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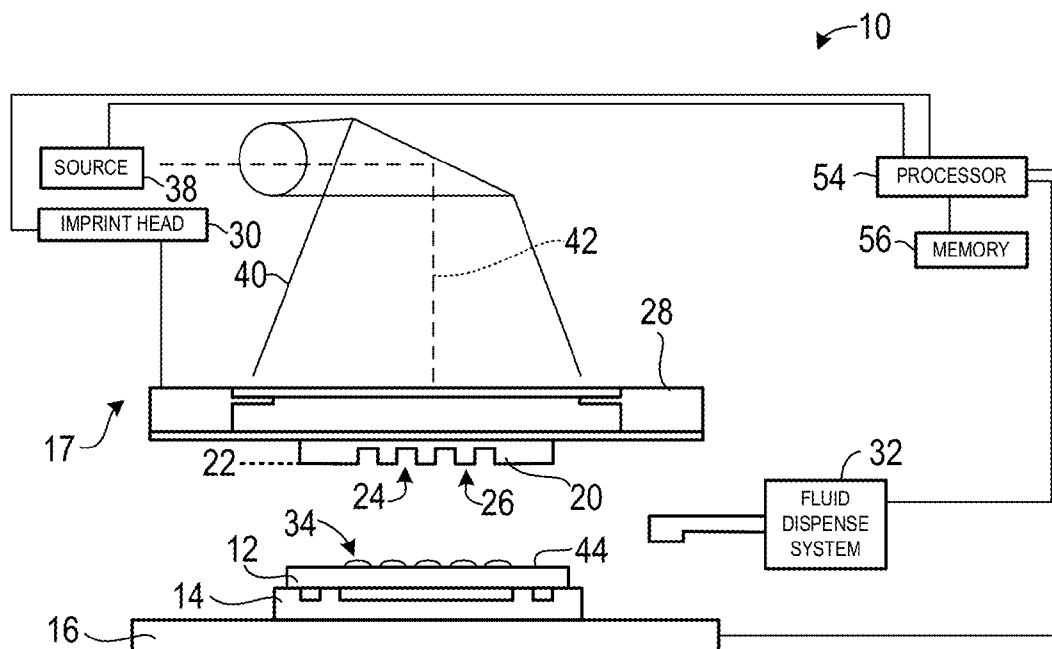
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(57) **ABSTRACT**

Methods for creating nano-shaped patterns are described. This approach may be used to directly pattern substrates and/or create imprint lithography molds that may be subsequently used to directly replicate nano-shaped patterns into other substrates in a high throughput process.

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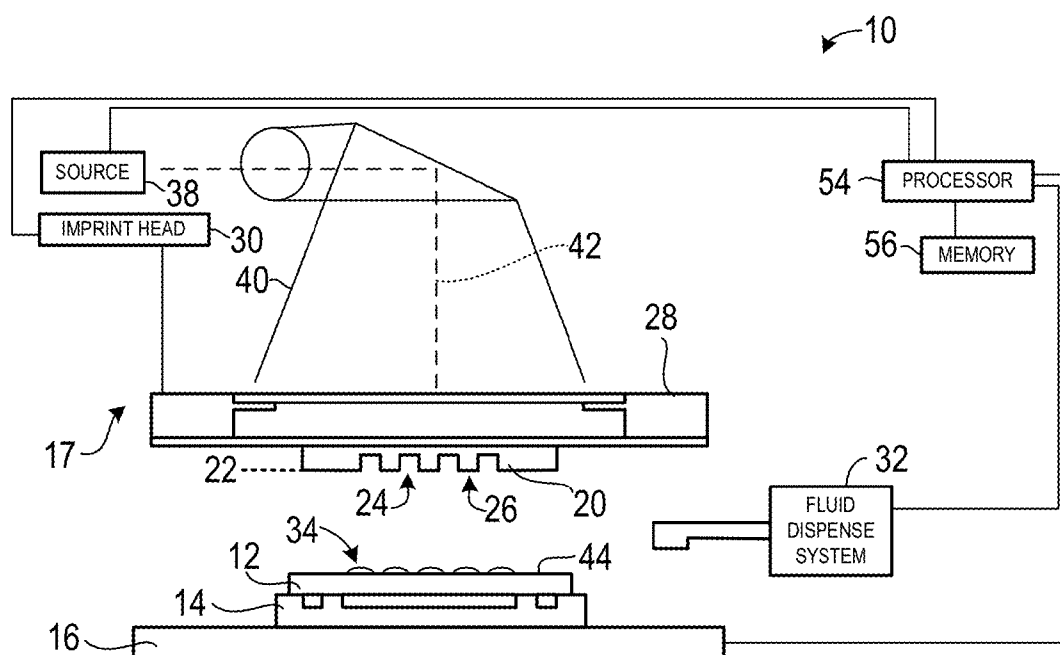


