodiments only and is not intended to be limiting.

It must be noted that, as used in this specification and the appended claims, the singular forms "a," "an" and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "a cutting element" includes one or more of such elements.

Definitions

In describing and claiming the present invention, the following terminology will be used in accordance with the definitions set forth below.

All mesh sizes referred to herein are U.S. mesh unless otherwise indicated. Further, mesh sizes are generally understood to indicate an average mesh size of a given collection of particles since each particle within a particular "mesh size" may actually vary over a small distribution of sizes.

As used herein, a "common plane" refers to a profile, including planar or contoured profiles, above a base surface with which the peaks or tips of cutting elements are to be aligned. Examples of such profiles may include, without limitation, flat profiles, wavy profiles, convex profiles, concave profiles, multi-tiered profiles, and the like.

As used herein, cutting "edge" refers to a portion of a cutting element that includes some measurable width across a portion that contacts and removes material from a workpiece. As an exemplary illustration, a typical knife blade has a cutting edge that extends longitudinally along the knife blade, and the knife blade would have to be oriented transversely to a workpiece to scrape or plane material from the workpiece in order for the cutting "edge" of the knife blade to remove material from the workpiece.

As used herein, cutting "tip" refers to a portion of a cutting element that protrudes

the greatest distance from a bonding material, e.g., that is the first portion of the cutting element that contacts a workpiece when the article of the present invention is in use. It is to be understood that a cutting "tip" can include a planar surface, a pointed surface, or an edge; so long as the planar surface, pointed surface or edge of the cutting element is the first portion of the cutting element that contacts a workpiece from which material is to be removed with a cutting device to which the cutting element is attached.

As used herein, "sintering" refers to the joining of two or more individual particles to form a continuous solid mass. The process of sintering involves the consolidation of particles to at least partially eliminate voids between particles. Sintering may occur in either metal or carbonaceous particles, such as diamond. Sintering of metal particles occurs at various temperatures depending on the composition of the material. Sintering of diamond particles generally requires ultrahigh pressures and the presence of a carbon solvent as a diamond sintering aid, and is discussed in more detail below. Sintering aids are often present to aid in the sintering process and a portion of such may remain in the final product.

As used herein, "superhard" may be used to refer to any crystalline, or polycrystalline material, or mixture of such materials which has a Mohr's hardness of about 8 or greater. In some aspects, the Mohr's hardness may be about 9.5 or greater. Such materials include but are not limited to diamond, polycrystalline diamond (PCD), cubic boron nitride (cBN), polycrystalline cubic boron nitride (PcBN) as well as other superhard materials known to those skilled in the art. Superhard materials may be incorporated into the present invention in a variety of forms including particles, grits, films, layers, etc. However, in most cases, the superhard materials of the present invention are in the form of polycrystalline superhard materials, such as PCD and PcBN materials. It is important to note that distinctions are made in the present disclosure between conventional superhard grits and polycrystalline superhard materials.

As used herein, "geometric configuration" refers to a shape that is capable of being described in readily understood and recognized mathematical terms. Examples of shapes qualifying as "geometric configurations" include, without limitation, cubic shapes, polyhedral (including regular polyhedral) shapes, triangular shapes (including equilateral triangles, isosceles triangles and three-dimensional triangular shapes), pyramidal shapes, spheres, rectangles, "pie" shapes, wedge shapes, octagonal shapes, circles, etc.

As used herein, "organic material" refers to a semisolid or solid complex amorphous mix of organic compounds. As such, "organic material layer" and "organic material matrix" may be used interchangeably, refer to a layer or mass of a semisolid or solid complex amorphous mix of organic compounds. Preferably the organic material will be a polymer or copolymer formed from the polymerization of one or more monomers.

As used herein, "metal" and "metallic" can be used interchangeably, and refer to a metal, or an alloy of two or more metals. A wide variety of metal or metallic materials is known to those skilled in the art, such as aluminum, copper, chromium, iron, steel, stainless steel, titanium, tungsten, zinc, zirconium, molybdenum, etc., including alloys and compounds thereof.

As used herein, "particle," when used in connection with a superabrasive material, refer to a particulate form of such material. Such particles may take a variety of shapes, including round, oblong, square, euhedral, etc., as well as a number of specific mesh sizes. As is known in the art, "mesh" refers to the number of holes per unit area as in the case of U.S. meshes.

As used herein, "particle" and "grit" may be used interchangeably.

As used herein, "cutting element" describes a variety of structures capable of removing (e.g., cutting) material from a workpiece. A cutting element can be a mass having several cutting points, ridges or mesas formed thereon or therein. It is notable that such cutting points, ridges or mesas may be from a multiplicity of protrusions or asperities included in the mass. Furthermore, a cutting element can also include an individual particle that may have only one cutting point, ridge or mesa formed thereon or therein.

As used herein, "grid" means a pattern of lines forming multiple squares.

As used herein, "mechanical force" and "mechanical forces" refer to any physical force that impinges on an object that causes mechanical stress within or surrounding the object. Example of mechanical forces would be frictional forces or drag forces. As such, the terms "frictional force" and "drag force" may be used interchangeably, and refer to mechanical forces impinging on an object as described.

As used herein, "mechanical stress" refers to a force per unit area that resists impinging mechanical forces that tend to compact, separate, or slide an object.

As used herein, the term "profile" refers to a contour above an organic material layer

surface to which the superabrasive particles are intended to protrude.

As used herein, "mechanical bond" and "mechanical bonding" may be used interchangeably, and refer to a bond interface between two objects or layers formed primarily by frictional forces. In some cases the frictional forces between the bonded objects may be increased by expanding the contacting surface areas between the objects, and by imposing other specific geometrical and physical configurations, such as substantially surrounding one object with another.

As used herein, the term "substantially" refers to the complete or nearly complete extent or degree of an action, characteristic, property, state, structure, item, or result. For example, an object that is "substantially" enclosed would mean that the object is either completely enclosed or nearly completely enclosed. The exact allowable degree of deviation from absolute completeness may in some cases depend on the specific context. However, generally speaking the nearness of completion will be so as to have the same overall result as if absolute and total completion were obtained. The use of "substantially" is equally applicable when used in a negative connotation to refer to the complete or near complete lack of an action, characteristic, property, state, structure, item, or result. For example, a composition that is "substantially free of" particles would either completely lack particles, or so nearly completely lack particles that the effect would be the same as if it completely lacked particles. In other words, a composition that is "substantially free of" an ingredient or element may still actually contain such item as long as there is no measurable effect thereof.

As used herein, the term "about" is used to provide flexibility to a numerical range endpoint by providing that a given value may be "a little above" or "a little below" the endpoint.

As used herein, a plurality of items, structural elements, compositional elements, and/or materials may be presented in a common list for convenience. However, these lists should be construed as though each member of the list is individually identified as a separate and unique member. Thus, no individual member of such list should be construed as a de facto equivalent of any other member of the same list solely based on their presentation in a common group without indications to the contrary.

Concentrations, amounts, and other numerical data may be expressed or presented herein in a range format. It is to be understood that such a range format is used

merely for convenience and brevity and thus should be interpreted flexibly to include not only the numerical values explicitly recited as the limits of the range, but also to include all the individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly recited. As an illustration, a numerical range of "about 1 to about 5" should be interpreted to include not only the explicitly recited values of about 1 to about 5, but also include individual values and sub-ranges within the indicated range. Thus, included in this numerical range are individual values such as 2, 3, and 4 and sub-ranges such as from 1-3, from 2-4, and from 3-5, etc., as well as 1, 2, 3, 4, and 5, individually.

This same principle applies to ranges reciting only one numerical value as a minimum or a maximum. Furthermore, such an interpretation should apply regardless of the breadth of the range or the characteristics being described.

The Invention

The present invention provides a cutting device and associated methods that can be utilized in cutting or otherwise affecting a workpiece to remove material from the workpiece and provide a finished, smooth and/or flat surface to the workpiece. Cutting devices of the present invention can be advantageously utilized, for example, as planing devices that plane material from a workpiece, as dressing devices that dress various workpieces, and as polishing devices that polish various workpieces.

In the embodiment of the invention illustrated in FIGs. 1A and 1B, a cutting device (e.g., disk) 10a is provided that optionally includes a base 12a that can have a solidified organic material layer (14 in FIGs. 1B and 2B) disposed thereon, attached thereto, or otherwise associated therewith. A plurality of individual polycrystalline cutting elements 16a can be secured in the solidified organic material layer. Each of the plurality of individual polycrystalline cutting elements can have or exhibit a substantially matching geometric configuration, e.g., the geometric configuration of the cutting elements can substantially match that of other of the cutting elements. In the example illustrated in FIG. 1B, each of the plurality of individual polycrystalline cutting elements 16a has geometric configuration that is substantially cubic in nature. In the embodiment illustrated in FIG. 2B, the individual polycrystalline cutting elements 16b have a geometric configuration that can be characterized as a three-dimensional triangular configuration.

As illustrated in both FIGs. 1B and 2B, in one aspect of the invention, the plurality of individual polycrystalline cutting elements 16a, 16b can include at least one cutting tip (18a and 18b, respectively), with the cutting tips of the cutting elements being aligned in a common plane (20a, 20b, respectively). In this example, the common plane is a flat plane of predetermined height above the solidified organic matrix. Thus, the plurality of individual polycrystalline cutting elements can be held within the solidified organic material layer in a very precise manner such that each of the cutting elements contacts a workpiece (not shown) from which material is to be removed at substantially the same depth. In this way, each of the individual polycrystalline cutting elements can be subject to substantially the same level of drag force as the cutting device is moved relative to a workpiece. This feature of the invention can advantageously limit the premature removal of individual cutting elements that might otherwise shorten the life of the tool, and/or damage the workpiece being treated.

The individual cutting elements 16a, 16b can be formed from a variety of materials including, in one embodiment, a polycrystalline material or a superhard polycrystalline material. While not so limited, the superhard polycrystalline material can be a polycrystalline diamond compact ("PCD") or a polycrystalline cubic boron nitride compact ("PcBN"). The PCD or PcBN compact can be formed in a variety of manners, as discussed in more detail below. By forming the individual cutting elements from a polycrystalline material, and attaching the cutting elements individually to the cutting device, the beneficial properties of polycrystalline cutting elements can be achieved without requiring that portions of the cutting device not used for cutting also be formed from the polycrystalline material. Thus, considerable cost savings can be achieved.

The cutting devices of the present invention can be utilized in a number of applications, and in one embodiment are particularly well adapted for use in planing substantially brittle materials, such as silicon wafers, glass sheets, metals, used silicon wafers to be reclaimed by planarization, LCD glass, LED substrates, SiC wafers, quartz wafers, silicon nitride, zirconia, etc. In conventional silicon wafer processing techniques, a wafer to be polished is generally held by a carrier positioned on a polishing pad attached above a rotating platen. As slurry is applied to the pad and pressure is applied to the carrier, the wafer is polished by relative movements of the platen and the carrier. Thus,

the silicon wafer is essentially ground or polished, by very fine abrasives, to a relatively smooth surface.

While grinding of silicon wafers has been used with some success, the process of grinding materials such as silicon wafers often results in pieces of the material being torn or gouged from the body of the material, resulting in a less than desirable finish. This is due, at least in part, to the fact that grinding or abrasive processes utilize very sharp points of abrasive materials (which are often not level relative to one another) to localize pressure to allow the abrasives to remove material from a workpiece.

The PCD or PcBN cutting elements of the present invention are generally superhard, resulting in little yielding by the cutting elements when pressed against a wafer. As hardness is generally a measure of energy concentration, e.g., energy per unit volume, the PCD or PcBN compacts of the present invention are capable of concentrating energy to a very small volume without breaking. These materials can also be maintained with a very sharp cutting edge due to their ability to maintain an edge within a few atoms.

While not so required, in one embodiment of the invention shown in FIG. 1A, the individual polycrystalline cutting elements 16a can be arranged in or across the organic material layer or base in a grid pattern, e.g., in a pattern of squares. The cutting elements can be evenly spaced from one another at a distance "d" of from about 100 microns to about 800 microns. In one aspect of the invention, the individual polycrystalline cutting elements can be evenly spaced from one another at a distance "d" of about 500 microns.

In the embodiment of the invention illustrated in FIG. 2A, the individual polycrystalline cutting elements 16b can be arranged in or across the organic material layer or base as a series of concentric circles. As in the embodiment discussed above, the individual cutting elements can be evenly spaced from one another at a distance "d" of from about 100 microns to about 800 microns. In one aspect, the individual polycrystalline cutting elements can be evenly spaced from one another at a distance "d" of about 500 microns. By evenly spacing the individual cutting elements one from another, the drag force applied to the cutting elements during the cutting process can be evenly distributed among each of the cutting elements, eliminating or reducing the risk of premature pullout of one or more individual cutting elements. Premature pullout of one or more individual cutting elements can result in serious damage being done the workpiece being worked upon.

