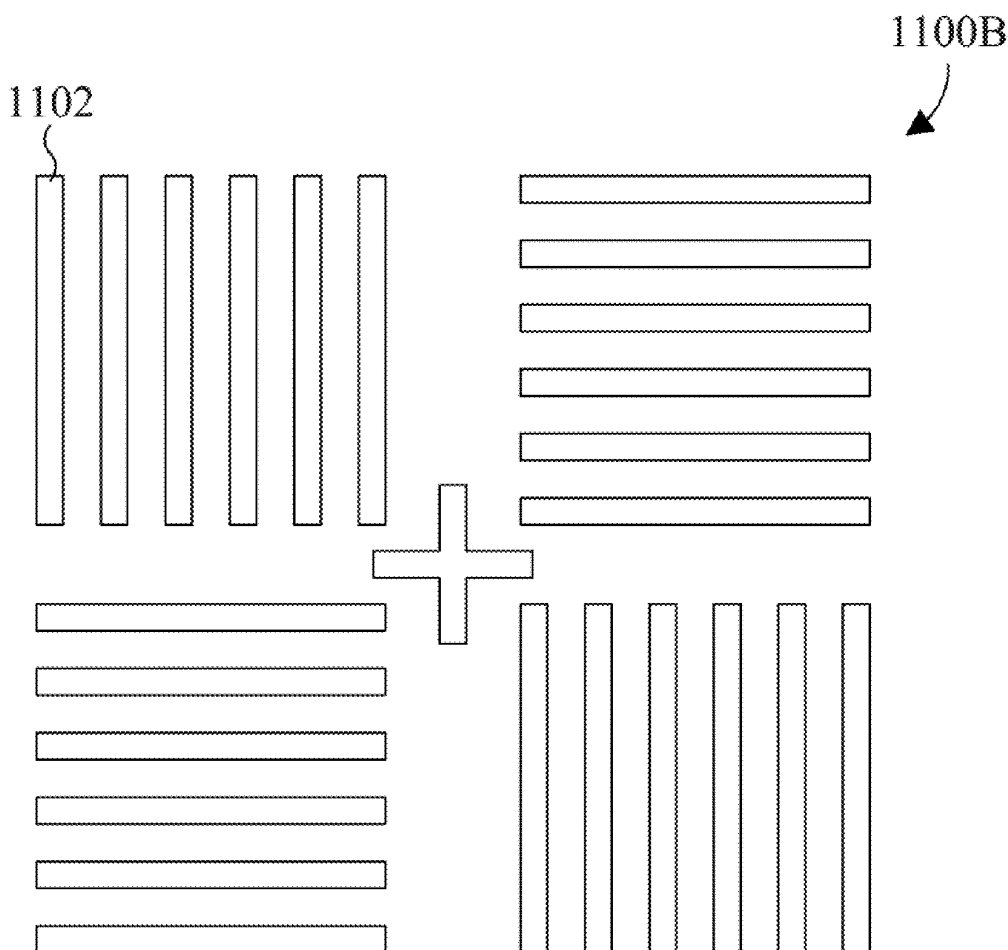




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Yoo(10) **Pub. No.: US 2017/0372917 A1**(43) **Pub. Date: Dec. 28, 2017**(54) **PATTERN TRANSFER TECHNIQUE AND
METHOD OF MANUFACTURING THE SAME**(71) Applicant: **Taiwan Semiconductor
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(TW)**(72) Inventor: **Chue San Yoo, Hsin-Chu (TW)**(21) Appl. No.: **15/194,631**(22) Filed: **Jun. 28, 2016****Publication Classification**(51) **Int. Cl.**
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(2013.01); **H01L 21/31116** (2013.01); **H01J**
2237/334 (2013.01); **H01L 2223/54426**
(2013.01)(57) **ABSTRACT**

A photo-free lithography process with low cost, high throughput, and high reliability is provided. A template mask is bonded to a production workpiece and comprises a plurality of openings defining a pattern. An etch is performed into the production workpiece, through the plurality of openings, to transfer the pattern of the template mask to the production workpiece. The template mask is de-bonded from the production workpiece. A system for performing the photo-free lithography process is also provided.



