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(54) **COMPONENT HAVING AT LEAST ONE FEATURE THAT HAS A VARYING CROSS-SECTIONAL SHAPE, SIZE, OR POSITION**

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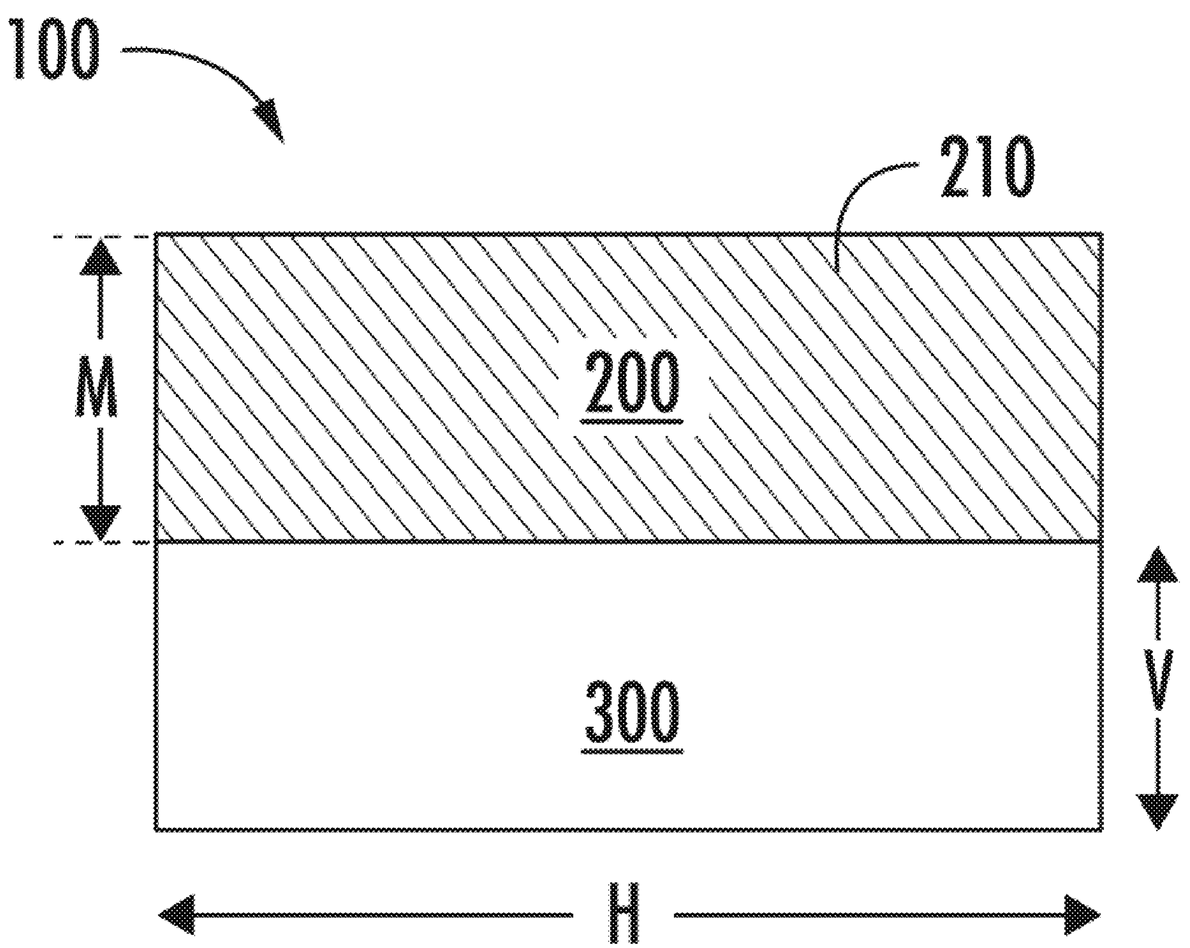
(52) **U.S. Cl.**

CPC ***H01L 21/30604*** (2013.01); ***C23C 16/045*** (2013.01); ***H01L 21/02164*** (2013.01); ***H01L 21/3065*** (2013.01)

(57) **ABSTRACT**

In various aspects, a method of forming at least one feature on a substrate for a component of an electrical or optical device is provided. The method may include forming at least one cavity in a mold layer that is on the substrate. The mold layer may include a mold material. The method may include applying a feature material within each of the at least one cavity and on the substrate. The feature material may define the at least one feature.



