

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization

International Bureau



(10) International Publication Number

WO 2018/102002 A1

(43) International Publication Date

07 June 2018 (07.06.2018)

(51) International Patent Classification:

B82Y 10/00 (2011.01)	B82Y 40/00 (2011.01)
B82Y 20/00 (2011.01)	G03F 7/00 (2006.01)

OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(21) International Application Number:

PCT/US2017/051444

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

(22) International Filing Date:

14 September 2017 (14.09.2017)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/429,214 02 December 2016 (02.12.2016) US

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

Published:

- with international search report (Art. 21(3))

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,

(54) Title: CONFIGURING OPTICAL LAYERS IN IMPRINT LITHOGRAPHY PROCESSES

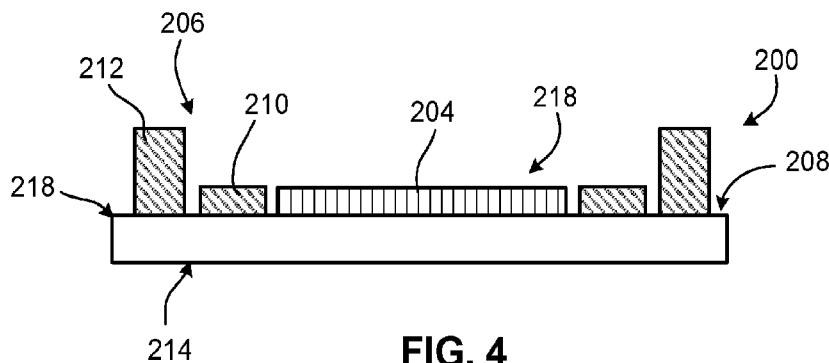


FIG. 4

(57) Abstract: An imprint lithography method of configuring an optical layer includes imprinting first features of a first order of magnitude in size on a side of a substrate with a patterning template, while imprinting second features of a second order of magnitude in size on the side of the substrate with the patterning template, the second features being sized and arranged to define a gap between the substrate and an adjacent surface.

CONFIGURING OPTICAL LAYERS IN IMPRINT LITHOGRAPHY PROCESSES

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of the filing date of U.S. Provisional Application No. 5 62/429,214, filed on December 2, 2016. The contents of U.S. Application No. 62/429,214 are incorporated herein by reference in their entirety.

TECHNICAL FIELD

This invention relates to configuring optical layers in imprint lithography processes, and 10 more particularly to forming features of different orders of magnitude in size on a substrate in one processing step.

BACKGROUND

Nanofabrication (e.g., nanoimprint lithography) can include the fabrication of very small 15 structures that have features on the order of 100 nanometers or smaller. One application in which nanofabrication has had a significant impact is in the processing of integrated circuits. The semiconductor processing industry continues to strive for larger production yields, while increasing a number of circuits formed on a substrate per unit area of the substrate. To this end, nanofabrication has become increasingly important to achieving desired results in the 20 semiconductor processing industry. Nanofabrication provides greater process control while allowing continued reduction of minimum feature dimensions of structures formed on substrates. Other areas of development in which nanofabrication has been employed include biotechnology, optical technology, mechanical systems, and the like. In some examples, nanofabrication includes fabricating structures on substrates that are assembled to form an optical device.

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SUMMARY

The invention involves a realization that improvements in imprinting three-dimensional (3D) patterns on substrates can increase an accuracy and a precision, while reducing a cost and a complexity associated with producing such patterns. Conventional imprint lithography processes 30 may include imprinting a nano-scale pattern on a substrate in a first step and subsequently imprinting features of a larger order of magnitude on the substrate in a second, subsequent step.

For such processes, cleaning and treating of the nano-scale pattern may be required prior to forming the larger features, which is associated with additional costs and additional time. Furthermore, aspects of forming the larger features in the subsequent step can sometimes jeopardize a mechanical integrity and/or a functional integrity of the nano-patterned substrate. In 5 this regard, various aspects of disclosed imprint lithography methods can allow imprinting of 3D structures with features that have different orders of magnitudes with multiple functions (e.g., any of optical functions, anti-reflective, and spacing) in a single imprinting step. Such methods yield precise, accurate structures at a reduced cost and duration, as compared to alternative methods.

10 One aspect of the invention features an imprint lithography method of configuring an optical layer. The imprint lithography method includes imprinting first features of a first order of magnitude in size on a side of a substrate with a patterning template, while imprinting second features of a second order of magnitude in size on the side of the substrate with the patterning template, wherein the second features are sized and arranged to define a gap between the 15 substrate and an adjacent surface.

In some embodiments, imprinting the first features includes forming one or both of diffraction gratings and anti-reflective features on the side of the substrate.

In certain embodiments, imprinting the second features includes forming spacers on the side of the substrate.

20 In some embodiments, the method further includes imprinting one or both of the spacers and the anti-reflective features along a peripheral edge of the side of the substrate.

In certain embodiments, the method further includes imprinting one or both of the spacers and the anti-reflective features within an interior region of the side of the substrate.

25 In some embodiments, the side of the substrate is a first side of the substrate, and the imprint lithography method further includes imprinting third features of the first order of magnitude in size on a second side of the substrate.

In certain embodiments, imprinting the third features includes forming diffraction gratings or anti-reflective features on the second side of the substrate.

30 In some embodiments, the second order of magnitude in size is greater than the first order of magnitude in size.

In certain embodiments, the first order of magnitude in size is of a nano-scale, and the second order of magnitude in size is of a micro-scale.

In some embodiments, the method further includes imprinting the second features on opposite sides of the first features.

5 In certain embodiments, the method further includes creating the patterning template from a predecessor mold.

In some embodiments, the method further includes forming deep features of the second order of magnitude in size in the predecessor mold.

10 In certain embodiments, the method further includes forming shallow features of the first order of magnitude in size in the predecessor mold.

In some embodiments, the substrate is a first substrate, and the adjacent surface is defined by a second substrate.

In certain embodiments, the method further includes aligning the first and second substrates with each other.

15 In some embodiments, the method further includes dispensing an adhesive substance atop the second features imprinted on the side of the first substrate.

In certain embodiments, the method further includes attaching the first and second substrates to each other at the adhesive substance atop the second features imprinted on the side of the first substrate to form the gap between the first substrate and the adjacent surface defined 20 by the second substrate.

In some embodiments, the method further includes attaching the first and second substrates to each other at the adhesive substance atop the second features imprinted on the side of the first substrate to form a multi-layer optical device.

25 In certain embodiments, the method further includes defining a layer of air between the first and second substrates with a thickness that is determined by heights of the second features.

In some embodiments, the gap provides a low index region.

In certain embodiments, the low index region is air with an index of refraction of 1.

In some embodiments, the imprint lithography method further includes providing the multi-layer optical device with layers characterized by alternating indexes of refraction.

30 Another aspect of the invention features an optical layer that includes a substrate and a pattern imprinted on a side of the substrate with a patterning template. The pattern includes first

features of a first order of magnitude in size and second features of a second order of magnitude in size. The second features are sized and arranged to define a gap between the substrate and an adjacent surface.

The details of one or more embodiments of the invention are set forth in the 5 accompanying drawings and the description below. Other features, aspects, and advantages of the invention will be apparent from the description, the drawings, and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagram of an imprint lithography system.

10 Fig. 2 is diagram of patterned layer formed by the imprint lithography system of Fig. 1.

Fig. 3 is a top view of an optical layer.

Fig. 4 is a side view of the optical layer of Fig. 3.

Fig. 5 is a top view of an optical layer with a configuration that is different from the configuration of the optical layer shown in Fig. 3.

15 Fig. 6 is a top view of an optical layer with a configuration that is different from the configurations of the optical layers shown in Figs. 3 and 5.

Fig. 7 is an exploded perspective view of a portion of an optical device that includes the optical layer of Fig. 3.

Fig. 8 is a side view of the portion of the optical device of Fig. 7.

20 Fig. 9 is a diagram illustrating a series of steps for creating a patterning mold that can be used to produce the optical layer of Fig. 3.

Fig. 10 is a side view of spacers formed with the patterning mold of Fig. 9.

Fig. 11 is a perspective view of the spacers of Fig. 10.

25 Fig. 12 is a side view of an optical layer with a configuration that is different from the configuration of the optical layer shown in Figs. 3 and 4.

Fig. 13 is a side view of an optical layer with a configuration that is different from the configurations of the optical layers shown in Figs. 3, 4, and 12.

Fig. 14 is a flow chart of an example process for configuring an optical layer in an imprint lithography process.

30 Like reference symbols in the various figures indicate like elements.

In some examples, illustrations shown in the drawings may not be drawn to scale.

DETAILED DESCRIPTION

An imprint lithography process for configuring an optical layer is described below. The imprint lithography process involves imprinting a multi-functional structure including features of different orders of magnitude from a single template. Such a process can improve a precision 5 and an accuracy and reduce a cost and a complexity associated with producing such structures for creating multi-layer optical devices.