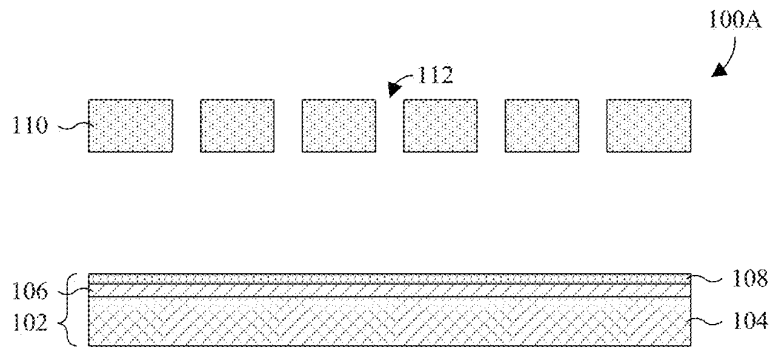


Fig. 1A

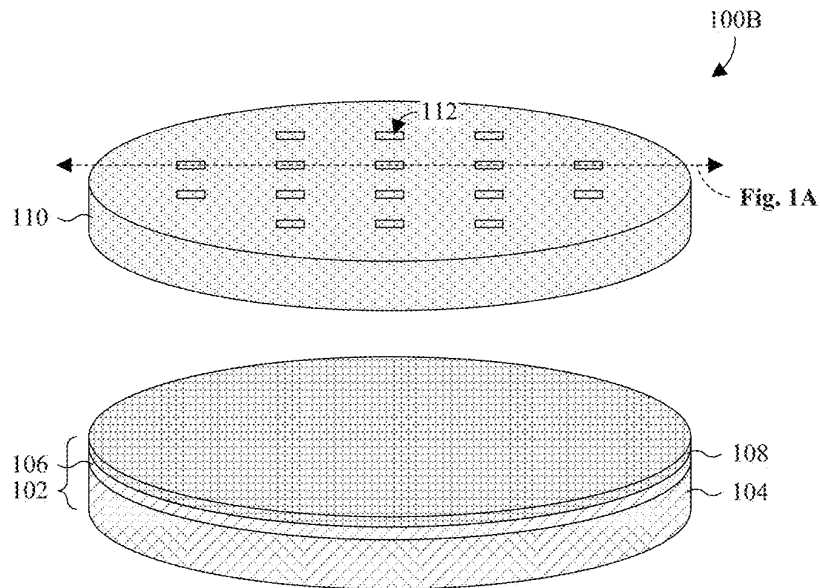


Fig. 1B

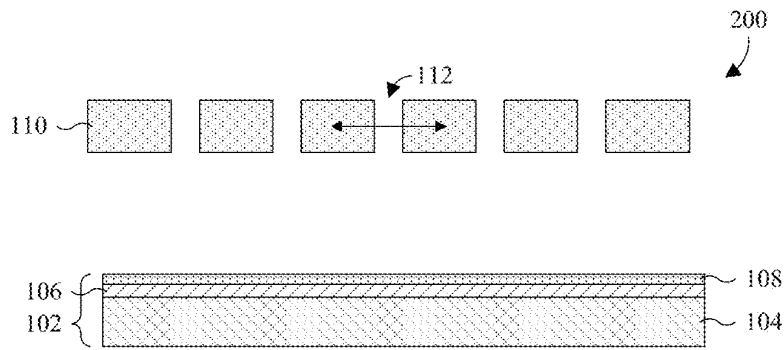


Fig. 2

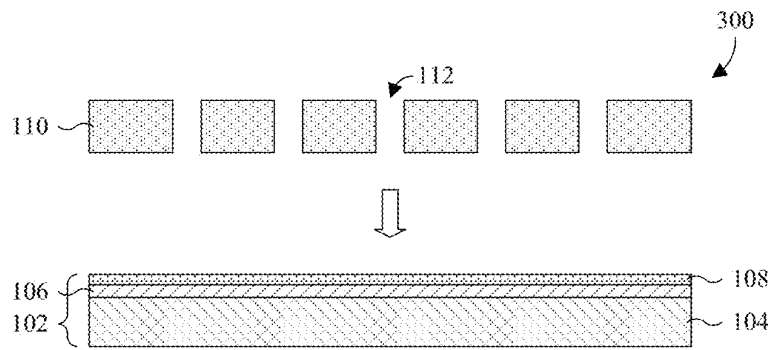


Fig. 3

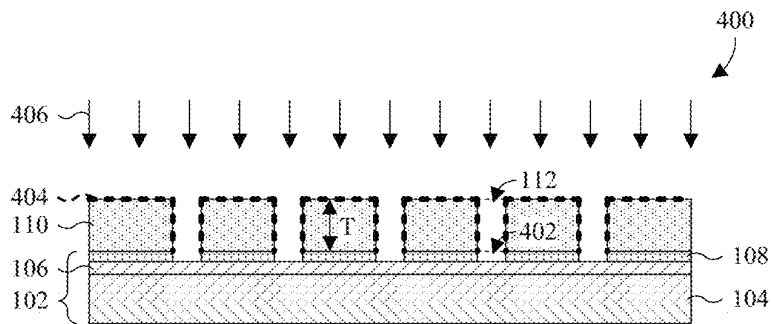


Fig. 4