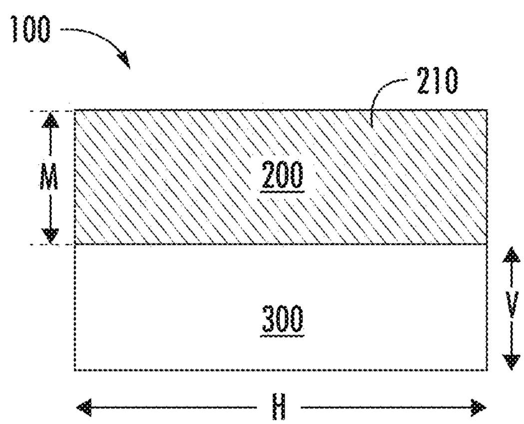


FIG. 1A

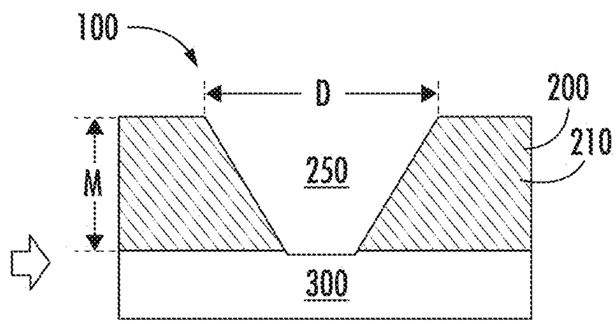


FIG. 1B

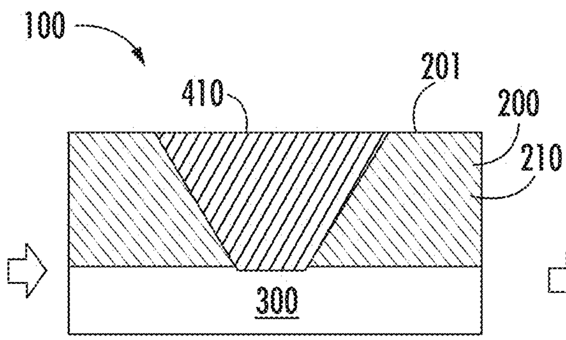


FIG. 1C

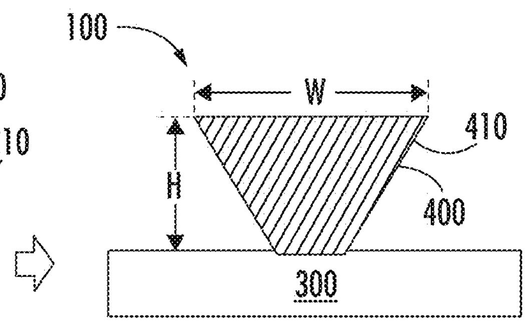


FIG. 1D

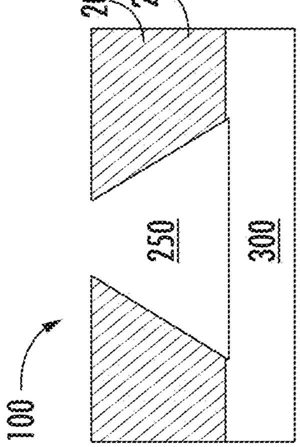


FIG. 2A

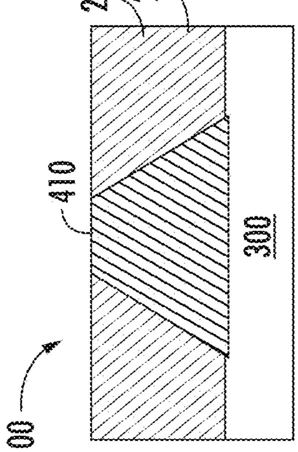


FIG. 2B

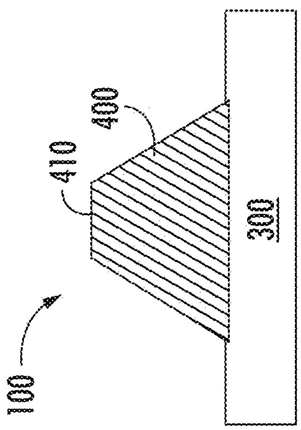


FIG. 2C

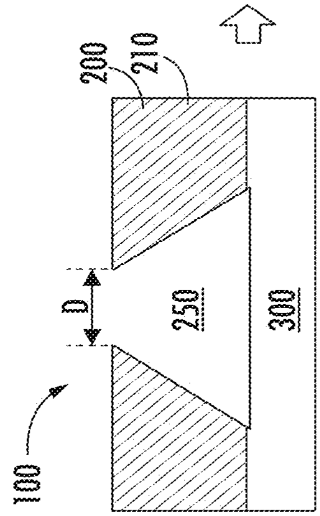


FIG. 2D

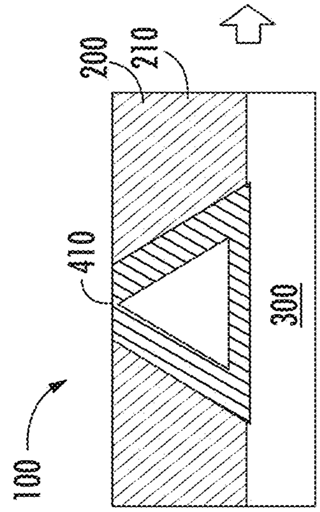


FIG. 2E

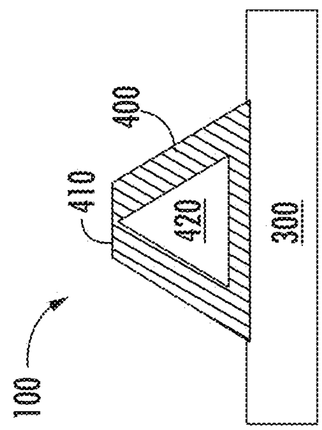


FIG. 2F

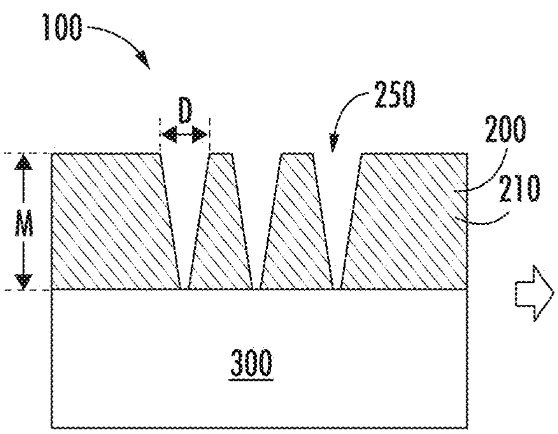


FIG. 3A

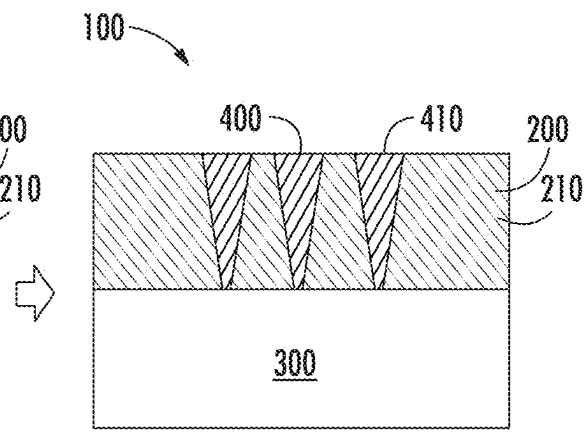


FIG. 3B

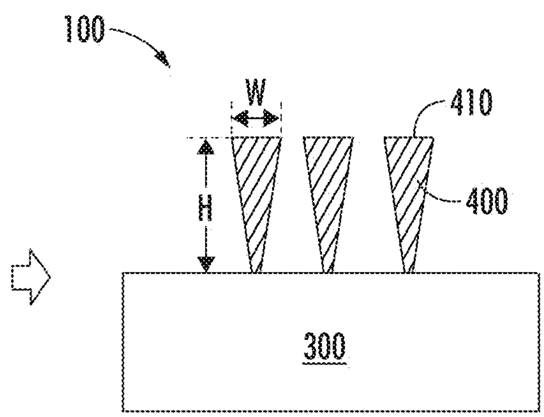


FIG. 3C

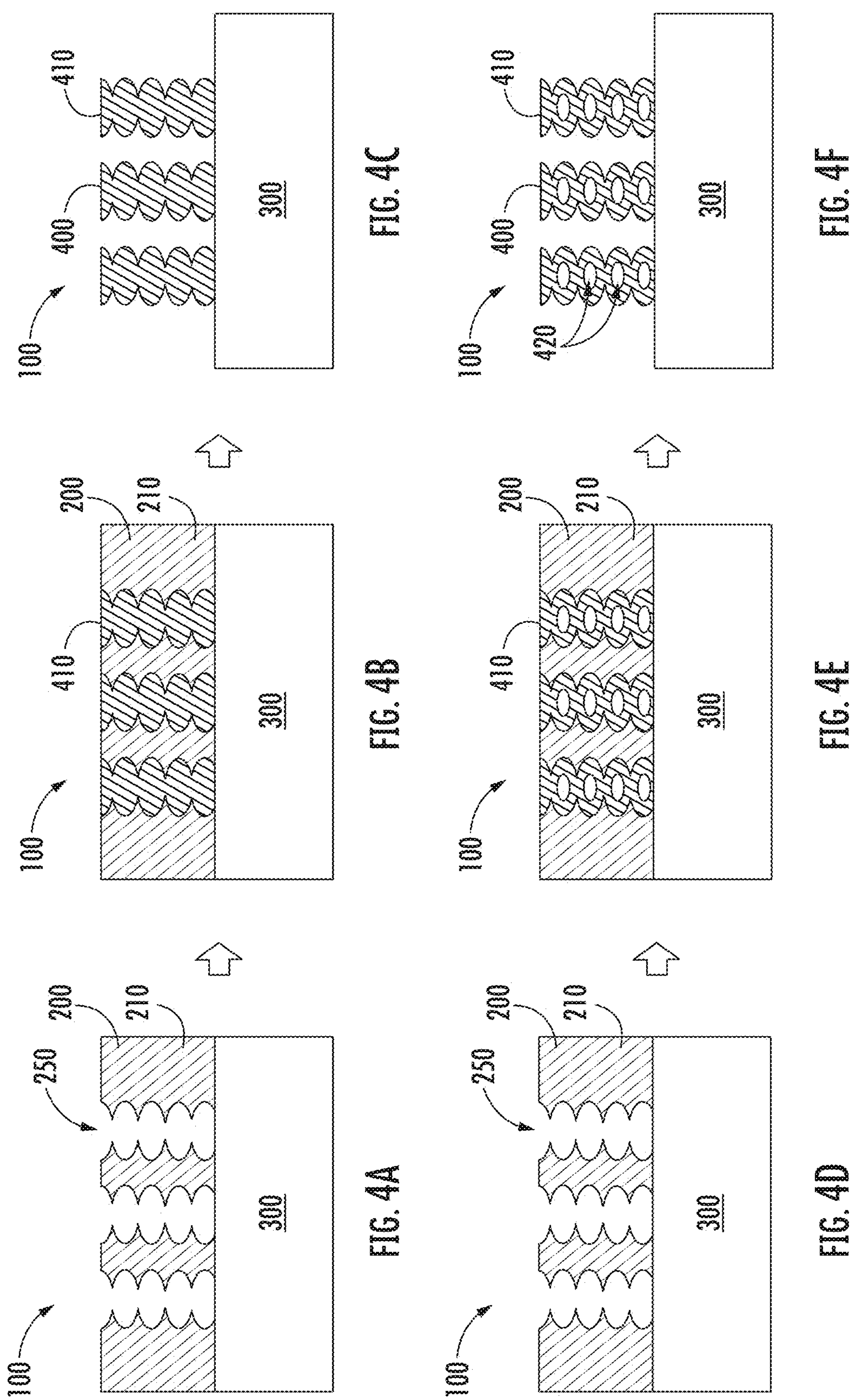


FIG. 4A

FIG. 4B

FIG. 4C

FIG. 4D

FIG. 4E

FIG. 4F

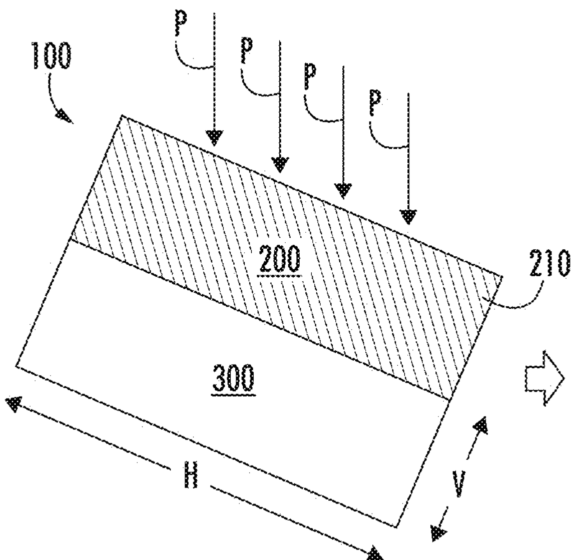


FIG. 5A

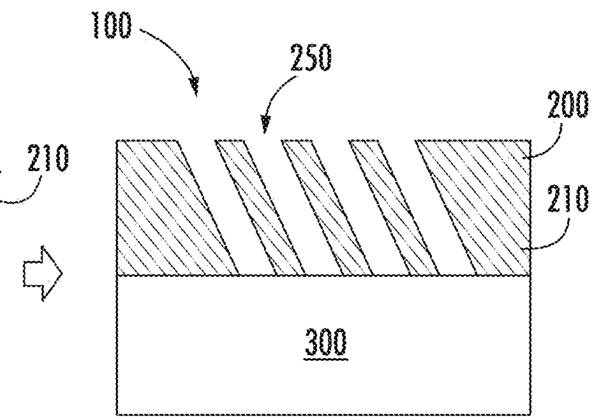


FIG. 5B

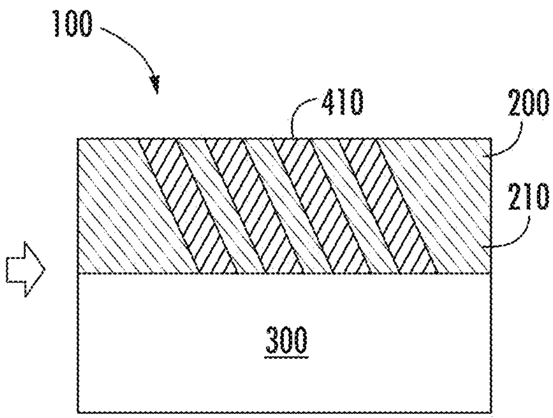


FIG. 5C

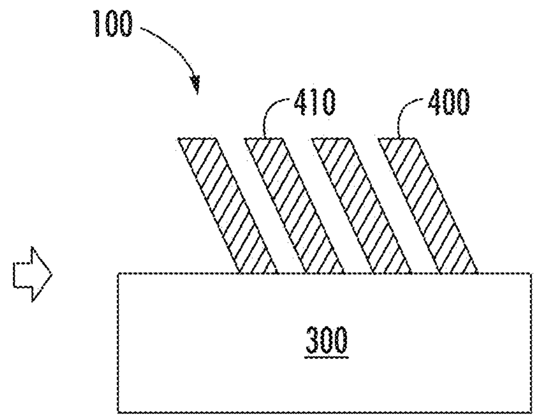


FIG. 5D

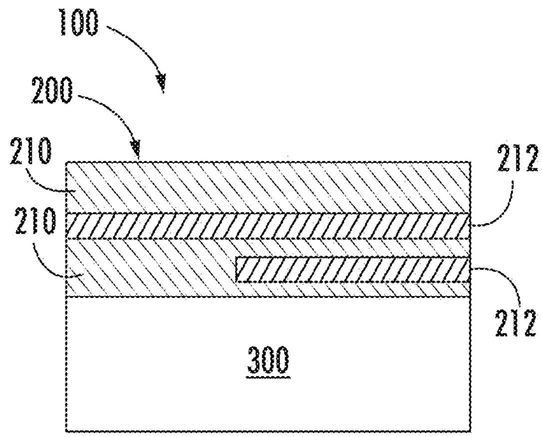


FIG. 6A

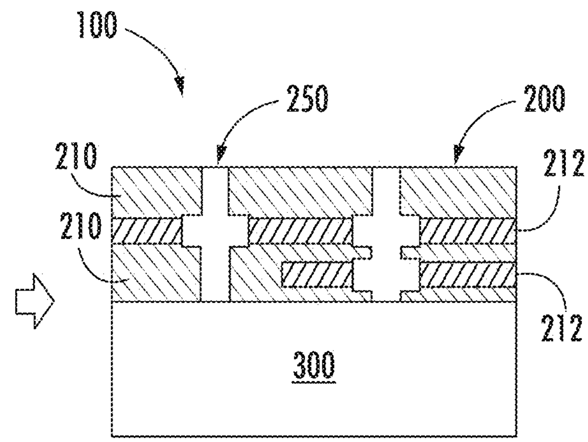


FIG. 6B

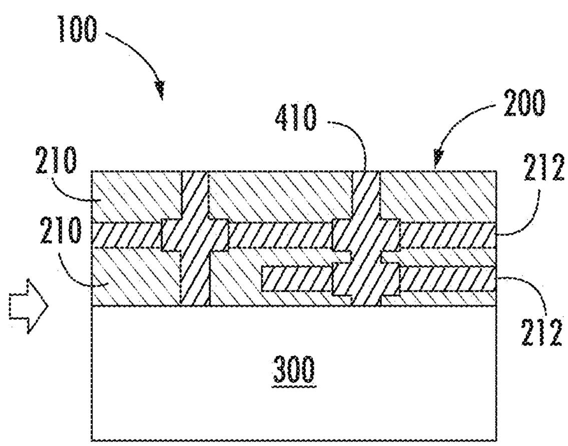


FIG. 6C

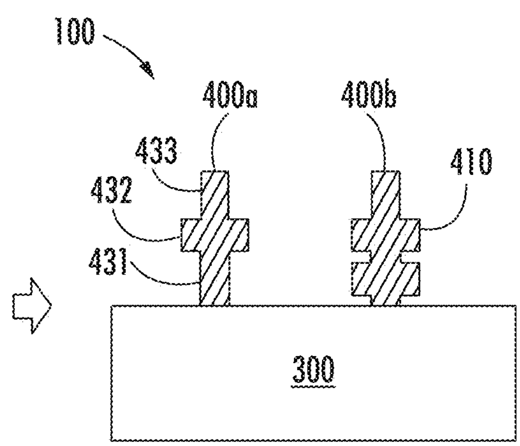


FIG. 6D

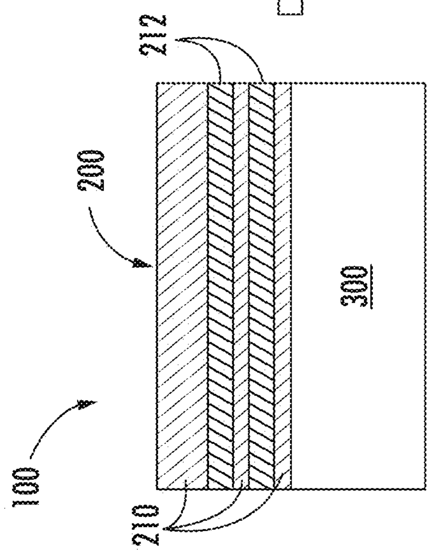


FIG. 7A

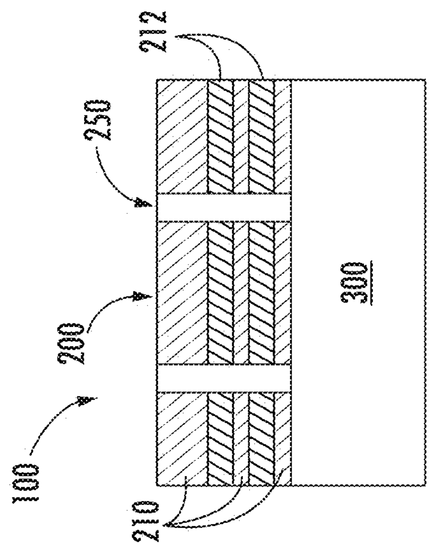


FIG. 7B

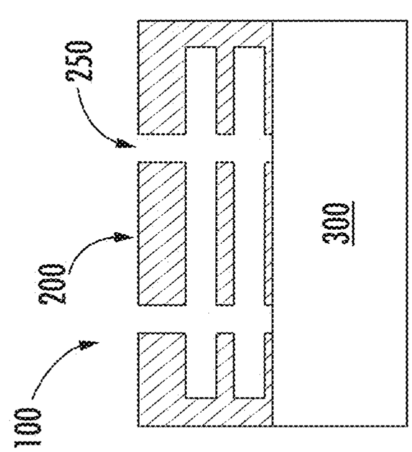


FIG. 7C

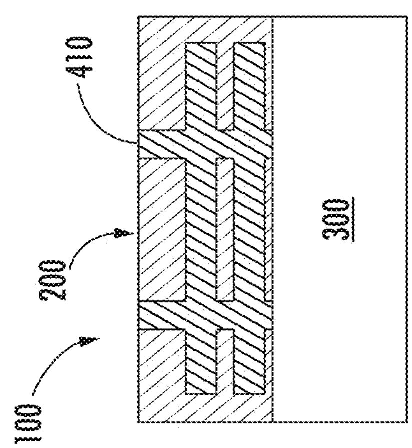


FIG. 7D

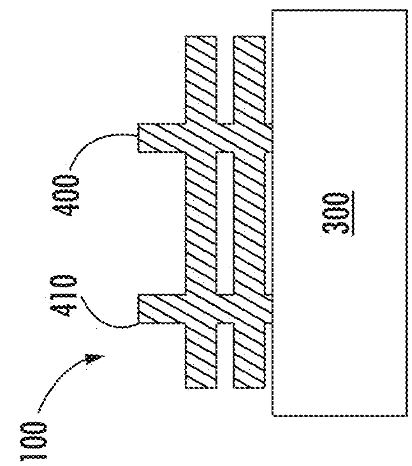


FIG. 7E

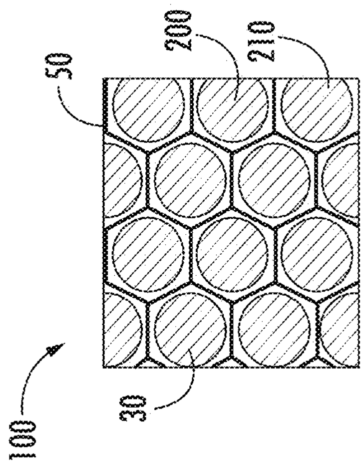


FIG. 8B

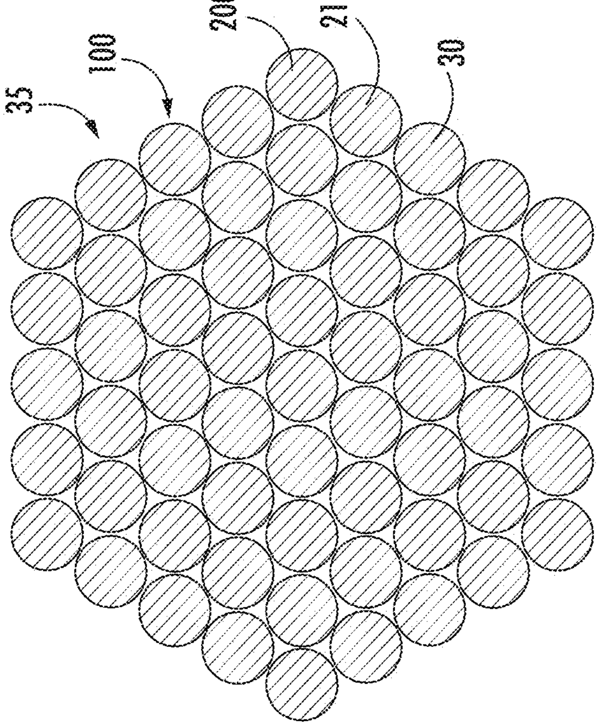


FIG. 8A

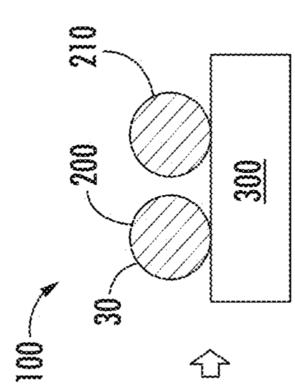


FIG. 8C

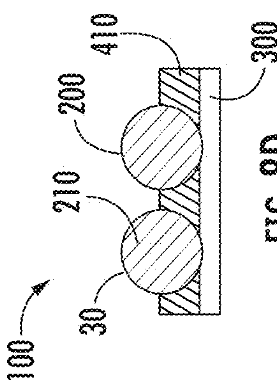


FIG. 8D

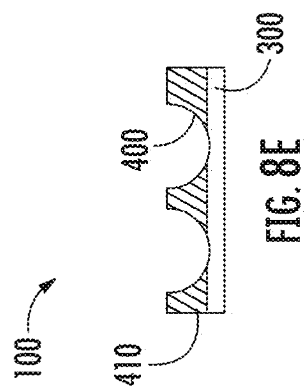


FIG. 8E

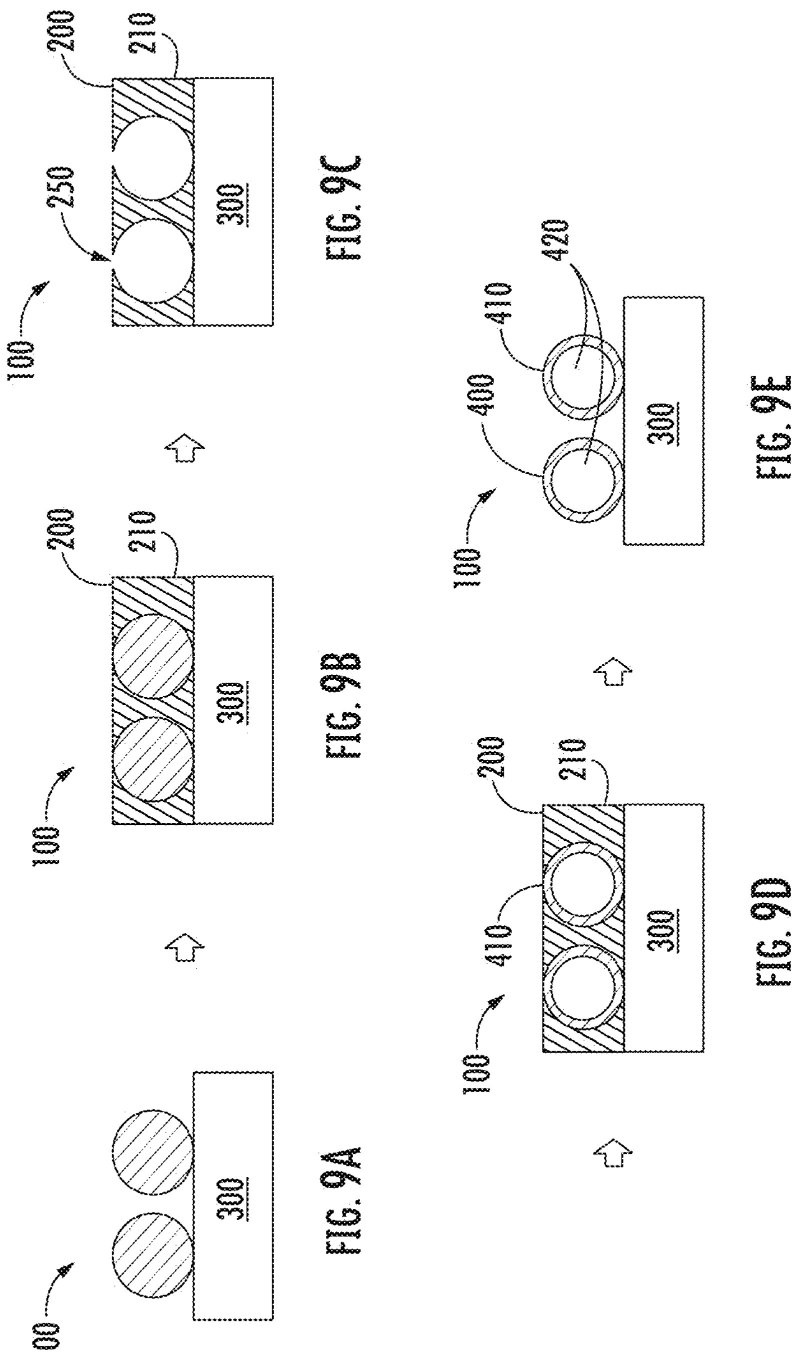


FIG. 9A

FIG. 9B

FIG. 9C

FIG. 9D

FIG. 9E

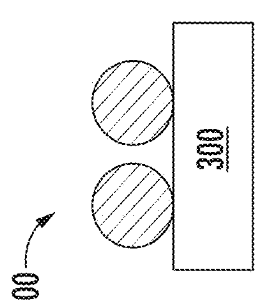


FIG. 10A

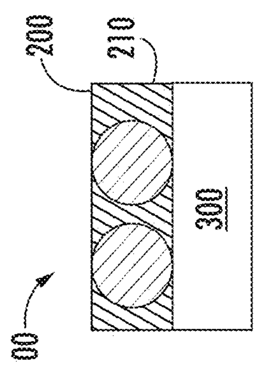


FIG. 10B

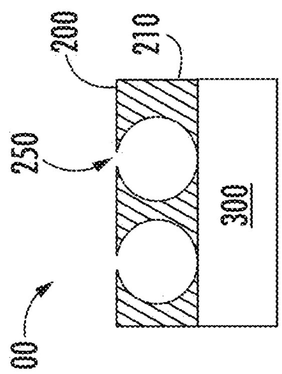


FIG. 10C

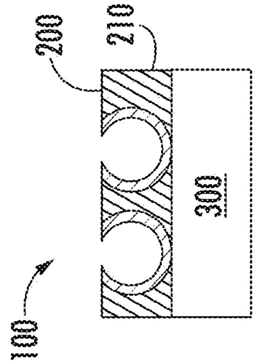


FIG. 10D

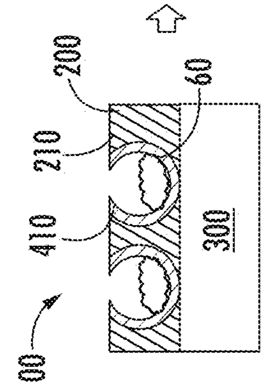


FIG. 10E

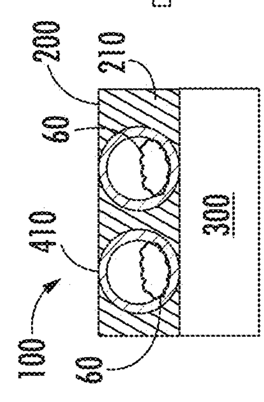


FIG. 10F

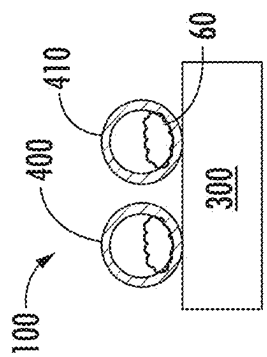


FIG. 10G

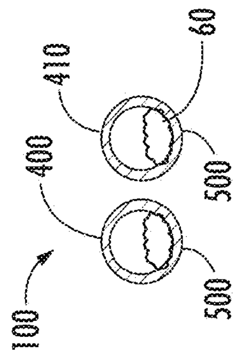


FIG. 10H

COMPONENT HAVING AT LEAST ONE FEATURE THAT HAS A VARYING CROSS-SECTIONAL SHAPE, SIZE, OR POSITION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application is a nonprovisional application, which claims priority to and the benefit of U.S. Provisional Application No. 63/554,624, filed Feb. 16, 2024, the contents of which are incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] The present application relates generally to fabrication of components of an electrical and/or optical device that includes at least one feature formed on a substrate of the component. More specifically, the present application relates to forming each feature on the substrate such that each feature has a varying cross-sectional shape, a varying cross-sectional size, or a varying cross-sectional position.

BACKGROUND

[0003] Components of electrical and/or optical devices often include features that are formed on a substrate, such as a semiconductor wafer. Conventional methods of forming these features may result in features that are uniform in out-of-plane dimensions, similar to an extrusion that only has a two-dimensional profile. Stated differently, conventional methods of forming features on a substrate may result in features that have a consistent cross-sectional shape, consistent cross-sectional size, and consistent cross-sectional position along a length of the conventional feature.

[0004] The inventors have identified numerous deficiencies and problems with the existing technologies in this field. Through applied effort, ingenuity, and innovation, many of these identified deficiencies and problems have been solved by developing solutions that are structured in accordance with the embodiments of the present disclosure, many examples of which are described in detail herein.

BRIEF SUMMARY

[0005] In general, embodiments of the present disclosure provided herein include methods and apparatuses to provide for improved components for electrical and/or optical devices. The components may each include a substrate and at least one feature formed on the substrate. The embodiments of the present disclosure describe various methods to form features on the substrate such that each feature has a varying cross-sectional shape, a varying cross-sectional size, or a varying cross-sectional position.

[0006] In various aspects, a method of forming at least one feature on a substrate for a component of an electrical or optical device is provided. The method may include forming at least one cavity in a mold layer that is on the substrate. The mold layer may include a mold material. The method may include applying a feature material within each of the at least one cavity and on the substrate. The feature material may define the at least one feature.