The retention of an individual polycrystalline cutting element in an organic material layer can be greatly improved by arranging the cutting elements the organic material layer such that mechanical stress impinging on any individual cutting element is minimized. By reducing the stress impinging on each individual cutting element they can be more readily retained in a solidified organic material layer, particularly for delicate tasks.

Various configurations or arrangements are contemplated for minimizing the mechanical stress impinging on the cutting elements held in the abrading tool. In addition to the spacing considerations discussed above, one potentially useful parameter may include the relative heights that the elements protrude above the organic material layer. A cutting element that protrudes to a significantly greater height than other cutting elements will experience a greater proportion of the impinging mechanical forces and thus is more prone to pull out of the solidified organic material layer. Thus, an even height distribution of the cutting elements may function to more effectively preserve the integrity of the abrading tool as compared to abrading tools lacking such an even height distribution.

As such, in one aspect, substantially all of the plurality of individual cutting elements may protrude to a predetermined height above the solidified organic material layer. Though any predetermined height that would be useful in an abrading or cutting tool would be considered to be within the presently claimed scope, in one specific aspect the predetermined height may produce a cutting depth of less than about 20 microns when used to abrade a workpiece. In another specific aspect, the predetermined height may produce a cutting depth of from about 1 micron to about 20 microns when used to abrade a workpiece. In yet another specific aspect, the predetermined height may produce a cutting depth of from about 10 micron to about 20 microns when used to abrade a workpiece. In yet another aspect, the predetermined height may produce a depth of up to or more than 50 or 100 microns.

It should also be noted that the leveling of the individual cutting elements to a predetermined height may be dependent on cutting element spacing. In other words, the farther the cutting elements are separated, the more the impinging forces will affect each cutting element. As such, patterns with increased spacing between the cutting elements may benefit from a smaller variation from predetermined height.

It may also be beneficial for the cutting elements to protrude from the solidified

organic material layer to a predetermined height or series of heights that is/are along a designated profile. Numerous configurations for designated profiles are possible, depending on the particular use of the abrading tool. In one aspect, the designated profile may be a plane. In planar profiles, the highest protruding points of the cutting elements are intended to be substantially level. It is important to point out that, though it is preferred that these points align with the designated profile, there may be some height deviation between cutting elements that occur due to limitations inherent in the manufacturing process.

In addition to planar profiles, in another aspect of the present invention the designated profile has a slope. Tools having sloping surfaces may function to more evenly spread the frictional forces impinging thereon across the cutting elements, particularly for rotating tools such as disk sanders and CMP pad dressers. The greater downward force applied by higher central portions of the tool may offset the higher rotational velocity at the periphery, thus reducing the mechanical stress experienced by cutting elements in that location. As such, the slope may be continuous from a central point of the tool to a peripheral point, or the slope may be discontinuous, and thus be present on only a portion of the tool. Similarly, a given tool may have a single slope or multiple slopes. In certain aspects, the tool may slope in a direction from a central point to a peripheral point, or it may slope from a peripheral point to a central point.

Various slopes are contemplated that may provide a benefit to solidified organic material layer tools. It is not intended that the claims of the present invention be limited as to specific slopes, as a variety of slopes in numerous different tools are possible. In one aspect, however, a CMP pad dresser may benefit from an average slope of 1/1000 from the center to the periphery.

As a variation on tools having a slope, in certain aspects the designated profile may have a curved shape. One specific example of a curved shape is a dome shape tool. Such curved profiles function in a similar manner to the sloped surfaces. Tools may include such curved profiles in order to more effectively distribute the frictional forces between all of the cutting elements, thus reducing failures of individual particles and prolonging the life of the tool.

As has been mentioned herein, while it is intended that the tips of the cutting elements align along the designated profile, some level of deviation may occur. These

deviations may be a result of the design or manufacturing process of the tool. Given the wide variety of sizes and shapes of cutting elements that may potentially be utilized in a given tool, such deviations may be highly dependent on a particular application. Also, when referring to the designated profile, it should be noted that the term "tip" is intended to include the highest protruding point of a cutting element, whether that point be an apex, an edge, or a face. Orientational positioning, tip leveling, and other techniques of manipulating superabrasive particles are further described in U.S. Patent Application No. 11/223,786, filed on September 9, 2005, and U.S. Patent Application No. 11/733,325, filed April 10, 2007, both of which are incorporated herein by reference.

As such, in one aspect a majority of the plurality of cutting elements is arranged such that the tips vary from the designated profile by from about 1 micron to about 150 microns. In another aspect, the plurality of cutting elements are arranged such that their tips vary from the designated profile by from about 5 microns to about 100 microns. In yet another aspect, the plurality of cutting elements are arranged such that their tips vary from the designated profile by from about 10 microns to about 75 microns. In a further aspect, the plurality of cutting elements are arranged such that their tips vary from the designated profile by from about 10 microns to about 50 microns. In another aspect, they are arranged such that their tips vary from the designated profile by from about 50 microns to about 150 microns. In yet another aspect, they are arranged such that their tips vary from the designated profile by from about 20 microns to about 100 microns. In a further aspect, they are arranged such that their tips vary from the designated profile by from about 20 microns to about 50 microns.

In another aspect, the plurality of cutting elements are arranged such that their tips vary from the designated profile by from about 20 microns to about 40 microns. Additionally, in one aspect, they are arranged such that their tips vary from the designated profile by less than about 20 microns. In another aspect, they are arranged such that their tips vary from the designated profile by less than about 10 microns. In yet another aspect, they are arranged such that their tips vary from the designated profile by less than about 5 microns. In yet another aspect, they are arranged such that their tips vary from the designated profile by less than about 1 micron. In a further aspect, a majority of the plurality of the cutting elements are arranged such that their tips vary from the designated profile to less than about 10% of the average size of the cutting elements.

The determination of the distance that the tips of the cutting elements extend from the organic binder can also be affected by considering how much of the cutting elements extend above the binder compared to how much of the cutting elements remain submerged beneath the binder surface. In the embodiment illustrated in FIGs. 1A and 1B, a ratio of an amount the cutting elements 16a protrude above the binder to an amount submerged beneath the binder is about 4 to 1. In the embodiment illustrated in FIGs. 2A and 2B, about 2/3 of the cutting elements 16b are submerged, with about 1/3 being exposed above the binder. Other ratios are also possible, from a 20 to 1 ratio to about 0.2 to 1, inclusive of ranges therebetween.

By forming the individual cutting elements in the shapes described herein, a relatively large portion of the cutting elements 16a, 16b can be submerged beneath the organic binder. In this manner, the area that affords the greatest cross section for engagement with the binder material is "buried" beneath the greatest amount of binder. This feature of the invention, namely that the widest (i.e. largest cross section of the cutting element) is closer to one end of the particle than the other, and thus the wider end can be placed below the surface of the organic matrix, provides great retention advantages over conventional diamond, or synthetic diamond, grits wherein a largest cross section of the grit is concentrated near a midpoint of the grit, and thus is placed at or near the surface of a matrix in which the grit is held. The widest portion may be at or near the end that is most distal from the working (e.g., cutting) end of the cutting element.

In addition to the shapes of cutting elements illustrated in the figures, in one embodiment of the invention, the cutting elements are formed in pyramidal shapes. The present inventor has found that such a configuration provides a number of advantages. For example, pyramidal-shaped cutting elements concentrate most of the volume/mass of the cutting element toward a lowermost portion of the cutting element, ensuring that the cutting element is more securely held to whichever type of base (e.g., cutting tool) the elements are bonded to, integrated with, or other associated with. In addition, by forming pyramids with a triangular base, the support base of the pyramids is even more massive relative to the tip, and the tip can be made sharper (e.g., 60 degrees) without breaking or fracturing during the dressing of CMP pads.

In general, sharper tips will cut pads faster, leading to a corresponding reduction in total dressing time. Moreover, the asperities formed on the pad are also sharper and more

dense. Such asperities can polish wafers, and/or dress CMP pads faster without causing undesirable non-uniformity on the wafer. Alternatively, square pyramids can be used when a lower cut rate is desired, as the tip angle likely has a larger magnitude (e.g. 90 degrees). Thus creating a wider cut path with greater drag and resulting in a lower cut rate. However, the square PCD cutter can be formed more sharply than conventional, single crystal diamond grits that have variable tip angles ranging from 90 degrees to over 125 degrees. Thus, pyramids formed of polycrystalline materials are generally much more effective cutters, with triangular pyramids (i.e. 3 sided) being particularly effective.

In addition, as the cutting elements of the present invention can be made with very closely controlled geometry, the present polycrystalline cutting elements can cut pads with less tearing. Also, with the addition of the secondary cutting elements formed on the major cutting elements, the present cutting elements can perform even better. In other words, serrations in the cutting surface may improve the cutting action of the cutting elements. In contrast, single crystal grits are generally very smooth, so they can cause a lot of plastic deformation on the pad and tearing of cut "shreds." It should be noted that the irregular surface of the polycrystalline cutting elements additionally improves retention in the organic material layer. Such irregular surfaces allow the organic material to "grip" a cutting element to a greater extent than would be possible with the smooth surfaces of a single crystal cutting element.

In addition, oftentimes pad conditioners dress pads under conditions in which work load is unevenly distributed across the cutting elements. Specifically, the outer rim of cutting elements often must do the most cutting work, with the interior elements not being subject to a as high a degree of stress. One manner in which the present invention addresses this problem is by configuring the "outer" cutting elements, some times as PCD grits, (e.g., those located closer to the outer perimeter of the cutting or dressing tool) more robust, and/or the inner elements slightly higher (e.g. about 10 microns higher) than the outer elements. The outer cutting elements can also be disposed on the cutting tool at a greater density, e.g., they can be spaced closer together, and/or be positioned at a slightly lower elevation. In this design, the distribution of cutting elements may not be in grid form, but can include a series of concentric rings that can be radially symmetric.

In one embodiment of the invention, the outer elements can be formed with larger support bases relative to the cutting tips (in one aspect they can have triangular bases),

and they may also have an edge formed on the cutting tip rather than just a point. Also, the outermost cutting elements may have a small (e.g. 50 microns) mesa formed at their cutting tips that can cut the pad with edge of the mesa rather than with a straight edge or a point.

In one embodiment of the invention, the cutting elements can be pyramids that are asymmetrical in shape. For example, since the cutting force is generally applied from "outside to inside," the pyramid design may have a relatively steeply sloped wall facing the outer perimeter of the cutting device, but with a relatively gentler slope (e.g. 10 degrees from the horizontal plane) in the trailing side. That is, the table portion on the tip of the pyramid may not be horizontal, but may exhibit a slight "tilt" toward inward to allow debris to escape more easily. This aspect of the invention differs from diamond grit cutting pads, as such conventional cutting pads include a negative angle such that the tearing or cutting force is superimposed with a compressive force. This embodiment of the invention can allow cutting without a great deal of compression so the removal of pad "shread" is much easier.

In other words, the present invention allows a majority of the energy consumed to be used in cutting, rather than plastic deformation. This advantage can be further improved upon by forming the vertical wall of the pyramids such that they slope slightly less than 90 degrees (e.g., about 80 degrees). In this case the table of the pyramids can be sharper on the top of the mesa, similar to an inverted pyramid. This can improve the efficiency of pad cutting because the cutting is performed with a positive angle, similar to a razor blade used in shaving. Such a design has not been possible with single crystal diamond designs, as the cutting edge contact with such designs is always negative in angle. The present pyramidal cutting elements can provide positive cutting edges that are not subject to premature failure due, at least in part, to its ability to support such a cutting edge with a more gently sloping wall on the trailing side of the cutting interface (e.g., with the asymmetrical shape of the pyramids). In one aspect, such an asymmetry can be formed by wire-EDM cutting, and it can be formed with pyramids with tips of point, edge, and mesa tops. Also, when the cutting elements are individual particles or grits, such particle or grit can receive the intended configuration, including an assymetrical configuration as described above by using a mold with a proper shape for processing of the PCT particle.

In one embodiment of the invention, the spacing of the pyramids can be adjusted to adjust the contact pressure of each cutting point, edge or mesa. In general, the farther the pyramids are spaced from one another, the higher the contact pressure between the pyramid and the pad. Thus, the fewer tips present to support the applied force, the deeper the penetration of each of the tips and the larger the formed asperities. Generally, the polishing rate of the wafer is dependent on the number and size of the asperities. Denser, smaller asperities can polish as fast as fewer, larger asperites. But the former is more uniform with no excessive force that may cause non-uniformity, scratching, erosion or dishing of the delicate wafer, etc. This can be particularly true with copper smaller than 90 nm and with low-k dielectric having greater than 20% pores.