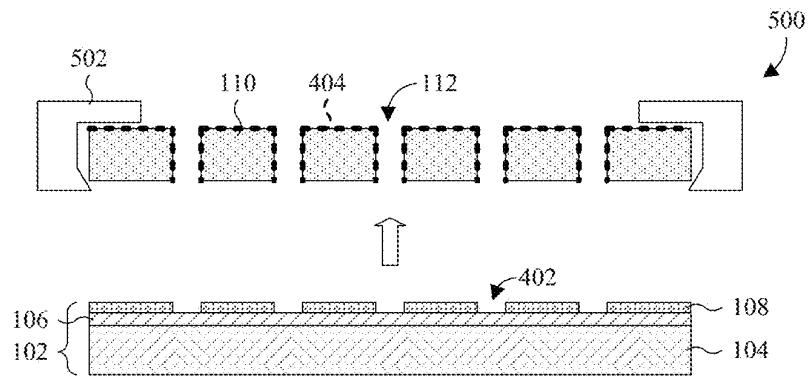


Fig. 5

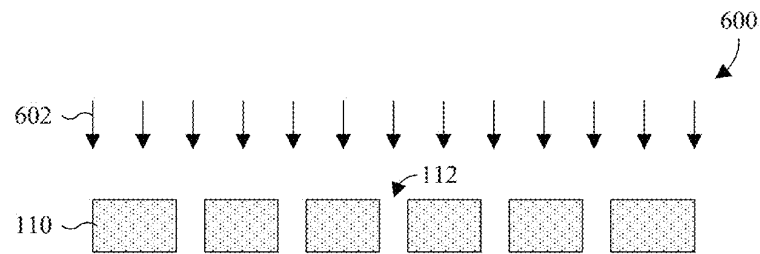


Fig. 6

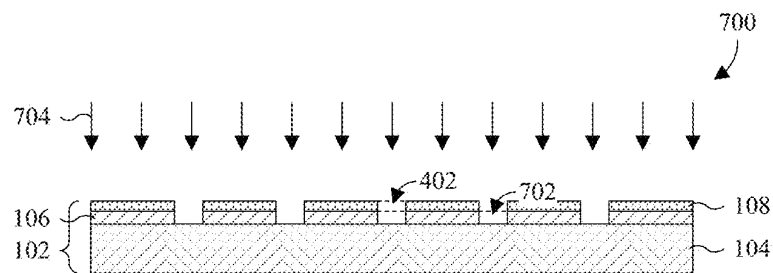


Fig. 7

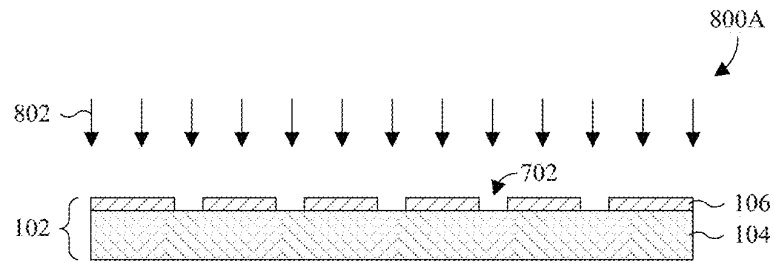


Fig. 8A

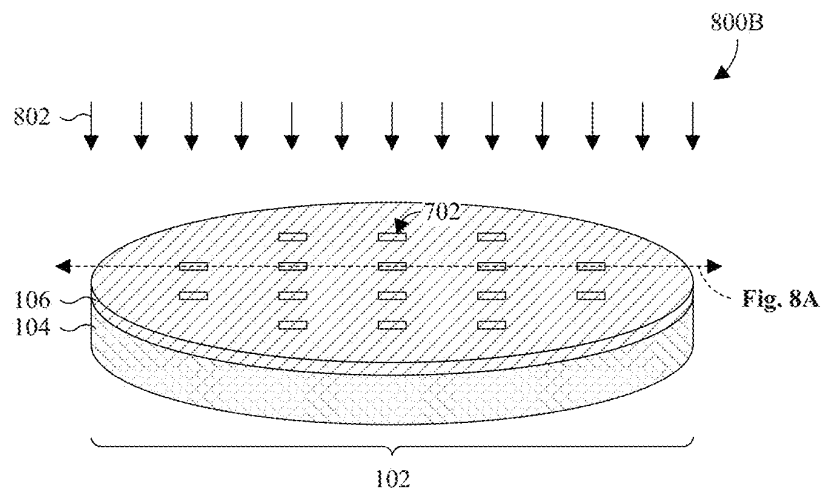
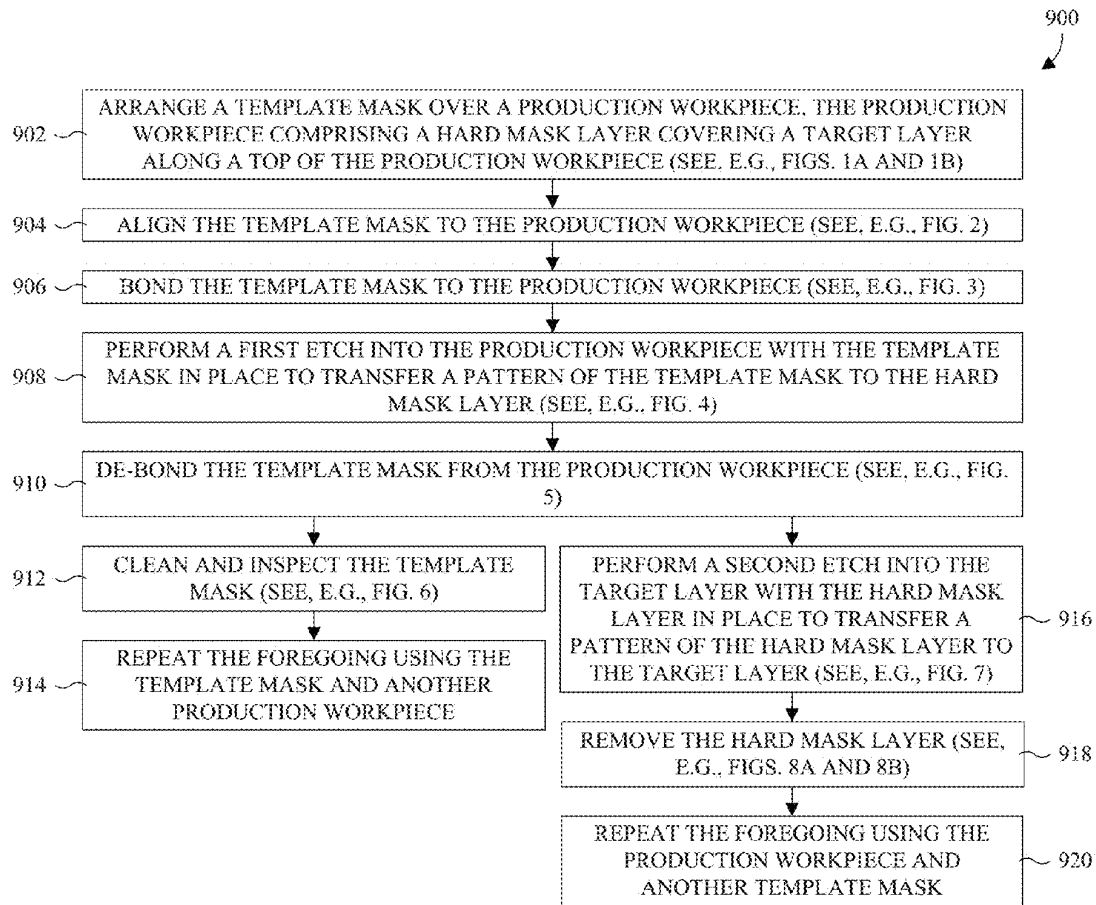