[0007] In various examples, the method further includes removing the mold layer. The feature material that remains on the substrate after the mold layer is removed may define the at least one feature.

[0008] In various examples, the mold material of the mold layer includes silicon.

[0009] In various examples, applying the feature material within each of the at least one cavity includes using a conformal chemical vapor deposition process to apply the feature material.

[0010] In various examples, the feature material is a dielectric material.

[0011] In various examples, the feature material is a metallic material.

[0012] In various examples, forming the at least one cavity includes forming the at least one cavity completely through a mold thickness of the mold layer.

[0013] In various examples, the at least one feature has a height that is less than 5 microns.

[0014] In various examples, the at least one feature has a width that is less than 5 microns.

[0015] In various examples, forming the at least one cavity in the mold layer includes removing a portion of the mold material with a wet chemical etching process to form the at least one cavity.

[0016] In various examples, removing the portion of the mold material includes removing the portion of the mold material with potassium hydroxide (KOH).

[0017] In various examples, at least one cavity defines a frustrum shape.

[0018] In various examples, a void is formed within the feature material that defines the at least one feature.

[0019] In various examples, the void includes an ultra-high vacuum environment.

[0020] In various examples, the void includes a low-pressure environment.

[0021] In various examples, the at least one cavity defines an inverted frustrum shape.

[0022] In various examples, forming the at least one cavity in the mold layer includes removing a portion of the mold material with a dry etching process to form the at least one cavity.

[0023] In various examples, the dry etching process results in reduced etching as the portion of the mold material is removed, which results in a tapered shape.

[0024] In various examples, each of the at least one cavity defines a conical shape.

[0025] In various examples, the mold layer defines a mold thickness and the at least one cavity formed in the mold layer defines an opening that has a diameter. The mold thickness may be greater than the diameter of the opening.

[0026] In various examples, forming the at least one cavity in the mold layer includes removing a portion of the mold material with alternating steps of etching the mold material, and passivating the mold material.

[0027] In various examples, etching the mold material includes etching the mold material with sulfur hexafluoride (SF6) and passivating the mold material includes passivating the mold material with octafluorocyclobutane (C4F8).

[0028] In various examples, each cavity defines a scallop shape.

[0029] In various examples, inner walls of each cavity define a plurality of parabolic-shaped inner walls.

[0030] In various examples, a plurality of voids is formed within the feature material that is applied within the cavity.

[0031] In various examples, each void includes a low-pressure environment.

[0032] In various examples, each void includes an ultra-high vacuum environment.

[0033] In various examples, forming the at least one cavity in the mold layer includes removing a portion of the mold material with a reactive ion etching process to form the at least one cavity.

[0034] In various examples, the method includes positioning the substrate at an angle relative to a direction of travel of ions being used in the reactive ion etching process.

[0035] In various examples, the mold layer includes a plurality of layers. Aat least one layer may include the mold material and at least another layer may include a second mold material.

[0036] In various examples, the method includes applying a masking layer on at least a portion of at least one of the plurality of layers.

[0037] In various examples, the plurality of layers may include the second mold material, and wherein each layer that includes the second mold material is distinct from the other layers that comprise the second mold material.

[0038] In various examples, the at least one layer that includes the mold material has a different thickness than the at least one layer that includes the second mold material.

[0039] In various examples, at least one of the layers that includes the second mold material has a different thickness than another one of the layers that includes the second mold material.

[0040] In various examples, at least one of the layers that includes the second mold material has a same thickness than another one of the layers that comprise the second mold material.

[0041] In various examples, the layers that includes the second mold material and have the same thickness also have different volumes.

[0042] In various examples, at least one of the layers that includes the second mold material has a portion that is not vertically aligned with at least one other layer that includes the second mold material.