Fig. 1 illustrates an imprint lithography system 100 that is operable to form a relief pattern on a top surface 103 of a substrate 101 (e.g., a wafer). The imprint lithography system 100 includes a support assembly 102 that supports and transports the substrate 101, an imprinting assembly 104 that forms the relief pattern on the top surface 103 of the substrate 101, a fluid dispenser 106 that deposits a polymerizable substance upon the top surface 103 of the substrate 101, and a robot 108 that places the substrate 101 on the support assembly 102. The imprint lithography system 100 also includes one or more processors 128 that can operate on a computer readable program stored in memory and that are in communication with and programmed to 10 control the support assembly 102, the imprinting assembly 104, the fluid dispenser 106, and the robot 108.

The substrate 101 is a substantially planar, thin slice that is typically made of one or more materials including silicon, silicon dioxide, aluminum oxide, sapphire, germanium, gallium arsenide (GaAs), an alloy of silicon and germanium, indium phosphide (InP), or other example 20 materials. The substrate 101 typically has a substantially circular or rectangular shape. The substrate 101 typically has a diameter in a range of about 50 mm to about 200 mm (e.g., about 65 mm, about 150 mm, or about 200 mm) or a length and a width in a range of about 50 mm to about 200 mm (e.g., about 65 mm, about 150 mm, or about 200 mm). The substrate 101 typically has and a thickness in a range of about 0.2 mm to about 1.0 mm. The thickness of the 25 substrate 101 is substantially uniform (e.g., constant) across the substrate 101. The relief pattern is formed as a set of structural features (e.g., protrusions and suction structures) in the polymerizable substance upon the top surface 103 of the substrate 101, as will be discussed in more detail below.

The support assembly 102 includes a chuck 110 that supports and secures the substrate 30 101, an air bearing 112 that supports the chuck 110, and a base 114 that supports the air bearing 112. The base 114 is located in a fixed position, while the air bearing 112 can move in up to

three directions (e.g., x , y , and z directions) to transport the chuck 110 (e.g., in some instances, carrying the substrate 101) to and from the robot 108, the fluid dispenser 106, and the imprinting assembly 104. In some embodiments, the chuck 110 is a vacuum chuck, a pin-type chuck, a groove-type chuck, an electromagnetic chuck, or another type of chuck.

5 Still referring to Fig. 1, the imprinting assembly 104 includes a flexible template 116 with a patterning surface defining an original pattern from which the relief pattern is formed complementarily on the top surface 103 of the substrate 101. Accordingly, the patterning surface of the flexible template 116 includes structural features such as protrusions and recesses. The imprinting assembly 104 also includes multiple rollers 118, 120, 122 of various diameters that 10 rotate to allow one or more portions of the flexible template 116 to be moved in the x direction within a processing region 130 of the imprint lithography system 100 to cause a selected portion of the flexible template 116 to be aligned (e.g., superimposed) with the substrate 101 along the processing region 130. One or more of the rollers 118, 120, 122 are individually or together moveable in the vertical direction (e.g., the z direction) to vary a vertical position of the flexible 15 template 116 in the processing region 130 of the imprinting assembly 104. Accordingly, the flexible template 116 can push down on the substrate 101 in the processing region 130 to form an imprint atop the substrate 101. An arrangement and a number of the rollers 118, 120, 122 can vary, depending upon various design parameters of the imprint lithography system 100. In some embodiments, the flexible template 116 is coupled to (e.g., supported or secured by) a vacuum 20 chuck, a pin-type chuck, a groove-type chuck, an electromagnetic chuck, or another type of chuck.

In operation of the imprint lithography system 100, the flexible template 116 and the substrate 101 are aligned in desired vertical and lateral positions by the rollers 118, 120, 122 and the air bearing 112, respectively. Such positioning defines a volume within the processing 25 region 130 between the flexible template 116 and the substrate 101. The volume can be filled by the polymerizable substance once the polymerizable substance is deposited upon the top surface 103 of the substrate 101 by the fluid dispenser 106, and the chuck 110 (e.g., carrying the substrate 101) is subsequently moved to the processing region 130 by the air bearing 112. Accordingly, both the flexible template 116 and the top surface 103 of the substrate 101 can be 30 in contact with the polymerizable substance in the processing region 130 of the imprint lithography system 100. Example polymerizable substances may be formulated from one or

more substances, such as isobornyl acrylate, n-hexyl acrylate, ethylene glycol diacrylate, 2-hydroxy-2-methyl-1-phenyl-propan-1-one, (2-Methyl-2-Ethyl-1,3-dioxolane-4-yl)methyl acrylate, hexanediol diacrylate, 2-methyl-1-[4-(methylthio)phenyl]-2-(4-morpholinyl)-1-propanone, diphenyl (2,4,6-trimethylbenzoyl)-phosphine oxide, 2-hydroxy-2-methyl-1-phenyl-1-propanone, and various surfactants. Example techniques by which the polymerizable substance may be deposited atop the substrate 101 by the fluid dispenser 106 include drop dispense, spin-coating, dip coating, chemical vapor deposition (CVD), physical vapor deposition (PVD), thin film deposition, thick film deposition, and other techniques. In some examples, the polymerizable substance is deposited atop the substrate 101 in multiple droplets.

The printing system 104 includes an energy source 126 that directs energy (e.g., broadband ultraviolet radiation) towards the polymerizable substance atop the substrate 101 within the processing region 130. Energy emitted from the energy source 126 causes the polymerizable substance to solidify and/or cross-link, thereby resulting in a patterned layer that conforms to a shape of the portion of the flexible template 116 in contact with the polymerizable substance in the processing region 130.

Fig. 2 illustrates an example patterned layer 105 formed on the substrate 101 by the imprint lithography system 100. The patterned layer 105 includes a residual layer 107 and multiple features including protrusions 109 extending from the residual layer 107 and recessions 111 formed by adjacent protrusions 109 and the residual layer 107.

While the imprint lithography system 100 is described and illustrated as a roll-to-plate or plate-to-roll system, imprint lithography systems of a different configurations can also be used to produce the example patterned layer 105 and the example patterns discussed below. Such imprint lithography systems may have a roll-to-roll or a plate-to-plate configuration.

In some embodiments, a substrate (e.g., the substrate 101 of the imprint lithography system 100) is processed (e.g., imprinted on one or both sides and cut out to shape) to form an optical layer of a multi-layer optical device (e.g., a wearable eyepiece, an optical sensor, or an optical film, such as that used in a display). For example, Figs. 3 and 4 illustrate a top view and a side view, respectively, of an optical layer 200 that includes a substrate 202, a functional pattern 204 imprinted on the substrate 202, and an auxiliary pattern 206 imprinted on the substrate 202. The substrate 202 may be laser cut from a larger substrate (e.g., the substrate 101) and is provided as a layer of transparent or semi-transparent plastic (e.g., flexible) or glass (e.g.,

rigid) that is made of one or more organic or inorganic materials, in accordance with the various material formulations described above with respect to the substrate 101. The substrate 202 has a maximum length of about 10 mm to about 500 mm and a maximum width of about 10 mm to about 500 mm. The substrate 202 has a relatively high refractive index in a range of about 1.6 to 5 about 1.9 and a transmissivity in a range of about 80% to about 95%.

The functional pattern 204 is imprinted atop an upper side 208 of the substrate 202 and is located along an interior region 218 with respect to a peripheral edge 216 of the substrate 202. The functional pattern 204 is a waveguide pattern formed of multiple diffraction gratings that provide a basic working functionality of the optical layer 200. The diffraction gratings have 10 dimensions in a range of about 10 nm to about 500 nm. The diffraction gratings are configured to project light of wavelengths within a particular range and to focus a virtual image at a particular depth plane. The focused light, together with focused light projected through proximal optical layers, forms a multi-color virtual image over one or more depth planes. The transmitted light may be red light with wavelengths in a range of about 560 nm to about 640 nm, green light 15 with wavelengths in a range of about 490 nm to about 570 nm, or blue light with wavelengths in a range of about 390 nm to about 470 nm. The diffraction gratings can include multiple combinations and arrangements of protrusions and recessions (e.g., such as the protrusions 109 and the recessions 111) that together provide desired optical effects. The diffraction gratings include in-coupling gratings 220 and form an orthogonal pupil expander region 222 and an exit 20 pupil expander region 224. The functional pattern 204 has a total length of about 10 mm to about 500 mm and a total width of about 10 mm to about 500 mm.

The auxiliary pattern 206 is imprinted atop the upper side 208 of the substrate 202 and surrounds the functional pattern 204. The auxiliary pattern 206 is also co-located with the interior region 218 of the substrate 202. The auxiliary pattern 206 includes both anti-reflective 25 features 210 of a nano-scale and spacers 212 of a micro-scale that may be distributed in various quantities and arrangements across the auxiliary pattern 206. The auxiliary pattern 206 coincides with the interior region 218 of the substrate 202 and has a total length of about 10 mm to about 500 mm and a total width of about 10 mm to about 500 mm.