Fig. 8B

**Fig. 9**

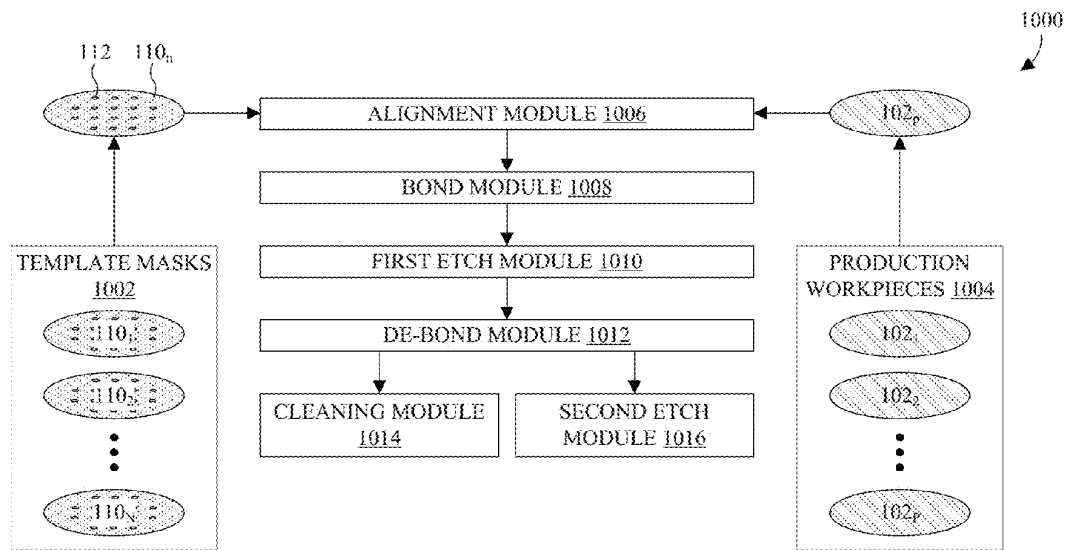


Fig. 10

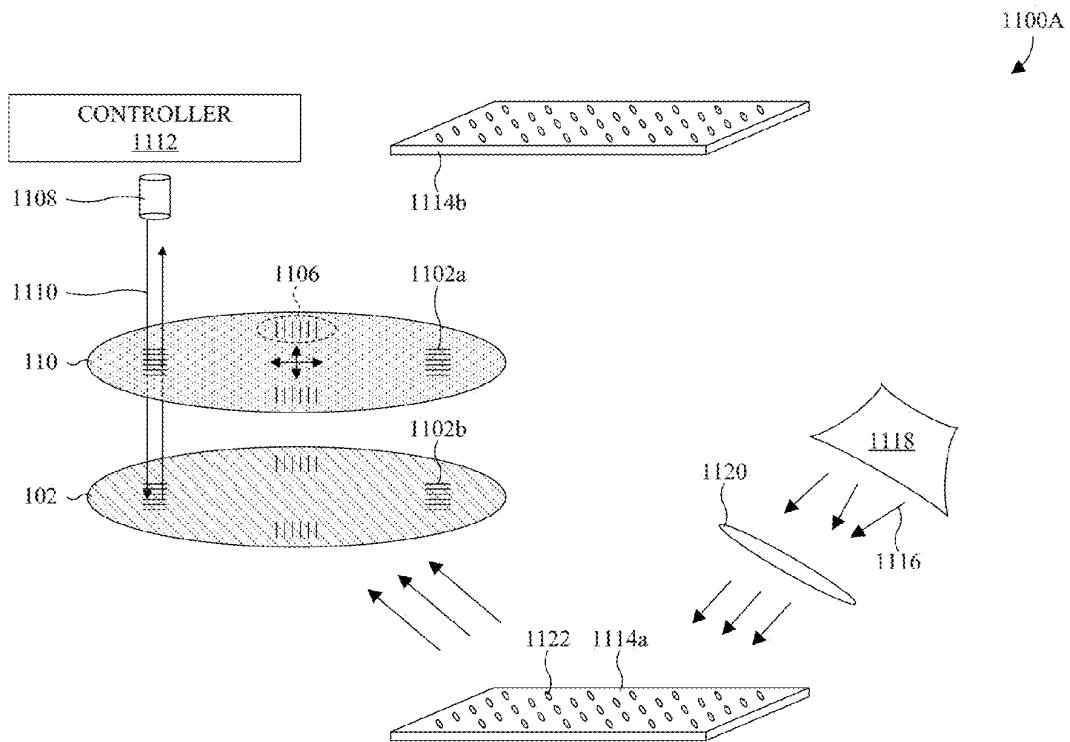


Fig. 11A

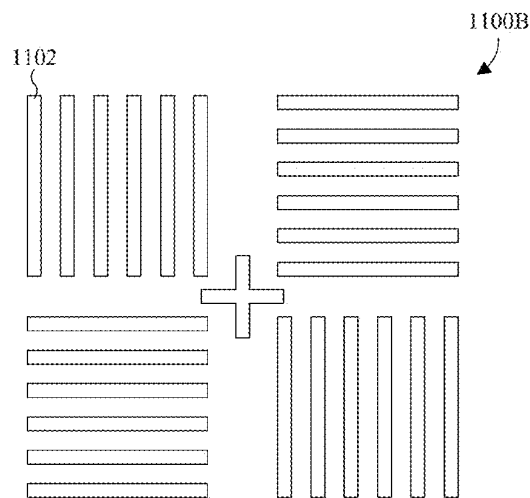


Fig. 11B

PATTERN TRANSFER TECHNIQUE AND METHOD OF MANUFACTURING THE SAME

BACKGROUND

[0001] During the manufacture of integrated circuits (ICs), multi-step sequences of semiconductor manufacturing processes are performed to gradually form electronic circuits on semiconductor workpieces. One such semiconductor manufacturing process is lithography. Lithography is a process for transferring a geometric pattern to semiconductor workpieces. Lithography may be performed by, for example, photolithography, charged particle lithography, or nanoimprint lithography.

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] Aspects of the present disclosure are best understood from the following detailed description when read with the accompanying figures. It is noted that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

[0003] FIGS. 1A, 1B, 2-7, 8A, and 8B illustrate a series of cross-sectional and perspective views of some embodiments of a photo-free lithography process.

[0004] FIG. 9 illustrates a flowchart of some embodiments of the photo-free lithography process of FIGS. 1A, 1B, 2-7, 8A, and 8B.

[0005] FIG. 10 illustrates a flowchart of some embodiments of a system for performing a photo-free lithography process.

[0006] FIG. 11A illustrates a block diagram of some embodiments of an alignment module within the system of FIG. 10.

[0007] FIG. 11B illustrates a layout view of some embodiments of an alignment mark set for use by the alignment module of FIG. 11A.

DETAILED DESCRIPTION

[0008] The present disclosure provides many different embodiments, or examples, for implementing different features of this disclosure. Specific examples of components and arrangements are described below to simplify the present disclosure. These are, of course, merely examples and are not intended to be limiting. For example, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed between the first and second features, such that the first and second features may not be in direct contact. In addition, the present disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed.

[0009] Further, spatially relative terms, such as “beneath,” “below,” “lower,” “above,” “upper” and the like, may be used herein for ease of description to describe one element or feature’s relationship to another element(s) or feature(s) as illustrated in the figures. The spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the

figures. The apparatus may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein may likewise be interpreted accordingly.

[0010] Photolithography is commonly used to fabricate geometric patterns on semiconductor workpieces. A photolithography process comprises depositing a photoresist layer over a semiconductor workpiece. Thereafter, radiation is selectively passed through a photomask to impart a pattern of the photomask on the radiation. Further, the photoresist layer is exposed to the radiation to chemically change exposed regions of the photoresist layer. With the photoresist layer exposed, a developer is applied to the photoresist layer to remove either exposed or unexposed regions of the photoresist layer and to develop the pattern in the photoresist layer. However, such kind of photolithography relies on a complicated photomask, and thus incurs high cost and low throughput.

[0011] An alternative to photolithography that has low cost and high throughput is nanoimprint lithography. A nanoimprint lithography process comprises depositing an imprint resist layer over a semiconductor workpiece and pressing a stamp into the imprint resist layer. The stamp has a pattern arranged along a bottom thereof, such that pressing the stamp into the imprint resist layer imprints the imprint resist layer with the pattern. With the imprint resist layer imprinted, the imprint resist layer is cured or hardened by, for example, exposure to ultraviolet radiation. Further, the stamp is removed from the imprint resist layer, thereby leaving the pattern in the imprint resist layer. However, nanoimprint lithography has contamination issues, since imprint resist may remain on the stamp. This, in turn, may reduce reliability by, for example, degrading the pattern, reducing yield, or damaging the stamp.

[0012] The present application is directed towards a photo-free lithography process. In some embodiments, a template mask is bonded to a production workpiece and comprises a plurality of openings defining a pattern. An etch is performed into the production workpiece, through the plurality of openings, to transfer the pattern of the template mask to the production workpiece. The template mask is de-bonded from the production workpiece. Advantageously, the photo-free lithography process is performed without depositing photoresist, exposing the photoresist to radiation, or developing the photoresist, such that cost is low and throughput is high compared to photolithography. Further, the photo-free lithography process is performed without imprint resist, such that reliability is high compared to nanoimprint lithography.

[0013] With reference to FIGS. 1A, 1B, 2-7, 8A, and 8B, a series of cross-sectional and perspective views **100A**, **100B**, **200-700**, **800A**, **800B** illustrate some embodiments of a photo-free lithography process.

[0014] As illustrated by the cross-sectional views **100A** of FIG. 1A, a production workpiece **102** is provided or otherwise formed. The production workpiece **102** comprises a substrate **104** upon which a target layer **106** and a hard mask layer **108** are stacked. In some embodiments, the substrate **104** comprises a semiconductor substrate (not shown). The semiconductor substrate may be, for example, a bulk silicon substrate, such as a bulk substrate of monocrystalline silicon, a silicon-on-insulator (SOI) substrate, or some other type of semiconductor substrate. Further, in some embodiments, the substrate **104** comprises additional layers (not

shown) and/or electronic devices (not shown) stacked or otherwise arranged over the semiconductor substrate. The target layer 106 covers the substrate 104 and may be, for example, an oxide, such as silicon dioxide, or some other dielectric. The hard mask layer 108 covers the target layer 106 and may be, for example, a nitride, such as silicon nitride, or some other dielectric.

[0015] In some embodiments, the process for forming the production workpiece 102 comprises depositing or growing the target layer 106 over the substrate 104, followed by depositing or growing the hard mask layer 108 over the target layer 106. The target layer 106 and the hard mask layer 108 may be deposited or grown by, for example, vapor deposition, spin coating, atomic layer deposition (ALD), thermal oxidation, some other deposition or growth process, or a combination of the foregoing. The vapor deposition may include, for example, chemical vapor deposition (CVD), physical vapor deposition (PVD), some other vapor deposition process, or a combination of the foregoing.