[0043] In various examples, the mold material is silicon and the second mold material is silicon oxide.

[0044] In various examples, the forming the at least one cavity in the mold layer includes using a single etch process that will etch the mold material differently than the second mold material.

[0045] In various examples, the forming the at least one cavity in the mold layer includes using a single etch process that results in a vertical etch component and an isotropic etch component of the mold material and the second mold material. The rate of the vertical etch component and/or the isotropic etch component may be higher for one of the mold material or the second mold material.

[0046] In various examples, the forming the at least one cavity in the mold layer includes using a single etch process that will etch the mold material vertically and the second mold material isotropically.

[0047] In various examples, the forming the at least one cavity in the mold layer includes etching the mold material and the second mold material vertically with a first etching process, and etching the second mold material with a second etching process that is chemically selective to etch the second mold material isotropically.

[0048] In various aspects, a method of forming at least one feature on a substrate is provided. The method may include bonding a self-assembled structure on the substrate, applying a feature material or a mold layer comprising a mold material on the substrate and around the self-assembled structure, and removing the self-assembled structure from the substrate and from the feature material or the mold layer.

[0049] In various examples, the method includes positioning a lattice tool on the substrate. The lattice tool may define a plurality of spaces. The method may include positioning a plurality of self-assembled structures within the lattice tool. Each self-assembled structure is positioned within a respective space of the plurality of spaces defined by the lattice tool. The method may include bonding each of the self-assembled structures on the substrate.

[0050] In various examples, the lattice tool is a hexagonal lattice tool.

[0051] In various examples, the self-assembled structure is a self-assembled nanosphere.

[0052] In various examples, the self-assembled structure is a self-assembled polystyrene nanosphere.

[0053] In various examples, the self-assembled structure is a silica (SiO2) nanosphere.

[0054] In various examples, the method further includes arranging a plurality of self-assembled structures on the substrate in a self-organized arrangement by suspending the plurality of self-assembled structures in a liquid suspension and allowing the liquid suspension to evaporate.

[0055] In various examples, the plurality of self-assembled structures are suspended in the liquid suspension on top of the substrate.

[0056] In various examples, the method includes applying the feature material on the substrate and around the self-assembled structure.

[0057] In various examples, the feature material is a dielectric material or a metallic material.

[0058] In various examples, the feature material is a reflective material having a reflectivity of at least 90%.

[0059] In various examples, the method includes applying a reflective coating on the feature material, the reflective coating having a reflectivity of at least 90%.

[0060] In various examples, the method includes applying the mold layer on the substrate and around the self-assembled structure.

[0061] In various examples, the method includes applying the feature material within a cavity that is formed in the mold layer. The cavity may be formed after the removing the self-assembled structure from the substrate and from the mold layer, and wherein the feature material defines the at least one feature.

[0062] In various examples, the applying the feature material within the cavity includes applying the feature material within the cavity with a conformal deposition process.

[0063] In various examples, the applying the feature material within the cavity includes enclosing the cavity to form a void within the feature material that defines the at least one feature.

[0064] In various examples, the void includes a low-pressure environment.

[0065] In various examples, the void includes an ultra-high vacuum environment.

[0066] In various examples, the at least one feature defines a hollow spherical shape.

[0067] In various examples, the method includes positioning or depositing a substance within the at least one feature.

[0068] In various examples, the substance is a medicinal substance.

[0069] In various examples, forming the at least one cavity in the mold layer that is on the substrate includes bonding a self-assembled structure on the substrate, and applying the mold layer on the substrate and around the self-assembled structure.

[0070] In various examples, the method includes removing the self-assembled structure from the substrate.