The individual polycrystalline cutting elements can be formed in a variety of manners and from a variety of materials, as would occur to one having ordinary skill in the relevant art. In one aspect of the invention, the cutting elements are sintered polycrystalline diamond cubes with silicon/SiC as the matrix. Each of the cubes can contain about 90 V% of diamond (about 10 microns in grain size) and the remaining phase can be either silicon or SiC. A very small amount of titanium can be used facilitate the sintering process. The cubes can be pressed in a graphite mold and formed in a size of about 1 mm on each side. While the cubic examples provided above have proven particularly efficacious, it is to be understood that a variety of sizes and configurations of polycrystalline materials can be utilized in the present invention.

By forming the cutting elements from individual units of superhard polycrystalline material, in defined geometric shapes, arrangement of the cutting elements in a very precise manner becomes much easier. As the defined geometric shapes can be replicated fairly precisely from one cutting element to another, the positioning of, and accordingly, the stress impinged upon, each cutting element can be accomplished fairly consistently across the face off the cutting device in question. With prior art abrasive grits, for example, the overall shape and size of each a plurality of grits might change considerably from one grit to another, making precise placement of the grits difficult to accomplish.

The material utilized in the organic material layer 14 can vary widely. Numerous organic materials are known to those skilled in the art which would be useful when utilized in embodiments of the present invention, and are considered to be included herein. The organic material layer can be any curable resin material, resin, or other

polymer with sufficient strength to retain the individual polycrystalline cutting elements of the present invention. It may be beneficial to use an organic material layer that is relatively hard, and maintains a flat surface with little or no warping. This allows the abrading tool to incorporate very small individual polycrystalline cutting elements at least partially therein, and to maintain these small cutting elements at relatively level and consistent heights.

Additionally, various organic materials may act to absorb mechanical forces impinging on the cutting elements disposed therein, and thus spread and equalize such forces across the abrading tool.

Methods of curing the organic material layer can be any process known to one skilled in the art that causes a phase transition in the organic material from at least a pliable state to at least a rigid state. Curing can occur, without limitation, by exposing the organic material to energy in the form of heat, electromagnetic radiation, such as ultraviolet, infrared, and microwave radiation, particle bombardment, such as an electron beam, organic catalysts, inorganic catalysts, or any other curing method known to one skilled in the art.

In one aspect of the present invention, the organic material layer may be a thermoplastic material. Thermoplastic materials can be reversibly hardened and softened by cooling and heating respectively. In another aspect, the organic material layer may be a thermosetting material. Thermosetting materials cannot be reversibly hardened and softened as with the thermoplastic materials. In other words, once curing has occurred, the process is essentially irreversible.

Organic materials that may be useful in embodiments of the present invention include, but are not limited to: amino resins including alkylated urea-formaldehyde resins, melamine-formaldehyde resins, and alkylated benzoguanamine-formaldehyde resins; acrylate resins including vinyl acrylates, acrylated epoxies, acrylated urethanes, acrylated polyesters, acrylated acrylics, acrylated polyethers, vinyl ethers, acrylated oils, acrylated silicons, and associated methacrylates; alkyd resins such as urethane alkyd resins; polyester resins; polyamide resins; polyimide resins; reactive urethane resins; polyurethane resins; phenolic resins such as resole and novolac resins; phenolic/latex resins; epoxy resins such as bisphenol epoxy resins; isocyanate resins; isocyanurate resins; polysiloxane resins including alkylalkoxysilane resins; reactive vinyl resins; resins

marketed under the Bakelite trade name, including polyethylene resins, polypropylene resins, epoxy resins, phenolic resins, polystyrene resins, phenoxy resins, perylene resins, polysulfone resins, ethylene copolymer resins, acrylonitrile-butadiene-styrene (ABS) resins, acrylic resins, and vinyl resins; acrylic resins; polycarbonate resins; and mixtures and combinations thereof. In one aspect of the present invention, the organic material may be an epoxy resin. In another aspect, the organic material may be a polyimide resin. In yet another aspect, the organic material may be a polyurethane resin. In yet another aspect, the organic material may be a polyurethane resin.

Numerous additives may be included in the organic material to facilitate its use. For example, additional crosslinking agents and fillers may be used to improve the cured characteristics of the organic material layer. Additionally, solvents may be utilized to alter the characteristics of the organic material in the uncured state. Also, a reinforcing material may be disposed within at least a portion of the solidified organic material layer. Such reinforcing material may function to increase the strength of the organic material layer, and thus further improve the retention of the individual polycrystalline cutting elements. In one aspect, the reinforcing material may include ceramics, metals, or combinations thereof. Examples of ceramics include alumina, aluminum carbide, silica, silicon carbide, zirconia, zirconium carbide, and mixtures thereof.

Additionally, in one aspect a coupling agent or an organometallic compound may be coated onto the surface of each superabrasive particle to facilitate the retention of the superabrasive particles in the organic material matrix via chemical bonding. A wide variety of organic and organometallic compounds are known to those of ordinary skill in the art and may be used. Organometallic coupling agents can form chemicals bonds between the superabrasive particles and the organic material matrix, thus increasing the retention of the particles therein. In this way, the organometallic coupling agent acts as a bridge to form bonds between the organic material matrix and the surface of the superabrasive particles. In one aspect of the present invention, the organometallic coupling agent can be a titanate, zirconate, silane, or mixture thereof.

Specific non-limiting examples of silanes suitable for use in the present invention include: 3- glycidoxypropyltrimethoxy silane (available from Dow Corning as Z-6040); γ-methacryloxy propyltrimethoxy silane (available from Union Carbide Chemicals Company as A-174); β-(3,4-epoxycyclohexyl)ethyltrimethoxy silane, γ-

aminopropyltriethoxy silane, N-(β-aminoethyl)-γ-aminopropylmethyldimethoxy silane (available from Union Carbide, Shin-etsu Kagaku Kogyo K.K., etc.); and additional examples of suitable silane coupling agents can be found in U.S. Pat. Nos. 4,795,678, 4,390,647, and 5,038,555, which are each incorporated herein by reference.

Specific non-limiting examples of titanate coupling agents include: isopropyltriisostearoyl titanate, di(cumylphenylate)oxyacetate titanate, 4-aminobenzenesulfonyldodecylbenzenesulfonyl titanate, tetraoctylbis (ditridecylphosphite) titanate, isopropyltri(N-ethylamino-ethylamino) titanate (available from Kenrich Petrochemicals. Inc.), neoalkyoxy titanates such as LICA-01, LICA-09, LICA-28, LICA-44 and LICA-97 (also available from Kenrich), and the like.

Specific non-limiting examples of aluminum coupling agents include acetoalkoxy aluminum diisopropylate (available from Ajinomoto K.K.), and the like.

Specific non-limiting examples of zirconate coupling agents include: neoalkoxy zirconates, LZ-01, LZ-09, LZ- 12, LZ-38, LZ-44, LZ-97 (all available from Kenrich Petrochemicals, Inc.), and the like. Other known organometallic coupling agents, e.g., thiolate based compounds, can be used in the present invention and are considered within the scope of the present invention.

The amount of organometallic coupling agent used depends on the coupling agent and on the surface area of the individual polycrystalline cutting elements. Typically, 0.05% to 10% by weight of the organic material layer is sufficient.

Turning now to FIG. 3A, in one aspect of the invention, the individual polycrystalline cutting elements can be obtained and/or formed from a polycrystalline blank of material. One such blank of material is shown at 30 in FIG. 3A, with the polycrystalline blank being formed in a disk having a diameter of roughly 30 mm and a thickness that can vary from around 0.2 mm to upwards of 2 mm.

The disk 30 can be divided into a series of individual cutting elements in a variety of manners known to those having ordinary skill in the art, including, without limitation, electro-chemical machining, by laser ablation, by plasma etching, by oxidation (to form carbon dioxide or monoxide gas), hydrogenation (to form methane gas), etc. Laser beams with relatively longer wavelengths (e.g. ND:YAG) have been shown to form cutting grooves on PCD effectively (laser beams with relatively short wavelengths (e.g. excimers) may be used to carve out the secondary cutting elements on top of the primary cutting

elements, as shown and discussed in connection with FIG. 3B. While the latter may be slower in cutting speed, it is generally more precise due to the shorter wavelength used. Moreover, the surface damage can be less with more concentrated energy in higher frequencies. This has been found suitable for shaving or planing a silicon wafer in accordance with the present invention.

In one aspect of the invention, the material is removed from the PCD or PcBN compact by electrical discharge machining ("EDM"). In this aspect, the EDM process can utilize one or more electrodes that include diamond. For example, the cathode used in the EDM process can be a boron doped diamond material and the anode used in the EDM process can be the PCD (in this case, the PCD would generally need to be at least partially electrically conductive). As current is applied through the boron doped diamond material, the material of the PCD can be carefully and controllably removed to form various cutting elements from the PCD.

As will be appreciated, the disk 30 is divided into 8 similarly shaped and sized wedges 32. In one embodiment of the invention, the wedges 32 can be attached to a base 12b by way of the solidified organic material layer discussed above. In the embodiment of the invention illustrated in FIG. 3A, the wedges 32 are radially distributed about the face of the cutting device and/or base or substrate. In this manner, the wedges 32 can be arranged so as to each be subject to substantially the same force (and each be substantially as likely to be retained within the organic matrix) when used to abrade or treat a workpiece (not shown). While not so required, in one embodiment of the invention, the PCD blank 30 can be on the order of about 30 mm in diameter, while the base 12b can be on the order of about 100 mm in diameter. Thus, a cutting device with a diameter of around 100 cm can be formed from superhard material taken from a PCD of only about 30 mm.

As shown in FIG. 4, in one aspect of the invention, a longitudinal axis of each of the individual polycrystalline cutting elements (e.g., wedges 32) is aligned along a radius R of the cutting device. In the embodiment shown, the individual polycrystalline cutting elements are distributed on the cutting device in alternating orientations. The manner of arranging the cutting elements across the face of the base or substrate 12b can be varied for particular applications. Due to the consistent shape and size of the individual polycrystalline cutting elements, however, arrangement and attachment of the cutting

elements to the base is made considerably easier. Accordingly, varying the arrangement for particular applications can be more easily and accurately accomplished.

By utilizing a relatively small amount of polycrystalline material (e.g., disk 30), relative to the size of the base 12b which is to be used to treat the workpiece (not shown), the amount polycrystalline material used can be greatly reduced, leading to considerable cost savings. The present inventor has found, however, that cutting devices of the present invention perform equally well, or nearly equally as well, as conventional cutting devices that utilize "full-face" polycrystalline cutting or grinding tools.

As will be appreciated, the blank 30 of FIG. 3A has been divided into 8 equal portions. However, as shown in FIGs. 5 through 12, the disks 30b, 30c and 30d can be divided into twelve equal portions (represented by wedges 32b), sixteen equal portions (represented by wedges 32c), two equal portions (represented by wedges 32d), and so forth. In this manner, the present invention provides additional flexibility for creation and arrangement of the individual polycrystalline cutting elements across the tool. It is contemplated that a variety of other configurations is also possible, including, without limitation, differently sized and shaped individual polycrystalline cutting elements.

Returning to FIG. 3B, in one aspect of the invention, the individual polycrystalline cutting elements 32 can include a series of secondary cutting elements 40 formed on a face of each of the individual polycrystalline cutting elements. The secondary cutting elements can be configured to maintain a sharpness of each of the cutting elements during use of the cutting device. The secondary cutting elements can vary in shape, and can include rectangular-shaped cutting elements, pyramidal-shaped cutting elements, triangular-shaped cutting elements, etc. The secondary cutting elements can also be formed in a truncated pyramidal shape (not shown). By utilizing secondary cutting elements on the primary cutting elements, the total cutting edge length of the cutting element can be extended by as much as 10,000 times.

In accordance with another aspect, the present invention provides a method of forming a cutting device, comprising: obtaining a substrate; arranging on the substrate a plurality of individual polycrystalline cutting elements, each of the plurality of individual polycrystalline cutting elements having a matching geometric configuration; and securing each of the plurality of individual polycrystalline cutting elements to the substrate with a solidified organic material layer.

The method can further comprise aligning at least one cutting tip of each of the plurality of individual polycrystalline cutting elements in a common plane.

Examples

The following examples present various methods for making the cutting tools of the present invention. Such examples are illustrative only, and no limitation on present invention is meant thereby.

Example 1:

Individual sintered polycrystalline diamond cubes with silicon/SiC as the matrix were used as the cutting elements for forming a CMP pad conditioner. Each of the cubes contains about 90 V% of diamond (about 10 microns in grain size) and the remaining phase is either silicon or SiC. A very small amount of titanium is also present to facilitate the sintering process. The cubes were pressed in a graphite mold and were formed in a size of about 1 mm on each side.

An epoxy mold was provided with cavities configured to receive one apex of the PCD cubes. A parting layer was spread on top of the mold. Subsequently, another epoxy is cast on the top in vacuum. After curing, the mold is removed, exposing the apex of each cube. The apexes become the cutting tip of a pad conditioner.