[0016] Also illustrated by the cross-sectional view 100A of FIG. 1A, a template mask 110 is provided or otherwise formed, and is arranged over the production workpiece 102. The template mask 110 comprises a plurality of openings 112 that extend through the template mask 110, from a top surface of the template mask 110 to a bottom surface of the template mask 110, and that are arranged to define a pattern to be transferred to the target layer 106. The pattern may, for example, correspond to that of a photomask in a photomask set for a tape-out of an integrated circuit (IC). The tape-out is the final result of the design cycle for the IC. The template mask 110 may be, for example, a bulk silicon substrate, such as a bulk substrate of monocrystalline silicon, or some other semiconductor substrate.

[0017] In some embodiments, the openings 112 correspond to vias in a via layer of a back-end-of-line (BEOL) interconnect structure under manufacture. In such embodiments, the substrate 104 may comprise, for example, the semiconductor substrate and a partially formed BEOL interconnect structure overlying the semiconductor substrate. Further, in such embodiments, the target layer 106 may correspond to an interlayer dielectric (ILD) layer. The ILD layer may be, for example, silicon dioxide or a low κ dielectric. A low κ dielectric is a dielectric with a dielectric κ that is less than about 3.9.

[0018] As illustrated by the perspective view 100B of FIG. 1B, in some embodiments, the production workpiece 102 and the template mask 110 are or otherwise comprise wafers. For example, the production workpiece 102 and the template mask 110 may each comprise 450 millimeter wafers of silicon.

[0019] As illustrated by the cross-sectional view 200 of FIG. 2, the template mask 110 is aligned to the production workpiece 102. While discussed in greater detail hereafter (see, e.g., FIGS. 11A and 11B), in some embodiments, the process for aligning the template mask 110 comprises measuring alignment between alignment marks on the template mask 110 and the production workpiece 102 using, for example, Moiré interferometry. Further, in some embodiments, the process comprises laterally shifting and/or selectively heating the template mask 110 and/or the production workpiece 102 based on the measurements to align the alignment marks. The selective heating causes select regions

of the template mask 110 and/or the production workpiece 102 to expand, thereby moving the alignment marks into alignment.

[0020] As illustrated by the cross-sectional view 300 of FIG. 3, the template mask 110 is bonded to the production workpiece 102 through the target layer 106 and the hard mask layer 108. In some embodiments, the template mask 110 is direct or fusion bonded to the production workpiece 102. For example, a hydrophilic fusion bonding process may be performed to bond the template mask 110 to the production workpiece 102.

[0021] In some embodiments, the process for bonding the template mask 110 to the production workpiece 102 comprises treating surfaces of the production workpiece 102 and the template mask 110 that are to be bonded together. The treating may comprise, for example, annealing the production workpiece 102 and/or the template mask 110 in the presence of nitrogen and/or hydrogen gas, and/or applying argon-based plasma to at least one of the surfaces. Further, in some embodiments, the process comprises cleaning the surfaces, pressing the surfaces together, and annealing. The cleaning may comprise, for example, rinsing the surfaces with water, such as deionized water. The annealing may comprise, for example, heating an environment of the production workpiece 102 and/or the template mask 110 to a low temperature, such as a temperature between about 200-300 degrees Celsius.

[0022] As illustrated by the cross-sectional view 400 of FIG. 4, a first etch is performed through the hard mask layer 108, with the template mask 110 in place, to transfer the pattern of the template mask 110 to the hard mask layer 108. As with the pattern of the template mask 110, the transferred pattern of the hard mask layer 108 is defined by an arrangement of openings 402 that extend through the hard mask layer 108, from a top surface of the hard mask layer 108 to a bottom surface of the hard mask layer 108. The first etch may stop, for example, on the target layer 106, such that the target layer 106 serves as an etch stop for the first etch. Further, the first etch may result, for example, in a residue 404 along surfaces of the production workpiece 102 and/or the template mask 110 that are exposed.

[0023] In some embodiments, the first etch is performed by plasma-based etching. For example, the first etch may be performed by application of chemically reactive plasma to the hard mask layer 108 through the template mask 110. As another example, the first etch may be performed by bombarding the hard mask layer 108 with plasma particles 406 through the template mask 110. In some embodiments, the template mask 110 facilitates highly anisotropic etching by a thickness T that is sufficient to collimate the plasma particles 406 before the plasma particles 406 bombard the hard mask layer 108.

[0024] As illustrated by the cross-sectional view 500 of FIG. 5, the template mask 110 is de-bonded from the production workpiece 102. In some embodiments, the process for de-bonding the template mask 110 from the production workpiece 102 comprises pulling the template mask 110 and the production workpiece 102 apart with sufficient force to break the bond between the template mask 110 and the production workpiece 102. The mechanical force may, for example, be applied by a wafer handling tool 502.

[0025] As illustrated by the cross-sectional view 600 of FIG. 6, the template mask 110 is cleaned and inspected for defects. In some embodiments, the cleaning removes the

residue **404** (see FIG. 5) along surfaces of the template mask **110**, and/or is performed by applying solvent **602** to the template mask **110**. The solvent **602** may be, for example, a diluted ammonium peroxide mixture and/or a diluted mixture of sulfuric acid and of hydrogen peroxide. Further, in some embodiments, the inspection seeks to identify defects and/or damage to the template mask **110**. To the extent that the template mask **110** is free of defects and/or damage, the template mask **110** may be used to pattern another production workpiece.

[0026] As illustrated by the cross-sectional view **700** of FIG. 7, a second etch is performed partially into or through the target layer **106**, with the hard mask layer **108** in place, to transfer the pattern of the hard mask layer **108** and the template mask **110** to the target layer **106**. Further, the second etch may stop, for example, on the substrate **104**. As with the pattern of the hard mask layer **108**, the transferred pattern of the target layer **106** is defined by an arrangement of openings **702** that extend partially into or through the target layer **106**, from a top surface of the target layer **106** to or towards a bottom surface of the target layer **106**.

[0027] In some embodiments, the second etch is performed by applying an etchant **704** to the target layer **106** through the hard mask layer **108**. For example, the second etch may be performed by application of chemically reactive plasma to the target layer **106** through the hard mask layer **108**. As another example, the second etch may be performed by bombarding the target layer **106** with plasma particles through the hard mask layer **108**. As yet another example, the second etch may be performed by applying a chemically reactive solution to the target layer **106** through the hard mask layer **108**.

[0028] As illustrated by the cross-sectional view **800A** of FIG. 8A and the perspective view **800B** of FIG. 8B, in some embodiments, the hard mask layer **108** (See FIG. 7) is removed. The hard mask layer **108** may, for example, be removed by applying an etchant **802** to the hard mask layer **108** until the hard mask layer **108** is removed. The etchant **802** may be, for example, a wet or dry etchant, and/or may be, for example, highly selective of the hard mask layer **108** relative to the target layer **106** and one or more additional layers of the substrate **104** that are exposed and that underlie the hard mask layer **108**.

[0029] In some embodiments, after transferring the pattern of the hard mask layer **108** to the target layer **106** and, in some embodiments, removing the hard mask layer **108**, the foregoing process is repeated with the production workpiece **102** and another target mask with a different pattern. For example, a new target layer may be deposited or otherwise grown over the target layer **106**, and the foregoing process may be used to pattern the new target layer with the other target mask. Such repetition may repeat, for example, until manufacture of one or more ICs on the production workpiece **102** is complete. Further, in some embodiments, the hard mask layer **108** (see, e.g., FIG. 1A) is omitted, such that the pattern of the template mask **110** (see, e.g., FIG. 1A) is transferred directly from the template mask **110** to the target layer **106**.