[0071] In various examples, the at least one feature formed on the substrate is for at least one of a component of an electrical or optical device or a nanoparticle.

[0072] In various aspects, a component for an electrical or optical device is provided. The component may include a substrate extending along a horizontal plane, and at least one feature on the substrate. The at least one feature may include a feature material, and the at least one feature may have a varying cross-sectional shape or position along at least two other horizontal planes.

[0073] In various examples, the feature material is a dielectric material.

[0074] In various examples, the feature material is a metallic material.

[0075] In various examples, the at least one feature has the varying cross-sectional shape along the at least two other horizontal planes.

[0076] In various examples, each feature has a first portion that has a first horizontal thickness and a second portion that has second horizontal thickness, and wherein a percent difference between the first horizontal thickness and the second horizontal thickness is at least five percent.

[0077] In various examples, the at least one feature has a pyramidal shape.

[0078] In various examples, the at least one feature has an inverted pyramidal shape.

[0079] In various examples, the at least one feature defines a void that is positioned within the at least one feature.

[0080] In various examples, the void includes a low-pressure environment.

[0081] In various examples, the void includes an ultra-high vacuum environment.

[0082] In various examples, the at least one feature has a tapered shape.

[0083] In various examples, the at least one feature has an inverted conical shape.

[0084] In various examples, the at least one feature has a scallop shape.

[0085] In various examples, an outer surface of the at least one feature defines a plurality of parabolic-shaped outer surfaces.

[0086] In various examples, the at least one feature includes a plurality of voids that are formed within the feature material of the at least one feature.

[0087] In various examples, each void includes a low-pressure environment.

[0088] In various examples, each void includes an ultra-high vacuum environment.

[0089] In various examples, the at least one feature has a varying cross-sectional position along the at least two other horizontal planes.

[0090] In various examples, the at least one feature has a consistent cross-sectional shape along the at least two other horizontal planes.

[0091] In various examples, the at least one feature extends at an angle relative to the horizontal plane. The angle may be at least 5 degrees and up to 85 degrees.

[0092] In various examples, each feature has a first portion that has a first horizontal thickness, a second portion that has a second horizontal thickness, and a third portion that has a third horizontal thickness, a first percent difference between the first horizontal thickness and the second horizontal thickness is at least five percent, and a second percent difference between the first horizontal thickness and the third horizontal thickness is less than five percent.

[0093] In various examples, a first feature of the at least one feature has a different shape than a second feature of the at least one feature.

[0094] In various examples, each of the first feature and the second feature comprise at least one protrusion, and wherein the second feature includes more protrusions than the first feature.

[0095] In various examples, the at least one feature has a three-dimensional lattice shape.

[0096] In various examples, the at least one feature has a portion that has concave shape.

[0097] In various examples, the feature material of the at least one feature is a reflective material having a reflectivity of at least 90%.

[0098] In various examples, the component includes a reflective coating positioned on the at least one feature. The reflective coating may have a reflectivity of at least 90%.

[0099] In various examples, the at least one feature has a plurality of portions that have a concave shape.

[0100] In various examples, the at least one feature has a spherical shape.

[0101] In various examples, the at least one feature defines a void that is positioned within the at least one feature.

[0102] In various examples, the void includes a low-pressure environment.

[0103] In various examples, the void includes an ultra-high vacuum environment.

[0104] In various examples, the at least one feature includes a substance encapsulated within the at least one feature.

[0105] In various examples, the at least one feature is a nanoparticle.

[0106] In various examples, the substance is a medicinal substance. The above summary is provided merely for purposes of summarizing some example embodiments to provide a basic understanding of some aspects of the present disclosure. Accordingly, it will be appreciated that the above-described embodiments are merely examples and should not be construed to narrow the scope or spirit of the present disclosure in any way. It will be appreciated that the scope of the present disclosure encompasses many potential embodiments in addition to those here summarized, some of which will be further described below. Other features, aspects, and advantages of the subject matter will become apparent from the description, the drawings, and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0107] Having thus described certain example embodiments of the present disclosure in general terms above, non-limiting and non-exhaustive embodiments of the subject disclosure are described with reference to the following figures, which are not necessarily drawn to scale and wherein like reference numerals refer to like parts throughout the various views unless otherwise specified. The components illustrated in the figures may or may not be present in certain embodiments described herein. Some embodiments may include fewer (or more) components than those shown in the figures.

[0108] FIGS. **1**A-**1**D provide cross-sectional, side views of at least a portion of a component during various manufacturing stages, in accordance with an example embodiment.

[0109] FIGS. **2**A-**2**F provide cross-sectional, side views of at least a portion of a component **100** during various manufacturing stages are provided, in accordance with an example embodiment.

[0110] FIGS. **3**A-**3**C provide cross-sectional, side views of at least a portion of a component during various manufacturing stages, in accordance with an example embodiment.

[0111] FIGS. **4**A-**4**C provide cross-sectional, side views of at least a portion of a component during various manufacturing stages, in accordance with an example embodiment.

[0112] FIGS. **4**D-**4**F provide cross-sectional, side views of at least a portion of a component during various manufacturing stages, in accordance with an example embodiment.

[0113] FIGS. **5**A-**5**Dprovide cross-sectional, side views of at least a portion of a component during various manufacturing stages, in accordance with an example embodiment.

[0114] FIGS. **6**A-**6**D provide cross-sectional, side views of at least a portion of a component during various manufacturing stages, in accordance with an example embodiment.

[0115] FIGS. **7**A-**7**E provide cross-sectional, side views of at least a portion of a component during various manufacturing stages, in accordance with an example embodiment.

[0116] FIG. **8**A provides a top view of at least a portion of a component during a manufacturing stage, in accordance with an example embodiment.

[0117] FIG. **8**B provides a top view of at least a portion of a component during a manufacturing stage, in accordance with an example embodiment.

[0118] FIGS. **8**C-**8**E provide cross-sectional, side views of at least a portion of the component of FIG. **8**B during various manufacturing stages, in accordance with an example embodiment.

[0119] FIGS. **9**A-**9**E provide cross-sectional, side views of at least a portion of a component during various manufacturing stages, in accordance with an example embodiment.

[0120] FIGS. **10**A-**10**H provide cross-sectional, side views of at least a portion of a component during various manufacturing stages, in accordance with an example embodiment.

DETAILED DESCRIPTION

[0121] One or more embodiments are now more fully described with reference to the accompanying drawings, wherein like reference numerals are used to refer to like elements throughout and in which some, but not all embodiments of the inventions are shown. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the various embodiments. It is evident, however, that the various embodiments can be practiced without these specific details. It should be understood that some, but not all embodiments are shown and described herein. Indeed, the embodiments may be embodied in many different forms, and accordingly this disclosure should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements.

[0122] As used herein, the term "exemplary" means serving as an example, instance, or illustration. Any aspect or design described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other aspects or designs. Rather, use of the word exemplary is intended to present concepts in a concrete fashion. In addition, while a particular feature may be disclosed with respect to only one of several implementations, such feature may be combined with one or more other features of the other implementations as may be desired and advantageous for any given or particular application. Furthermore, to the extent that the terms "includes" and "including" and variants thereof are used in either the detailed description or the claims, these terms are intended to be inclusive in a manner similar to the term "comprising."

[0123] As used herein, the term "or" is intended to mean an inclusive "or" rather than an exclusive "or". That is, unless specified otherwise, or clear from context, "X employs A or B" is intended to mean any of the natural inclusive permutations. That is, if X employs A; X employs B; or X employs both A and B, then "X employs A or B" is satisfied under any of the foregoing instances. In addition, the articles "a" and "an" as used in this application and the appended claims should generally be construed to mean "one or more" unless specified otherwise or clear from context to be directed to a singular form.

[0124] As used herein, the term "positioned on" refers to a first component being positioned on a second component such that they make contact.

[0125] As used herein, the term "cross-sectional position" refers to a position of a feature on an XY plane that extends horizontally (i.e., parallel to a horizontal plane defined by a surface of a substrate). The cross-sectional position may be defined by an X coordinate and a Y coordinate. The term "cross-sectional shape" refers to a shape of a feature along an intersection of an XY plane. The term "cross-sectional size" refers to a size of a feature (i.e., area and dimensions of the feature) along an intersection of an XY plane.

[0126] The term "varying cross-sectional position" refers to a feature that has different X coordinate and/or Y coordinate positions depending on the Z coordinate (i.e., a vertical location relative to the horizontal plane defined by the surface of the substrate). Stated differently, the feature may define a first XY coordinate at a first Z coordinate and a second XY coordinate at a second Z coordinate, the first XY coordinate being different than the second XY coordinate. The first XY coordinate may be located at or near a first end of the feature and the second XY coordinate may be located at or near a second end of the feature. In contrast, the term "consistent cross-sectional position" refers to a feature that has the same XY coordinates at all points along the Z direction for which the feature is located.

[0127] The term "varying cross-sectional shape" refers to a feature that has a first cross-sectional shape at a first Z coordinate that is different than at least a second cross-sectional shape at a second Z coordinate. In contrast, the term "consistent cross-sectional shape" refers to a feature that has the same cross-sectional shape at all points along the Z direction for which the feature is located.

[0128] The term "varying cross-sectional size" refers to a feature that has a first cross-sectional size at a first Z coordinate that is different than at least a second cross-sectional size at a second Z coordinate. In contrast, the term "consistent cross-sectional size" refers to a feature that has the same cross-sectional size at all points along the Z direction for which the feature is located.

[0129] As used herein, terms of approximation, such as "approximately," "substantially," or "about," refer to being within manufacturing or engineering tolerances. For example, terms of approximation may refer to being within a five percent margin of error.

[0130] Various embodiments provide a component of an electrical or optical device having a varying cross-sectional shape or position and/or methods for fabricating such components. In various embodiments, the component is an integrated photonic and/or optical component that may be a passive or active component. Various embodiments, provide nanometer-scale structures, such as nanoparticles, and methods for fabricating such structures.

[0131] For example, in an example embodiment, a component for an electrical or optical device and/or a nanometer-scale structure is provided that includes a substrate extending along a horizontal plane; and at least one feature on the substrate. The at least one feature comprises a feature material and has a varying cross-sectional shape or position along at least two other horizontal planes. In an example embodiment, the nanometer-scale structure may be removed from the substrate for use. In an example embodiment, the component is fabricated or formed by forming at least one cavity in a mold layer that is on the substrate, wherein the mold layer comprises a mold material; applying a feature material within each of the at least one cavity and on the substrate; and removing the mold layer. The feature material that remains on the substrate after the mold layer is removed defines the at least one feature.

[0132] Referring now to FIGS. **1A-1D**, cross-sectional, side views of at least a portion of a component **100** during various manufacturing or fabrication stages are provided, in accordance with an example embodiment. The component **100** can be a component **100** of an electrical and/or optical device (not depicted). In various examples, the electrical and/or optical device is a quantum information device, such as a quantum computer, an ion trap for a quantum computer, an atomic clock, or various other devices that are configured for sensing, such as photonic sensing, networking, cryptography, etc.