The anti-reflective features 210 may be arranged anywhere within the auxiliary pattern 30 206. The anti-reflective features 210 are sized (e.g., having a height of less than or equal to about 300 nm and a pitch of about 50 nm to about 150 nm) and shaped to reduce surface

reflection at the side (e.g., the upper side 208) of the substrate 202 on which the anti-reflective features 210 are imprinted. For example, the anti-reflective features 210 may reduce the surface reflection of the substrate 202 by about 1.0% to about 4.5%. The anti-reflective features 210 are further sized and shaped to increase the transmissivity of the substrate 202 to greater than about 5 98.5% (e.g., for a plastic substrate 202) and up to about 99.5% (e.g., for a glass substrate 202). The anti-reflective features 210 are also sized and shaped to provide the substrate 202 with a new effective refractive index in a range of about 1.2 to about 1.4. Additionally, the anti-reflective features 210 can introduce birefringence to diminish or enhance refraction of certain light wavelengths transmitted through the substrate 202.

10 The spacers 212 are sized to produce a gap (e.g., a layer of air) between the optical layer 200 and an adjacent optical layer that together form a part of a multi-layer stacked optical device when the two optical layers are adhered to one another, as will be discussed in more detail below with respect to Figs. 7 and 8. The spacers 212 may be arranged anywhere within the auxiliary pattern 206 as necessary to provide adequate structural support for the substrate 202 and for an 15 adjacent optical layer that is in contact with the spacers 212. In some embodiments, the spacers 212 (e.g., in a cured state) have a modulus of elasticity that is greater than 1 GPa. The spacers 212 can be imprinted in a pre-defined geometry (e.g., tetrahedral, cylindrical, conical, etc.) and therefore may have a cross-sectional shape that is circular, rectangular, etc. The spacers 212 may have a lateral dimension (e.g., a width or a diameter) in a range of about 1 μm to about 100 μm 20 and a vertical dimension (e.g., a height) of about 1 μm to about 50 μm . Each spacer 212 may be located about 5 μm to about 100 μm from another adjacent spacer 212, from an anti-reflective feature 210, or from a diffraction grating of the functional pattern 204.

Other arrangements of functional patterns and auxiliary patterns are possible. For 25 example, Fig. 5 illustrates a top view of an optical layer 300 that includes the substrate 202 and the functional pattern 204 of the optical layer 200, as well as an auxiliary pattern 306. The functional pattern 204 is imprinted atop the upper layer 208 of the substrate 202, as in the optical layer 200. The auxiliary pattern 306 is also imprinted atop the upper layer 208 of the substrate 202 and is substantially similar in construction and function to the auxiliary pattern 206, except that the auxiliary pattern 306 extends across the interior region 218 to the peripheral edge 216 of 30 the substrate 202.

In another example embodiment, Fig. 6 illustrates a top view of an optical layer 400 that includes the substrate 202 and the functional pattern 204 of the optical layer 200, as well as an auxiliary pattern 406. The functional pattern 204 is imprinted atop the upper layer 208 of the substrate 202, as in the optical layer 200. The auxiliary pattern 406 is also imprinted atop the 5 upper layer 208 of the substrate 202 and is substantially similar in construction and function to the auxiliary pattern 206, except that the auxiliary pattern 406 is imprinted along the peripheral edge 216 of the substrate 202, such that the interior region 218 of the substrate 202 remains non-patterned and surrounds the functional pattern 204. In other embodiments, optical layers may include functional patterns and auxiliary patterns with different shapes and/or arrangements not 10 shown in the example optical layers 200, 300, 400.

Fig. 7 illustrates an exploded perspective view of a portion of an optical device 500 (e.g., a wearable eyepiece) that includes multiple optical layers, including three of the example optical layers 200. Fig. 8 illustrates a (non-exploded) side view of the same portion of the optical device 500. The optical device 500 includes additional optical layers that are not shown. Referring to 15 Figs. 7 and 8, the optical device 500 is formed by aligning the optical layers 200 with one another and adhering the optical layers 200 to one another with adhesive drops dispensed atop the spacers 212. The optical layers 200 are subsequently further adhered to each other with a seal that serves as an attachment mechanism to which all of the peripheral edges 216 of the optical layers 200 are joined. The optical device 500 can include multiple of any of the optical 20 layers 200, 300, 400, and other optical layers, and can include from 3 to 20 optical layers in total.

For each optical layer 200 in the optical device 500, the spacers 212 together form a spacer layer that creates a gap 530 defining a layer of air between adjacent optical layers 200, as shown in Fig. 8. The layers of air defined by the spacers 212 have a low index of refraction in a range of about 1.0 to about 1.2. The low index layers of air, alternating with the high index 25 optical layers 200, enhances 3D visualization and reduces or eliminates coupling of light between adjacent optical layers 200. The support structure formed by the arrangement of spacers 212 supports the substrate 202 on which the spacers 212 are imprinted and the adjacent substrate 202 in a way that prevents or reduces warping of the substrates 202 that may otherwise occur if the optical layers 200 were to be adhered via a different technique, such as dispensing drops of 30 glue within interior portions or along the peripheral edges 216 of the substrates 202.

Fig. 9 illustrates a series of steps for creating a patterning mold 600 (e.g., such as the patterning surface provided by the flexible template 116) from a predecessor mold 642 (e.g., a non-featured mold). The patterning mold 600 defines both shallow features 644 of a nano-scale and deep features 646 of a micro-scale. Accordingly, the shallow features 644 can be used to 5 form the diffraction gratings of the functional pattern 204 and the anti-reflective features 210 of the auxiliary pattern 206 on the substrate 202, while the deep features 646 can be used to form the spacers 212 on the substrate 202 in a single imprinting step, as will be discussed in more detail below with respect to Fig. 14.

In a first step (a) for creating the patterning mold 600, the deep features 646 are formed in 10 the predecessor mold 642 via a course method to create a micro-featured mold 648. Example course methods include lithography and reactive ion etching. In a next step (b), a polymerizable substance 650 is deposited atop the micro-featured mold 648 and patterned with fine features 652 of a nano-scale that project from a residual layer 654 in the manner as described above with respect to Figs. 1 and 2. In a next step (c), the residual layer 654 is removed, and the fine 15 features 652 are processed to form the shallow features 644 in the micro-featured mold 648 via plasma-based dry etching, reactive ion etching, or wet KOH etching of silicon to form the patterning mold 600. The deep features 646 of the patterning mold 600 are produced with an improved precision and accuracy as compared to spacer features that can be produced with other techniques that involve dispensing substances to form spacer features for adhering adjacent 20 optical layers. In this regard, heights of the spacers 212 produced from the deep features 646 exhibit good co-planarity (e.g., to within a tolerance of +/- 100 nm across a span of about 50 mm), and widths or diameters of the spacers 212 are consistent to within a +/- 100 nm tolerance. As a result, the spacers 212 that are formed on the substrates 202 by the deep features 646 of the patterning mold 600 provide the spacer layers with an improved uniformity in thickness across 25 single spacer layers such that adjacent substrates 202 can be aligned and oriented accurately and with reduced or eliminated warping. Additionally, an accuracy of the widths of the deep features 646 advantageously allows for improved structural integrity and functional integrity along the interior regions 218 of the substrates 202 according to use of the spacers 212, as compared to use of dispensed drops of glue, which tend to cause warping of substrates, sometimes lack sufficient 30 adhesiveness, and tend to spread into functional patterns imprinted on the substrates. Furthermore, dispensed glue drops may span a relatively large area (e.g., about 500 μm in

diameter) across a substrate with a spacer height of about 25 μm , whereas the spacers 212 may span a limited area (e.g., about 10 μm to about 20 μm in diameter) across a substrate with a spacer height of about 25 μm .

5 Figs. 10 and 11 respectively illustrate side and perspective views of spacers 212 of the auxiliary pattern 206 that are formed by the deep features 646 of the patterning mold 600. In the examples of Figs. 10 and 11, the spacers 212 have a generally cylindrical shape and have features (e.g., heights and effective diameters) in a range of about 5 μm to about 100 μm .