Example 2

A disk of sintered polycrystalline diamond with silicon/SiC as the matrix is divided into a series of wedges of substantially the same volume. The wedges are used as the cutting elements for forming a CMP pad conditioner. Each of the wedges contains about 90 V% of diamond (about 10 microns in grain size) and the remaining phase is either silicon or SiC. A very small amount of titanium is also present to facilitate the sintering process.

An epoxy mold was provided with cavities configured to receive each of the PCD wedges. A parting layer was spread on top of the mold. Subsequently, another epoxy is cast on the top in vacuum. After curing, the mold is removed, exposing the face of each wedge. The faces (and edges of the faces) of the wedges become the cutting elements of a pad conditioner.

Example 3

PCD blanks pressed from a cubic press were trimmed from both sides to remove refractary metal container (e.g. Ta). The outside diameter of the blanks were ground off. The PCD blanks were bonded to a cemented WC base and the PCD layer was EDM shaped to form pyramids distributed in a predetermined pattern. The PCD blanks were subsequently divided into a series of wedge-shaped cutting pieces and the cutting pieces were placed on a flat mold with the cutting pieces leveled with the mold.

The mold was placed in a vacuum chamber and epoxy is poured over the top. Finally, a stainless steel plate was placed on the top of the flowing epoxy and pressed toward the PCD until only a thin layer of epoxy remained between the backing of the PCD and the steel substrate. After curing of the epoxy, the PCD cutting tool was cleaned and mounting structure (e.g., holes) was formed on the back of the steel substrate.

The PCT cutting pieces can be arranged on the stainless steel plate in an annular ring pattern, circular plates, squares, etc. These patterns can be optimized to suit a particular CMP application.

It is to be understood that the above-described arrangements are only illustrative of the application of the principles of the present invention. Numerous modifications and alternative arrangements may be devised by those skilled in the art without departing from the spirit and scope of the present invention and the appended claims are intended to cover such modifications and arrangements. Thus, while the present invention has been described above with particularity and detail in connection with what is presently deemed to be the most practical and preferred embodiments of the invention, it will be apparent to those of ordinary skill in the art that numerous modifications, including, but not limited to, variations in size, materials, shape, form, function and manner of operation, assembly and use may be made without departing from the principles and concepts set forth herein.

CLAIMS

What is claimed is:

1. A cutting device, comprising:

a base having a solidified organic material layer disposed thereon; and

a plurality of individual polycrystalline cutting elements secured in the solidified organic material layer, each of the plurality of individual polycrystalline cutting elements having a substantially matching geometric configuration.

2. The cutting device of claim 1, wherein each of the plurality of individual polycrystalline cutting elements includes at least one cutting tip, the tips of the cutting elements being aligned in a common plane.

3. The cutting device of claim 1, wherein each of the individual polycrystalline cutting elements is a divided portion of a polycrystalline blank of material.

4. The cutting device of claim 3, wherein the polycrystalline blank is shaped as a disk, and wherein each of the individual polycrystalline cutting elements is a divided portion of the disk.

5. The cutting device of claim 4, wherein each of the individual polycrystalline cutting elements is an equal portion of the disk.

6. The cutting device of claim 4, wherein each of the individual polycrystalline cutting elements is substantially wedge-shaped.

7. The cutting device of claim 4, wherein the individual polycrystalline cutting elements are radially distributed about the face of the cutting device.

8. The cutting device of claim 7, wherein a longitudinal axis of each of the individual polycrystalline cutting elements is aligned along a radius of the cutting device.

9. The cutting device of claim 8, wherein the individual polycrystalline cutting elements are distributed on the cutting device in alternating orientations.

10. The cutting device of claim 1, further comprising a series of secondary cutting elements formed on a face of each of the individual polycrystalline cutting elements, the secondary cutting elements being configured to maintain a sharpness of each of the cutting elements during use of the cutting device.

11. A cutting device, comprising:

a plurality of individual polycrystalline cutting elements secured in a solidified organic material layer, each of the plurality of individual polycrystalline cutting elements including at least one cutting tip, the tips of the cutting elements being aligned in a common plane.

12. The cutting device of claim 11, wherein arrangement of the individual polycrystalline cutting elements uniformly distributes drag forces across substantially each individual polycrystalline cutting element.

13. The cutting device of claim 11, wherein a majority of each of the individual polycrystalline cutting elements protrudes to a predetermined height above the solidified organic material layer.

14. The cutting device of claim 13, wherein the predetermined height produces a cutting depth of less than about 20 microns when used to abrade a workpiece.

15. The cutting device of claim 11, wherein each of the plurality of individual polycrystalline cutting elements has a substantially matching geometric configuration.

16. The cutting device of claim 11, wherein each of the individual polycrystalline cutting elements is a divided portion of a polycrystalline blank of material.

17. The cutting device of claim 16, wherein the polycrystalline blank is shaped as a disk, and wherein each of the individual polycrystalline cutting elements is a divided portion of the disk.

18. The cutting device of claim 17, wherein each of the individual polycrystalline cutting elements is an equal portion of the disk.

19. The cutting device of claim 17, wherein each of the individual polycrystalline cutting elements is substantially wedge-shaped.

20. The cutting device of claim 17, wherein the individual polycrystalline cutting elements are radially distributed in the organic material layer.

21. The cutting device of claim 11, wherein the individual polycrystalline cutting elements are of substantially the same size and substantially the same shape.

22. The cutting device of claim 11, wherein the individual polycrystalline cutting elements are arranged as a grid.

23. The cutting device of claim 22, wherein the individual polycrystalline cutting elements are evenly spaced from one another at a distance of from about 100 microns to about 800 microns.

24. The cutting device of claim 23, wherein the individual polycrystalline cutting elements are evenly spaced from one another at a distance of about 500 microns.

25. The cutting device of either of claim 1 or claim 11, wherein the solidified organic material layer comprises a member selected from the group consisting of amino resins, acrylate resins, alkyd resins, polyester resins, polyamide resins, polyimide resins, polyurethane resins, phenolic resins, phenolic/latex resins, epoxy resins, isocyanate resins, isocyanurate resins, polysiloxane resins, reactive vinyl resins, polyethylene resins, polypropylene resins, polystyrene resins, phenoxy resins, perylene resins, polysulfone

resins, acrylonitrile-butadiene-styrene resins, acrylic resins, polycarbonate resins, polyimide resins, and mixtures thereof.

26. The cutting device of claim 25, wherein the solidified organic material layer is an epoxy resin.

27. The cutting device of claim 25, wherein the solidified organic material layer is a polyurethane resin.

28. The cutting device of claim 25, wherein the solidified organic material layer is a polyimide resin.

29. The cutting device of claim 25, further comprising a reinforcing material disposed within at least a portion of the solidified organic material layer.

30. The cutting device of claim 29, wherein the reinforcing material is a material selected from the group consisting of ceramics, metals, or combinations thereof.

31. A method of forming a cutting device, comprising:

obtaining a substrate;

arranging on the substrate a plurality of individual polycrystalline cutting elements, each of the plurality of individual polycrystalline cutting elements having a substantially matching geometric configuration; and

securing each of the plurality of individual polycrystalline cutting elements to the substrate with a solidified organic material layer.

32. The method of claim 31, further comprising aligning at least one cutting tip of each of the plurality of individual polycrystalline cutting elements in a common plane.

33. The method of claim 31, wherein each of the individual polycrystalline cutting elements is a divided portion of a polycrystalline blank of material.

34. The method of claim 33, wherein the polycrystalline blank is shaped as a disk, and wherein each of the individual polycrystalline cutting elements is a divided portion of the disk.

35. The method of claim 34, wherein each of the individual polycrystalline cutting elements is an equal portion of the disk.

36. The method of claim 34, wherein each of the individual polycrystalline cutting elements is substantially wedge-shaped.

37. The method of claim 34, wherein the individual polycrystalline cutting elements are radially distributed about the substrate.

38. The method of claim 31, wherein the individual polycrystalline cutting elements are of substantially the same size and substantially the same shape.

39. The method of claim 31, wherein the individual polycrystalline cutting elements are arranged as a grid.

40. The method of claim 39, wherein the individual polycrystalline cutting elements are evenly spaced from one another at a distance of from about 100 microns to about 800 microns.

41. The cutting device of either of claim 1 or claim 11, wherein the polycrystalline cutting elements comprise superhard polycrystalline cutting elements.

42. The cutting device of claim 41, wherein the superhard polycrystalline cutting elements comprise superhard polycrystalline particles.

43. The method of claim 31, where the polycrystalline cutting elements comprise superhard polycrystalline cutting elements.

44. The method of claim 43, wherein the superhard polycrystalline cutting elements comprise superhard polycrystalline particles.

45. The method of claim 43, wherein the superhard polycrystalline cutting elements are selected from the group consisting of: polycrystalline diamond and polycrystalline cubic boron nitride.