FIG. 1

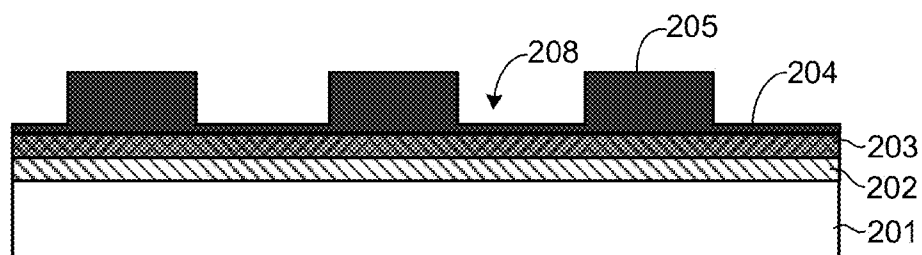


FIG. 2A

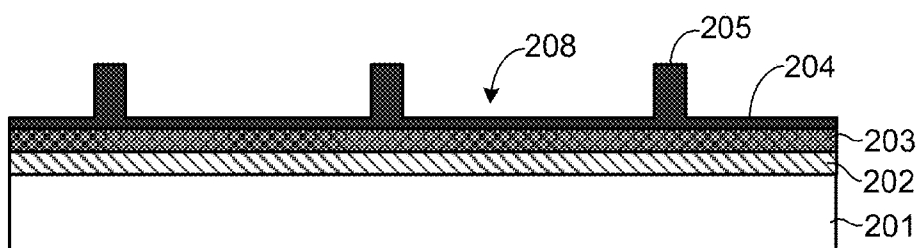


FIG. 2B

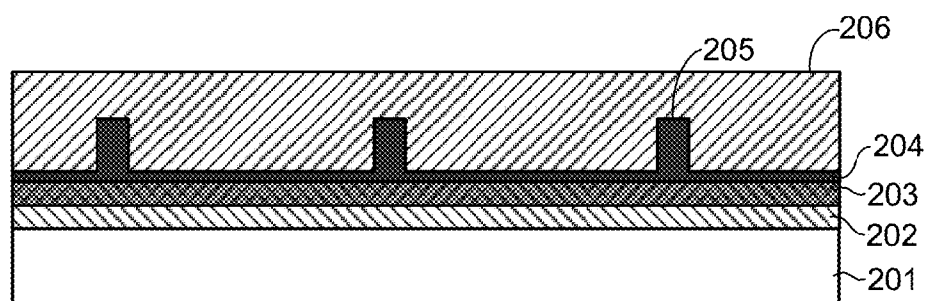


FIG. 2C

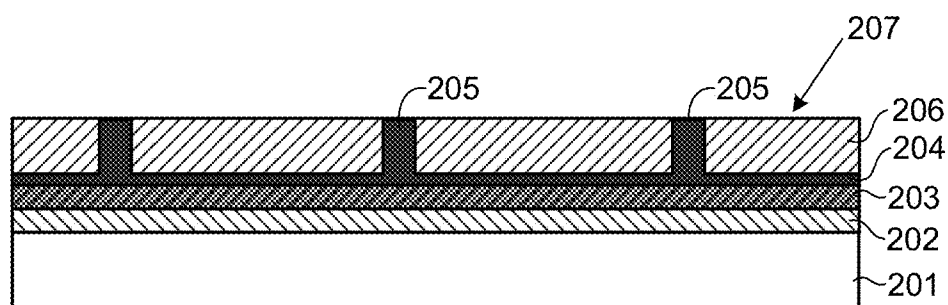


FIG. 3A

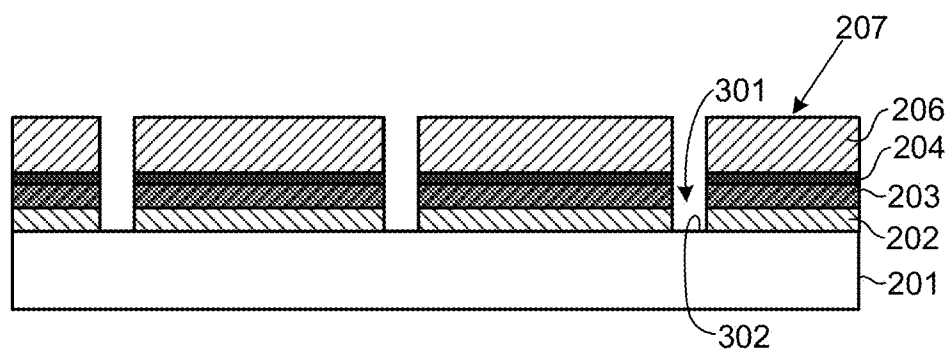


FIG. 3B

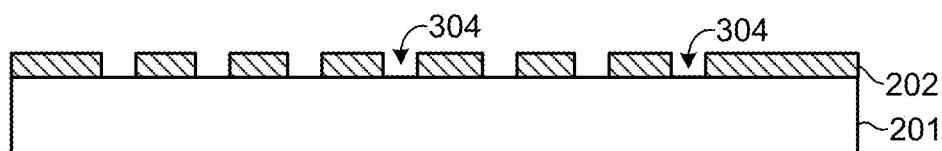


FIG. 3C

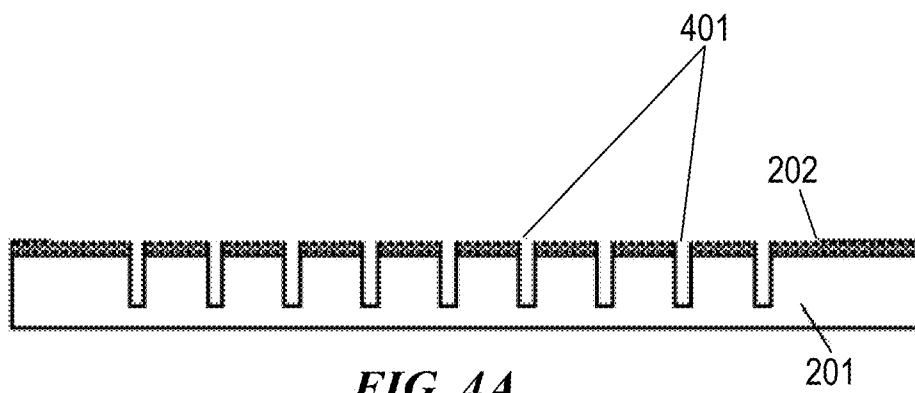


FIG. 4A

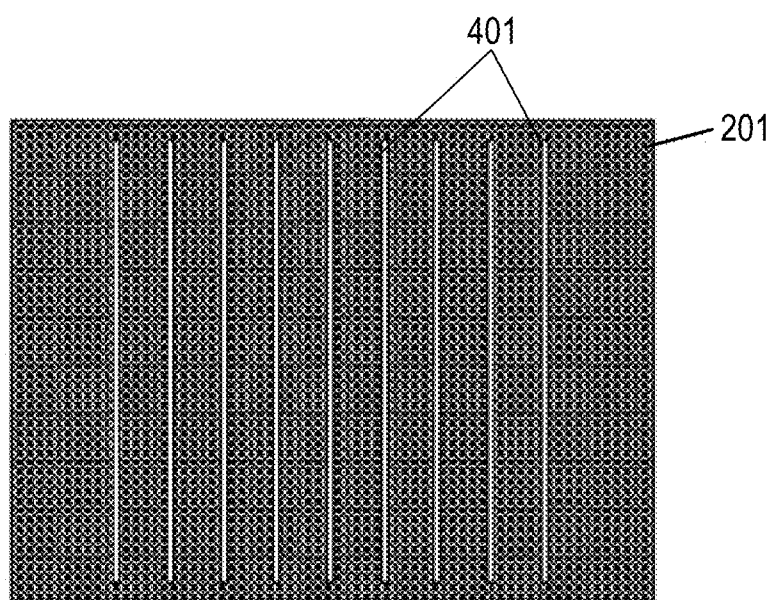


FIG. 4B

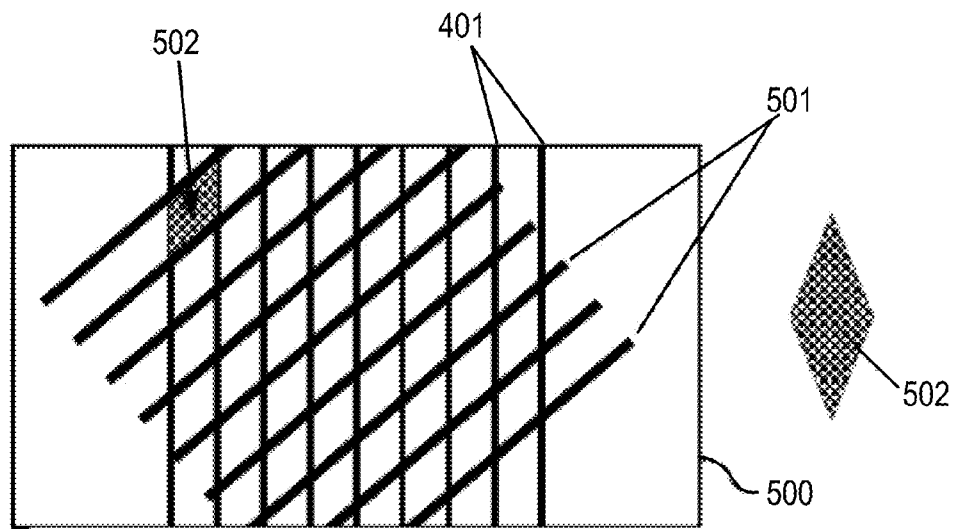


FIG. 5A

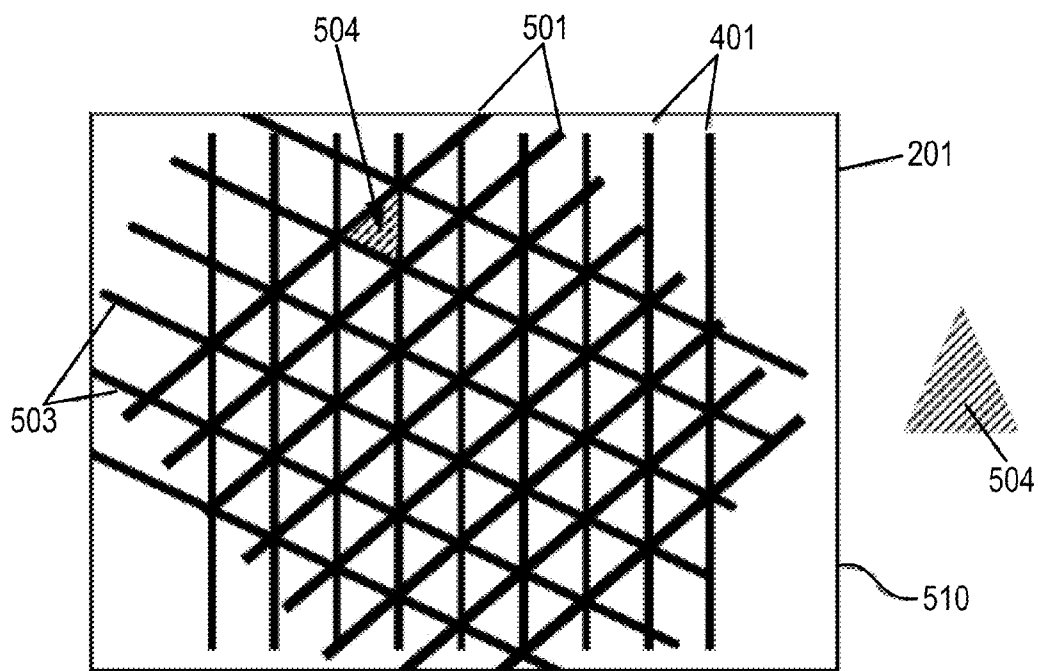


FIG. 5B

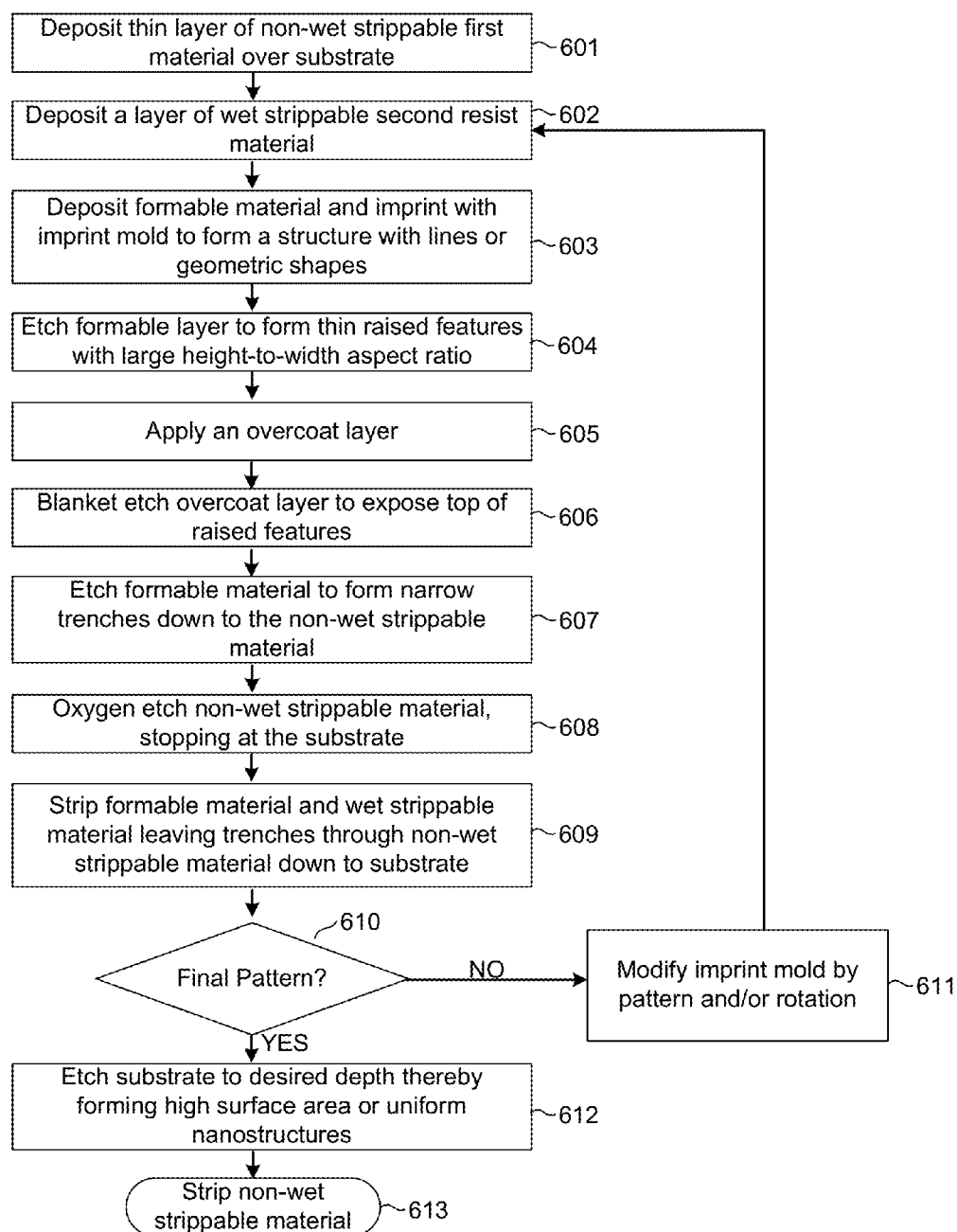


FIG. 6

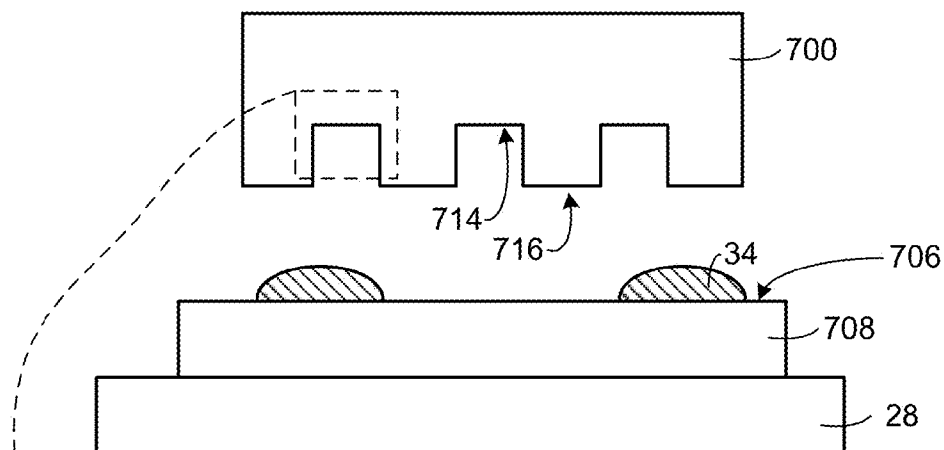


FIG. 7A

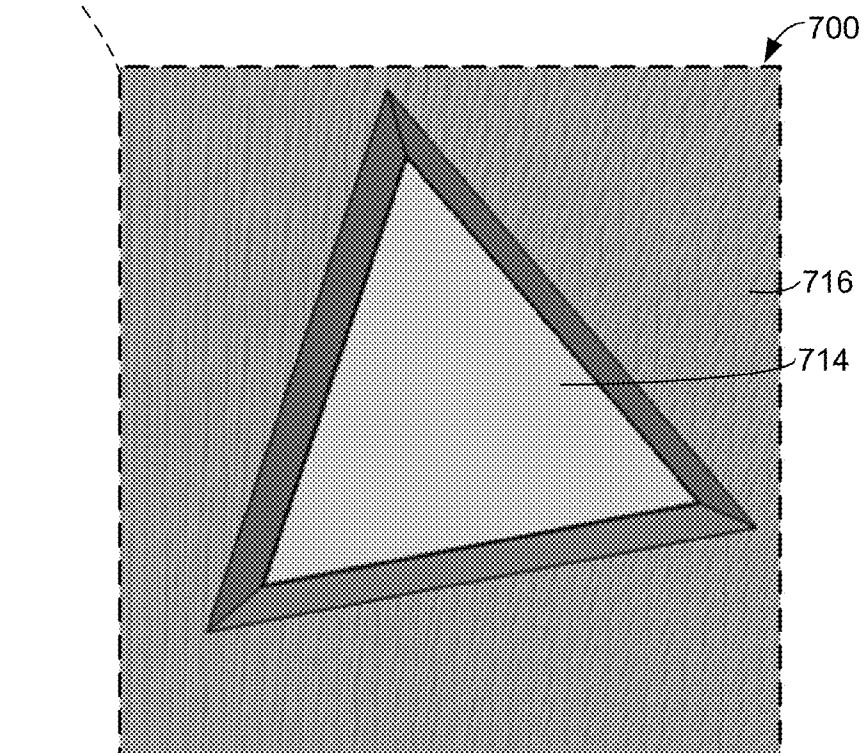


FIG. 7B

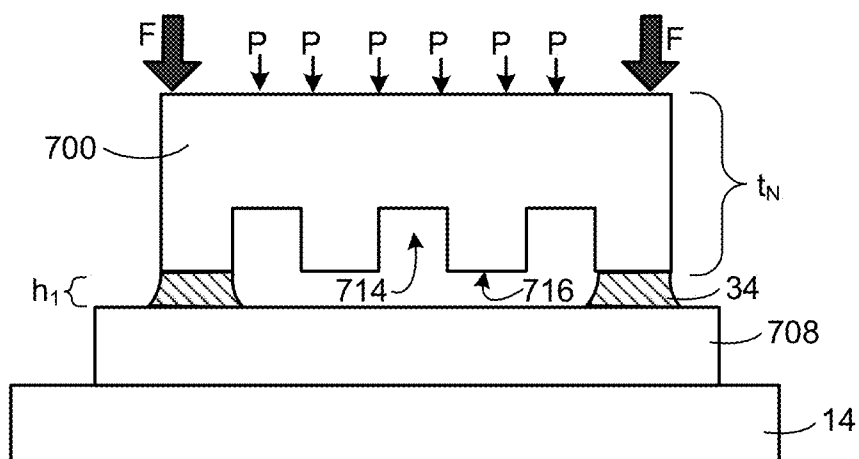


FIG. 8

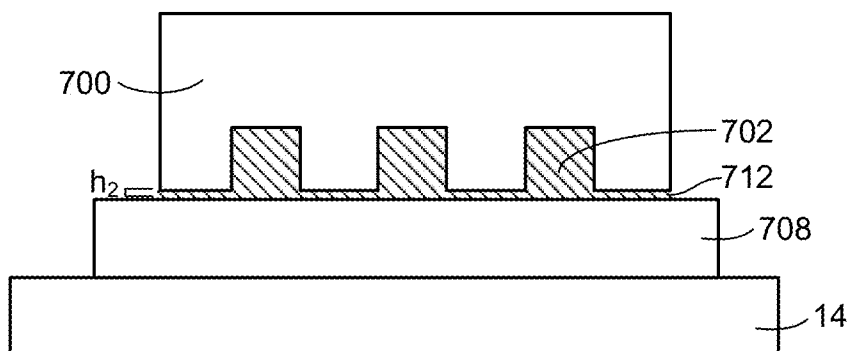


FIG. 9

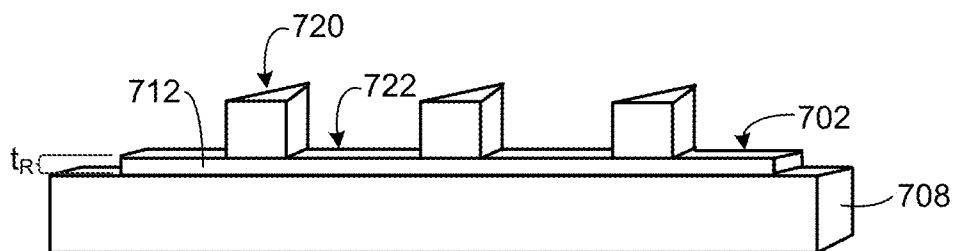


FIG. 10

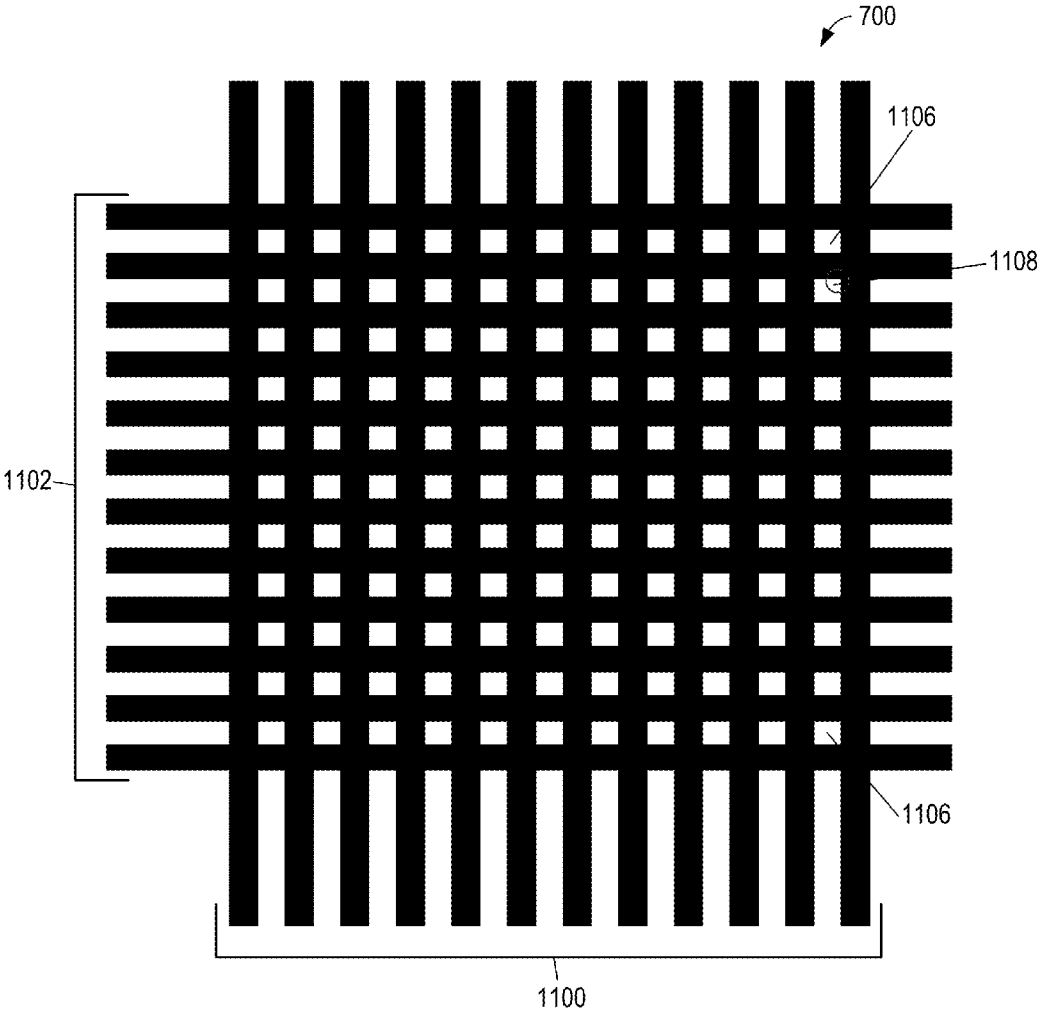


FIG. 11A

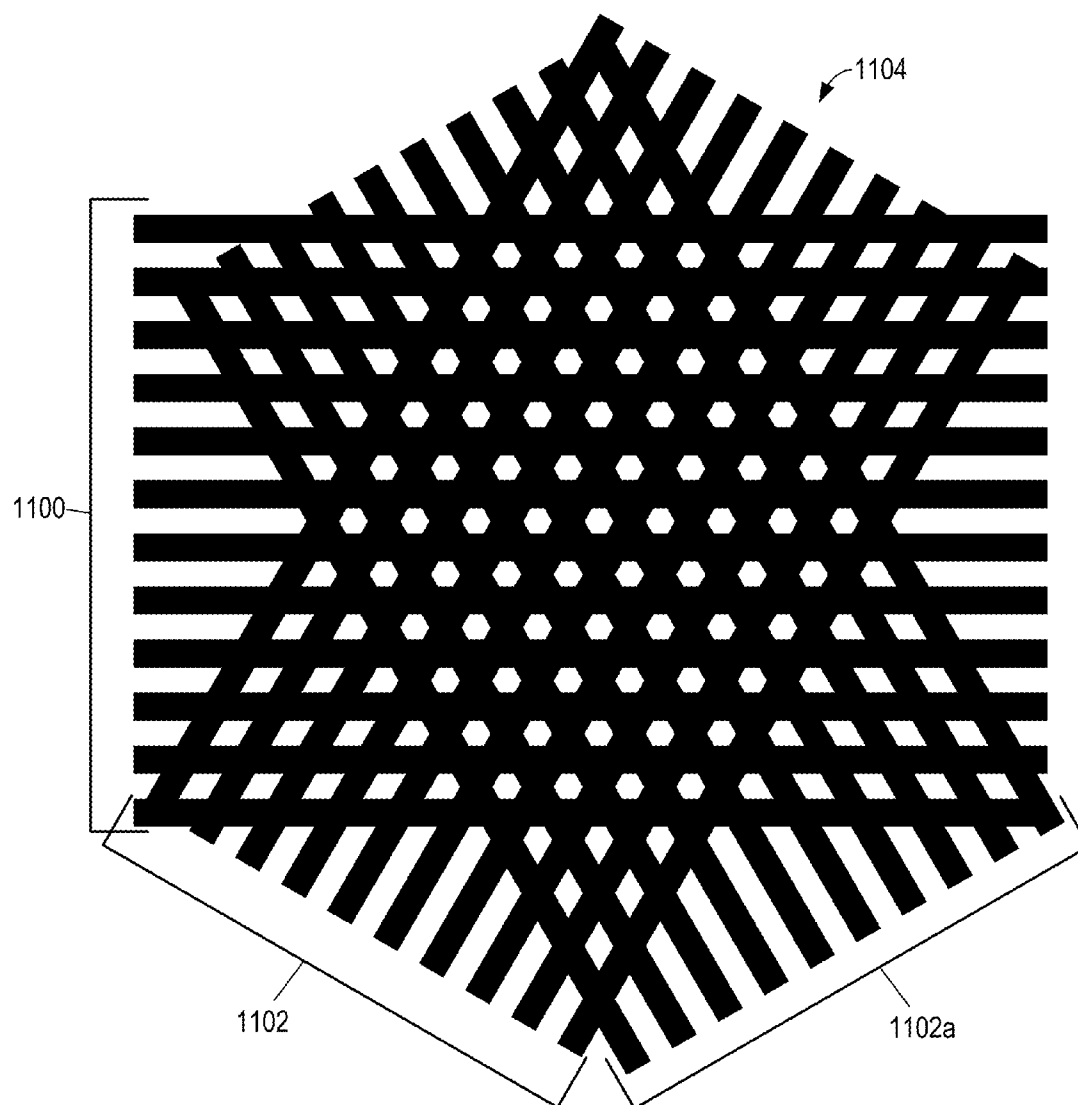


FIG. 11B

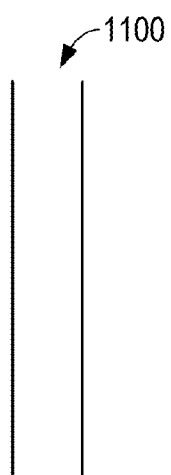


FIG. 12A

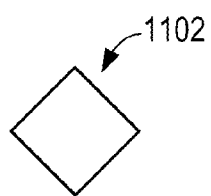


FIG. 12B

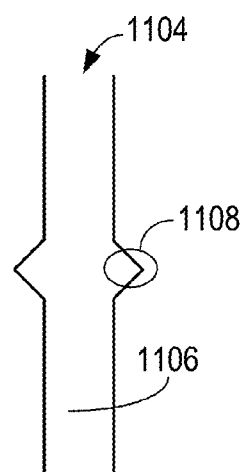


FIG. 12C

LARGE AREA PATTERNING OF NANO-SIZED SHAPES

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is a continuation of U.S. application Ser. No. 12/616,896 filed Nov. 12, 2009, which claims the benefit under 35 U.S.C. §119(e)(1) of U.S. Provisional Application No. 61/114,239 filed Nov. 13, 2008; each of which is hereby incorporated by reference herein in its entirety.

BACKGROUND

[0002] Nano-fabrication involves the fabrication of very small structures, e.g., having features on the order of 100 nanometers or smaller. One area in which nano-fabrication has had a sizeable impact is in the processing of integrated circuits. As the semiconductor processing industry continues to strive for larger production yields while increasing the circuits per unit area formed on a substrate, nano-fabrication becomes increasingly important. Nano-fabrication provides greater process control while allowing increased reduction of the minimum feature dimension of the structures formed. Other areas of development in which nano-fabrication has been employed include biotechnology, optical technology, energy systems and the like.

