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Dressing Behaviors of PCD Conditioners on CMP Polishing Pads

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Abstract. Diamond pad conditioner or dresser can determine the efficiency of chemical mechanical polishing (CMP) processes and the quality of polished wafers. Conventional diamond pad conditioners are made by adhering discrete diamond grits on a flat substrate. The size distribution of diamond grits coupled with the deformation of the substrate often make the tips of diamond grits lying at different heights. Instead of attaching individual diamond grits to a metal substrate, a revolutionary design of pad conditioners is based on carving a structure out of sintered polycrystalline diamond (PCD) matrix. The PCD dresser is manufactured by wire electro discharge machining to form cutting pyramids of a specific size with a designed shape. The dressing characteristics of pad surface textures are studied by comparison with conventional diamond pad conditioner. Experimental results indicate that the PCD dresser can dress asperities of the pad more uniformly than the conventional diamond dresser due to PCD dresser having identically shaped tip and the same height diamond. In addition the cutting rate of PCD dresser for IC1000 pad not only is reduced by about 30% but also it can dress pad more effectively than conventional diamond dresser.

Introduction

Chemical mechanical polishing (CMP), a surface planarization process, is essential as the line width continues to shrink and circuit geometries get tighter in ULSI technology. [1-3]. A typical orbital type CMP system is divided into two main parts. The first is polishing action that takes place between a semiconductor wafer and a polishing pad. During the CMP process, the silicon wafer is held on the carrier with face pressed against the polishing pad, which is attached to a rotating polishing platen. Both the wafer carrier and the platen are rotating, either in the same or in the opposite direction, to generate relative motion between the wafer and the pad. At the same time slurry, which contains abrasive particles in chemical solution, is supplied to form a liquid film between the wafer and the pad. The slurry chemically attacks the wafer surface thus weakens or breaks molecular bonds on the wafer surface so that wafer molecules can be mechanically removed by abrasives in the polishing process. The second is dressing action that takes place between a diamond dresser and a polishing pad. With the polishing of the wafer underway, the reaction product would gradually accumulate onto the pores and asperities of the pad surface leading to the so-called glazing of the pad. As a result, the polishing rate of the wafer falls substantially [4-7]. In order to allow CMP to continue, a diamond pad conditioner is employed periodically and continually either in-situ dressing, in which conditioning is performed while wafers are being polished, or in ex-situ dressing, in which conditioning is conducted after the wafers have been polished, to regenerate the asperity structure of the pad that is optimized for polishing wafers efficiently. [8].

Currently the CMP diamond pad conditioner holds numerous diamond grits on the flat surface of a metal substrate by either electroplating nickel or brazing with alloy. Although the conventional diamond pad conditioner has a regular distribution diamond grits, tips of diamond grits are not leveled to the same height. Moreover, diamond grits are different in shapes and they orient differently, so their dressing behaviors are not predictable. Liao et al [9] studied that the fundamental characteristics of dressing action on the polyurethane pad are investigated first via dressing by single diamond of different orientations. They pointed out that a groove with ridge on

both side walls forms as the diamond moves over the pad. The diamond orientations drastically influence the asperities on the pad, and point-dressing can perform more effective cutting than plowing. On the contrary, plowing is found to be the major mechanism responsible for this surface topology if dressing is conducted by face-dressing. In addition in order to cope with the delicate dielectric layer, the Applied Materials Company as the dominant polisher maker is advancing Electrolysis Chemical Mechanical Polishing (ECMP) technology with electrical oxidation of copper upon the contact with the high points of pad asperities [10]. On the other hand, Rohm and Haas Electronic Materials Company, the major pad supplier, is introducing a new pad (EV4000) with a much larger compressibility of the pad surface compared to conventional IC1000 pad that has been the industrial standard for CMP. As new polishing pad and polishing machine are being increasingly demanded, a better and more reliable pad conditioner is required in the future. The ideal conditioner should have exactly the same shape, size and orientation as the diamond grits, and the spacing between the diamond grits should be identical [11]. In this investigation, a revolutionary design of diamond pad conditioners is based on the pattern forming of sintered polycrystalline diamond (PCD) composite to form specific shape of cutting tips. The new diamond pad conditioner contains identically shaped tip and the same height diamond. The dressing characteristics of pad surface textures are studied by comparison with conventional diamond pad conditioner.