[0133] The component **100** may be a photonic component or an integrated optical component. For example, the component **100** can be a photonic coupling element, which may be a device that couples light from a guided mode to a free space propagating mode. The component **100** can be a metasurface of an optical device. For example, the component **100** can be a lens, a quarter or half waveplate metasurface, a spatial beam shaping metasurface, a beam directing metasurface, a lens for an image sensor, a laser beam splitter, or a color filter. In various examples, the component **100** can be a diffractive optic-phase-array or a hologram (e.g., lens hologram, graded arrays for beam direction, or spatial beam shaping holograms). In yet other examples, the component **100** can be a ring resonator, a power modulator, a waveguide, an input taper, a splitter (e.g., multi-mode interference (MMI), or y-branch), or a directional coupler. In yet other examples, the component **100** can be phonetic component **100**, such as a metasurface for an antenna or a sound absorbing device.

[0134] The component **100** can include a substrate **300** that extends along a horizontal plane and at least one feature **400** that is positioned on the substrate **300**. As will be discussed further, each feature **400** may have a varying cross-sectional shape or varying position along at least two other horizontal planes. The component **100** can include one feature **400** or a plurality of features **400**, such as up to five-thousand features **400**. Each feature **400** can be configured substantially similarly or at least some features **400** can be configured differently than other features **400** of the component **100**. As will be appreciated in light of the present disclosure, different methodologies are provided that may be used to form various-shaped features **400**. Each or some of these methodologies may be used to form features **400** that are different than other features **400**.

[0135] With reference to FIG. **1A**, the component **100** can be manufactured by applying (e.g., depositing) a mold layer **200** on a substrate **300**. The substrate **300** can be a wafer that includes silicon (Si), such as silicon dioxide (SiO2) or silicon nitride (Si3N4), germanium (Ge), or a combination thereof. The substrate **300** can define a horizontal direction H and a vertical direction V that extends orthogonally to the horizontal direction H. For example, the vertical direction V extends out from the horizontal direction H. An upper surface of the substrate **300** can be substantially planar.

[0136] The mold layer **200** can include any mold material **210** that can be subsequently removed from the substrate **300**. For example, the mold layer **200** can include any mold material **210** that can be subsequently removed from the substrate **300** with an etching process, such as a wet etching process, a dry etching process, a reactive ion etching process, a plasma etching process, an isotropic etching process, an anisotropic etching process, an acidic etching process, a chemically-selective etching process, etc. For example, the mold material **210** of the mold layer **200** can include aluminum (Al), Si, silicon carbide (SiC), Si3N4, SiO2, copper (Cu), or a combination thereof. In various examples, the mold material **210** of the mold layer **200** includes any electron beam lithography resist material and/or a photolithography resist material. The mold material **210** of the mold layer **200** can be applied and/or deposited on the substrate **300**.

[0137] The mold layer **200** can have a mold thickness M. The mold layer **200** can have a mold thickness M that extends across at least a portion of the surface of the substrate **300**. In various examples, the mold layer **200** can have a mold thickness M that is less than 5 microns, such as less than 2 microns, such as less than 1 micron, such as less than 500 nanometers. As will become apparent with the present disclosure, the mold thickness M can substantially correspond (e.g., within a five percent difference) to a height H (FIG. **1D**) of at least one feature **400** of the component **100**. The height H of the at least one feature **400** of the component **100** may be less than 5 microns, such as less than 2 microns, such as less than 1 micron, such as less than 500 nanometers.

[0138] In various examples, the at least one feature **400** can be formed on the substrate **300** by forming at least one cavity **250** in the mold layer **200** that is on the substrate **300**, as depicted in FIG. **1B**. Forming the at least one cavity **250** can include forming the at least one cavity **250** completely through a mold thickness of the mold layer **200**. For example, the at least one cavity **250** may extend completely through the mold layer **200** and to the substrate **300**.

[0139] In various examples, at least a portion of the mold material **210** of the mold layer **200** can be removed with a wet chemical etching process to form each cavity **250**. The wet chemical etching process may be any etching process that uses liquid chemicals or etchants to remove the portion of the mold material **210** of the mold layer **200**. In various example, at least a portion of the mold material **210** is removed with potassium hydroxide (KOH) in a wet chemical etching process to form each cavity **250**. Each cavity **250** may have any shape. For example, and as depicted in FIG. **1**B, the resulting cavity **250** can define an inverted frustrum shape. In various examples, the resulting cavity **250** can define an inverted pyramid shape. Other shapes for each cavity **250** are contemplated, such as a half-sphere shape or a shape that includes spherically-shaped regions.

[0140] Each cavity **250** can define an opening in the mold layer **200**. The opening of each cavity **250** can define a distance D. As will become apparent in light of the present disclosure, the distance D defined by the opening of each cavity **250** in the mold layer **200** can substantially correspond to a width W (FIG. **1**D) of an upper portion of the resulting feature **400** that is formed within the respective cavity **250**. The distance D defined by the opening of each cavity **250** and the width W of an upper portion of the resulting at least one feature **400** may be less than 5 microns. In various examples, the width W and/or the distance D may be a "critical dimension", a term of art in lithography, which may be measured at a specific height above the substrate **300**.

[0141] In various examples, and with reference to FIG. **1**C, each feature **400** can be formed on the substrate **300** by applying a feature material **410** within each cavity **250** and on the substrate **300**. The feature material **410** may be any material. For example, the feature material **410** may be or comprise a conductive material, such as a metallic material, such as aluminum, copper, tungsten, or a combination thereof. The feature material **410** may be or comprise an insulative material, such as a dielectric material, such as an oxide (e.g., silicon dioxide), a nitride, silicon, or a combination thereof. In various examples, a plurality of different feature materials **410** are use. For example, a first feature material **410** can be applied within a first cavity **250** and a second feature material **410** can be applied within a second cavity **250**. The first feature material **410** may be a conductive material whereas the second feature material **410** may be an insulative material. In various examples, both the first feature material **410** and the second feature material **410** are conductive materials, but the first feature material **410** may be different than the second feature material **410**. Similarly, both the first feature material **410** and the second feature material **410** may be insulative materials, but the first feature material **410** may be different than the second feature material **410**.

[0142] The feature material **410** can be applied within each cavity **250** with a conformal chemical vapor deposition process. For example, the feature material **410** can be applied within each cavity **250** with a chemical vapor deposition (CVD) process. The CVD process can be an atomic layer deposition (ALD) process. The ALD process is a deposition technique that may deposit highly conformal coatings on substrates with a controlled and uniform thickness. The ALD process can include adding a first precursor to a reaction chamber that contains the substrate **300** and the at least one cavity **250** to be filled. After the first precursor is absorbed by the substrate **300** and the mold material **210** of the mold layer **200**, the first precursor can be removed from the reaction chamber and a second precursor can be added to the chamber to react with the first precursor, which may create a layer on the surface of the substrate **300** and/or on an inner wall of the cavity **250** to be filled. The second precursor can then be removed from the reaction chamber and the process can be repeated until the first material fills each cavity **250**.

[0143] In various examples, the feature material **410** can be applied within each cavity **250** with a physical vapor deposition (PVD) process, such as sputtering and evaporation. The PVD process is a process where a solid material is vaporized in a vacuum and deposited onto a substrate **300** and/or within the cavity **250** of the mold layer **200**. In various examples, the feature material **410** can be applied on the substrate **300** and/or within the cavity **250** of the mold layer **200** with a flux-controlled CVD process. In various examples, the feature material **410** can be applied on the substrate **300** and/or within the cavity **250** of the mold layer **200** with an electroplating process.

[0144] In various examples, an overburden removal step can be performed. For example, and as will be appreciated in light of the present disclosure, when the feature material **410** is applied within each cavity **20**, the feature material **410** may also be deposited on a top surface **201** of the mold layer. Having the feature material **410** present on the top surface **201** may be unintentional or undesirable. As such, the portions of the feature material **410** that are positioned higher than the top surface **201** of the mold layer may be removed with an overburden removal step.

[0145] In various examples, and with reference to FIG. **1**D, each feature **400** can be formed on the substrate **300** by removing the mold layer **200** from the component **100**. The mold layer **200** can be removed from the component **100** with an etching process, such as a wet etching process, a dry etching process, a reactive ion etching process, a plasma etching process, an isotropic etching process, an anisotropic etching process, an acidic etching process, a chemically-selective etching process, etc. The feature material **410** that remains on the substrate **300** after the mold layer **200** is removed may define the at least one feature **400**.

[0146] Referring now to FIGS. **2**A-**2**F, cross-sectional, side views of at least a portion of a component **100** during various manufacturing stages are provided, in accordance with an example embodiment. The component **100** of FIGS. **2**A-**2**F can be manufactured the same as, or similarly to, the component **100** of FIGS. **1**A-**1**D. For example, at least a portion of the mold material **210** of the mold layer **200** can be removed with a wet chemical etching process to form each cavity **250**. As depicted, the cavity **250** formed within the mold layer **200** can define a frustrum shape. In various examples, the cavity **250** formed within the mold layer **200** can define a pyramid shape.

[0147] With reference to FIG. **2**E, when the feature material **410** is applied within each cavity **250** with a conformal deposition process, such as a conformal chemical vapor deposition process, the feature material **410** may conformally coat the inner walls of the cavity **250**. When the cavity **250** has a reentrant shape (e.g., the cavity **250** has a larger cross-sectional area near the substrate **300** than near the opening of the cavity **250**), such as a pyramid or frustrum shape, the coating may also close the cavity **250** once the thickness of the feature material **410** exceeds half of the distance D defined by the cavity **250**. As such, a void **420** may be formed within the feature material **410** that defines the at least one feature **400**. When the at least one feature **400** is formed on the substrate **300** in a low pressure environment (e.g., less than 1 millibar), such as an ultra-high vacuum environment (e.g., less than 1.0×10−8 millibar), a low pressure environment, such as an ultra-high vacuum environment, can exist within the void **420**.

[0148] Referring now to FIGS. **3**A-**3**C, cross-sectional, side views of at least a portion of a component **100** during various manufacturing stages are provided, in accordance with an example embodiment. The component **100** of FIGS. **3**A-**3**C can be manufactured the same as, or similarly to, any of the components as described with reference to FIGS. **1**A-**2**F. In various examples, and with reference to FIG. **3**A, forming the at least one cavity **250** in the mold layer **200** includes removing a portion of the mold material **210** with a dry etching process, such as a reactive ion etching process, to form the at least one cavity **250**. A dry etching process may remove the mold material **210** by exposing the mold material **210** to a continuous flow of particles, such as ions, electrons, or photons. The kinetic energy of the particles may knock out the atoms of the mold material **210**. As will be appreciated, dry etching processes often result in reduced etching as the portion of the mold material **210** is removed, which may result in a tapered shape, such as an inverted conical shape, as depicted in FIG. **3**A. The tapered shape of the cavity **250** may result in a feature **400** that also has a tapered shape, as depicted in FIG. **3**C.

[0149] The dry etching process may be used to form high-aspect cavities **250**, which may result in the formation of high-aspect features **400**. For example, the dry etching process may be used to form a cavity **250** that extends completely through a mold thickness M of the mold layer **200** and defines an opening that defines a distance D. The mold thickness M may be greater than the distance D defined by the opening of the cavity **250**. The resulting feature **400** may have a height H that is greater than a width W.

[0150] Referring now to FIGS. **4**A-**4**F, cross-sectional, side views of at least a portion of two components **100** during various manufacturing stages are provided, in accordance with an example embodiment. The components **100** of FIGS. **4**A-**4**F can be manufactured the same as, or similarly to, any of the components as described with reference to FIGS. **1**A-**3**C. In various examples, forming the at least one cavity **250** in the mold layer **200** may include removing a portion of the mold material **210** with alternating steps of etching the mold material **210** and passivating the mold material **210**. In various examples, etching the mold material **210** may include etching the mold material **210** with sulfur hexafluoride (SF_6). Passivating the mold material **210** may include passivating the mold material **210** with octafluorocyclobutane (C_4F_8).