[0003] An exemplary nano-fabrication technique is referred to as imprint lithography. Exemplary imprint lithography processes are described in detail in numerous publications, such as U.S. Pat. Publication No. 2004/0065976, U.S. Pat. Publication No. 2004/0065252, and U.S. Pat. No. 6,936,194, all of which are assigned to an assignee of the present invention.

[0004] An imprint lithography technique disclosed in each of the aforementioned U.S. patent application publications and U.S. patent includes formation of a relief pattern in a formable liquid (polymerizable layer) and transferring a pattern corresponding to the relief pattern into an underlying substrate. The substrate may be positioned upon a motion stage to obtain a desired position to facilitate patterning thereof. To that end, a template is employed spaced-apart from the substrate with a formable liquid present between the template and the substrate. The liquid is solidified to form a solidified layer that has a pattern recorded therein that is conforming to a shape of the surface of the template in contact with the liquid. The template is then separated from the solidified layer such that the template and the substrate are spaced-apart. The substrate and the solidified layer are then subjected to processes to transfer, into the substrate, a relief image that corresponds to the pattern in the solidified layer.

[0005] Many nano-patterning applications take advantage of the size and uniform shape of nano-scale features to achieve a desired result. Many processes employed to make nano-patterns use a "growth" process to grow a particular type and size of nano-patterns. Unfortunately, these types of processes may be slow and prone to producing nano-patterns whose size and shape may be insufficiently controlled to produce desired performance cost effectively.

DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1 illustrates a system suitable to form a relief pattern on a substrate according to embodiments herein.