[0030] With reference to FIG. 9, a flowchart **900** of some embodiments of the photo-free lithography process of FIGS. 1A, 1B, 2-7, 8A, and 8B is provided.

[0031] At **902**, a template mask is arranged over a production workpiece. The production workpiece comprises a hard mask layer covering a target layer along a top of the

production workpiece. See, for example, FIGS. 1A and 1B. In some embodiments, the template mask is part of a template mask set representing a photomask set of an IC tape-out. For example, each template mask of the template mask set corresponds to one of the photomasks in the photomask set and has a pattern of openings arranged according to a pattern of the corresponding photomask. The correspondence may be, for example, one to one.

[0032] At **904**, the template mask is aligned to the production workpiece. See, for example, FIG. 2.

[0033] At **906**, the template mask is bonded to the production workpiece. See, for example, FIG. 3. The template mask may, for example, be bonded by fusion bonding.

[0034] At **908**, a first etch is performed into the production workpiece with the template mask in place to transfer a pattern of the template mask to the hard mask layer. See, for example, FIG. 4.

[0035] At **910**, the template mask is de-bonded from the production workpiece. See, for example, FIG. 5.

[0036] At **912**, the template mask is cleaned and inspected. See, for example, FIG. 6.

[0037] At **914**, the foregoing (**902-912**) is repeated using the template mask and another production workpiece. In some embodiments, the other production workpiece is the same as the production workpiece before the photo-free lithography process.

[0038] At **916**, a second etch is performed into the target layer with the hard mask layer in place to transfer a pattern of the hard mask layer to the target layer. See, for example, FIG. 7.

[0039] At **918**, the hard mask layer is removed by, for example, a third etch. See, for example, FIGS. 8A and 8B.

[0040] At **920**, the foregoing (**902-912**) is repeated using the production workpiece and another template mask. In some embodiments, the other template mask is next in the template mask set for the production workpiece.

[0041] Advantageously, using the template mask to pattern the target layer results in low cost, high throughput, and high reliability at least relative to photolithography and nanoimprint lithography. The photo-free lithography process is performed without depositing photoresist, exposing the photoresist to radiation, or developing the photoresist, such that cost is low and throughput is high compared to photolithography. Further, the photo-free lithography process is performed without imprint resist, such that reliability is high compared to nanoimprint lithography. As discussed above, the imprint resist can stick to a stamp used in nanoimprint lithography to degrade a pattern of the stamp, reduce yield, or damage the stamp.

[0042] While the method described by the flowchart **900** is illustrated and described herein as a series of acts or events, it will be appreciated that the illustrated ordering of such acts or events are not to be interpreted in a limiting sense. For example, some acts may occur in different orders and/or concurrently with other acts or events apart from those illustrated and/or described herein. Further, not all illustrated acts may be required to implement one or more aspects or embodiments of the description herein, and one or more of the acts depicted herein may be carried out in one or more separate acts and/or phases. For example, the hard mask layer may be omitted, such that **908** transfers the pattern of the template mask directly to the target layer and **916** and **918** are omitted.

[0043] With reference to FIG. 10, a flowchart 1000 of some embodiments of a system for performing a photo-free lithography process is provided. The system may, for example, be configured to perform the photo-free lithography process of FIGS. 1A, 1B, 2-7, 8A, and 8B and/or the photo-lithography process of FIG. 9. As illustrated, the system comprises a template mask set 1002 and a production workpiece set 1004.

[0044] The template mask set 1002 comprises N template masks $110_1, 110_2, 110_N$ arranged in a sequence spanning from 1 to N. N may be, for example, one or more, such as 80. Each of the N template masks $110_1, 110_2, 110_N$ has a plurality of openings 112 that extend through the template mask $110_1, 110_2, 110_N$ from a top surface of the template mask $110_1, 110_2, 110_N$ to a bottom surface of the template mask $110_1, 110_2, 110_N$, and that are arranged in a pattern. The patterns of the N template masks $110_1, 110_2, 110_N$ may, for example, be different. Further, each of the N template masks $110_1, 110_2, 110_N$ may be, for example, a bulk silicon substrate, such as a bulk substrate of monocrystalline silicon, or some other semiconductor substrate. An example of a template mask may be seen, for example, in FIGS. 1A and 1B.

[0045] In some embodiments, the N template masks $110_1, 110_2, 110_N$ correspond to the photomasks in a photomask set of an IC tape-out, such that the pattern of each template mask $110_1, 110_2, 110_N$ is that of the corresponding photomask. The correspondence between the N template masks $110_1, 110_2, 110_N$ and the photomasks may be, for example, one to one. Further, in some embodiments, the N template masks $110_1, 110_2, 110_N$ correspond to different layers in the IC tape-out, such that the pattern of each template mask $110_1, 110_2, 110_N$ is that of a pattern to be transferred to the corresponding layer. The correspondence between the N template masks $110_1, 110_2, 110_N$ and the layers may be, for example, one to one. The layers may, for example, correspond to interconnect layers within a BEOL interconnect structure, such as interconnect layers of vias and interconnect layers of metal lines.

[0046] The production workpiece set 1004 comprises P production workpieces $102_1, 102_2, 102_P$. P may be, for example, one or more. Each of the P production workpieces $102_1, 102_2, 102_P$ is either unprocessed by the template masks $110_1, 110_2, 110_N$ or has been processed up to one of the N template masks $110_1, 110_2, 110_N$ in the sequence of the template mask set 1002. In some embodiments, each of the P production workpieces $102_1, 102_2, 102_P$ comprises a semiconductor substrate. Further, in some embodiments, each of the P production workpieces $102_1, 102_2, 102_P$ comprises one or more layers and/or electronics devices stacked or otherwise arranged thereover. An example of a production workpiece may be seen, for example, in FIGS. 1A and 1B.

[0047] An alignment module 1006 receives a production workpiece 102_p from the production workpiece set 1004, and also a template mask 110_n from the template mask set 1002. The production workpiece 102_p corresponds to the pth element in the production workpiece set 1004, and the template mask 110_n corresponds to the nth element in the template mask set 1002. Further, n is dependent upon the extent to which the production workpiece 102_p has been processed by the template mask set 1002. When the production workpiece 102_p is unprocessed by the template mask set 1002, the template mask 110_n is first in the sequence of the template mask set 1002. Otherwise, the template mask 110_n is next in the sequence of the template mask set 1002

for the production workpiece 102_p . In other words, the production workpiece 102_p is processed up to the n-1 element in the template mask set 1002.

[0048] After receiving the template mask 110_n and the production workpiece 102_p , the alignment module 1006 aligns the template mask 110_n to the production workpiece 102_p , over the production workpiece 102_p , and a bond module 1008 subsequently bonds the production workpiece 102_p to the template mask 110_n . The alignment module 1006 may, for example, align the production workpiece 102_p to the template mask 110_n using interferometry, such as Moiré interferometry. The bond module 1008 may, for example, bond the production workpiece 102_p and the template mask 110_n together using a fusion bonding process, such as a hydrophilic fusion bonding process. Examples of alignment and bonding are respectively shown in FIGS. 2 and 3. Further, in some embodiments, the alignment module 1006 and the bond module 1008 are integrated together into a common process tool.