Experiments

The dressing experiments were conducted using a commercially modified polishing machine with a varying speed and a polishing plate with a diameter of 200mm, where a polishing pad is mounted. The diamond pad conditioner is attached to a holder that is connected to a head rotating at 120rpm. A polyurethane pad is mounted on a table disk that rotates at a speed of 110rpm. The applied load is about 6kg. After the pad has been dressed, its surface topology is measured by a stylus type three-dimensional surface roughness measuring instrument. The radius of the diamond tip probe, the nose angle and the measuring force are 5μm, 90° and 4mN, respectively. A Scanning Electron Microscope (SEM) was employed to examine the pad morphology such as pores and grooves.

The two type of polishing pads used is hard IC 1000 pad with a Shore Hardness (HS) of about 59 and soft EV4000 pad with a HS of about 28 which are manufactured by Rohm-Haas from polyurethane-based foam. The pads are skived, or cut, from a cake. Foam density, open or closed cells, cell shape along with the intrinsic polymer properties determines the final pad properties. [12-13]. Polyurethane pads contain a distribution of asperities, pores, and grooves. The fraction of pore is about 35% of the total volume, but can be changed by manufacturing conditions. The isolated pores are spherical and diameters are in the range of 20-50 μm.

Conventional diamond pad conditioner contains single crystal diamond grits (e.g. 200 microns) that are attached to a metal substrate by either electroplating of nickel or brazing with alloy. Conventional diamond pad conditioner used is a DiaGrid dresser manufactured by Kinik Company, Taiwan and it is bonded with metal by brazed nickel alloy. The experiments in the paper the DiaGrid dresser is called brazed diamond disk (BDD) dresser. The diameter of the brazed diamond disk was 100mm, with a diamond spacing of 800 microns and the amount of diamond protrusion of 80 microns as presented in Fig. 1(a).

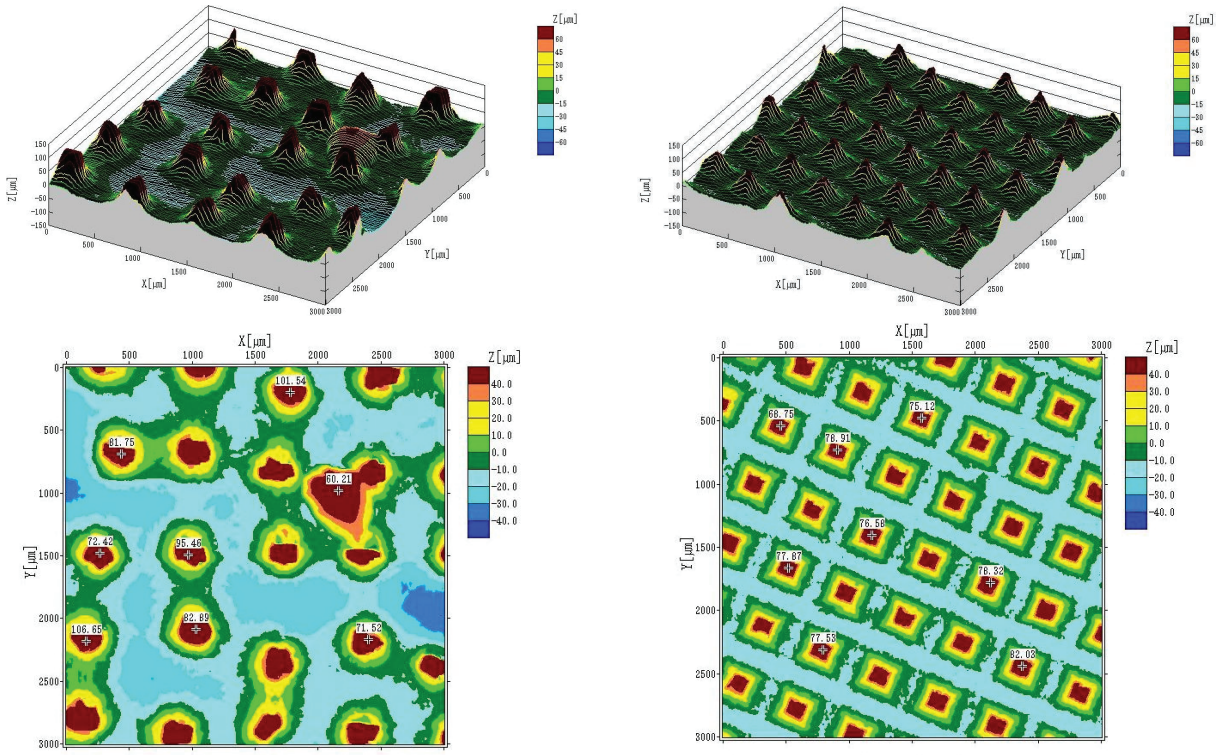
The revolutionary design of diamond dresser is based on the pattern forming of a strong polycrystalline diamond material that is sintered at ultrahigh pressure (about 6 Gpa) and high temperature (about 1350^0C). The PCD dresser will be named advanced diamond disk (ADD) in the paper. Such an advanced diamond disk is developed by Kinik Company and is manufactured by the wire electro discharge machining to produce cutting pyramids of a particular size with the designed shape. The diameter of the advanced diamond disk was 100mm, with a diamond spacing of 800 and 500 microns and the amount of diamond protrusion of 80 microns as presented in Fig. 1(b).