[0007] FIGS. 2A-2C illustrate cross-section views showing material layers after processing according to embodiments herein.

[0008] FIGS. 3A-3C illustrate cross-section views showing material layers after further processing according to embodiments herein.

[0009] FIG. 4A illustrates a cross-section view showing trenches etched into the substrate according to embodiments herein.

[0010] FIG. 4B illustrates a top view of the trenches of FIG. 4A.

[0011] FIG. 5A illustrates a top view of an exemplary patterned surface having nano-structures formed by etching trenches formed by a first pattern and a second pattern.

[0012] FIG. 5B illustrates a top view of another exemplary patterned surface having nano-structures formed by etching trenches formed by a first pattern and additional overlaying patterns.

[0013] FIG. 6 illustrates a flow diagram of an exemplary for forming nano-structures according to embodiments herein.

[0014] FIG. 7A illustrates a simplified cross-sectional view of a nano-pattern mold positioned above a substrate.

[0015] FIG. 7B illustrates a top-down magnified view of a recession of the nano-pattern mold in FIG. 7A.

[0016] FIG. 8 illustrates a simplified cross-sectional view of a nano-pattern mold positioned above a substrate at a first height.

[0017] FIG. 9 illustrates a simplified cross-sectional view of a nano-pattern mold positioned above a substrate at a second height.

[0018] FIG. 10 illustrates a simplified perspective view of a nano-pattern structure formed on a substrate.

[0019] FIG. 11A illustrates a top-down view of an exemplary rectangular column formed by using a first pattern and an overlaying pattern.

[0020] FIG. 11B illustrates a top-down view of an exemplary hexagonal column formed by using a first pattern and overlaying patterns.

[0021] FIGS. 12A-12C illustrate a top-down view of an exemplary first pattern, an exemplary second pattern, and an exemplary patterned surface formed by the first pattern and the second pattern.

DETAILED DESCRIPTION