While the optical layer 200 has been described and illustrated as having the functional pattern 204 and the auxiliary pattern 206 imprinted on a single side (e.g., the upper side 208) of the substrate 202, other configurations are possible. For example, Fig. 12 illustrates a side view of an optical layer 700 that includes the substrate 202 and the functional pattern 204 of the optical layer 200 imprinted atop the upper side 208 of the substrate 202, as well as an auxiliary pattern 706 imprinted on the lower side 214 of the substrate 202. The auxiliary pattern 706 is substantially similar in construction and function to the auxiliary pattern 206, except that the auxiliary pattern 706 has a different size and shape than a size and a shape of the auxiliary pattern 206. For example, the auxiliary pattern 706 includes anti-reflective features 710 located opposite the functional pattern 204 and that span a width that is larger than a total width of a span of the anti-reflective features 210 of the auxiliary pattern 206. The auxiliary pattern 706 further includes spacers 712 located on opposite sides of the anti-reflective features 710. Owing 10 to the functional pattern 204 and the auxiliary pattern 706 being located on opposite sides of the substrate 202, the functional pattern 204 and the auxiliary pattern 706 are patterned on the substrate 202 in separate imprinting steps, as opposed to being patterned in a single imprinting step, as is the case for the optical layer 200. Accordingly, a patterning mold with fine features and deep features that correspond to a configuration of the auxiliary pattern 706 can be created 15 for forming the auxiliary pattern 706 in a manner similar to that described above with respect to the patterning mold 600. A separate patterning mold with fine features that correspond to a configuration of the functional pattern 204 can be created for forming the functional pattern 204. 20

In another example, Fig. 13 illustrates a side view of an optical layer 800 that includes the substrate 202 and the functional pattern 204 of the optical layer 200 imprinted atop the upper side 208 of the substrate 202, as well as a first auxiliary pattern 806 imprinted atop the upper side 208 of the substrate 202 and a second auxiliary pattern 860 imprinted on the lower side 214 of 25

the substrate 202. For example, the first auxiliary pattern 806 includes spacers 812 located on opposite sides of the functional pattern 204. The second auxiliary pattern 860 includes anti-reflective features 810 located opposite the functional pattern 204. Accordingly, a patterning mold with fine features and deep features that correspond to a configuration of the functional 5 pattern 204 and the first auxiliary pattern 806 can be created for forming the functional pattern 204 and the first auxiliary pattern 806 in a single imprinting step in a manner similar to that described above with respect to the patterning mold 600. A separate patterning mold with fine features that correspond to a configuration of the second auxiliary pattern 860 can be created for forming the second auxiliary pattern 860. Owing to the functional pattern 204 and the first 10 auxiliary pattern 706 being located on a side of the substrate that is opposite a side the substrate 202 on which the second auxiliary pattern 860 is located, the functional pattern 204 and the first auxiliary pattern 806 are patterned on the substrate 202 together in one imprinting step, and the second auxiliary pattern 860 is patterned on the substrate 202 in another imprinting step.

Fig. 14 displays a flow chart of an example process 900 for configuring an optical layer 15 (e.g., the optical layer 200, 300, 400) in an imprint lithography process. First features of a first order of magnitude in size are imprinted on a first side (e.g., the upper side 208 or the lower side 214) of a substrate (e.g., the substrate 202) with a patterning template (e.g., the patterning mold 600) (902). The first features may include one or both of diffraction gratings (e.g., the diffraction gratings provided by the functional pattern 204) and anti-reflective features (e.g., the 20 anti-reflective features provided by the auxiliary patterns 206, 306, 406). Second features of a second order of magnitude in size are imprinted on the first side of the substrate with the patterning template while the first features are imprinted on the first side of the substrate with the patterning template, where the second features are sized and arranged to define a gap (e.g., the gap 530) between the substrate and an adjacent surface (e.g., a side of an adjacent substrate) 25 (904). The second features may include spacers (e.g., spacers provided by the auxiliary patterns 206, 306, 406). In some examples, one or both of the spacers and the anti-reflective features are imprinted along a peripheral edge (e.g., the peripheral edge 216) of the first side of the substrate. In some examples, one or both of the spacers and the anti-reflective features are imprinted along an interior region (e.g., the interior region 218) of the first side of the substrate. In some 30 examples, the second features are imprinted on opposite sides of (e.g., around) the first features.

The second order of magnitude in size is greater than the first order of magnitude in size. In some examples, the first order of magnitude in size is of a nano-scale, and the second order of magnitude in size is of a micro-scale. In some embodiments, the process further includes imprinting third features of the first order of magnitude in size on a second side (e.g., the upper 5 side 208 or the lower side 214) of the substrate. The third features may include diffraction gratings or anti-reflective features.

In some embodiments, the process further includes creating the patterning template from a predecessor mold (e.g., the predecessor mold 642). In some embodiments, the process further includes forming deep features (e.g., the deep features 646) of the second order of magnitude in 10 size in the predecessor mold. In some embodiments, the process further includes forming shallow features (e.g., the shallow features 644) of the first order of magnitude in size in the predecessor mold.

In some examples, the substrate is a first substrate, and the adjacent surface is defined by a second substrate. In some embodiments, the process further includes aligning the first and 15 second substrates with each other. In some embodiments, the process further includes dispensing an adhesive substance (e.g., a drop of glue) atop the second features imprinted on the first side of the first substrate. In some embodiments, the process further includes attaching the first and second substrates to each other at the adhesive substance atop the second features imprinted on the first side of the first substrate to form a multi-layer optical device (e.g., the 20 optical device 500). In some embodiments, the process further includes attaching the first and second substrates to each other at the adhesive substance atop the second features imprinted on the first side of the first substrate to form the gap between the first substrate and the adjacent surface defined by the second substrate. In some embodiments, the process further includes defining a layer of air between the first and second substrates with a thickness that is determined 25 by heights of the second features such that the multi-layer optical device has alternating indexes of refraction.

Advantageously, the process 600 can be used to imprint a multi-functional (e.g., any of functional, anti-reflective, and spacing) 3D structure in a single step (e.g., via a single patterning mold) at ambient conditions (e.g., at an ambient temperature and at an ambient pressure) that 30 reduces a complexity, a duration, and a cost associated with imprinting such 3D structures as compared to producing the 3D structures according to other processes. For example,

conventionally formed anti-reflective patterns are deposited under vacuum and can be relatively costly, with spacer components being added in a separate, subsequent process that may include imprinting of large spacer structures, dispensing of microspheres, or dispensing of curable resist material. Additional time and complexity is associated with cleaning and treating the anti-
5 reflective pattern prior to performing such a second processing step.

While a number of embodiments have been described for illustration purposes, the foregoing description is not intended to limit the scope of the invention, which is defined by the scope of the appended claims. There are and will be other examples, modifications, and combinations within the scope of the following claims.

WHAT IS CLAIMED IS:

1. An imprint lithography method of configuring an optical layer, the imprint lithography method comprising:

imprinting first features of a first order of magnitude in size on a side of a substrate with a
5 patterning template; while

imprinting second features of a second order of magnitude in size on the side of the substrate with the patterning template, the second features being sized and arranged to define a gap between the substrate and an adjacent surface.

10 2. The imprint lithography method of claim 1, wherein imprinting the first features comprises forming one or both of diffraction gratings and anti-reflective features on the side of the substrate.

15 3. The imprint lithography method of claim 2, wherein imprinting the second features comprises forming spacers on the side of the substrate.

4. The imprint lithography method of claim 3, further comprising imprinting one or both of the spacers and the anti-reflective features along a peripheral edge of the side of the substrate.

20 5. The imprint lithography method of claim 3, further comprising imprinting one or both of the spacers and the anti-reflective features within an interior region of the side of the substrate.

25 6. The imprint lithography method of claim 1, wherein the side of the substrate is a first side of the substrate, the imprint lithography method further comprising imprinting third features of the first order of magnitude in size on a second side of the substrate.

7. The imprint lithography method of claim 6, wherein imprinting the third features comprises forming diffraction gratings or anti-reflective features on the second side of the substrate.

8. The imprint lithography method of claim 1, wherein the second order of magnitude in size is greater than the first order of magnitude in size.
9. The imprint lithography method of claim 1, wherein the first order of magnitude in size is of a nano-scale and the second order of magnitude in size is of a micro-scale.
10. The imprint lithography method of claim 1, further comprising imprinting the second features on opposite sides of the first features.
- 10 11. The imprint lithography method of claim 1, further comprising creating the patterning template from a predecessor mold.
12. The imprint lithography method of claim 11, further comprising forming deep features of the second order of magnitude in size in the predecessor mold.
- 15 13. The imprint lithography method of claim 11, further comprising forming shallow features of the first order of magnitude in size in the predecessor mold.
14. The imprint lithography method of claim 1, wherein the substrate is a first substrate, and the adjacent surface is defined by a second substrate.
- 20 15. The imprint lithography method of claim 14, further comprising aligning the first and second substrates with each other.
- 25 16. The imprint lithography method of claim 14, further comprising dispensing an adhesive substance atop the second features imprinted on the side of the first substrate.
17. The imprint lithography method of claim 16, further comprising attaching the first and second substrates to each other at the adhesive substance atop the second features imprinted on the side of the first substrate to form the gap between the first substrate and the adjacent surface defined by the second substrate.

18. The imprint lithography method of claim 1, wherein the gap provides a low index region.

19. The imprint lithography method of claim 18, wherein the low index region comprises air with an index of refraction of 1.