Results and Discussions

Fig. 2 shows cutter images of ADD and BDD produced by a stylus type 3D surface roughness instrument. It is found that cutter profiles show dramatic differences between ADD and BDD. The variations of ADD cutting elements are significantly smaller than the BDD. Although BDD has been the industrial regulation for CMP, its cutters distribution is still not regular, and the diamond tip leveling is larger than 45 microns so the diamond-to-diamond distance control becomes less meaningful. In contrast, ADD has regular diamond cutters pattern. The diamond tips can be leveled to within 15 microns. The better leveled ADD has much more cutters that can dress the pad simultaneously. In addition, the cutting tips are all in same angle (90^0) that is also designable. Due to the shaping capability of PCD, the ADD formed is much more regular than conventional designs of diamond pad conditioners.

(a) (b)

Fig. 1 (a) BDD dresser and (b) ADD dresser

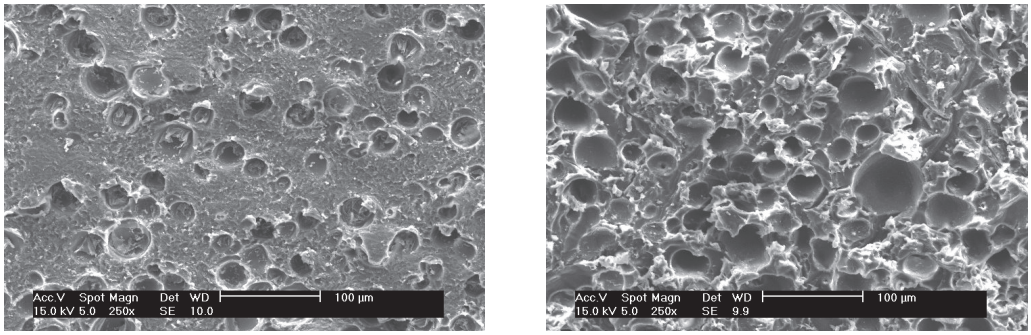


(a) (b)

Fig. 2 Comparison of the cutting tips between (a) BDD dresser and (b) ADD dresser