[0022] Referring to FIG. 1, a system 10 to form a relief pattern on a substrate 12 is shown. Substrate 12 may be coupled to a substrate chuck 14. As shown substrate chuck 14 is a vacuum chuck, however, substrate chuck 14 may be any chuck including, but not limited to, vacuum, pin-type, groove-type, or electromagnetic, as described in U.S. Pat. No. 6,873,087, which is incorporated herein by reference. Substrate 12 and substrate chuck 14 may be supported upon a stage 16. Further, stage 16, substrate 12, and substrate chuck 14 may be positioned on a base (not shown). Stage 16 may provide motion along the x, y, and z axes.

[0023] Spaced-apart from substrate 12 is a master patterning device 17. Master patterning device 17 comprises a template 28 having a mesa 20 extending therefrom towards substrate 12 with a patterning surface 22 thereon. Further, mesa 20 may be referred to as a mold 20. Mesa 20 may also be referred to as a nano-imprint mold 20. In a further embodiment, template 28 may be substantially absent of mold 20. In still a further embodiment, mold 20 may be integrally formed with template 28. Template 28 and/or mold 20 may be formed

from such materials including, but not limited to, fused-silica, quartz, silicon, organic polymers, siloxane polymers, borosilicate glass, fluorocarbon polymers, metal, and hardened sapphire. As shown, patterning surface **22** comprises features defined by a plurality of spaced-apart recesses **24** and protrusions **26**. However, in a further embodiment, patterning surface **22** may be substantially smooth and/or planar. Patterning surface **22** may define an original pattern that forms the basis of a pattern to be formed on substrate **12**. Master patterning device **17** may be formed employing electron beam (e-beam) lithography.

[0024] Master patterning device **17** may be coupled to a chuck **28**, chuck **28** being any chuck including, but not limited to, vacuum, pin-type, groove-type, or electromagnetic, as described in U.S. Pat. No. 6,873,087. Further, chuck **28** may be coupled to an imprint head **30** to facilitate movement of master patterning device **17**.