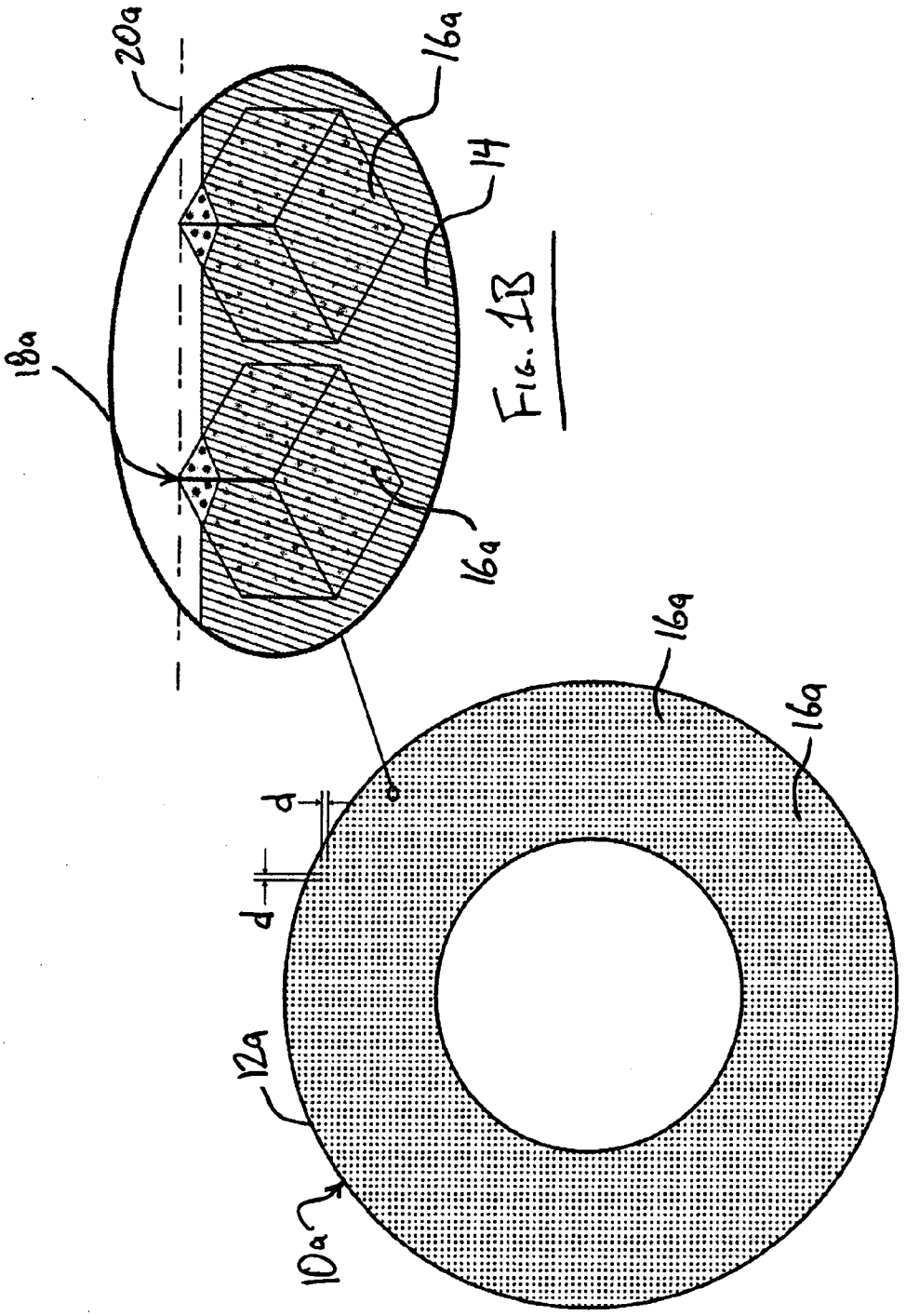


FIG. 1B

FIG. 1A

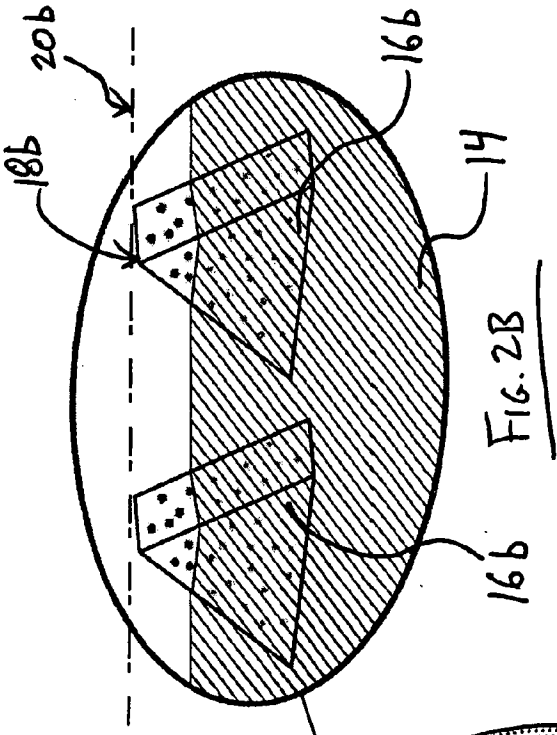


FIG. 2B

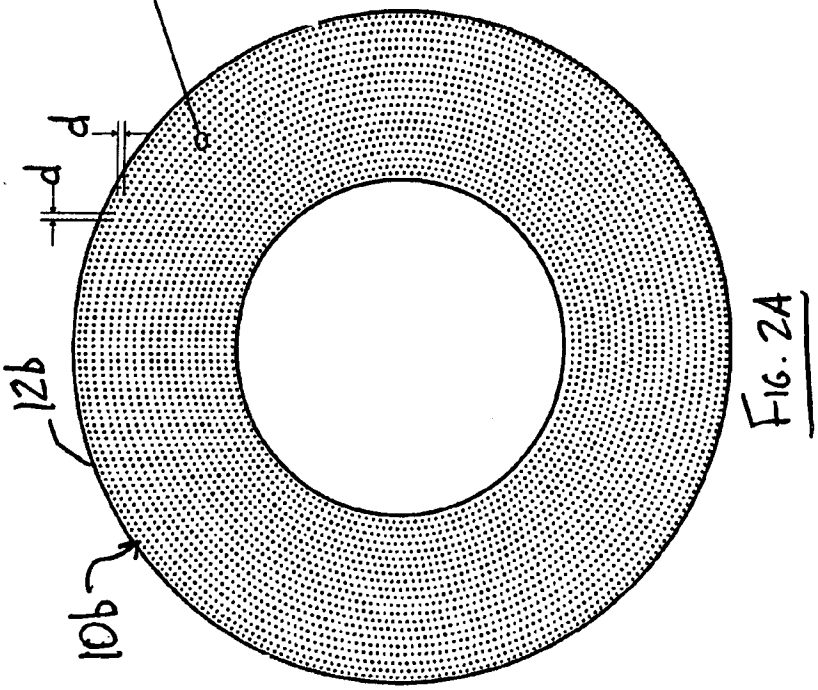


FIG. 2A

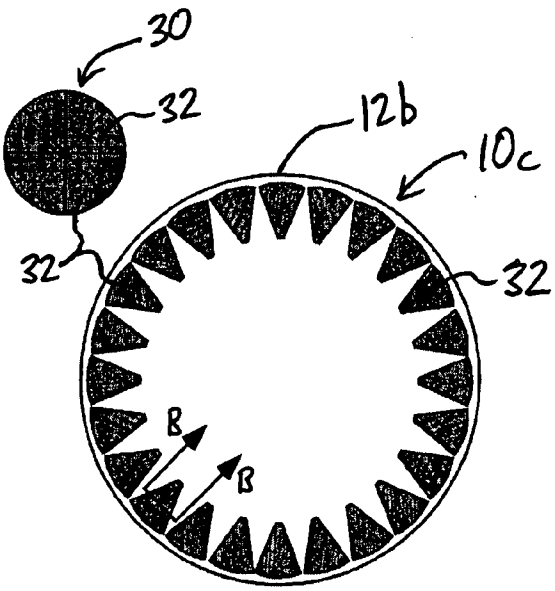


FIG. 3A

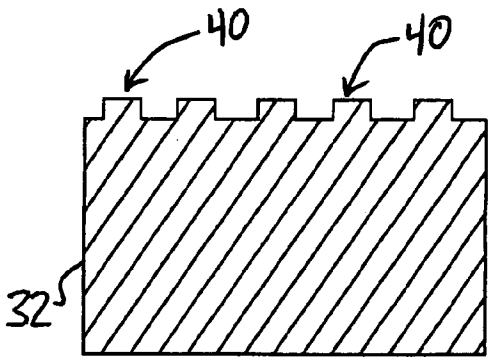


FIG. 3B

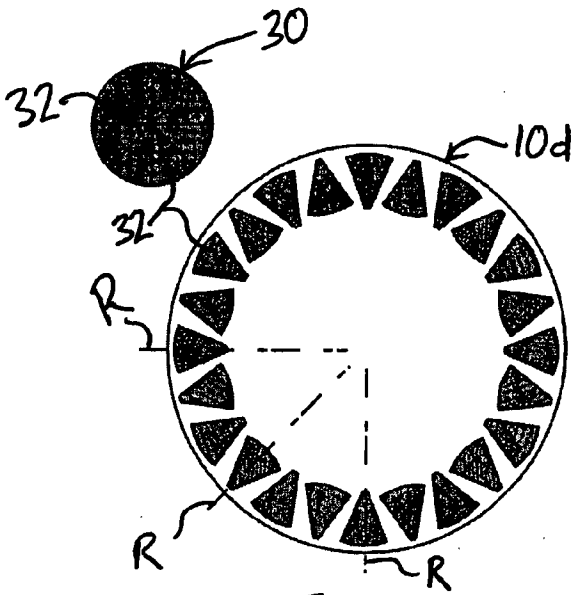


FIG. 4

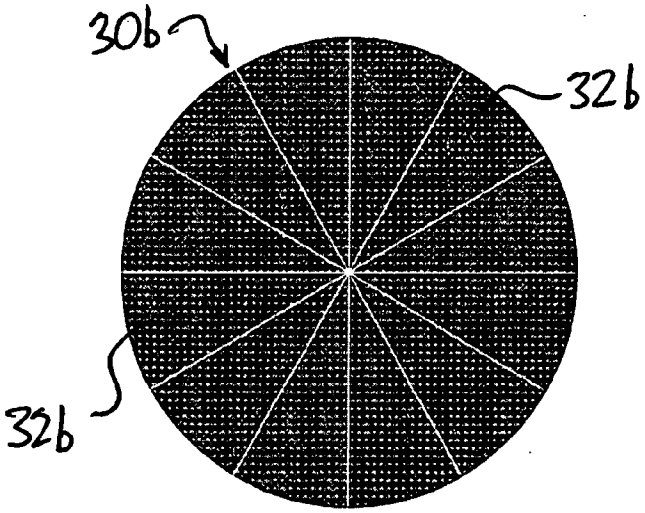


FIG. 5

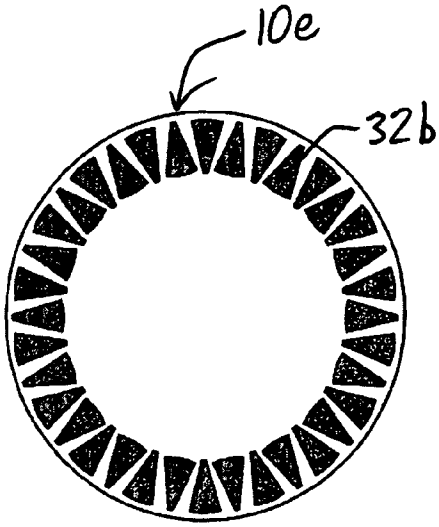


FIG. 6

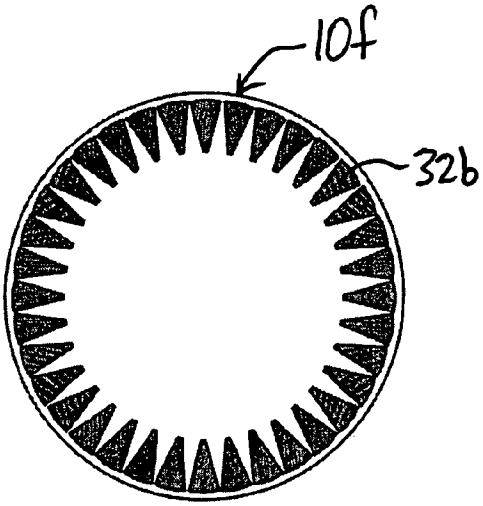


FIG. 7

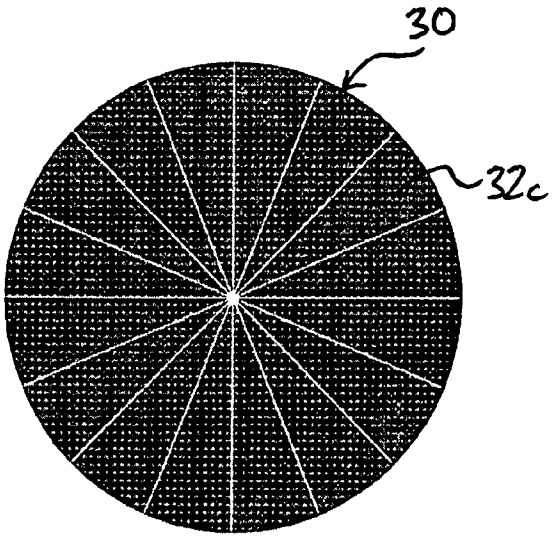


FIG. 8

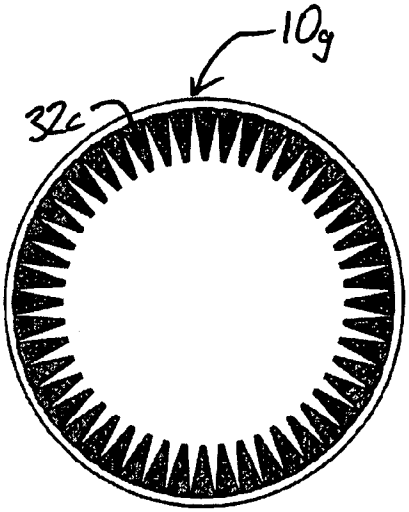


FIG. 9

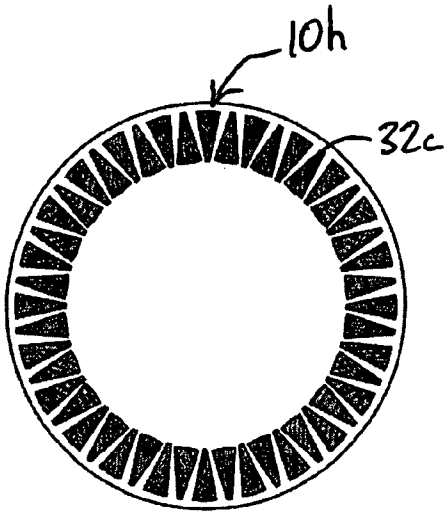


FIG. 10

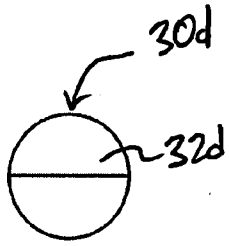


FIG. 11

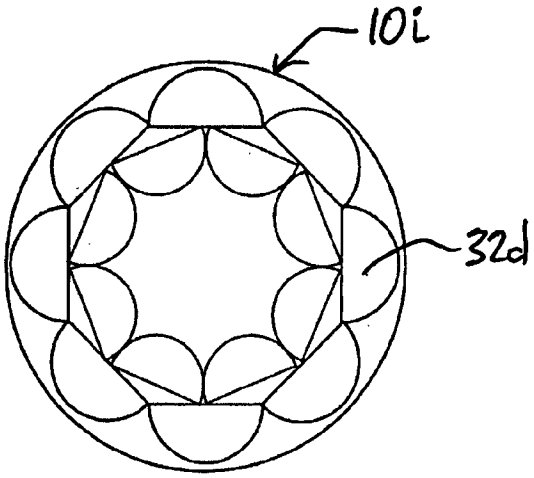


FIG. 12

WO2009064677

Publication Title:

CMP PAD DRESSERS

Abstract:

Abstract of WO 2009064677

(A2) Translate this text An abrasive tool (112) includes an assembly of tool precursors (116). At least one of the tool precursors has a continuous polycrystalline diamond, polycrystalline cubic boron nitride, or ceramic material cutting element (18) formed into a blade shape. The abrasive tool can additionally include a setting material (68), which is configured to attach the tool precursors and form a single mass. The selection, arrangement, and setting of the tool precursors can result in an abrasive tool having a predetermined cutting configuration. Methods for forming such an abrasive tool are also disclosed.