[0151] The two-step process of alternating steps of etching and passivating the mold material **210** may result in a cavity **250** that defines a scallop shape, as depicted in FIGS. **4**A and **4**D. For example, the inner walls of each cavity **250** may define a plurality of parabolic-shaped inner walls that collectively extend vertically. After each cavity **250** is filled with the feature material **410**, as depicted in FIGS. **4**B and **4**E, and the mold material **210** subsequently removed, as depicted in FIGS. **4**C and **4**F, the resulting at least one feature **400** can have a scallop shape. In various examples, the outer surface of the at least one feature **400** may define a plurality of parabolic-shaped outer surfaces.

[0152] In various examples, and as depicted in FIG. **4**E, a plurality of voids **420** may be formed within the feature material **410** that is applied within the cavity **250**, which may result in a plurality of voids **420** being formed within the resulting feature **400**, as depicted in FIG. **4**F. A low-pressure environment, such as an ultra-high vacuum environment, may exist in each of the plurality of voids **420** when the component **100** is manufactured in a low-pressure environment, such as an ultra-high vacuum environment. As already discussed, each of the plurality of voids **420** being formed within the feature material **410** may be a result of the feature material **410** being applied with a conformal deposition process, such as a conformal chemical vapor deposition process.

[0153] Referring now to FIGS. **5**A-**5**D, cross-sectional, side views of at least a portion of a component **100** during various manufacturing stages are provided, in accordance with an example embodiment. The component **100** of FIGS. **5**A-**5**D can be manufactured the same as, or similarly to, any of the components as described with reference to FIGS. **1**A-**4**F. As previously discussed, forming the at least one cavity **250** in the mold layer **200** may include removing a portion of the mold material **210** with a dry etching process, such as a reactive ion etching process, which may expose the mold material **210** to a continuous flow of particles, such as ions, electrons, or photons, to form the at least one cavity **250**. The particles may travel in a direction P towards the mold layer **200** to remove one or more portions of the mold material **210**.

[0154] In various examples, forming the at least one cavity **250** may include positioning the substrate **300** and/or the mold layer **200** at an angle relative to a direction P of travel of particles being used in the dry etching process, such as a reactive ion etching process, as depicted in FIG. **5**A. Positioning the substrate **300** and/or the mold layer **200** at an angle relative to a direction P of travel of the particles may form at least one feature **400** that has a slanted configuration such that each feature **400** has a varying cross-sectional position along at least two planes that are parallel to the horizontal plane defined by the surface of the substrate **300**. The angle may be at least 5 degrees and up to 85 degrees, such as at least 45 degrees and up to 85 degrees, relative to the horizontal plane defined by the surface of the substrate **300**.

[0155] In various examples, each feature **400** has a varying cross-sectional position along at least two planes that are parallel to the horizontal plane defined by the surface of the substrate **300**, but can have a consistent cross-sectional shape along those two planes. Stated differently, each feature **400** can have a consisted shape, but may be slanted relative to the horizontal plane defined by the substrate **300**. In various examples, each feature **400** may have an inconsistent shape. For example, and as discussed, the dry etching process may result in a tapered shape of each feature **400**, as depicted in FIG. **3**C. As such, each feature **400** may be tapered and slanted relative to the horizontal plane defined by the substrate **300**. In yet another example, the two-step etch process as described with reference to FIGS. **4**A-**4**F may be used, along with positioning the substrate **300** at an angle, to form features **400** that have a scallop shape and are also tilted.

[0156] Referring now to FIGS. **6**A-**6**D, cross-sectional, side views of at least a portion of a component **100** during various manufacturing stages are provided, in accordance with an example embodiment. The component **100** of FIGS. **6**A-**6**D can be manufactured the same as, or similarly to, any of the components as described with reference to FIGS. **1**A-**5**D. In various examples, the mold layer **200** may include a plurality of different mold layers **200**. For example, at least one layer may include the mold material **210** and at least another layer may include a second mold material **212**. In various examples, the mold material **210** is silicon and the second mold material **212** is silicon oxide, or vice-versa.

[0157] The mold layer **200** may be formed by depositing a layer of the mold material **210** on the substrate **300**, depositing a masking layer (not depicted) on at least a portion of the layer that includes the mold material **210**, depositing another layer with the second mold material **212** on the layer that includes the mold material **210**, subsequently removing the masking layer, depositing another layer of the mold material **210**, etc.

[0158] As used herein, the term "layer" should be understood to mean a singular layer or a plurality of layers of the same material. As will be appreciated by those skilled in the art, common deposition methods involve depositing a plurality of thin layers to form a "layer". Therefore, even though the term "layer" is often used herein in the singular, it should be understood that a layer may include a plurality of layers of the same material. As such, "depositing a layer of the mold material **210**" may refer to depositing a plurality of thin layers of the mold material **210**, "depositing a masking layer" may refer to depositing a plurality of thin layers of a masking material, etc. In an example embodiment, a thin layer consists of one to a dozen atomic layers of a respective material.

[0159] In various examples, and as depicted in FIG. **6**A, each mold layer **200** that includes the second mold material **212** may be distinct from the other layers that comprise the second mold material **212**. In other words, each mold layer **200** that includes the second mold material **212** may be separated by a layer that includes the mold material **210** or another mold material **210**, such as a third mold material **210**, a fourth mold material **210**, etc. As also depicted in FIG. **6**A, at least one of the layers that includes the second mold material **212** may have a same thickness than another one of the layers that includes the second mold material **212**. The layers that include the second mold material **212** and have the same thickness may also have different volumes, as depicted in FIG. **6**A. Stated differently, the layers that include the second mold material **212** and have the same thickness may not extend horizontally the same distance. In various examples, at least one of the layers that includes the second mold material **212** may have a portion that is not vertically aligned with at least one other layer that comprises the second mold material **212**.

[0160] In various examples, at least one of the layers that includes the second mold material **212** may have a different thickness than another one of the layers that includes the second mold material **212**. In various examples, the at least one layer that includes the mold material **210** may have the same, or a different thickness than the at least one layer that includes the second mold material **212**.

[0161] In various examples, forming the at least one cavity **250** in the mold layer **200** may include using a single etch process that may etch the mold material **210** differently than the second mold material **212**, as depicted in FIG. **6**B. For example, the single etch process may result in a vertical etch component and an isotropic etch component of each the mold material **210** and the second mold material **212**. The rate of the vertical etch component and/or the isotropic etch component may be higher for the mold material **210** than the second mold material **212**, or vice-versa. In various examples, forming the at least one cavity **250** in the mold layer **200** may include using a single etch process that will etch the mold material **210** vertically and the second mold material **212** isotropically. As another example, the single etch process may etch both the mold material **210** and the second mold material **212** isotropically. For example, forming the at least one cavity **250** may include using a reactive ion etching process that has a chemical etch rate that etches the second mold material **212** at a faster rate than the mold material **210**. As will be appreciated in light of the present disclosure, the reactive ion etching process may etch both the mold material **210** and the second mold material **212** vertically, but only the second mold material **212** may be etched laterally at a meaningful rate. For example, the second mold material **212** may be etched at a rate that is at least two times faster, such as at least five times faster, such as at least ten times faster than the mold material **210**.

[0162] After the cavity **250** is filled, as depicted in FIG. **6**C, and the mold layer **200** removed, as depicted in FIG. **6**D, each resulting feature **400** may have a first portion **431** that has a first horizontal thickness, a second portion **432** that has a second horizontal thickness, and a third portion **433** that has a third horizontal thickness. A first percent difference between the first horizontal thickness and the second horizontal thickness may be at least 5 percent and up to 200 percent, such as at least 5 percent and up to 100 percent, such as at least 5 percent and up to 100 percent. A second percent difference between the first horizontal thickness and the third horizontal thickness may be less than 5 percent, such as less than 1 percent. Stated differently, the feature **400** may have varying thickness at different portions of the feature **400**.

[0163] In various examples, and as depicted in FIG. **6**D, one of the features **400***a* may have a different shape than at least another feature **400***b*. For example, at least one of the first feature **400***a* or the second feature **400***b* may include at least one protrusion that extends horizontally. The second feature **400***b* may include more protrusions than the first feature **400***a*. Forming features **400** of different shapes may be a result of applying the masking layer so that at least one layer that includes the second mold material **212** has a portion that is not vertically aligned with at least one other layer that comprises the second mold material **212**.

[0164] Referring now to FIGS. **7**A-**7**E, cross-sectional, side views of at least a portion of a component **100** during various manufacturing stages are provided, in accordance with an example embodiment. The component **100** of FIGS. **7**A-**7**E can be manufactured the same as, or similarly to, any of the components as described with reference to FIGS. **1**A-**6**D. For example, the component **100** of FIGS. **7**A-**7**E can be manufactured the same as, or similarly to, the component of FIG. **6**A-**6**D. As discussed, and as depicted in FIG. **7**A, the mold layer **200** can include a plurality of mold layers **200**, which may include at least one layer of the mold material **210** and at least another layer of the second mold material **212**.

[0165] In various examples, each cavity **250** can be formed by etching the mold material **210** and the second mold material **212** vertically, as depicted in FIG. **7**B, and etching the second mold material **212** with a second etching process that is chemically selective to etch the second mold material **212** isotropically, as depicted in FIG. **7**C. After each cavity **250** is filled with the feature material **410**, as depicted in FIG. **7**D, and the mold material **210** removed, as depicted in FIG. **7**E, each resulting feature **400** may have a three-dimensional lattice shape.

[0166] Referring now to FIGS. **8**B-**8**E, various views of at least a portion of a component **100** during various manufacturing stages are provided, in accordance with an example embodiment. FIG. **8**B provides a top view and FIGS. **8**C-**8**E provide cross-sectional, side views of at least a portion of a component **100** during various manufacturing stages, in accordance with an example embodiment. The component **100** of FIGS. **8**B-**8**E can be manufactured the same as, or similarly to, any of the components as described with reference to FIGS. **1**A-**7**E.

[0167] In various examples, forming the at least one feature **400** on a substrate **300** may include bonding at least one self-assembled structure **30** on the substrate **300**, as depicted in FIG. **8**C. Each self-assembled structure **30** may be a self-assembled nanosphere, such as a self-assembled polystyrene nanosphere or a silica ($SiO2$) nanosphere.

[0168] In various examples, each self-assembled structure **30** can be arranged on the substrate in a self-organized arrangement **35**. For example, and as depicted in FIG. **8**A, a plurality of self-assembled structures **30** can be suspended in a liquid suspension. The self-assembled structures **30** can be suspended in the liquid suspension on top of the substrate **300**. In various examples, each self-assembled structure **30** may be colloidal such that the self-assembled structures **30** are substantially evenly distributed in the liquid suspension. The liquid suspension can be subsequently evaporated. As will be appreciated, as the liquid suspension is evaporated, the plurality of self-assembled structures **30** are attracted to each other and consolidate into a self-organized arrangement **35**. A confinement device (not depicted), such as a microscope cover glass, may be used to prevent the self-organized arrangement **35** of self-assembled structures **30** from assembling vertically such that some self-assembled structures **30** are positioned on top of other self-assembled structures **30** instead of on the substrate **300**. In various examples, a confinement device is not used and the self-assembled structures **30** are allowed to form a self-organized arrangement **35** that has multiple layers of self-assembled structures **30**. In various examples, and as depicted in FIG. **8**A, the self-organized arrangement **35** may be hexagonal shaped.