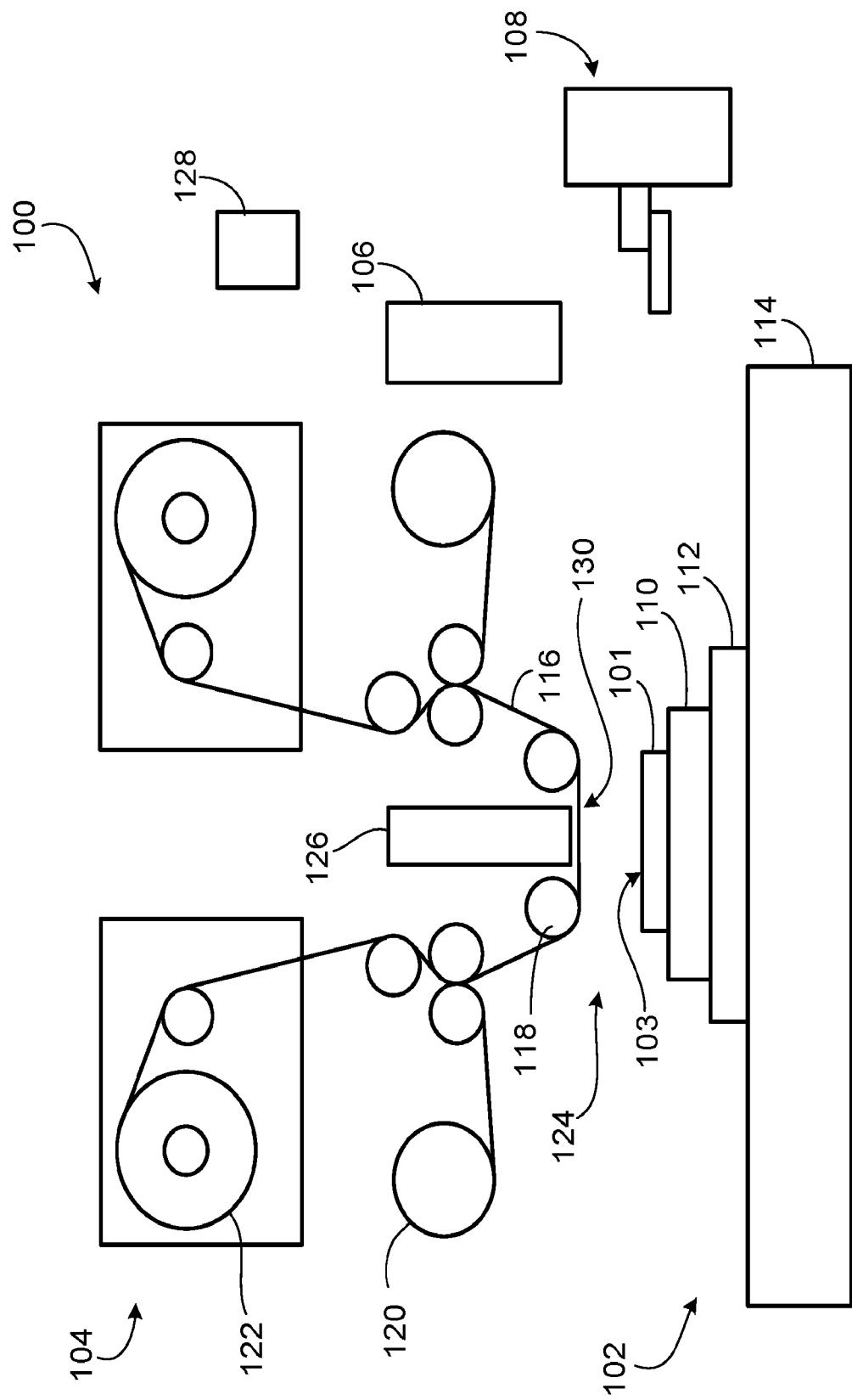
5

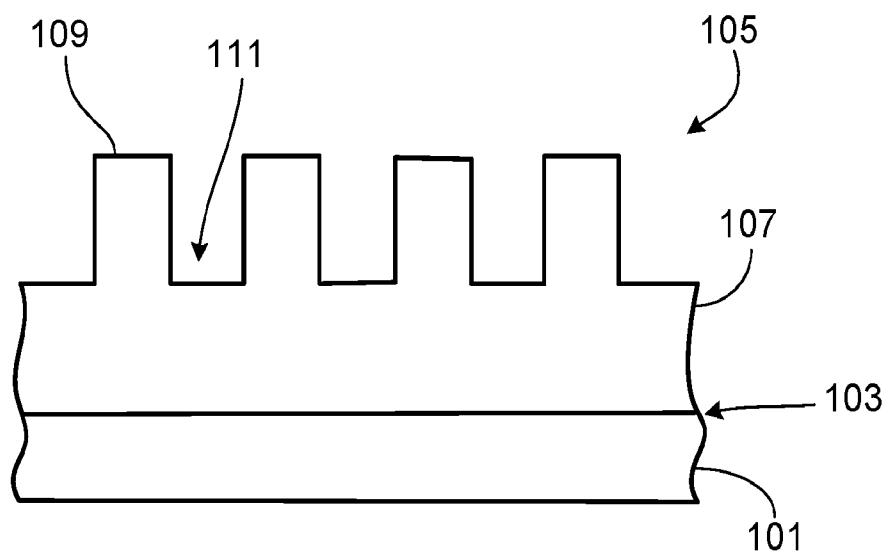
20. An optical layer, comprising:

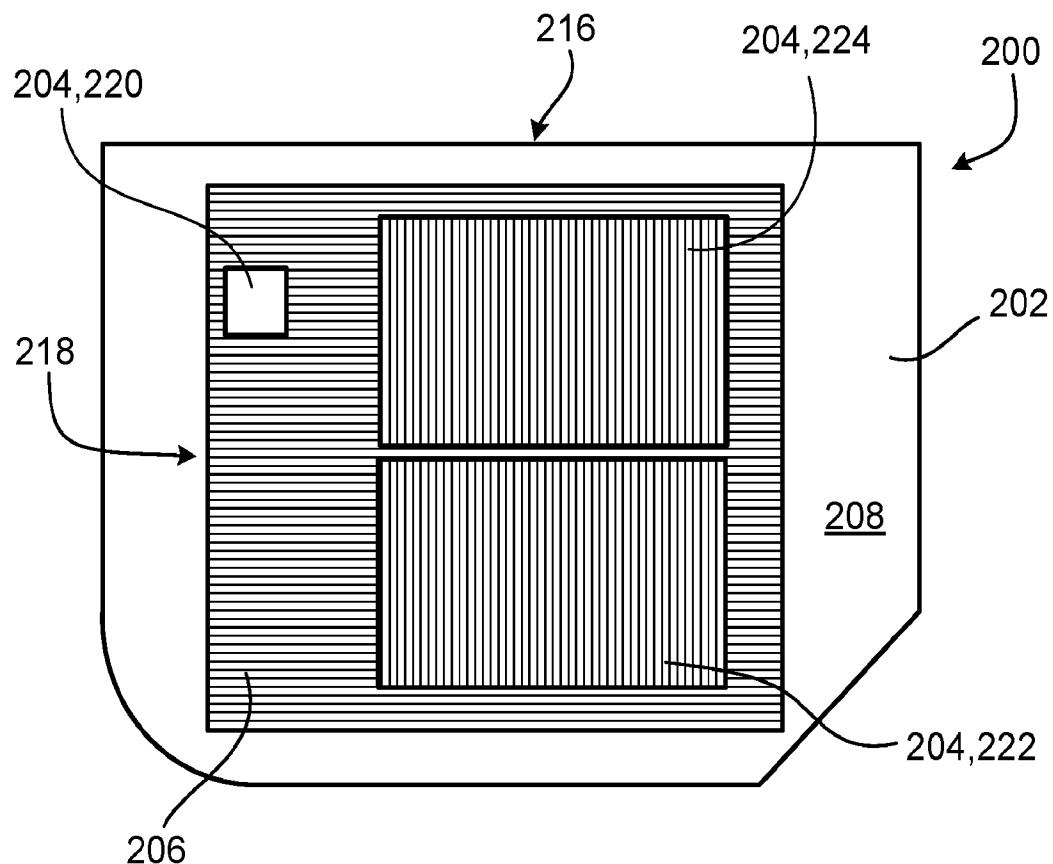
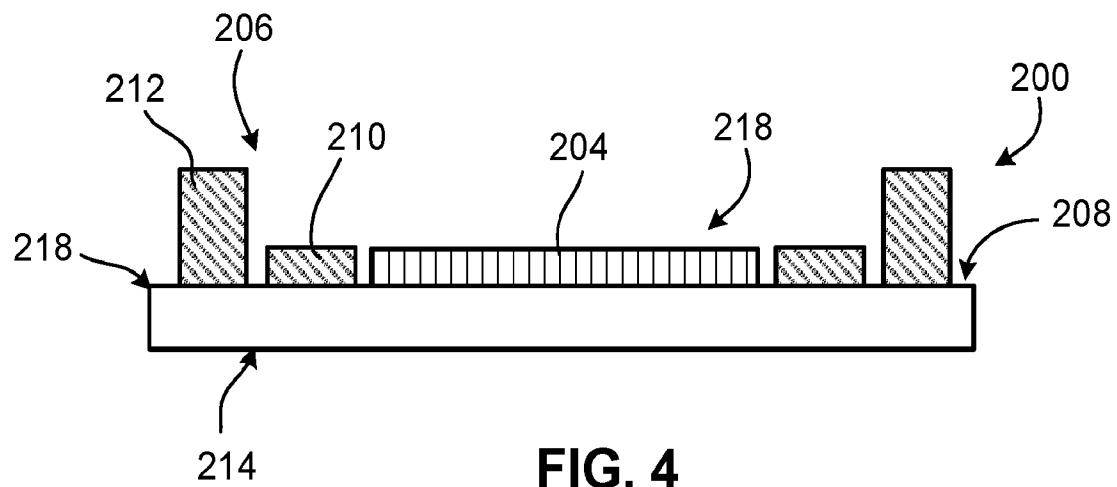
a substrate; and