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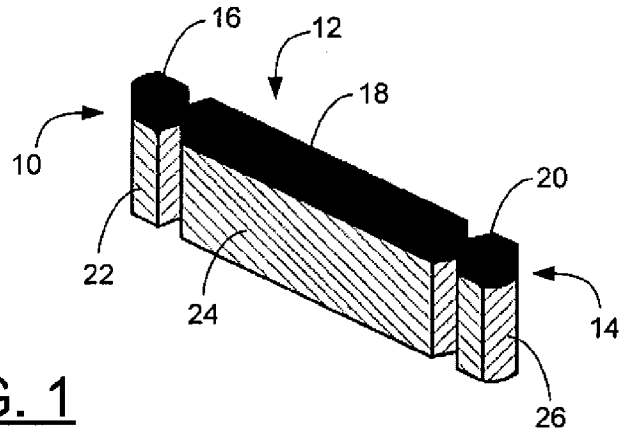


FIG. 1

(57) Abstract: An abrasive tool (112) includes an assembly of tool precursors (116). At least one of the tool precursors has a continuous polycrystalline diamond, polycrystalline cubic boron nitride, or ceramic material cutting element (18) formed into a blade shape. The abrasive tool can additionally include a setting material (68), which is configured to attach the tool precursors and form a single mass. The selection, arrangement, and setting of the tool precursors can result in an abrasive tool having a predetermined cutting configuration. Methods for forming such an abrasive tool are also disclosed.

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CMP PAD DRESSERS

PRIORITY CLAIM

This application claims the benefit of: U.S. Provisional Patent Application Serial No. 60/987,687, filed November 13, 2007; and U.S. Provisional Patent Application Serial No. 60/988,643, filed November 16, 2007, each of which is hereby incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates generally to devices and methods for use in connection with dressing or conditioning a chemical mechanical polishing (CMP) pad. Accordingly, the present invention involves the fields of chemical engineering, chemistry, metallurgy, and materials science.

BACKGROUND OF THE INVENTION

Chemical mechanical process (CMP) has become a widely used technique for polishing certain work pieces. Particularly, the computer manufacturing industry has begun to rely heavily on CMP processes for polishing wafers of ceramics, silicon, glass, quartz, metals, and mixtures thereof for use in semiconductor fabrication. Such polishing processes generally entail applying the wafer against a rotating pad made from a durable organic substance such as polyurethane. To the pad is added a chemical slurry containing a chemical solution capable of breaking down the wafer substance and an amount of abrasive particles which act to physically erode the wafer surface. The slurry is continually added to the spinning CMP pad, and the dual chemical and mechanical forces exerted on the wafer cause it to be polished in a desired manner.

To effectively work over a period of time, a CMP pad needs to be kept in good condition so that distribution of abrasive particles is optimized for each polishing. One method of reducing "glazing" or accumulation of debris on the CMP pad is dressing or conditioning the pad. Dressing refers to attempts made to revive the top of the pad by "combing" or "cutting" it with various devices. Many types of devices and processes have been used for this purpose. Some CMP pad dressers cause the CMP pads to prematurely wear out.

SUMMARY OF THE INVENTION

In accordance with one aspect of the invention, an abrasive tool can be provided and can include an assembly of tool precursors. At least one of the tool precursors can include a continuous polycrystalline diamond or polycrystalline cubic boron nitride, or other ceramic material cutting element formed into a blade shape. The abrasive tool can additionally include a setting material, which is configured to attach the tool precursors and form a single mass. The selection, arrangement, and setting of the tool precursors can result in an abrasive tool having a predetermined cutting configuration.

In accordance with another aspect of the invention, an abrasive tool can be provided and can include an assembly of tool precursors. The tool precursors can include at least one elongated substrate with a continuous polycrystalline diamond, cubic boron nitride (cBN), or other ceramic material cutting element on a surface thereof. The precursor assembly can provide a tool having a surface with a predetermined cutting configuration. The abrasive tool can further include a setting material configured to attach the tool precursors into a single mass that forms the predetermined cutting configuration.

In accordance with another aspect of the invention, a method of forming an abrasive tool can be provided, including providing a plurality of tool precursors. At least one of the tool precursors can have a continuous diamond or cubic boron nitride, or other ceramic cutting element formed in a blade shape. The method can further include securing the tool precursors together to form a tool having a working surface that includes the polycrystalline diamond, cubic boron nitride, or other ceramic material cutting element formed into a blade shape.

In accordance with another aspect of the invention, a CMP pad conditioner can be provided, including a base and a plurality of cutting elements extending from the base. The plurality of cutting elements can each have a cutting tip operable to engage material of the CMP pad. At least some of the cutting elements can have a cutting tip oriented at a different elevation relative to cutting tips of other cutting elements.

In accordance with another aspect of the invention, at least one of the cutting elements can include a cutting tip oriented at a greater elevation, relative to a base of

the pad conditioner, than does a cutting tip of an immediately adjacent cutting element.

In accordance with another aspect of the invention, the at least one cutting element abuts the immediately adjacent cutting element.

In accordance with another aspect of the invention, the cutting elements can include a cutting face oriented at 90 degrees or less relative to a surface of the CMP pad conditioned by the cutting elements.

In accordance with another aspect of the invention, the cutting elements can include a trailing edge angled to provide a relief area between the cutting elements and a surface of the CMP pad conditioned by the cutting elements.

In accordance with another aspect of the invention, the cutting elements and the base can be formed from an integral piece of material. In one embodiment, the cutting elements and the base are formed from an integral piece of a polycrystalline diamond compact.

In accordance with another aspect of the invention, the cutting elements can be coupled to the base.

In accordance with another aspect of the invention, at least two of the cutting elements are arranged such that movement of the pad conditioner and the CMP pad relative to one another results in a first, lower elevation cutting element removing material from the CMP pad, followed by a second, higher elevation cutting element removing further material from the CMP pad.

In accordance with another aspect of the invention, a method of conditioning a CMP pad is provided, including: engaging material of the CMP pad with a cutting tip of at least one cutting element; moving the cutting element and the CMP pad relative to one another to thereby remove material from the CMP pad with the cutting tip of the cutting element to create an exposed layer of CMP pad material; engaging the exposed layer of CMP pad material with the cutting tip of the cutting element, or with a cutting tip of a second cutting element; and moving the cutting element engaged with the exposed layer of CMP pad material and the CMP pad relative to one another to thereby remove the exposed layer of CMP pad material.

In accordance with another aspect of the invention, engaging the exposed layer of CMP pad material comprises engaging the exposed layer with the cutting tip of the cutting element used to create the exposed layer.

In one embodiment, engaging the exposed layer of CMP pad material comprises engaging the exposed layer with the cutting tip of the second cutting element.

In accordance with another aspect of the invention, the cutting element and the second cutting element extend from a common base.

In accordance with another aspect of the invention, a method of conditioning a CMP pad is provided, including: removing, with a cutting element, a thin layer of material from the CMP pad; and removing, with the same or a different cutting element, a second layer of material from the CMP, the second layer of material being revealed by removal of the thin layer of material.

There has thus been outlined, rather broadly, various features of the invention so that the detailed description thereof that follows may be better understood, and so that the present contribution to the art may be better appreciated. Other features of the present invention will become clearer from the following detailed description of the invention, taken with the accompanying claims, or may be learned by the practice of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side perspective view of a plurality of tool precursors, in accordance with an embodiment of the present invention;

FIG. 2 is a side perspective view of a tool precursor having a PCD or cBN, or ceramic layer in a blade formation, in accordance with an embodiment of the present invention;

FIG. 3 is a side perspective view of a tool precursor having a PCD or cBN, or ceramic layer formed in a plurality of asperities, in accordance with an embodiment of the present invention;

FIG. 4 is a side perspective view of an assembly of tool precursors, in accordance with an embodiment of the present invention;

FIG. 5 is a side perspective view of an assembly of tool precursors, in accordance with an embodiment of the present invention;

FIG. 6 is a side perspective view of an assembly of tool precursors, in accordance with an embodiment of the present invention;

FIG. 7 is a side perspective view of an assembly of tool precursors, in accordance with an embodiment of the present invention;

FIG. 8 is a side view of a tool precursors leveled and set in an epoxy, thus forming an abrasive tool, in accordance with an embodiment of the present invention;

FIG. 9 is a top view of an abrasive tool having tool precursors arranged in a spoke formation, in accordance with an embodiment of the present invention;

FIG. 10 is a perspective view of a mass from which tool precursors can optionally be formed, in accordance with an embodiment of the present invention;

FIG. 11 is a perspective view of a mass from which tool precursors can optionally be formed, in accordance with an embodiment of the present invention;

FIG. 12 is a side view of a mass, similar to FIG. 11, from which tool precursors can optionally be formed, in accordance with an embodiment of the present invention;

FIG. 13 is a side perspective view of a tool precursor having a PCD or CBN or ceramic layer in a blade formation, in accordance with an embodiment of the present invention;

FIG. 14 is a side perspective view of an assembly of tool precursors, in accordance with an embodiment of the present invention;

FIG. 15 is a side cross-sectional view of an abrasive tool, in accordance with an embodiment of the present invention;

FIG. 16 is a side view of a pad conditioner engaging a CMP pad in accordance with an embodiment of the invention;

FIG. 17 is a side view of another pad conditioner engaging a CMP pad in accordance with an embodiment of the invention;

FIG. 18 is a side view of another pad conditioner engaging a CMP pad in accordance with an embodiment of the invention;

FIG. 19 is a partial view of a pad being conditioned in accordance with another embodiment of the invention;

FIG. 20 is a top view of an exemplary pad conditioner illustrating one possible arrangement of cutting elements across the face of the pad conditioner;

FIG. 21 is a top view of another exemplary pad conditioner illustrating one possible arrangement of cutting elements across the face of the pad conditioner;

FIG. 22 is a top view of another exemplary pad conditioner illustrating one possible arrangement of cutting elements across the face of the pad conditioner;

FIG. 23 is a top view of another exemplary pad conditioner illustrating one possible arrangement of cutting elements across the face of the pad conditioner;

FIG. 24 illustrates the performance of various cutting teeth (varied in both shape and spacing) of the present invention; and

FIG. 25 illustrates a comparison of a pad dresser in accordance with the present invention as compared to conventional technology.

It will be understood that the above figures are merely for illustrative purposes in furthering an understanding of the invention. Further, the figures are not drawn to scale, thus dimensions and other aspects may, and generally are, exaggerated or changed to make illustrations thereof clearer. Therefore, departure can be made from the specific dimensions and aspects shown in the figures in order to produce abrasive tools or tool precursors of the present invention.

DETAILED DESCRIPTION

Before the present invention is disclosed and described, it is to be understood that this invention is not limited to the particular structures, process steps, or materials disclosed herein, but is extended to equivalents thereof as would be recognized by those ordinarily skilled in the relevant arts. It should also be understood that terminology employed herein is used for the purpose of describing particular embodiments only and is not intended to be limiting.

It must be noted that, as used in this specification and the appended claims, the singular forms "a," "an" and, "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "a CMP pad dresser" includes one or more of such dressers, reference to "an operating parameter" includes reference to one or

more of such operating parameters, and reference to "the asperity" includes reference to one or more of such asperities.

Definitions

In describing and claiming the present invention, the following terminology will be used in accordance with the definitions set forth below.

As used herein, the term "substantially" refers to the complete or nearly complete extent or degree of an action, characteristic, property, state, structure, item, or result. For example, an object that is "substantially" translucent would mean that the object is either completely translucent or nearly completely translucent. The exact allowable degree of deviation from absolute completeness may in some cases depend on the specific context. However, generally speaking the nearness of completion will be so as to have the same overall result as if absolute and total completion were obtained. The use of "substantially" is equally applicable when used in a negative connotation to refer to the complete or near complete lack of an action, characteristic, property, state, structure, item, or result. In other words, a composition that is "substantially free of" an ingredient or element may still actually contain such item as long as there is no measurable effect thereof.

The terms "dressing" and "conditioning" are interchangeable and refer to the process of rejuvenating a CMP pad by removing debris from the pad, as well as optionally lifting matted fibers and creating new grooves. Likewise, the terms "dresser" and "conditioner" are used interchangeably and indicate the apparatus used for dressing or conditioning.

As used herein, "substrate" means a material which supports or can support a PCD or cBN, or ceramic layer, and to which a PCD or cBN, or ceramic layer may be affixed. Substrates useful in the present invention may be any shape, thickness, or material, that is capable of supporting abrasive particles in a manner that is sufficient provide a tool useful for its intended purpose. Substrates may be of a solid material, a powdered material that becomes solid when processed, or a flexible material. Examples of typical substrate materials include without limitation, metals, metal alloys, ceramics, solidified resins and polymeric materials and mixtures thereof.