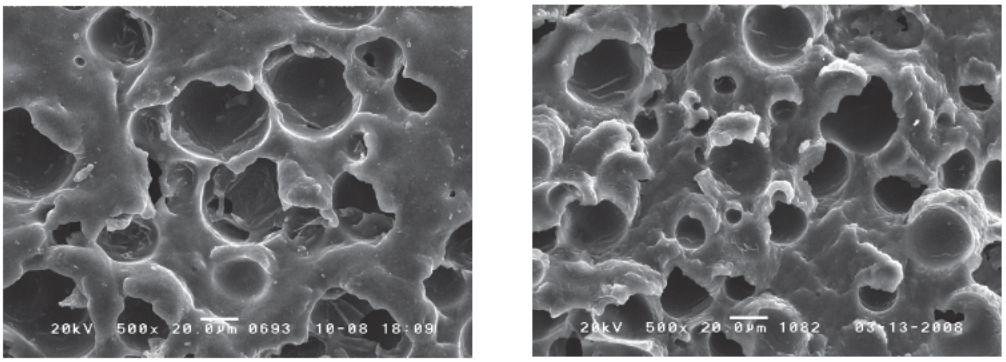
The cross-sectional SEM images of the pores on the IC1000 polishing pad after 60 minutes of dressing formed by ADD and BDD are shown in Fig. 3. It is observed that most pores still remain round like that of the unused polishing pad dressed by ADD as shown in Fig. 3(a). On the contrary, for BDD the shape of the pores changes irregular and rough. As a result, the amount of slurry used in the CMP process may increase substantially. In the figure, the uneven texture with variable asperities is formed by the BDD. The ADD dresser can dress the pad surface more uniformly, implying more asperities sharing polishing pressure and higher density of asperities in closely contacts with the wafer surface in the CMP process. In addition the average surface roughness, Ra, of about 2.97 μm dressed using the ADD is markedly less than Ra of about 5.68 μm obtained after dressing using a BDD. This result was also observed with EV4000 pad as shown in Fig. 4. the average surface roughness, Ra, of about 5.942 μm dressed using the BDD is larger than Ra of about 3.82 μm obtained after dressing using a ADD. One of the more interesting observation is the residual chips of pad material adhered to pores after 60 minutes dressed as shown in Fig. 5(a). The groove of an unused polishing pad is shown to be residue-free in Fig. 5(b).Also the groove of the polishing pad after 60 minutes dressing was filled with the residual chips, as shown in Fig. 5(c). The experimental result can be attributed to the visco-elastic property of the soft EV4000 pad. The residual chips trapped in the groove decreased the area for slurry transport that should be taken into account during dressing in the CMP process [14].

The cutting rate was one of the most important factors that affected the surface condition of the pad. The amount of pad surface that is removed per unit time is referred to the cutting rate. Fig. 6(a) shows the variation of the cutting rate with the diamond conditioners for hard IC1000 pad. The cutting rate of the ADD is lower than that of the BDD, and the conditioner with a larger diamond spacing (800 microns) results in a higher cutting rate, as expected. Based on the observations made herein, the ADD can consume less pad material, and hence the pad life is extended. As a result, reduction of the cost CMP is expected. Another interesting observation is that the cutting rate of the ADD for the soft EV4000 pad is larger than that of the BDD, as presented in Fig. 6 (b). The cutting rate of the BDD, approximately 15μm/hr, is extremely low. This result revealing that the cutting action is markedly weakened when BDD is used to dress the soft EV4000 pad. This result can be explained as follows. Diamond grit whose cutting depth exceeds the elastic deformation generates a groove with ridges on both sides. When the diamond grit is dragged across a polyurethane pad, it forms a groove. The groove, however, is shallower than the dressing depth because the pad material springs back due to elastic deformation [15]. Furthermore, although the BDD dresser has been the industrial norm for CMP, its diamond grit has obtuse solid angles for cutting and the unequal tip heights. Sung et al. [16] pointed out that most diamond grit was oriented such that it faced the pad surface, reducing its ability to penetrate the soft EV4000 pad surface. This discussion probably explains why the cutting rate of the EV4000 pad dressed by BDD is substantially low. On the contrary, the cutting rate of the ADD dresser, approximately 190μm/hr, is high because the cutters of ADD were designed as cutting pyramids that face the pad surface. This result shows that the sharp teeth of ADD can cut resilient pads. In contrast, diamond grit cannot effectively cut the pliable pad, suggesting that for a resilient pad, ADD is preferred to BDD.