[0049] In some embodiments, the alignment module 1006 comprises an interferometry camera to measure alignment between alignment marks on the template mask 110_n and the production workpiece 102_p . Further, in some embodiments, the alignment module 1006 comprises one or more systems or devices for bringing the template mask 110_n and the production workpiece 102_p into alignment based on the measurements. For example, the alignment module 1006 may comprise one or more mechanical devices, such as a mechanical arm, to move the template mask 110_n laterally into alignment with the production workpiece 102_p , and/or to move the production workpiece 102_p laterally into alignment with the template mask 110_n . As another example, the alignment module 1006 may comprise a heating system to selectively heat regions of the production workpiece 102_p and/or the template mask 110_n , while not heating other regions of the production workpiece 102_p and/or the template mask 110_n , to expand the heated regions into alignment. The heating system may comprise, for example, a heat source, one or more digital mirror arrays, and a collimator.

[0050] In some embodiments, the bond module 1008 comprises a process chamber accommodating a lower plate and an upper plate. The lower plate supports one of the production workpiece 102_p and the template mask 110_n , and may be configured to apply heat. The upper plate supports the other one of the production workpiece 102_p and the template mask 110_n , and is arranged at the end of a vertical column configured to press the upper plate against the lower plate. Further, the upper plate may be configured to apply heat. To the extent that the alignment module 1006 and the bond module 1008 are integrated, the alignment module 1006 is at least partially arranged within the process chamber of the bond module 1008. For example, the interferometry camera and/or a digital mirror array may be arranged within the process chamber.

[0051] After aligning and bonding the production workpiece 102_p and the template mask 110_n together, a first etch module 1010 performs a first etch into the production workpiece 102_p , through the template mask 110_n , to transfer a pattern of the template mask 110_n to the production workpiece 102_p . In some embodiments, the pattern is transferred to a hard mask layer of the production workpiece 102_p , which is subsequently used to transfer the pattern to an underlying target layer of the production workpiece 102_p . An example is illustrated in, for example, FIG. 4. In other

embodiments, the pattern is transferred directly the target layer without an intervening hard mask layer. The first etch module 1010 may be, for example, a plasma etch process tool.

[0052] Further, a de-bond module 1012 subsequently de-bonds the template mask 110_n from the production workpiece 102_p. In some embodiments, the de-bond module 1012 comprises a mechanical system or device, such as a mechanical arm, that is configured to pull the template mask 110_n away from the production workpiece 102_p with sufficient force to break the bond therebetween. An example is illustrated in, for example, FIG. 5.

[0053] In some embodiments, the first etch leaves etch residue on the template mask 110_n, which may degrade the pattern of the template mask 110_n and/or damage the template mask 110_n. Therefore, a cleaning module 1014 may clean the template mask 110_n after the first etch. In some embodiments, the cleaning is performed by applying a diluted ammonium peroxide mixture and/or a diluted mixture of sulfuric acid and hydrogen peroxide to the template mask 110_n. An example is illustrated in, for example, FIG. 6. The cleaning module 1014 may be, for example, a wet or dry cleaning process tool.

[0054] After cleaning the template mask 110_n, or otherwise de-bonding the template mask 110_n, the system may use the template mask 110_n to process another production workpiece from the production workpiece set 1004. To the extent that the template mask 110_n is first in the template mask set 1002, the other production workpiece is unprocessed by the template mask set 1002. Otherwise, the other production workpiece is processed up to the n-1 element in the template mask set 1002. This may, for example, continue until all production workpieces 102₁, 102₂, 102_p in the production workpiece set 1004 are processed by the template mask 110_n.

[0055] In some embodiments, the first etch transfers the pattern of the template mask 110_n to a hard mask layer, such that a second etch module 1016 performs a second etch into a target layer underlying the hard mask layer, through the hard mask layer, to transfer a pattern of the hard mask layer to the target layer. An example is illustrated in, for example, FIG. 7. Further, in some embodiments, the second etch module 1016 performs a third etch into the hard mask layer to remove the hard mask layer from over the target layer. An example is illustrated in, for example, FIGS. 8A and 8B. The second etch module 1016 may be, for example, a plasma etch process tool, and/or may be, for example, the same as the first etch module 1010.

[0056] After performing the second and/or third etch, or otherwise de-bonding the production workpiece 102_p, the system may use the production workpiece 102_p with the next template mask in the template mask set 1002 for the production workpiece 102_p. For example, n may be incremented by one and/or a new target layer may be deposited or otherwise grown over the production workpiece 102_p. This may, for example, continue until the production workpiece 102_p has been processed by all template masks 110₁, 110₂, 110_N in the template mask set 1002.

[0057] With reference to FIG. 11A, a block diagram 1100A of some embodiments of the alignment module 1006 of FIG. 10 is provided. As illustrated, a template mask 110 is arranged over a production workpiece 102. The template mask 110 has a first pattern of alignment marks 1102a arranged thereon, and the production workpiece 102 has a

second pattern of alignment marks 1102b that is arranged thereon and that is the same as the first pattern. In some embodiments, first and second patterns each comprise multiple alignment mark sets 1106, such as, for example, an alignment mark set comprising a plurality of parallel lines.

[0058] An interferometry camera 1108 measures alignment between the first pattern and the second pattern using, for example, Moiré interferometry and the superimposition of electromagnetic waves 1110 reflecting off the alignment marks 1102a, 1102b. Based on the one or more measurements, an overlay error between the template mask 110 and the production workpiece 102 is calculated and used to adjust the relative positioning of the production workpiece 102 and the template mask 110. For example, the template mask 110 may be moved laterally to compensate for the overlay error. The calculation may, for example, be performed by a controller 1112 controlling the alignment. The controller 1112 may, for example, be a microcontroller, an electronic processor, or some other electronic device programmed or configured to perform the alignment.

[0059] In some embodiments, after compensating for overlay error, fine alignment may be performed to compensate for residual error. The fine alignment may, for example, always be performed or may, for example, only be performed when the residual error exceeds a predetermined threshold. Further, the residual error may include, for example, run-out error between the template mask 110 and the production workpiece 102. The fine alignment is controlled by the controller 1112 and, in some embodiments, comprises exposing one or more digital mirror arrays 1114a, 1114b to radiation 1116 from a heat source 1118, and subsequently reflecting the radiation 1116 off the one or more digital mirror arrays 1114a, 1114b towards the production workpiece 102 and/or template mask 110. The radiation 1116 may, for example, be ultraviolet (UV) radiation or vacuum UV (VUV), and/or may, for example, be collimated by, for example, a lens 1120 before impinging on the one or more digital mirror arrays 1114a, 1114b.