As used herein, the terms "base" or "substrate" can be used to refer to a

portion of a pad conditioner that supports abrasive materials, and to which abrasive materials may be affixed, or may extend from. Substrates useful in the present invention may be any shape, thickness, or material, that is capable of supporting abrasive materials in a manner that is sufficient provide a pad conditioner useful for its intended purpose. Substrates may be of a solid material, a powdered material that becomes solid when processed, or a flexible material. Examples of typical substrate materials include without limitation, metals, metal alloys, ceramics, relatively hard polymers or other organic materials, glasses, and mixtures thereof. Further the substrate may include material that aids in attaching abrasive materials to the substrate, including, without limitation, brazing alloy material, sintering aids and the like. The substrate and the abrasive cutting elements can, in some embodiments, be formed from the same material and can be formed from an integral, single piece of material.

As used herein, "leading edge" means the edge of a CMP pad dresser that is a frontal edge based on the direction that the CMP pad is moving, or the direction that the pad is moving, or both. Notably, in some aspects, the leading edge may be considered to encompass not only the area specifically at the edge of a dresser, but may also include portions of the dresser which extend slightly inward from the actual edge. In one aspect, the leading edge may be located along an outer edge of the CMP pad dresser. In another aspect, the CMP pad dresser may be configured with a pattern of abrasive particles that provides at least one effective leading edge on a central or inner portion of the CMP pad dresser working surface. In other words, a central or inner portion of the dresser may be configured to provide a functional effect similar to that of a leading edge on the outer edge of the dresser.

As used herein, the process of "brazing" is intended to refer to the creation of chemical bonds between the atoms of the non-metallic, such as diamond, CBN, or ceramic materials and the braze material. Further, "chemical bond" means a covalent bond, such as a carbide, nitride, or boride bond, rather than mechanical or weaker inter-atom attractive forces. Thus, when "brazing" is used in connection with superabrasive particles a true chemical bond is being formed. However, when "brazing" is used in connection with metal to metal bonding the term is used in the

more traditional sense of a metallurgical bond. Therefore, brazing of a superabrasive segment to a tool body does not require the presence of a carbide, nitride, or boride former.

As used herein, "ceramic" refers to a hard, often crystalline, substantially heat and corrosion resistant material which may be made by firing a non-metallic material, sometimes with a metallic material. A number of oxide, nitride, and carbide materials considered to be ceramic are well known in the art, including without limitation, aluminum oxides, silicon oxides, boron nitrides, silicon nitrides, and silicon carbides, tungsten carbides, etc.

As used herein, "metallic" means any type of metal, metal alloy, or mixture thereof, and specifically includes but is not limited to steel, iron, and stainless steel.

As used herein, "abrasive profile" is to be understood to refer to a shape or a space defined by abrasive materials that can be used to remove material from a CMP pad. Examples of abrasive profiles include, without limitation, rectangular shapes, tapering rectangular shapes, truncated wedge shapes, wedge shapes, and the like. In some embodiments, the abrasive profile exhibited by abrasive segments of the present invention will apparent when viewed through a plane in which the CMP pad will be oriented during removal of material from the CMP pad.

As used herein, "superhard" may be used to refer to any crystalline, or polycrystalline material, or mixture of such materials which has a Mohr's hardness of about 8 or greater. In some aspects, the Mohr's hardness may be about 9.5 or greater. Such materials include but are not limited to diamond, polycrystalline diamond (PCD), cubic boron nitride (cBN), polycrystalline cubic boron nitride (PcBN), corundum and sapphire, as well as other superhard materials known to those skilled in the art. Superhard materials may be incorporated into the present invention in a variety of forms including particles, grits, films, layers, pieces, segments, etc. In some cases, the superhard materials of the present invention are in the form of polycrystalline superhard materials, such as PCD and PcBN materials.

As used herein, "organic material" refers to a semisolid or solid complex amorphous mix of organic compounds. As such, "organic material layer" and "organic material matrix" may be used interchangeably, refer to a layer or mass of a

semisolid or solid complex amorphous mix of organic compounds. Preferably the organic material will be a polymer or copolymer formed from the polymerization of one or more monomers.

As used herein, "particle" and "grit" may be used interchangeably.

As used herein, the term "abrasive" can be used to describe a variety of structures capable of removing (e.g., cutting, polishing, scraping) material from a CMP pad. An abrasive can include a mass having several cutting points, ridges or mesas formed thereon or therein. It is notable that such cutting points, ridges or mesas may be from a multiplicity of protrusions or asperities included in the mass. Furthermore, an abrasive can include a plurality of individual abrasive particles that may have only one cutting point, ridge or mesa formed thereon or therein. An abrasive can also include composite masses, such as PCD pieces, segment or blanks, either individually comprising the abrasive layer or collectively comprising the abrasive layer.

As used herein, the term "cutting tip" is generally used to refer to a portion of a cutting element that engages and removes material from a workpiece (generally a CMP pad). "Cutting tips" can include points, edges, surfaces, etc., that are capable of cutting material from a CMP pad. The terms "cutting tip," "edge," "blade," etc., can be, but are not always, used interchangeably.

As used herein, a plurality of components may be presented in a common list for convenience. However, these lists should be construed as though each member of the list is individually identified as a separate and unique member. Thus, no individual member of such list should be construed as a *de facto* equivalent of any other member of the same list solely based on their presentation in a common group without indications to the contrary.

Concentrations, amounts, particle sizes, volumes, and other numerical data may be expressed or presented herein in a range format. It is to be understood that such a range format is used merely for convenience and brevity and thus should be interpreted flexibly to include not only the numerical values explicitly recited as the limits of the range, but also to include all the individual numerical values or sub-

ranges encompassed within that range as if each numerical value and sub-range is explicitly recited.

As an illustration, a numerical range of "about 1 to about 5" should be interpreted to include not only the explicitly recited values of about 1 to about 5, but also include individual values and sub-ranges within the indicated range. Thus, included in this numerical range are individual values such as 2, 3, and 4 and sub-ranges such as from 1-3, from 2-4, and from 3-5, etc. This same principle applies to ranges reciting only one numerical value. Furthermore, such an interpretation should apply regardless of the breadth of the range or the characteristics being described.

The Invention

It has been found that the overall CMP process can be improved through dressing or conditioning with a CMP pad dresser that effectively dresses the CMP pad, so as to optimally allow for extended CMP pad life, while reducing glazing and other negative effects on the CMP pad. Such improvements can occur as a result of precisely-machined CMP pad dressers. By utilizing dressers as disclosed herein, CMP pads can be refreshed, without losing CMP pad life as with the use of typical CMP pad dressers. Furthermore, the methods disclosed herein for creating such dressers provide a relative fast and economical way to create such precise tools. Additionally, the method provides for the creation of a CMP pad dresser that has a predetermined working surface.

In accordance with embodiments presented herein, various details are provided which are applicable to each of the CMP pad dressers and method for creating or forming the CMP pad dressers. Thus, discussion of one specific embodiment is related to and provides support for this discussion in the context of the other related embodiments.

An abrasive tool can include an assembly of tool precursors. Tool precursors can be of a variety of shapes and sizes. FIGs 1-3 illustrate a plurality of tool precursors. FIG. 1 illustrates three tool precursors 10, 12, 14. Each of the illustrated precursors includes a polycrystalline diamond (PCD), cubic boron nitride (PcBN), or ceramic layer 16, 18, 20, on one surface of a substrate 22, 24, 26, of the tool precursor. In each embodiment, the layer could alternatively comprise or consist essentially of

either PCD or PcBN. Additionally, the layer may comprise or consist of diamond in other forms, including CVD deposited diamond and also various ceramic materials. In one embodiment (not shown), the layer may be a ceramic or PcBN layer which is overlayed with an outer layer of CVD diamond. The layers illustrated are substantially uniform in thickness across the full area of the surface of the substrate. Tool precursor 12 illustrates an elongated tool precursor having a continuous polycrystalline diamond or polycrystalline cubic boron nitride cutting element formed thereon. In one embodiment, the tool precursor 12 of FIG. 1 can be further machined to form a blade shape as illustrated in FIG. 2. As shown, the tool precursor 30 includes an elongated substrate 32 and a continuous polycrystalline diamond or cubic boron nitride cutting element 34 on a surface of the substrate. The cutting element is formed into of a blade shape, having a single tip 36 of the cutting element substantially along the length the elongated tool precursor.

It should be understood that while much discussion is directed to PCD, diamond, PcBN, and/or cubic boron nitride cutting elements, other materials can be used as the cutting element, either alone or in combination with other materials, and are to be included in the scope of the disclosure herein. For example, the cutting element can comprise or consist essentially of ceramics, or other diamond or cBN films, including those deposited via chemical vapor deposition (CVD). Non-limiting examples of ceramics that can be used as a cutting element include alumina, aluminum carbide, silica, silicon carbide, silicon nitride, zirconia, zirconium carbide, and mixtures thereof. Cutting elements can be, in one embodiment, sintered masses, partially sintered masses, and/or layers of material attached to the substrate of the tool precursor according to any method known in the art. The cutting element can, in one aspect, include a mixture, homogeneous or otherwise, of a plurality of materials, optionally including abrasive particles. In another aspect, the cutting element can include a plurality of layers of material. As a non-limiting example, the cutting element can include a ceramic overcoated with CVD diamond.

In one aspect, the tool precursor of FIG. 2 can be further machined to form a plurality of asperities as illustrated in FIG. 3. As shown, the tool precursor 40 has an elongated substrate 42 with a continuous polycrystalline diamond or cubic boron

nitride cutting element 44 on one surface of the substrate. The diamond or cubic boron nitride cutting element is formed into a plurality of asperities 46 having a single tip or point. As shown, the asperities are of a pyramidal shape. Although pyramidal shape is illustrated as the asperity shape, any shape having a tip that can form an asperity is to be explicitly included herein. Regarding pyramidal shapes, the pyramidal shaped asperities can include irregular and regularly shaped pyramids. Such asperities can include any three-dimensional shape having triangular non-base surfaces that converge on one point. The base shape is typically quadrilateral or trilateral, but can be any polygon shape. In the case of FIG. 3, pyramid shaped asperities having a triangular base are shown and such pyramids have a substantially flat vertical side as will be explained in more detail. Alternatively, pyramids with a cubic base could be used. One of the faces of the pyramidal asperities of FIG. 3 is substantially perpendicular to the plane of the substrate surface. In such case, it is possible to pair two similar tool precursors in a back-to-front manner so as to form a pyramid shape having a larger base, i.e. each tool precursor would provide approximately one half of the asperity. In the case of arranging the tool precursors of FIG. 3 in a back-to-front manner, the pyramids formed by aligning two of the tool precursors together to form a single line of pyramidal asperities have a quadrilateral base shape, with half of each base being provided by a single tool precursor. In one embodiment, tool precursors of the present invention can be prepared by forming a PCD or PcBN blank with a PCD or PcBN layer attached to a substrate as shown in FIG. 10, and an elongated segment can be removed as shown. Next, an electro discharge machining (EDM) wire can be used to form the tool precursors by shaping the PCD or PcBN layer of each segment. The precursors can then be assembled into a finished tool.

In one aspect, a substrate having a continuous PCD or PcBN layer can be formed into a blade shape, either through EDM wire or other grinding or material removal method. Such blade shape is illustrated in FIG. 2. With the blade shape formed, asperities can be formed through use of EDM wire, or other precise material removal method. In forming asperities from a blade shape, the asperities can be formed immediately adjacent to each other, or can be spaced. The angles of each

asperity can be uniform or non-uniform. The EDM wire and other tools are easily used to sculpt the PCD or PcBN of the segments because of the fact that the individual segments present a two dimensional area to be carved rather than a three dimensional area that would have portions not easily accessible by the wire.

As noted, the abrasive tool is an assembly of tool precursors. The assembly can include any number of tool precursors, and can include tool precursors of varying design. Alternatively, the assembly can include a plurality of tool precursors having substantially the same shape and cutting elements. The assembly can be arranged so as to have a pattern of cutting element design. In one embodiment, an alternating design may be desirable. Furthermore, assembly of the tool precursors can include varying the height dimension, or the difference of asperity or blade projection in relation to adjacent tool precursors to effectuate a particular predetermined cutting configuration.