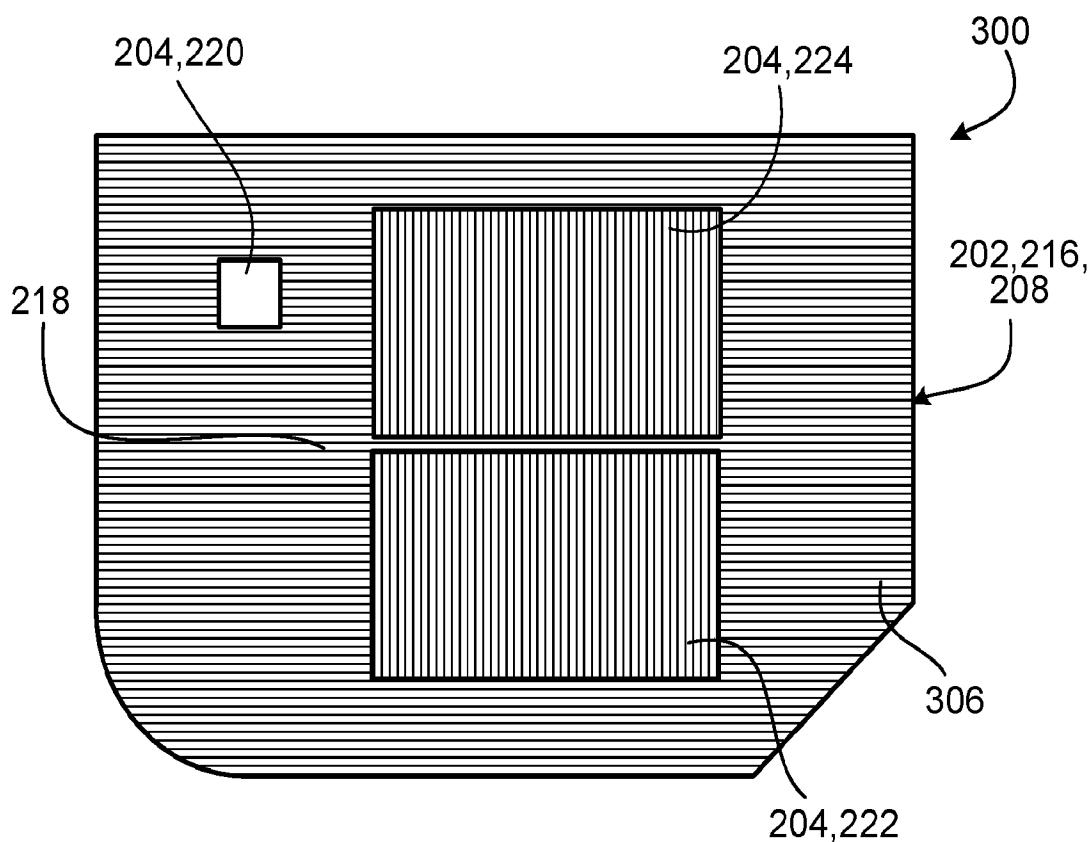
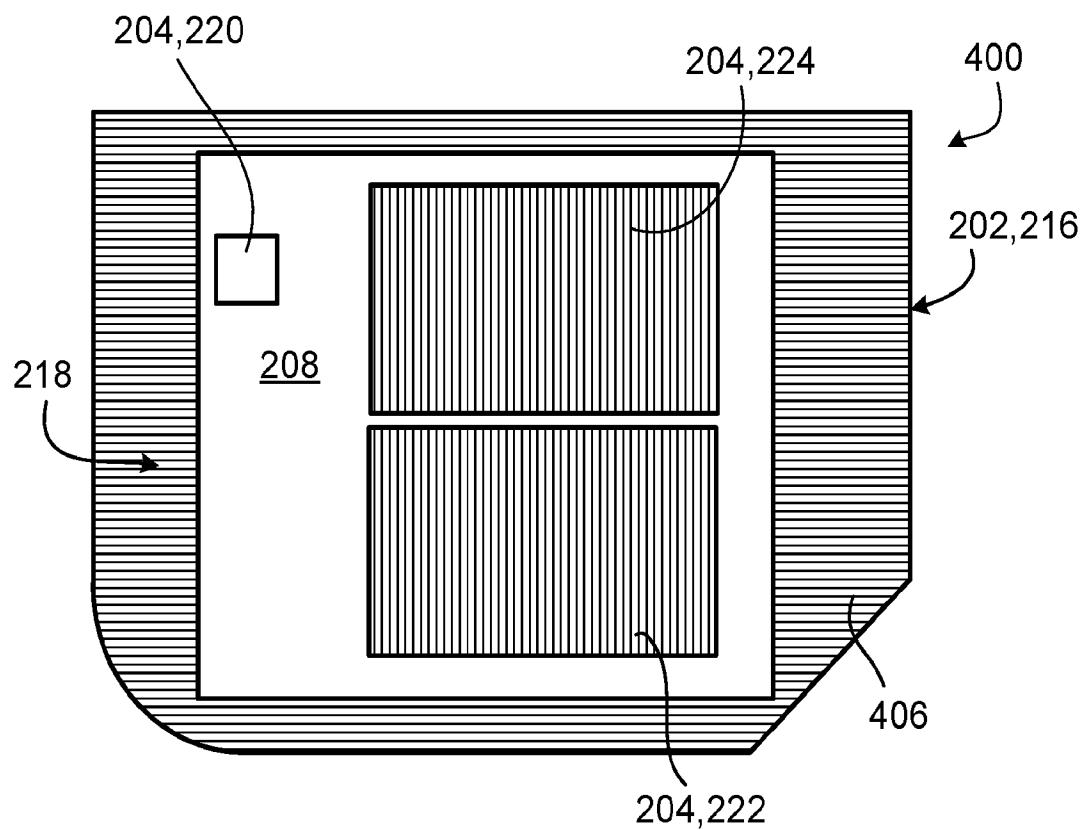
a pattern imprinted on a side of the substrate with a patterning template, the pattern comprising first features of a first order of magnitude in size and second features of a second order of magnitude in size,

10 wherein the second features are sized and arranged to define a gap between the substrate and an adjacent surface.