[0060] The one or more digital mirror arrays 1114a, 1114b are configured to reflect the radiation 1116 and are each defined by a plurality of individual mirrors 1122. The individual mirrors 1122 may be, for example, individually controllable and/or movable. Further, the one or more digital mirror arrays 1114a, 1114b comprise a lower digital mirror array 1114a arranged under the production workpiece 102 and/or an upper digital mirror array 1114b arranged over the template mask 110. In operation, the one or more digital mirror arrays 1114a, 1114b selectively heat regions of the production workpiece 102 and/or the template mask 110, while not heating other regions of the production workpiece 102 and/or the template mask 110, to expand the heated regions and to bring the first pattern of alignment marks 1102a into alignment with the second pattern of alignment marks 1102b. The one or more digital mirror arrays 1114a, 1114b may, for example, be controlled based on feedback from the interferometry camera 1108.

[0061] With reference to FIG. 11B, a layout view 1100B of some embodiments of an individual one of the alignment mark sets 1106 of FIG. 11A is provided. The layout view 1100B may, for example, be representative of each of the alignment mark sets 1106. As illustrated, the alignment mark set comprises multiple alignment marks 1102. The multiple alignment marks 1102 comprise a plus-shaped alignment mark around which four groups of line-shaped alignment

marks are arranged, and each group of line-shaped alignment marks comprises multiple line-shaped alignment marks arranged in parallel.

[0062] In view of the foregoing, in some embodiments, the present disclosure provides a lithography process. A template mask is bonded to a production workpiece and comprises a plurality of openings defining a pattern. An etch is performed into the production workpiece, through the plurality of openings, to transfer the pattern of the template mask to the production workpiece. The template mask is de-bonded from the production workpiece.

[0063] In other embodiments, the present disclosure provides a system for performing a lithography process. A template mask comprises a plurality of openings that define a pattern and that extend through the template mask. A bond module is configured to bond a bottom surface of the template mask to a top surface of a production workpiece. An etch module is configured to perform an etch into the production workpiece, through the plurality of openings, to transfer the pattern to the production workpiece. A de-bond module is configured to de-bond the template mask from the production workpiece.

[0064] In yet other embodiments, the present disclosure provides another lithography process. A template mask is provided that comprises a plurality of openings extending through the template mask and arranged in a pattern. A production workpiece is provided that comprises a hard mask layer and a target layer stacked along a top surface of the production workpiece. A bottom surface of the template mask is directly bonded to the top surface of the production workpiece by fusion bonding. A first etch is performed into the hard mask layer, through the template mask, to transfer the pattern of the template mask to the hard mask layer. The first etch stops on the target layer and is a dry etch. The template mask is de-bonded from the production workpiece. A second etch is performed into the target layer, through the hard mask layer, to transfer the pattern of the template mask from the hard mask layer to the target layer. A third etch is performed into the hard mask layer to remove the hard mask layer.

[0065] The foregoing outlines features of several embodiments so that those skilled in the art may better understand the aspects of the present disclosure. Those skilled in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions, and alterations herein without departing from the spirit and scope of the present disclosure.

What is claimed is:

1. A lithography process comprising:

bonding a template mask to a production workpiece, wherein the template mask comprises a plurality of openings defining a pattern;

performing an etch into the production workpiece, through the plurality of openings, to transfer the pattern of the template mask to the production workpiece; and

de-bonding the template mask from the production workpiece.

2. The lithography process according to claim 1, where the lithography process comprises forming the template mask with the openings extending through the template mask, from a top surface of the template mask to a bottom surface of the template mask, and wherein bonding the template mask to the production workpiece comprises directly bonding the bottom surface of the template mask to a top surface of the production workpiece by fusion bonding.

3. The lithography process according to claim 1, further comprising:

forming the template mask from a bulk silicon substrate.

4. The lithography process according to claim 1, wherein the production workpiece comprises a substrate, and wherein the lithography process comprises:

forming a target layer covering the substrate;

forming a hard mask layer covering the target layer; and

performing the etch into the hard mask layer.

5. The lithography process according to claim 4, further comprising:

performing the etch into the hard mask layer and stopping on the target layer; and

after de-bonding the template mask from the production workpiece, performing a second etch into the target layer with the hard mask in place to transfer the pattern of the template mask from the hard mask layer to the target layer.

6. The lithography process according to claim 5, further comprising:

performing a third etch into the hard mask layer to remove the hard mask from the target layer.

7. The lithography process according to claim 1, wherein performing the etch comprises bombarding the production workpiece with plasma particles.

8. The lithography process according to claim 7, wherein performing the etch comprises collimating the plasma particles with the template mask.

9. The lithography process according to claim 1, further comprising:

aligning the template mask to the production workpiece using a first pattern of alignment marks on the template mask and a second pattern of alignment marks on the production workpiece.

10. The lithography process according to claim 9, wherein aligning the template mask to the production workpiece comprises measuring alignment between the first pattern of alignment marks and the second pattern of alignment marks using interferometry.

11. The lithography process according to claim 9, wherein aligning the template mask to the production workpiece comprises heating some regions of the template mask or the production workpiece, while not heating other regions of the template mask or the production workpiece, so as to expand the heated regions into alignment.

12. A system for performing a pattern transferring process, the system comprising:

a template mask comprising a plurality of openings that define a pattern and that extend through the template mask;

a bond module configured to bond a bottom surface of the template mask to a top surface of a production workpiece;

an etch module configured to perform an etch into the production workpiece, through the plurality of openings, to transfer the pattern to the production workpiece; and

a de-bond module configured to de-bond the template mask from the production workpiece.

13. The system according to claim **12**, wherein the template mask is a bulk silicon wafer.

14. The system according to claim **12**, wherein the production workpiece comprises a substrate, a target layer covering the substrate, and a hard mask layer covering the target layer, and wherein the etch module is configured to perform the etch into the hard mask layer and to stop on the target layer.

15. The system according to claim **14**, wherein the system further comprises:

a second etch module configured to perform a second etch into the target layer, through the hard mask layer, to transfer the pattern of the template mask from the hard mask layer to the target layer.

16. The system according to claim **12**, wherein etch module is configured to bombard the production workpiece with plasma particles to perform the etch.

17. The system according to claim **16**, wherein the template mask is configured to collimate the plasma particles.

18. The system according to claim **12**, further comprising:

an alignment module configured to align the template mask and the production workpiece using interferometry.

19. The system according to claim **18**, wherein the alignment module comprises:

an interferometry camera configured to measure alignment between the template mask and the production workpiece using interferometry;

a digital mirror array configured to focus radiation that is incident thereon on some regions of the template mask or the production workpiece, but not other regions of the template mask or the production workpiece;

a heat source configured to emit the radiation towards the digital mirror array; and

a lens configured to collimate the radiation.

20. A pattern transferring process comprising:

providing a template mask comprising a plurality of openings that extend through the template mask and that are arranged in a pattern;

providing a production workpiece comprising a hard mask layer and a target layer stacked along a top surface of the production workpiece;

directly bonding a bottom surface of the template mask to the top surface of the production workpiece by fusion bonding;

performing a first etch into the hard mask layer, through the template mask, to transfer the pattern of the template mask to the hard mask layer, wherein the first etch stops on the target layer and is a dry etch;

de-bonding the template mask from the production workpiece;

performing a second etch into the target layer, through the hard mask layer, to transfer the pattern of the template mask from the hard mask layer to the target layer; and performing a third etch into the hard mask layer to remove the hard mask layer.

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