[0025] System **10** further comprises a fluid dispense system **32**. Fluid dispense system **32** may be in fluid communication with substrate **12** so as to deposit polymerizable material **34** thereon. System **10** may comprise any number of fluid dispensers, and fluid dispense system **32** may comprise a plurality of dispensing units therein. Polymerizable material **34** may be positioned upon substrate **12** using any known technique, e.g., drop dispense, spin-coating, dip coating, chemical vapor deposition (CVD), physical vapor deposition (PVD), thin film deposition, thick film deposition, and the like. Typically, polymerizable material **34** is disposed upon substrate **12** before the desired volume is defined between mold **20** and substrate **12**. However, polymerizable material **34** may fill the volume after the desired volume has been obtained.

[0026] Polymerizable material **34** may comprise a solvent based monomer or a spin-on material. Further, polymerizable material **34** may comprise a monomer mixture as described in U.S. Pat. No. 7,157,036 and U.S. Pat. No. 8,076,386, both of which are incorporated herein by reference.

[0027] System **10** further comprises a source **38** of energy **40** coupled to direct energy **40** along a path **42**. Imprint head **30** and stage **16** are configured to arrange master patterning device **17** and substrate **12**, respectively, to be in superimposition and disposed in path **42**. System **10** may be regulated by a processor **54** that is in data communication with stage **16**, imprint head **30**, fluid dispense system **32**, and source **38**, operating on a computer readable program stored in memory **56**.

[0028] The above-mentioned system and process may be further employed in imprint lithography processes and systems referred to in U.S. Pat. No. 6,932,934, U.S. Pat. No. 7,077,992, U.S. Pat. No. 6,900,881, U.S. Pat. No. 7,077,992, U.S. Pat. No. 7,179,396, and U.S. Pat. No. 7,396,475, all of which are incorporated by reference herein. In a further embodiment, the above-mentioned relief pattern may be created by any known technique, e.g., photolithography (various wavelengths including G line, I line, 248 nm, 193 nm, 157 nm, and 13.2-13.4 nm), contact lithography, e-beam lithography, x-ray lithography, ion-beam lithography and atomic beam lithography. For example, the above-mentioned relief pattern may be created using techniques described in U.S. Pat. No. 5,772,905, which is hereby incorporated by reference.

[0029] Nano-structures with varying geometric cross-sections may be fabricated using techniques described herein. Generally, this process may include two phases. In Phase 1, a

combination of multiple lithographic steps may be used to create an imprint template with shaped cross-sections (referred to here as nano-shaped templates). The multiple lithographic steps may use one or more kinds of lithography processes such as electron beam, imprint lithography or photolithography. In Phase 2, the nano-shaped template may be used in conjunction with an imprint lithography process to obtain a high-speed approach for replicating the nano-shapes.

Phase 1: Formation of Nano-Shaped Template

[0030] Generally, Phase 1 may comprise multiple process steps. For simplification in description, the formation of the nano-shaped template is described herein using imprint lithography. However, it should be noted that the patterning steps may use photolithography, electron beam lithography, and the like.

[0031] Generally, a thin layer of first material (e.g., non-wet strippable material), including polymers, dielectrics, metals, etc., may be deposited on a desired substrate made of a nano structure material. A layer of second resist (e.g., wet stripable material) may be deposited over the first material. The second resist may be selectively wet-stripped with the first material substantially remaining intact. A formable imprint lithography material may be deposited over the second resist material and the lithography material may be imprinted to form a relief pattern. The mold used to create the relief pattern using imprinting may be comprised of simple geometries formable from an e-beam process (e.g., lines, dots, holes, and the like). An optional adhesion material may be deposited between the second resist material and the third formable material to facilitate adhesion of the formable material to the underlying substrate. Adhesive layer may be formed of adhesion materials as further described in U.S. Publication No. 2007/0212494, which is hereby incorporated by reference. The relief pattern in the formable layer may be optionally etched to produce raised patterns of formable material, wherein the raised patterns have a smaller size as compared to the size prior to the etch.

[0032] An overcoat material may be deposited over the etched formable layer. Overcoat material may be blanket etched to expose a top surface of the thin raised lines. The exposed formable material may be etched to form trenches extending down to the non wet strippable first resist material. Non-wet strippable resist may be dry etched stopping when the substrate is reached. The formable layer material and the wet stripable material may be stripped leaving the non-wet strippable material with trenches extending down to the substrate. The substrate may be etched down to a desired depth if a pattern in the surface is final. Finally, the imprint mold may be modified in form and/or orientation and the process is repeated from step **2** if the pattern in the surface is not final.

[0033] FIGS. 2A-4B illustrate an exemplary formation of a nano-shaped template having nano-patterned structures. FIG. 2A illustrates a cross-section view of a substrate **201** with resist layer **202** (e.g., a non-wet strippable) and resist layer **203** (e.g., a wet strippable) disposed over layer **202**. A formable material **204** may be deposited over the two resist layers and imprinted to form exemplary features (e.g., lines) **205** with spaces **208**, that may be of equal dimensions using system and methods described in relation to FIG. 1.

[0034] FIG. 2B illustrates a cross-section view of the multi-layer structure of FIG. 2A after the formable material **204** has been etched thereby thinning features **205** to form features

that have a high aspect ratio of height to width. Substrate **201**, resist layer **202** and resist layer **203** are also visible in this view.

[0035] FIG. 2C illustrates a cross-section view of the multi-layer structure of FIG. 2B after an overcoat layer **206** has been applied over the surface to a height above the features **205**. This overcoat layer may be a silicon-containing polymer similar to the disclosure in U.S. Pat. No. 7,186,656; which is hereby incorporated by reference. Substrate **201**, resist layer **202**, and resist layer **203** are again visible in this view.

[0036] FIG. 3A illustrates a cross-section view of the structure of FIG. 2C after overcoat layer **206** has been planarized to expose the tops of the features **205** above surface **207**. Substrate **201**, resist layer **202**, resist layer **203**, and overcoat layer **206** are visible in this view.

[0037] FIG. 3B illustrates a cross-section view of the structure of FIG. 3A after the formable material **204** has been etched through to resist layer **203**. Further, non-wet etching (e.g., with O₂) removes resist layer **202** in the trenches stopping at substrate **201**. Substrate **201**, resist layer **202**, resist layer **203**, formable layer **204**, and overcoat layer **206** are visible in this view. Channel **301** may be formed when features **205** are etched. Further, removal of the layers **202-204** in channel **301** may extend channel depth **302** to a surface of substrate **201**.

[0038] FIG. 3C illustrates a cross-section view of the structure in FIG. 3B after overcoat layer **206**, formable material **204**, and resist layer **203** have been stripped leaving only the resist layer **202** with grooves **304** to the substrate **201**. Forming nano-patterns or surface features of a particular shape may be provided by repeating the process steps of FIG. 2A-FIG. 3C until a desired surface pattern corresponding to the desired nanostructure(s) has been achieved.

[0039] FIG. 4A illustrates a cross-section view of the exemplary pattern of FIG. 3C etched to a particular depth forming grooves **401**. Substrate **201** and resist layer **202** are visible in this view. FIG. 4B illustrates a top view of grooves **401** in substrate **201**.

[0040] FIG. 5A illustrates a top view of the substrate **201** after processing with a first pattern **501** using process steps of FIGS. 2A-4B. A rhombus shaped surface pattern **502** may thereby be formed using this process sequence. The trenches and surface pattern **502** may be used to increase the surface area of structure **500**.

[0041] FIG. 5B illustrates a top view of the substrate **201** after processing with an additional overlaid pattern **503** using process steps of FIGS. 2A-4B. A triangular shaped surface pattern **504** may thereby be formed using this process sequence. The trenches and the surface pattern **504** may be used to increase the surface area of structure **510**. In another embodiment, the trenches are etched through thereby producing uniform nano-shaped patterns that have the triangular cross-section and a length corresponding to the substrate thickness.