**FIG. 1**

**FIG. 2**

**FIG. 3****FIG. 4**

**FIG. 5****FIG. 6**

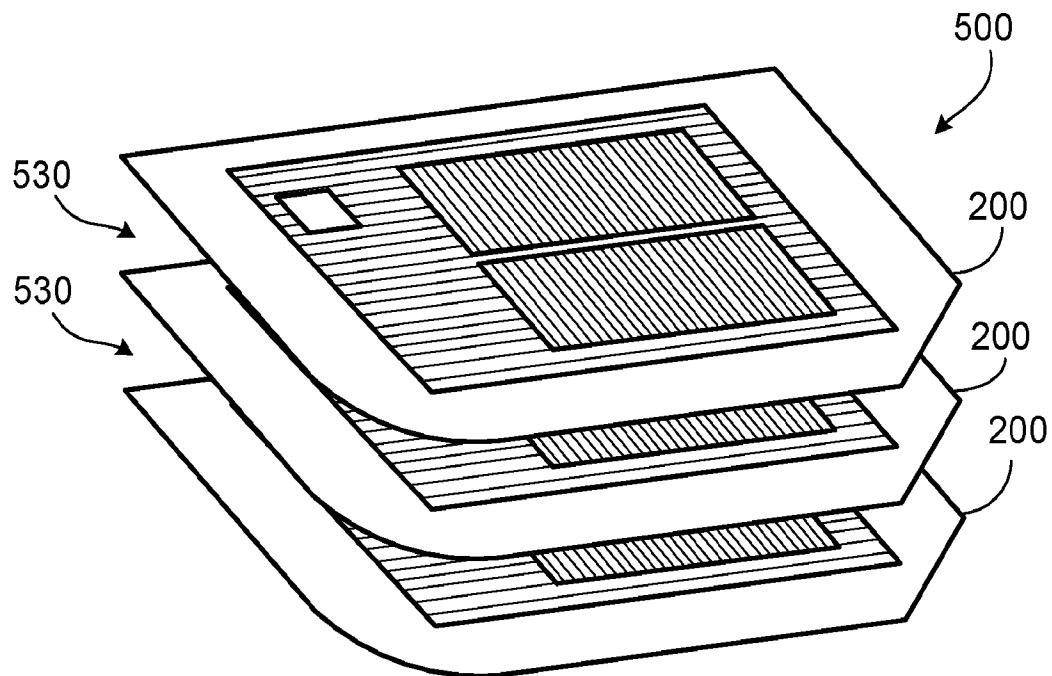


FIG. 7

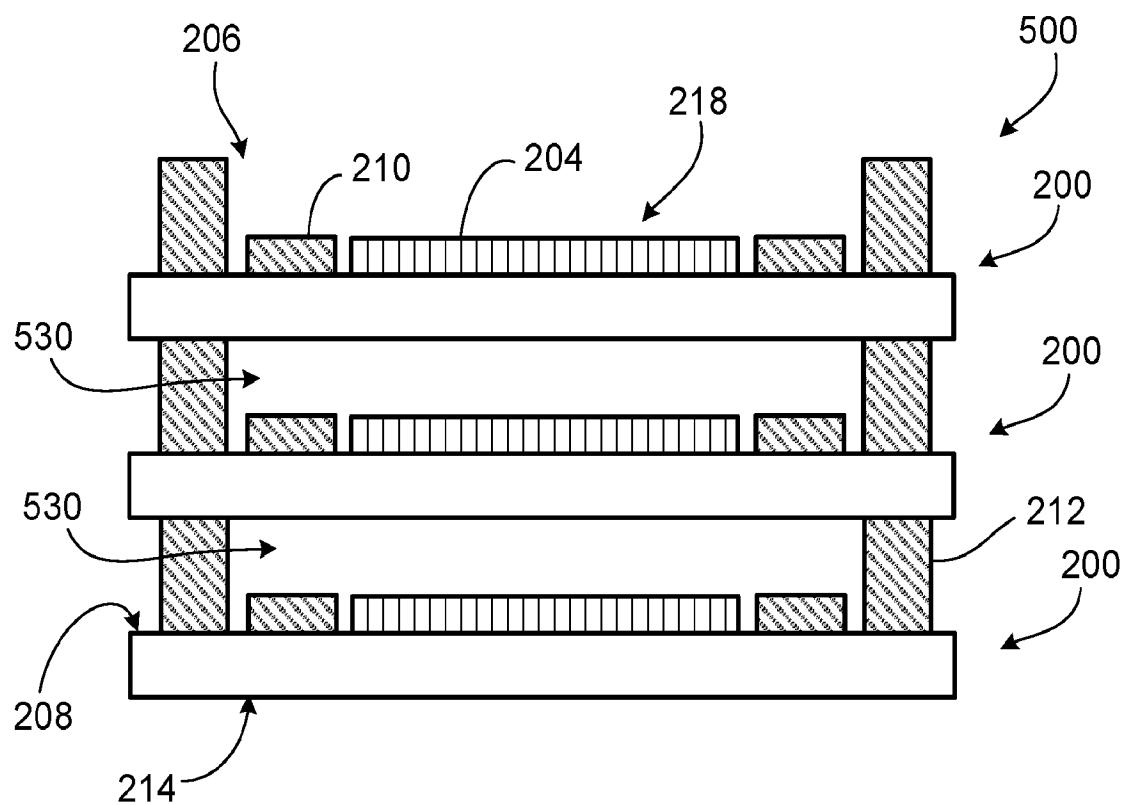
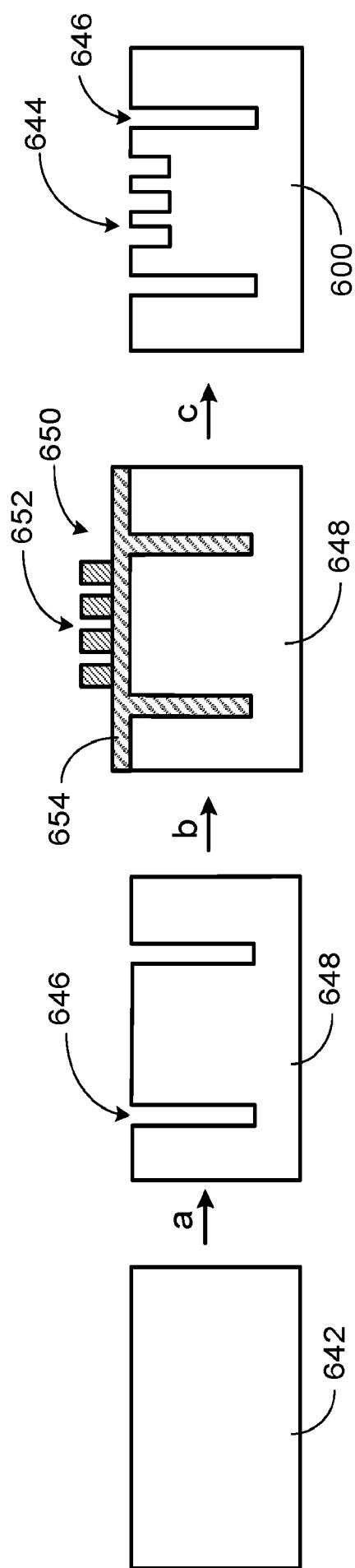
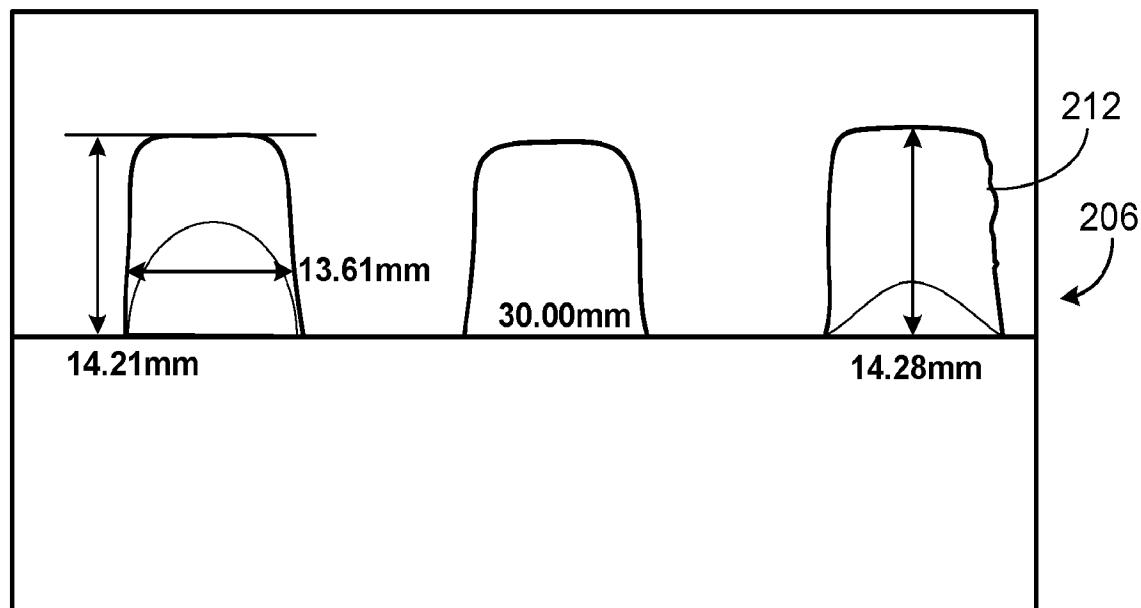
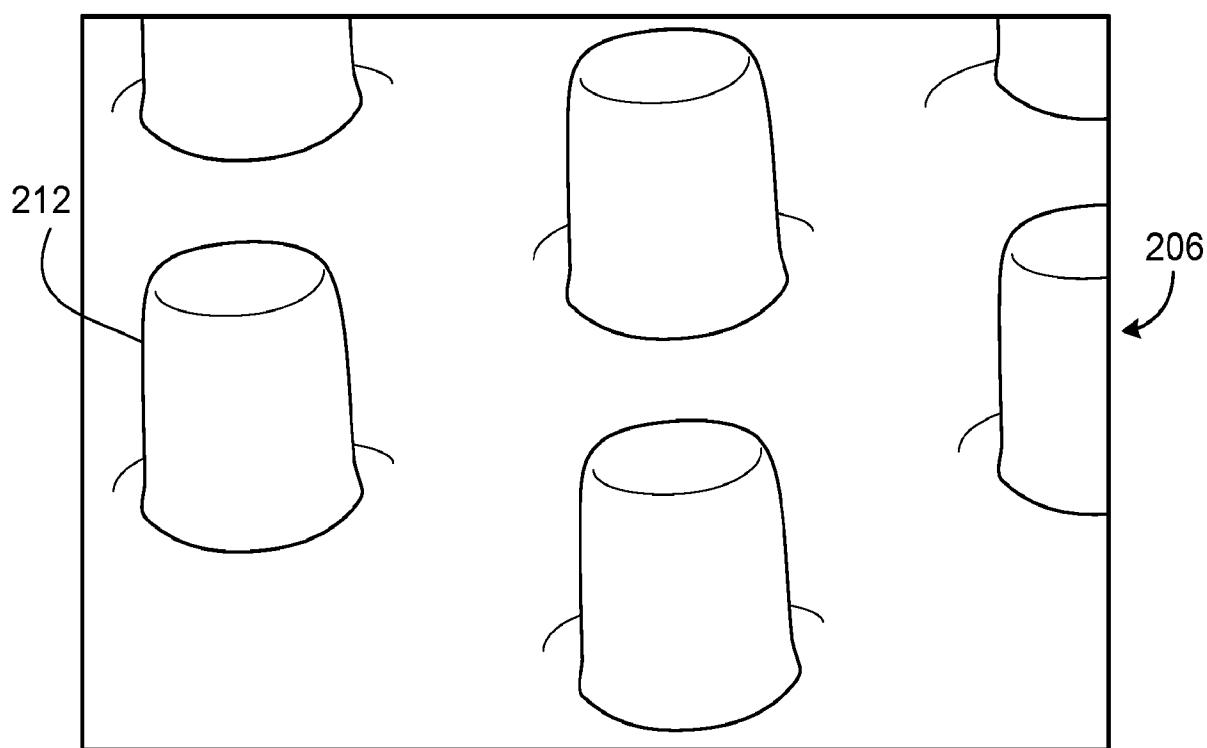
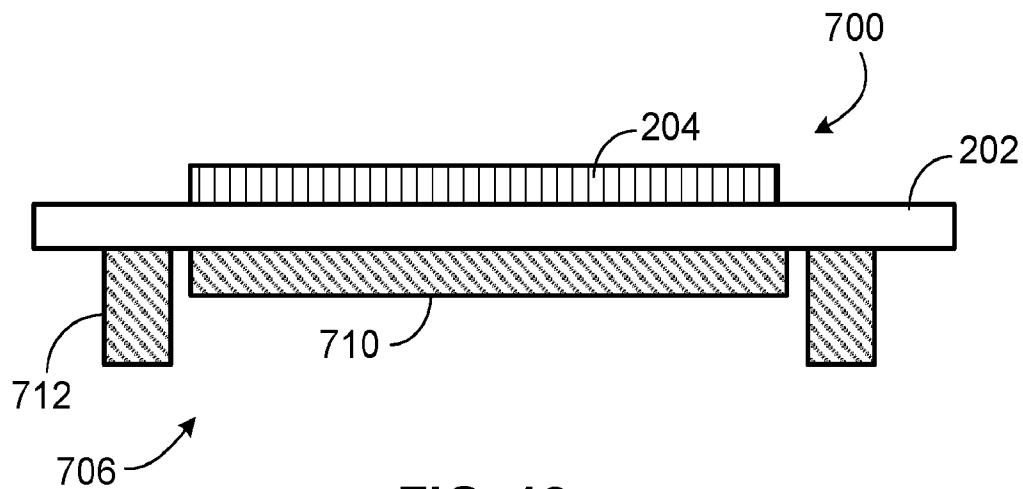
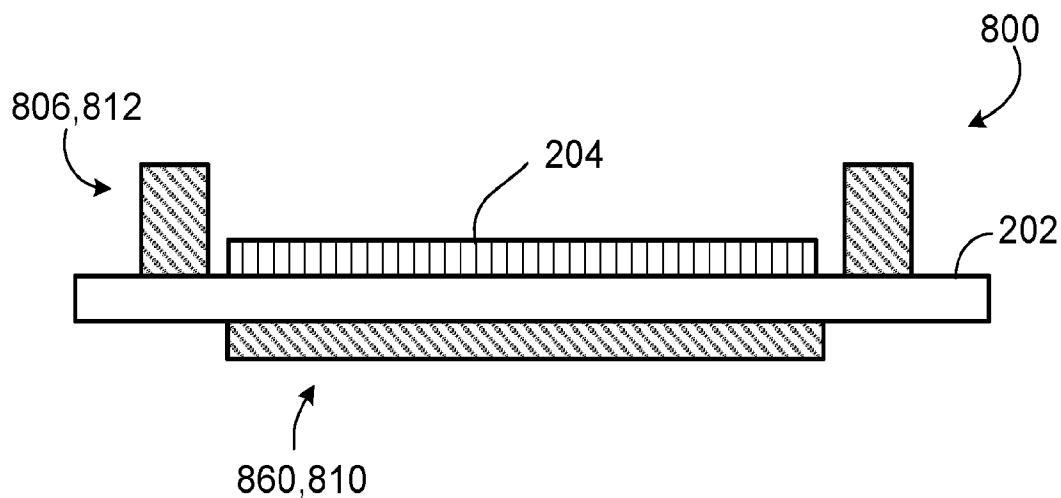
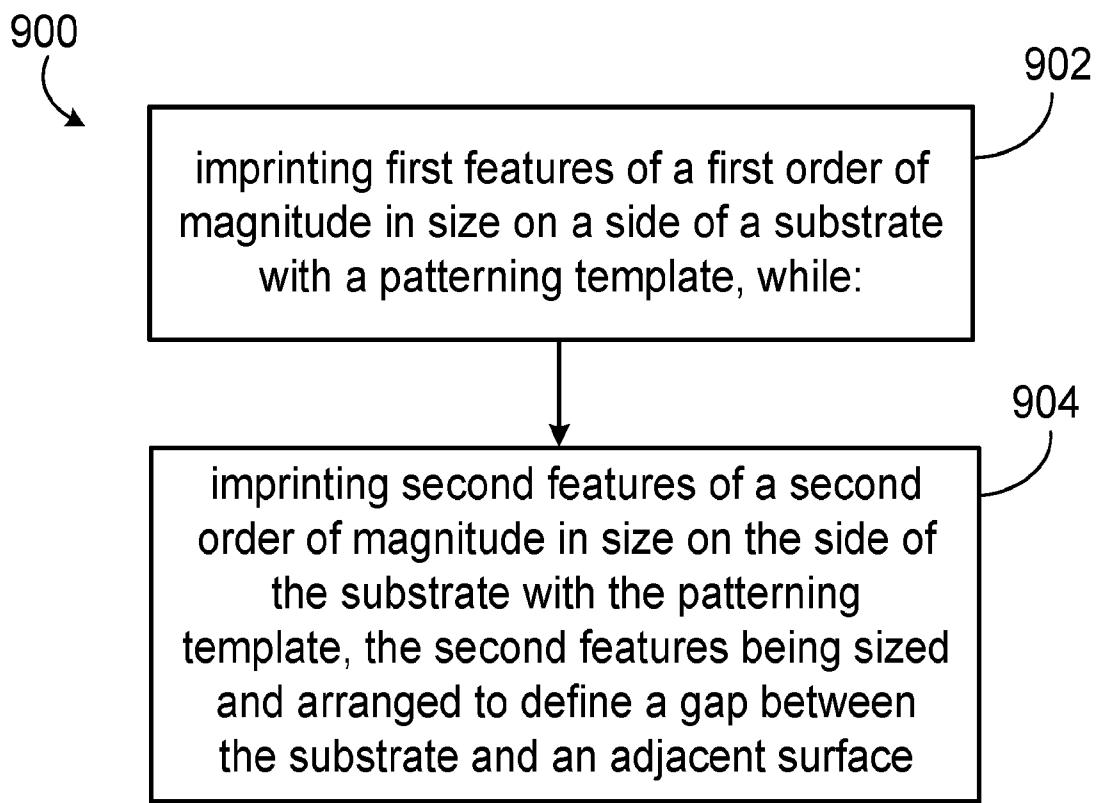