Non-limiting examples of arrangement of tool precursors includes alternating, as illustrated in FIG. 4, with alternating asperities 50 and blades 52 tool precursors; leading as in FIG. 5, with a blade 54 on one end and a plurality of asperity tool 56 precursors attached thereto; a following pattern as in FIG. 6, with a plurality of asperities aligned such that each tip is substantially in line with the asperities of the adjacent tool precursors; and offset patterns as in FIG. 7 with a plurality of tool precursors having asperities, where the asperities are aligned so as to not be in line with the asperities of the adjacent tool precursors. It should be noted that the illustrations are non-limiting arrangements of the tool precursors. Those illustrated could be combined in various ways. Additionally, blanks could be used in a variety of ways with patterns and predetermined placement so as to create a predetermined cutting configuration. Blanks can include simple substrate without PCD, or could include a layer of PCD or PcBN, continuous or discontinuous, as an unformed layer or coating. Furthermore, the arrangements illustrated do not account for the variety obtained from orienting one or more tool precursor in a reverse direction, such as the back-to-front orientation with the pyramidal shaped asperities. Such orientation of the tool precursors greatly increases the possibilities available for creating a cutting configuration. It should also be noted that the assemblies of tool precursors illustrated

in FIGs 4-7 can, along with a setting material, constitute the abrasive tool, or they may alternatively be a portion of an assembly of tool precursors in an abrasive tool.

Substrates used in the abrasive tool can be of a variety of compositions and shapes. In one aspect, the substrate can comprise or consist essentially of metals, metallics, ceramics, organics, and combinations thereof. Furthermore, the substrate can be directly in contact with the PCD or PcBN layer, or may include a layer, continuous or discontinuous, along the interface of the PCD or PcBN and substrate.

Forming an abrasive tool includes providing a plurality of tool precursors and securing the tool precursors together, into a tool having a working surface. The working surface can include a polycrystalline diamond or polycrystalline cubic boron nitride cutting element thereon. Securing the tool precursors together can include a variety of steps. In one aspect, a setting material can be used to form the consolidated tool. Non-limiting examples of steps used to secure the assembly of tool precursors include brazing, soldering, sintering, cementing, and combinations thereof. As such, setting materials can include braze material, soldering material, sintering agents, cementing material, organic materials including polymeric materials and resins, and combinations thereof. Furthermore, a setting material can include an adhesive.

Any process and any related material or materials can be used to set the tool precursors into a single mass. Such materials can be distributed or used between some or each of the tool precursors, or can be used to encompass that thereby set the tool precursors. One non-limiting example of a process that can be used to secure abrasive tool precursors can include securing the abrasive precursors with an organic material. The abrasive precursors can be arranged as desired against a steel or other plate, with the asperity, blade, or other tips arranged as desired. In the illustrated case of FIG. 8, the tips 60 of the asperities of the tool precursors 62 are arranged against a plate 64 so as to be level. The tips can be covered with an adhesive or other covering 66, and then an epoxy 68 can be placed over the arranged tool precursors. In one aspect, the epoxy can be reinforced with glass fibers, color-coded with pigments, reinforced with backing, or any combination thereof. Once the epoxy is cured, the tool precursors are arranged and set in a manner so as to provide a desired cutting surface. It should be noted that arranging the asperities and other tips in a level

manner is illustrated by the example, however such arrangement is only one embodiment of the present method and tool. It can be beneficial to deliberately arrange the tips tool precursors so as to provide for a vertical pattern, such that the asperity and other tips or points protrude different amounts from the working surface.

Various reverse casting methods may be utilized to set the tool precursors into a single mass. For example, a spacer layer of a material sufficiently soft so as to allow penetration of at least a tip portion of the precursors thereinto, may be applied to a working surface of a temporary substrate. The tool precursors can be arranged so that at least a portion of the cutting element of each precursor is at least partially embedded in the spacer layer and comes in contact with, or nearly in contact with, the temporary substrate. In one aspect, the tool precursors can be pressed by any mechanism or means such that the tips of asperities and/or blades come into contact with the temporary substrate. In this manner, the temporary substrate can define the final leveling contour of the assembled mass. As such, the temporary substrate can include any contour, levelness, slope, stepped, etc., according to the desired contours of the assembled mass. In an alternative aspect, the spacer layer may be optional. In yet another aspect, the spacer may be an adhesive or other organic resin.

An adhesive may be optionally applied to the temporary substrate and/or the spacer layer and/or the cutting elements to facilitate proper arrangement and temporary attachment. The adhesive used on any noted surface may be any adhesive known to one skilled in the art, such as, without limitation, a polyvinyl alcohol (PVA), a polyvinyl butyral (PVB), a polyethylene glycol (PEG), a pariffin, a phenolic resin, a wax emulsion, an acrylic resin, or combinations thereof. In one aspect, the fixative is a sprayed acrylic glue.

The spacer layer may be made from any soft, deformable material with a relatively uniform thickness, and may be selected according to particular needs of manufacturing, future use, compositional considerations of tool precursors, etc. Examples of useful materials include, but are not limited to, rubbers, plastics, waxes, graphites, clays, tapes, grafoils, metals, powders, and combinations thereof. In one aspect, the spacer layer may be a rolled sheet comprising a metal or other powder and

a binder. For example, the metal may be a stainless steel powder and a polyethylene glycol binder. Various binders can be utilized, which are well known to those skilled in the art, such as, but not limited to, a polyvinyl alcohol (PVA), a polyvinyl butyral (PVB), a polyethylene glycol (PEG), a pariffin, a phenolic resin, a wax emulsions, an acrylic resin, and combinations thereof.

An at least partially uncured resin material can be applied to the spacer layer opposite of the temporary substrate. A mold, e.g. of stainless steel or otherwise, may be utilized to contain the uncured resin material during manufacture. Upon curing the resin material, a resin layer is formed, cementing at least a portion of tool precursor. Optionally, a permanent tool substrate may be coupled to the resin layer to facilitate its use in dressing a CMP pad or in other uses. In one aspect, the permanent substrate may be coupled to the resin layer by means of an appropriate adhesive. The coupling may be facilitated by roughing the contact surfaces between the permanent substrate and the resin layer. In another aspect, the permanent substrate may be associated with the resin material, and thus become coupled to the resin layer as a result of curing.

The mold and the temporary substrate can subsequently be removed from the CMP pad dresser once the resin is cured. Additionally, the spacer layer can be removed from the resin layer. This may be accomplished by any mechanism known in the art including peeling, grinding, sandblasting, scraping, rubbing, abrasion, etc. Therefore, the protrusion of the tool precursors from the resin is dependent on the amount covered or concealed by the spacer layer. Additionally, the arrangement of the tool precursors is relatively fixed by the resin. As such, the tool precursors can be placed in a variety of configurations, thus creating a variety of configurations of a surface of an assembled tool.

Furthermore, the tool precursors can be set in a parallel formation, such as illustrated in FIGs 4-7, or can be placed in any arrangement that forms a desired cutting configuration. In one aspect, the tool precursors can be arranged in a spoke formation as illustrated in FIG. 9, wherein the tool precursors 70 are arranged as spokes of a wheel of the illustrated circular abrasive tool.

Tool precursors can be arranged at various angles to form abrasive tools. Blades can be angled to better interact with the various materials they contact. For

example, it may be found that angling a blade shaped tool precursor at a specific angle, or angling a plurality of blade shaped tool precursors at differing angles, can better handle material removal from a CMP pad.

In one embodiment, the tool precursors can be formed from a single mass. For example, a substrate, such as tungsten carbide, can be formed into a desired overall tool shape. Such formation of the overall tool is not required. In FIG. 10, however, a single substrate 72 is formed into a truncated cylindrical shape. One of the circular surfaces can be covered with a PCD or PcBN layer 74. A continuous layer is illustrated in the figure; however, a discontinuous layer could likewise be used. With the PCD or PcBN layer on the substrate, the individual tool precursors can be cut from the overall piece shown in FIG. 10. Once cut from the larger body, they can be of the form illustrated in FIG. 1, or any other shape cut from the larger body. Once cut, they can be further shaped, if desired. Once the tool precursors are formed, they can be optionally returned to the larger body, wherein each piece includes an inverse-image of neighboring surfaces as from being cut from the same original mass. Thus would form an abrasive tool having a substantially continuous PCD or PcBN layer, supposing the original mass included a substantially continuous PCD or PcBN layer. Optionally, only portions of the original mass can be reformed into the abrasive tool. In such case, the working surface of the abrasive tool may or may not include a substantially continuous PCD or PcBN layer, depending on the tool precursors selected to form the abrasive tool.

In another embodiment, another overall piece, such as that shown in FIG. 10, can be cut at a different angle, as illustrated in FIG. 11. As with FIG. 10, FIG. 11 depicts a single substrate 72 formed into a truncated cylindrical shape, with one of the circular surfaces covered with a PCD or PcBN layer 74. In this case, however, the overall piece is cut at a plane between perpendicular and parallel to the surface of the PCD or PcBN layer. A view of the side of the overall piece, including an additional cutting line and illustrating the cutting angle of FIG. 11 is illustrated in FIG. 12. Cutting or dividing the overall piece at an angle can produce a tool precursor as shown in FIG. 13, having an elongated substrate 78 and a continuous polycrystalline diamond or continuous polycrystalline cubic boron nitride, or other ceramic material cutting

element 80 on a surface of the substrate. The cutting element is formed into a blade shape, having a single tip of the cutting element substantially along the length the elongated tool precursor, as a result of cutting the tool precursor from the overall piece. To compare, the tool precursor of FIG. 13 is similar to the tool precursor of FIG. 2, where the FIG. 2 tool precursor has been cut and undergone a shaping step to produce the blade formation. One notable difference between the two tool precursors is the flat base of the elongated substrate in FIG. 2 versus the angled base of the elongated substrate of FIG. 13.

The cutting element of the abrasive tool precursors of FIG. 13 can be further shaped as with the other tool precursors disclosed herein. In a specific embodiment, a plurality of asperities can optionally be formed of the blade shape of the cutting element. Furthermore, the cutting elements having the angled base can be assembled as with other tool precursors disclosed herein. One non-limiting example is illustrated in FIG. 14, wherein abrasive precursors having a blade shaped cutting element and those having pyramidal asperities are alternated. It should be noted that blanks, i.e. substrates having no cutting element, other spacers, and other configurations of tool precursors in patterned or random arrangement are contemplated by the present disclosure. Furthermore, the tool precursors having angled bases and those having flat bases can be used in combination to form abrasive tools.

As with previously-disclosed tool precursors, the tool precursors having a angled bases can be included in an abrasive tool. Such tool precursors can be included along with other tool precursors, or the abrasive tool can be composed of tool precursors only having the angled bases. An example abrasive tool is shown as FIG. 15, wherein the substrates 82 and cutting element 74, in this embodiment, each shaped with a plurality of asperities, are held together with an epoxy 86. Such tool can be manufactured according to the methods disclosed herein, particularly with respect to the discussion around FIG. 8, and the resulting tool differs from previous embodiments primarily in that the base of the tool precursors is angled and thus creates a zig-zag design along the epoxy interface 88.

FIGs. 21-23 illustrate various other manners in which the tool precursors or cutting elements 70 can be arranged on the abrasive tool or pad dresser 112 to

maximize particular abrading functions while minimizing possible damage to the pad or workpiece being abraded. In these embodiments, the precursors or cutting elements are arranged such that the pad dresser or abrasive tool can "sweep" across the pad and completely, or nearly completely, dress the pad without internal features of cutting elements catching or "snagging" the pad to cause unwanted asperities.

As will appreciated, a periphery of any particular cutting element (or precursor) "knot" or assemblage is closed, such that the precursor assemblage can approach a portion of a pad (or the pad can approach the precursor assemblage) from any angle without having internal angles formed by the precursors "snag" on the pad material. Also, using this technique, more of the cutting tips can be faced outwardly (from any particular assemblage of cutting elements or precursors) in the direction of pad movement. The inner side can contain fewer cutting tips for less work (and less wear). In essence, one precursor (or cutting element) assemblage is defined in the embodiments of FIGs. 21 and 22 (each assemblage formed from a plurality of the precursors 70), whereas a plurality of knots or assemblages 71 are illustrated in FIG. 23, each formed from 3 precursors 70.

Turning now to FIGs. 16-20, in accordance with another aspect of the invention, various cutting devices and associated methods are provided that can be used to remove material from a CMP pad 118 in a manner that creates a smooth and even surface on the CMP pad. In accordance with one embodiment, the invention provides a CMP pad conditioner (shown by arbitrary example 112 in FIG. 20) that can include a base (e.g., 114 in FIG. 20) and a plurality of cutting elements 116 extending from the base. The cutting elements 116 shown in FIG. 20 are shown in one exemplary orientation showing one manner of spacing, placement, relative size, etc., of the cutting elements. Other embodiments can include a variety of differing sizes of cutting elements or blades, different physical layouts (e.g., spacing, angular arrangement, etc.), lengths of cutting elements or blades, etc., are also encompassed by the present invention.

As shown in FIG. 16, the cutting elements 116a, 116b, etc., can each have a cutting tip 120a, 120b, etc., that is operable to engage material of the CMP pad 118. At least some of the cutting elements can have a cutting tip oriented at a different