[0042] FIG. 6 is a flow diagram of process steps for formation of an exemplary nano-shaped template having nano-shaped structures. In step **601**, a thin layer of first resist may be deposited on a substrate. In step **602**, an overlay of second resist may be deposited. For example, second resist may include a wet strippable material, a soluble material, such as PMGI (Polymethylglutarimide), and/or the like. PMGI may be wet-stripped by tetramethylammonium hydroxide (TMAH) that may be obtained under the trade name CD260 from Shipley Company, L.L.C. (now Rohm Haas). Altern-

tively, the second resist may be any negative photoresist, for example poly hydroxyl styrene. Each resist layer may include an intermediate layer for adhesion purposes such as the material disclosed in U.S. Publication No. 2007/0212494. In step **603**, a layer of formable material may be deposited and imprinted with an imprint mold to form a third resist layer that has relief patterns of raised patterns separated by depressions as spaces. In one embodiment, the width of the raised patterns and spaces are equal. In step **604**, the relief pattern may be etched forming smaller raised patterns with a large height to width ratio. In step **605**, an overcoat of silicon-containing organic material may be applied to cover the raised lines. In one embodiment, overcoat layer may be a silicon-containing polymer similar to the disclosure in U.S. Pat. No. 7,186,656. In step **606**, a blanket etch may expose the top surface of the raised lines. In step **607**, the formable material may be etched to form trenches down to the first resist material, which responds to a different etch chemistry. In step **608**, the first resist material may be dry etched (e.g., with oxygen) stopping at the substrate. In step **609**, the formable material and the second resist may be stripped leaving trenches through the first resist down to the substrate. In step **610**, a decision may be made if the pattern formed in the surface of the substrate is the final pattern. If the decision is NO, then in step **611**, the imprint mold may be modified either by an overlaying pattern, alterations to the current pattern, and/or rotation of an existing pattern. For example, a branch may be taken back to step **602** wherein some of the process steps may be repeated forming a second pattern overlaying the first pattern in the substrate. If the decision in step **610** is YES, then in step **612**, the substrate may be etched through the patterned first resist layer to a desired depth thereby forming a shaped nano-structure on the substrate. In step **613**, the first resist material may be stripped away.

[0043] In another embodiment, FIG. 6 may involve using a metal film (such as chromium). For example, the metal film may be included in Step **601**. Step **602** may be eliminated. Steps **604-608** may be as is in FIG. 6. However, step **609** may be replaced by a halogen and O₂ plasma ashing processes to remove all the organic materials leaving behind the etched pattern in the metal film. This process may be repeated as many times as needed to create nano-shapes. Additionally, an optional adhesion layer (described earlier) may be used just prior to the imprinting step in Step **603**.

[0044] In another embodiment of the process of FIG. 6, Steps **604-606** may be eliminated and the formable imprinted material of Step **603** may be directly etched into materials put down in earlier steps (whether it is a wet strippable second material and a non-wet strippable first material or a metal film such as chromium used without the wet strippable material). This embodiment leads to patterns that have the opposite tone of the patterns obtained in the process steps **603-606** in FIG. 6.

[0045] In another embodiment of the process of FIG. 6, Steps **601** and **602** may be eliminated and a metal film (e.g., chromium) may be deposited on the substrate. Formable material of Step **603** may be imprinted and etched; however, the pattern may be etched directly into the substrate. Steps **605-608** may be eliminated and formable material stripped leaving trenches in the metal film and the substrate. The process may then be repeated as many times as needed to create nano-shapes.

[0046] The FIGS. 2-5 illustrate process steps that result in a substrate with shaped nano-structures which are valuable in

many applications. Nano-structures other than those shown may be produced by the method described herein and are considered within the scope of the present invention. Additionally, elements of process systems and methods disclosed in U.S. Pat. No. 7,186,656, U.S. Pat. No. 7,252,777, and U.S. Pat. No. 7,261,831 may be used to aid in formation of nano-structures, all of which are hereby incorporated by reference in their entirety.

[0047] Exemplary nano-structures are illustrated in FIGS. 11-12. For example, FIGS. 11A and 11B illustrate shapes such as rectangles, squares, and hexagons that may be created. It should be noted that other shape may be formed including, but not limited to triangles, and any other fanciful shape. In FIG. 11A, a first pattern 1100 may be overlayed by a second pattern 1102 providing a surface pattern 1104 having a plurality of nano-shapes 1106 having at least one sharp edge 1108. In FIG. 11B, first pattern 1100a may be overlayed by second pattern 1102 and additional pattern 1102a.

[0048] In some embodiments, the second pattern 1102 and/or additional patterns may be substantially similar to first pattern 1100, for example, a rotation of the pattern. Alternatively, the second pattern 1102 and/or additional patterns may be substantially different than first pattern 1100. For example, FIG. 12A illustrates first pattern 1100 and FIG. 12B illustrates second pattern 1102. As shown in FIG. 12C, overlay of first pattern 110 and second pattern 1102 may provide surface pattern 1104 having a plurality of nano-shapes 1106 having at least one sharp edge 1108.

[0049] The above detailed description describes a process where nano-patterns for a final product or for fabricating an imprint mold may be realized. For certain nano-patterns, it may not be practical to directly create a mold using a typical e-beam process. In this case, the disclosed process may be used to create a first imprint mold that has desired nano-patterns with desired sharp corners or edges. This first imprint mold may then be used to repeatedly pattern a new substrate to create more complex nano-patterns, again with the desired sharp corners or edges. Once the desired complex nano-patterns are achieved on the new substrate, it in turn may be used in a step and repeat process to fabricate a large area imprint mold that now is able to produce the complex nano-pattern for production that is both fast and cost effective.

[0050] Phase 2: Nano-Pattern Structure Replication

[0051] FIGS. 7-10 illustrate side views of exemplary formation of nano-pattern structures 702. Generally, polymerizable material 34 may be deposited on the surface 706 of a substrate 708 and contacted by a nano-pattern mold 700 to form the nano-pattern structures 702 using the imprint lithography process described herein in relation to FIG. 1. The nano-pattern structures 702 may include a residual layer 712 and features (e.g. protrusions 720 and/or recessions 722) having at least one sharp edge. Residual layer 712 may have a thickness t_R . A thin residual layer 712 may reduce the occurrence of rounded features (e.g. protrusions 720) during subsequent processing of nano-pattern structures 702. For example, residual layer 712 may have a thickness t_R of 1-25 nm to reduce the occurrence of rounded features.

[0052] The residual layer thickness t_R may be controlled by the volume of polymerizable material 34, surface energy, and/or the like. The description below outlines methods for controlling residual layer thickness t_R to reduce and/or eliminate occurrence of rounded features and provide sharp edges.

Volume Control

[0053] The selection for the volume of polymerizable material 34 may be determined by three features: 1) drop volume, 2) drop spreading, and 3) template volume.

[0054] Polymerizable material 34 may be a low viscosity polymerizable imprint solution having a pre-determined drop volume. Drop volume of polymerizable material 34 may be selected based on how far drops spread before contact between the nano-pattern mold 700 and substrate 708 due to high capillary forces at the perimeter of the drop. For example, polymerizable material 34 may have a drop volume of 0.5-50 cps.

[0055] Drop spread is generally a function of the drop volume, volume of nano-pattern mold 700, surface energy of nano-pattern mold 700 and/or surface energy of substrate 708. For example, for a blank nano-pattern mold 700, a 6 pl drop volume may provide a drop spread of approximately seven times the dispensed diameter of the drop. This drop volume may further result in the residual layer 712 having a range of between 10 and 15 nm.

[0056] Generally, the residual layer may further be defined by the excess polymerizable material 34 above the volume of the nano-patterned mold 700 within the area that the drop will spread over a given time. In some cases, the volume of polymerizable material 34 per drop spread area may be significantly large compared to the volume of nano-patterned mold 700. This may result in a thick residual layer 712, e.g. >5 nm.

[0057] The surface energies enable the polymerizable material 34 to wet the nano-patterned mold 700 and surface 706 of the substrate 708 such that the polymerizable material 34 may be transported over large distances well in excess of the initial drop size, i.e. <100 μ m diameter. Fluid movement once the nano-patterned mold 700 contacts the polymerizable material 34 may be driven by capillary action and the contact geometry between the nano-patterned mold 700 and substrate 708. For example, drops may expand up to 6 or 7 times their drop diameter to form a uniform film. However, it is important there is not a great excess of monomer above the template volume, or the residual layer thickness will be >5 nm.

Dummy Volume Fill Features

[0058] Dummy volume fill features may be introduced in certain nano-patterned mold 700 regions to "soak up" the excess polymerizable material 34. The need for such structures may be determined by the following equation. If the nano-patterned mold 700 feature volume is small compared to the local drop volume, dummy fill may be required for <5 nm residual layer thickness t_R .