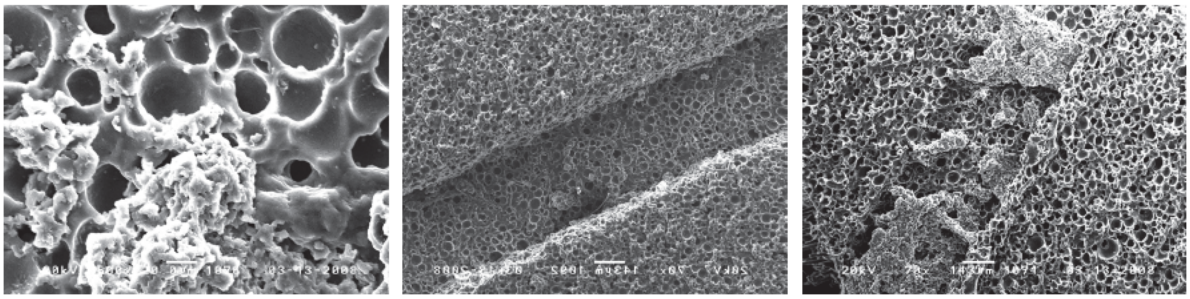
(a) (b)

Fig. 3 SEM images of IC1000 pad surface formed by (a) ADD, (b) BDD after 60 minutes of dressing



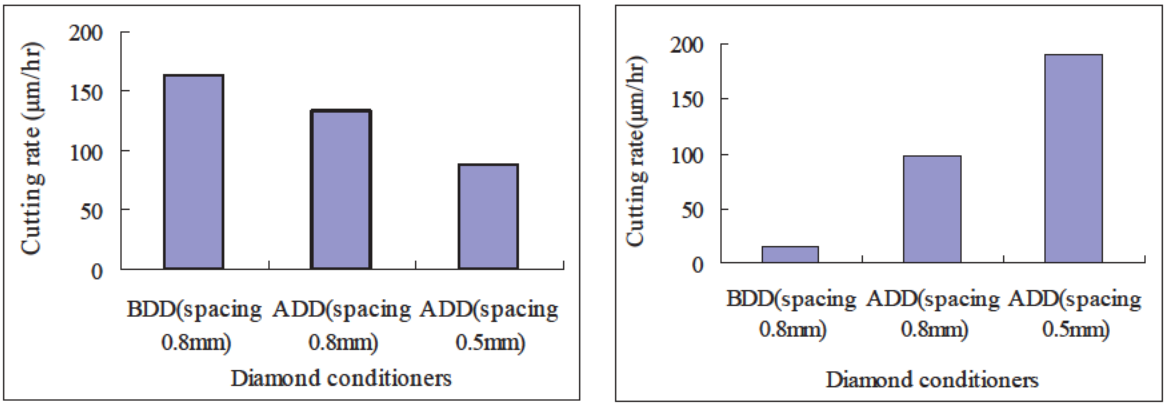
(a) (b)

Fig. 4 SEM images of the EV4000 pad dressed by (a) ADD and (b) BDD after 60 minutes of dressing



(a) (b) (c)

Fig. 5 SEM images of (a) pores after 60 minutes of dressing, (b) unused groove and (c) groove after 60 minutes of dressing



(a) (b)

Fig. 6 Variation of cutting rate with diamond conditioners for (a) IC1000 pad, (b) EV4000 pad

Conclusion

In this work a new design of diamond dresser is made by sculpturing a sintered polycrystalline diamond material to form specific pattern of cutting tips. This is in contrast of conventional design by attaching random diamond grits with metal by brazing. The dressing characteristics of the pad surface textures by experimentally are investigated by comparison with conventional diamond conditioner. The variations of ADD cutting elements are significantly smaller than the BDD dresser because ADD dresser has regular diamond cutters pattern and cutters are protruding to the same height. Compared to BDD dresser, ADD dresser can create pad asperities more uniformly. It is

found that the cutting rate of the ADD dresser for IC1000 pad is reduced by about 30%, and hence the pad life is prolonged. For resilient EV4000 pad the use of ADD dresser is superior to BDD dresser. Further studies to investigate the effect of the texture of the polishing pad on the wafer removal rate and non-uniformity dressed by ADD dresser in CMP are under way.

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