FIG. 8



**FIG. 10****FIG. 11**

**FIG. 12****FIG. 13**

**FIG. 14**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US17/51444

A. CLASSIFICATION OF SUBJECT MATTER

IPC - B82Y 10/00, 20/00, 40/00; G03F 7/00 (2017.01)
 CPC - B82Y 10/00, 20/00, 40/00; G03F 7/0002

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

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

See Search History document

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

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2013/0214452 A1 (CHOI, B-J et al.) August 22, 2013; abstract; figure 6; paragraphs [0020], [0022], [0055], [0057], [0084]	1-20
Y	US 2007/0178666 A1 (DO, BT et al) August 2, 2007; figure 1, paragraphs [0009], [0028], [0034]	1-20
Y	US 2013/0203193 A1 (SAMSUNG DISPLAY CO., LTD.) August 8, 2013; abstract; paragraph [0003]	4
Y	US 2010/0052216 A1 (KIM, YH et al.) March 4, 2010; figures 1, 5; paragraphs [0002], [0004], [0016], [0021]	6-7
Y	US 2013/0052414 A1 (DOBBINS, MS et al.) February 28, 2013; abstract; paragraphs [0002], [0009], [0014], [0077]	10
Y	US 8,427,747 B2 (LE, HT et al.) April 23, 2013; figure 3, column 1, lines 10-15; column 3, lines 20-25, 30-35; column 4, lines 11-16	18-19

Further documents are listed in the continuation of Box C.

See patent family annex.

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

Date of the actual completion of the international search

20 October 2017 (20.10.2017)

Date of mailing of the international search report

16 NOV 2017

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