DEFINITION OF VARIABLES

- [0059] r =the drop radius
- [0060] r_i =as-dispensed drop radius
- [0061] t_s =drop spreading time
- [0062] t =time
- [0063] V_d =as-dispensed drop volume
- [0064] V_f =template feature volume
- [0065] df =template feature depth
- [0066] v =template duty cycle in the case of a grating
- [0067] af =area occupied by features
- [0068] RLT =residual layer thickness
- [0069] ad =drop spread area
- [0070] Residual layer thickness t_R over the area where a drop spreads for a grating structure is defined by:

$$ad=[ri+(dr/dt)*ts]^2*v$$

$$Vf=af*d/v \text{ for the case of a grating structure}$$

$$RLT=[Vd-(af*d/v)]/[ri+(dr/dt)*ts]^2*v\}$$

[0071] If the residual layer thickness t_R is positive and >5 nm, then dummy fill may be required such that Vf is on the order of the drop volume for a given spread area. If the residual layer thickness t_R is negative, then additional polymerizable material may be added.

[0072] If the feature area is too small or etch depth too shallow for a given drop spread area, dummy fill may be required to consume the excess volume within the drop spread area. The drop spread area is a function of the feature area and depth and can limit the spread of a drop as the volume of the polymerizable material **34** is consumed.

Surface Energy

[0073] The area over which the drop will spread may be a function of the surface energies between polymerizable material **34**, nano-patterned mold **700** and substrate **708**, the viscosity of the polymerizable material **34**, and/or capillary forces. If the capillary forces are high, spreading may occur fast and as such may require low viscosity fluids and a thin film within the drop area.

[0074] To enable efficient fluid spreading and feature filling, the contact angles of the polymerizable material **34** with the nano-patterned mold **708** and/or substrate **708** may be controlled. The contact angles may be managed by applying Transpin® or ValMat® adhesion promoters to the substrate **708**, and through the use of surfactants in the polymerizable material **34** that may coat the nano-patterned mold **700**. As such, the contact angle of the polymerizable material **34** with the nano-patterned mold **700** may be about $<500^\circ$, while the contact angle of the polymerizable material **34** with the substrate **708** may be about $<150^\circ$. The contact angles as a measure of surface energies may enable the features of the nano-patterned mold **700** to readily fill the nano-patterned mold **700** and the polymerizable material **34** to readily spread large distances over the substrate **708**. Long distance spreading may be controlled by surface energies, viscosity and capillary forces. The ability to control surface energies may enable the monomer to spread over large distances.

Formation of Nano-Shaped Structures

[0075] FIGS. 7A and 7B illustrate nano-pattern mold **700** positioned above substrate **708** having polymerizable material **34** deposited thereon. Nano-pattern mold **700** may have features (e.g., recessions **714** and/or protrusions **716**). Recessions **714** and/or protrusions **716** may be formed having sharp edges using the process described herein. For example, nano-pattern mold **700** may be formed having recessions **714** in a triangular shape as illustrate in FIG. 7B. Although a triangular shape is illustrated, it should be noted that any shape having sharp edges and features may be formed including, but not limited to, rectangular, hexagonal, or any other fanciful shape.

[0076] FIGS. 8-9 illustrate the spread of polymerizable material **34** as nano-pattern mold **700** positioned at a height h_1 (FIG. 8) moves to height h_2 (FIG. 9). Nano-pattern mold **700** may have a thickness t_N . For example, nano-pattern mold **700** may have a thickness of 0.5 nm-10 nm.

[0077] The spreading of polymerizable material **34** during movement of the nano-pattern mold **700** from height h_1 to height h_2 is generally capillary driven with some additional applied forces. For example, an amount of force F may be provided by imprint head **38** (shown in FIG. 1) on nano-pattern mold **700** to position nano-pattern mold **700** at height h above substrate **708**. The force F , however, may be minimal (e.g. 0-10 N). Additionally, chuck **28** (shown in FIG. 1) may apply pressure P . Pressure P may also be just enough to provide suitable positioning of nano-pattern mold **700** without substantial bowing or other substantial deformations. For example, pressure P may be approximately 0-0.1 atm. Minimal applied forces (e.g., force F and pressure P) may reduce deformation of the residual layer **712**. Additionally, it should be noted, that chuck **14** may provide minimal force to substrate **12** to reduce deformation of residual layer **712** during formation and separation of nano-pattern structure **702**.

[0078] FIG. 10 illustrates the formed nano-pattern structure **702** with residual layer **712** having thickness t_R and protrusions **720** having sharp edges. It should be noted that with such thin residual layers, and the fact that adhesion layers may be 1 nm thick, pattern transfer that begins with the substrate etch and no descum is enabled. To this end, an imprint pattern transfer manufacturing process may include: vapor coat adhesion layer (1 nm thick), drop-on-demand resist dispense (dispense pattern and monomer volume is based on template volume calculation), imprint patterning (dummy fill if needed) with <5 nm RLT, substrate only etch (no descum), strip and clean substrate. It should be noted that if a descum etch is needed, it may be for removing a thin residual film, and as such may not impact the shape of the shaped nano-structures substantially. This may allow for etching of the substrate while retaining the nano-shapes present in the mold. This is in contrast to conventional imprint lithography wherein the following steps are taken: vapor coat adhesion layer (1 nm thick), spin-on imprint material, imprint patterning >5 nm RLT, substantial imprint resist descum (by O_2 plasma), substrate etch, strip and clean substrate.

[0079] Embodiments of the present invention described above are exemplary. Many changes and modifications may be made to the disclosure recited above while remaining within the scope of the invention. Therefore, the scope of the invention should not be limited by the above description, but instead should be determined with reference to any appended claims along with their full scope of equivalents.

What is claimed is:

1. An imprint lithography method of patterning a substrate comprising the steps of:

- providing a substrate;
- coating the substrate with an adhesive layer having a thickness of 1 nm or less;
- depositing polymerizable material on the adhesive layer;
- positioning an imprint lithography template having a relief pattern with sharp edged features in contact with the deposited polymerizable material at a first height relative to the substrate;
- moving the imprint lithography template to a second height relative to the substrate to spread the polymerizable material;
- solidifying the polymerizable material to form a patterned layer having sharp edged features and a residual layer thickness t_R of less than 5 nm;
- separating the imprint lithography template from the formed patterned layer;

directly etching the pattern into the substrate without a descum etching step wherein the etched substrate substantially retains the sharp edged features of the patterned layer.

2. The method of claim 1 wherein the adhesive layer is coated onto the substrate by vapor deposition.

3. The method of claim 1 wherein the depositing polymerizable material on the adhesive layer further comprises dispensing the polymerizable material as a plurality of droplets.

4. The method of claim 1 wherein the imprint template relief pattern further comprises dummy fill features.

5. An imprint lithography method of patterning a substrate comprising the steps of:

providing a substrate;

depositing polymerizable material on the substrate;

positioning an imprint lithography template having a relief pattern with sharp edged features in contact with the deposited polymerizable material at a first height relative to the substrate;

moving the imprint lithography template to a second height relative to the substrate to spread the polymerizable material;

solidifying the polymerizable material to form a patterned layer having sharp edged features and a residual layer thickness t_R of less than 5 nm;

separating the imprint lithography template from the formed patterned layer;

directly etching the pattern into the substrate without a descum etching step wherein the etched substrate substantially retains the sharp edged features of the patterned layer.

6. The method of claim 5 wherein the depositing polymerizable material on the substrate further comprises dispensing the polymerizable material as a plurality of droplets.

7. The method of claim 5 wherein the imprint template relief pattern further comprises dummy fill features.

8. An imprint lithography method of patterning a substrate comprising the steps of:

providing a substrate;

depositing polymerizable material on the substrate;

contacting the polymerizable material with an imprint lithography template having a relief pattern with sharp edged features;

solidifying the polymerizable material to form a patterned layer having sharp edged features and a residual layer thickness t_R of less than 5 nm;

separating the imprint lithography template from the formed patterned layer;

directly etching the pattern into the substrate without a descum etching step wherein the etched substrate substantially retains the sharp edged features of the patterned layer.

9. The method of claim 8 wherein the depositing polymerizable material on the substrate further comprises dispensing the polymerizable material as a plurality of droplets.

10. The method of claim 8 wherein the imprint template relief pattern further comprises dummy fill features.

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