[0169] The self-organized arrangement **35** may compact as the liquid suspension is evaporated further, which may deform each self-assembled structure **30** to be hexagonal. In various examples, and as depicted in FIG. **8**A, each self-assembled structure **30** may comprise of a material (e.g., a mold material **210**, as discussed with reference to FIGS. **8**C-**8**E, or a feature material **410**, as will be discussed with reference to FIGS. **9**A-**10**H.

[0170] In various examples, and as depicted in FIG. **8**B, a lattice tool **50** may be positioned on the substrate **300**. The lattice tool **50** may define a plurality of spaces and a plurality of self-assembled structures **30** may be positioned within the lattice tool **50**. For example, each self-assembled structure **30** may be positioned within a respective space of the plurality of spaces defined by the lattice tool **50** and subsequently bonded to the substrate **300**.

[0171] In various examples, a feature material **410** may be applied on the substrate **300** and around each self-assembled structure **30**, as depicted in FIG. **8**D. As such, each self-assembled structure **30** may serve the purpose of a mold layer **200**. The feature material **410** may be applied such that the feature material **410** does not completely cover the self-assembled structure **30**. For example, the feature material **410** may be applied such that about half, such as at least 30 percent and up to 70 percent, such as at least 30 percent and up to 50 percent, of a diameter of each self-assembled structure **30** is covered with the feature material **410**. In various examples, self-assembled structures **30** of various sizes may be bonded to the substrate **300**. As such, the amount that each self-assembled structure **30** is covered with the feature material **410** may also vary.

[0172] In various examples, the self-assembled structure **30** may be removed from the substrate **300** and from the feature material **410** to form the feature **400**, as depicted in FIG. **8**E. The self-assembled structure **30** may be removed from the substrate **300** mechanically, chemically, or thermally. Once each self-assembled structure **30** is removed from the substrate **300** and from the feature material **410**, the resulting feature **400** may have a portion that has a concave shape or each feature **400** may have a plurality of portions that each have a concave shape.

[0173] The feature material **410** may be a reflective material having a reflectivity of at least 90%. In various examples, the feature material **410** may not have a reflectivity of at least 90%, but a reflective coating can be applied on each feature **400** that has a reflectivity of at least 90%. Applying reflective coating or using a reflective material as the feature material **410** has various benefits. For example, the resulting feature **400** may be used as a high-reflectivity focusing mirror.

[0174] Referring now to FIGS. **9**A-**9**E, cross-sectional, side views of at least a portion of a component **100** during various manufacturing stages are provided, in accordance with an example embodiment. The component **100** of FIGS. **9**A-**9**E can be manufactured the same as, or similarly to, any of the components as described with reference to FIGS. **1**A-**8**E. In various examples, the self-assembled structure **30** may be applied to the substrate **300**, as previously described with reference to FIGS. **8**A-**8**E. A mold layer **200** may be applied on the substrate **300** and around the self-assembled structure **30**, as depicted in FIG. **9**B. The mold layer **200** may be applied on the substrate **300** and around the self-assembled structure **30** such that a majority of the self-assembled structure **30** is covered. For example, the mold layer **200** may be applied such that at least 50% and up to 98%, such as at least 75% and up to 98%, such as at least 85% and up to 98% of a diameter of the self-assembled structure **30** is covered with the mold layer **200**. Each self-assembled structure **30** may be removed from the mold layer **200** mechanically, chemically, or thermally, as depicted in FIG. **9**C.

[0175] In various examples, the feature **400** can be formed by applying the feature material **410** within a cavity **250** that is formed in the mold layer **200** after removing each self-assembled structure **30** from the substrate **300** and from the mold layer **200**. In various examples, a conformal deposition process can be used that may result in the opening of the cavity **250** being closed by the feature material **410**. The resulting feature **400** may be spherical and may include a void **420** that is positioned within the resulting feature **400**, as depicted in FIG. **9**E.

[0176] Referring now to FIGS. **10**A-**10**H, cross-sectional, side views of at least a portion of a component **100** during various manufacturing stages are provided, in accordance with an example embodiment. The component **100** of FIGS. **10**A-**10**H can be manufactured the same as, or similarly to, the component **100** as described with reference to FIGS. **9**A-**9**E. For example, at least one self-assembled structure **30** may be bonded to the substrate **300**, the mold layer **200** may be applied around the self-assembled structure **30**, and the self-assembled structure **30** may be subsequently removed, as depicted in FIGS. **10**A-**10**C.

[0177] In an example embodiment, the self-assembled structures **30** are nanometer-scale spheres made of Styrofoam and/or another material. While the self-assembled structures **30** are shown as spheres, in various embodiments, the self-assembled structures **30** may have a variety of shapes. For example, the self-assembled structures **30** may be extruded structures and/or the like.

[0178] In various examples, the feature material **410** may be applied within the cavity **250**, but the feature material **410** may not completely close the opening or completely form a spherical shape. Instead, an opening may remain in the feature material **410**, as depicted in FIG. **10**D. In various examples, a substance **60** may be positioned within the open spherical shape, as depicted in FIG. **10**E. The substance **60** may be a medicinal substance **60**.

[0179] The open spherical shape defined by the feature material **410** may be subsequently enclosed after positioning the substance **60** within the open spherical shape, as depicted in FIG. **10**F. For example, additional feature material **410** may be applied to the open spherical shape, which may encapsulate the substance **60** within the resulting shape, as depicted in FIG. **10**G.

[0180] In various embodiments, and as depicted in FIG. **10**H, the feature material **410** is removed from the substrate **300** for use. For example, the feature material **410**, when removed from the substrate **300**, may form one or more nanometer-scale structures **500**, such as nanoparticles. For example, the nanoparticles may be used to deliver the substance **60** to a target. For example, the nanoparticles may be injected or otherwise delivered into the interior of a living being (e.g., animal, plant, and/or the like) and then caused to burst and/or break open by applying electromagnetic radiation of a wavelength/frequency selected based on the material used as the feature material **410**. For example, the electromagnetic radiation may be directed and/or focused on the target to only cause the nanoparticles disposed at or near the target to burst or break open. The substance **60** may then be delivered to the interior of the living being from the burst and/or broken open nanoparticles to provide a therapeutic effect and/or to aid in various types of imaging (e.g., as a contrast agent and/or marker). In an example embodiment, the nanometer-scale structures are quantum dots.

[0181] The feature material **410** may be removed from the substrate **300**, which may form one or more nanometer-scale structures **500**, mechanically or chemically. For example, the bond between the feature material **410** and the substrate **300** may be broken using a mechanical agitation method, such as sonication or applying a pressurized fluid, such as a gas (e.g., air or nitrogen) or liquid (e.g., water) onto the feature material **410** to mechanically force the feature material **410** from the substrate **300**. In various examples, the feature material **410** may be removed from the substrate **300** by applying a sacrificial layer (not depicted) on the substrate **300** prior to applying the feature material **410** onto the substrate **300**. The sacrificial layer may be removed by a removal process, such as a selective etching process or a dissolving process using chemicals to release the feature material **410** from the substrate **300**. The sacrificial layer may be water soluble or removable using a solvent, such as acetone.

[0182] The components as described in reference to FIGS. **1**A-**10**G have various benefits. For example, and as will be appreciated by those skilled in the art in light of the present disclosure, conventional lithographically patterned features are often uniform in out-of-plane dimensions—the resulting shapes of the features are similar to an extrusion that only have a two-dimensional profile. Stated differently, conventional lithographically patterned features have a consistent cross-sectional shape, consistent cross-sectional size, and consistent cross-sectional position along a length of the conventional feature. In contrast, the resulting features **400** of the present disclosure may have a varying cross-sectional shape and/or size, as depicted in FIGS. **1**D, **2**F, **3**C, **4**C, **4**F, **6**D, **7**E, **8**E, **9**E, and **10**G. In various examples, and as depicted in FIG. **5**D, the resulting features **400** of the present disclosure may have a consistent cross-sectional shape, but the cross-sectional position may vary relative to a vertical plane (i.e., the resulting feature **400** may be slanted relative to the vertical plane).

[0183] The resulting features **400** of the present disclosure that have a varying cross-sectional shape and/or varying cross sectional position may result in the fabrication of features **400** of particular shapes that may not be possible to achieve with conventional methods. For example, various quantum computing and photonic sensing components may be manufactured using the methods described herein that may not be manufacturable with conventional methodologies. In various examples, the disclosed methods of forming features **400** on a substrate **300** may be used to create features **400** for resonators, such as photonic resonators or phononic resonators. For example, the features **400** as described in reference to FIGS. **1**A-**4**F may be used to manufacture resonators, such as photonic resonators or phononic resonators. In various examples, the disclosed methods of forming features **400** on a substrate **300** may be used to create features **400** for integrated lasers, three-dimensional metamaterials and photonic crystals. For example, the features **400** as described in reference to FIGS. **6**D and **7**E may be used to manufacture integrated lasers, three-dimensional metamaterials and photonic crystals. In various examples, the disclosed methods of forming features **400** on a substrate **300** may be used to create features **400** for nanoscale or microscale spherical mirrors. For example, the features **400** as described in reference to FIG. **8**E may be used to manufacture nanoscale or microscale spherical mirrors.

Conclusion

[0184] The above descriptions of various embodiments of the subject disclosure and corresponding figures and what is described in the Abstract, are described herein for illustrative purposes, and are not intended to be exhaustive or to limit the disclosed embodiments to the precise forms disclosed. It is to be understood that one of ordinary skill in the art may recognize that other embodiments having modifications, permutations, combinations, and additions can be implemented for performing the same, similar, alternative, or substitute functions of the disclosed subject matter, and are therefore considered within the scope of this disclosure. Therefore, the disclosed subject matter should not be limited to any single embodiment described herein, but rather should be construed in breadth and scope in accordance with the appended claims below. Moreover, although the foregoing descriptions and the associated drawings describe example embodiments in the context of certain example combinations of elements and/or functions, it should be appreciated that different combinations of elements and/or functions may be provided by alternative embodiments without departing from the scope of the appended claims. In this regard, for example, different combinations of elements and/or functions than those explicitly described above are also contemplated as may be set forth in some of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

1-42. (canceled)

43. A method of forming at least one feature on a substrate, the method comprising:

bonding a self-assembled structure on the substrate;

applying a feature material or a mold layer comprising a mold material on the substrate and around the self-assembled structure; and

removing the self-assembled structure from the substrate and from the feature material or the mold layer.

44. The method of claim **43**, further comprising:

positioning a lattice tool on the substrate, wherein the lattice tool defines a plurality of spaces;

positioning a plurality of self-assembled structures within the lattice tool, wherein each self-assembled structure is positioned within a respective space of the plurality of spaces defined by the lattice tool; and

bonding each of the self-assembled structures on the substrate.

45. The method of claim **44**, wherein the lattice tool is a hexagonal lattice tool.

46. The method of claim **43**, wherein the self-assembled structure is a self-assembled nanosphere.

47. (canceled)

48. (canceled)

49. The method of claim **43**, wherein the method further comprises:

arranging a plurality of self-assembled structures on the substrate in a self-organized arrangement by suspending the plurality of self-assembled structures in a liquid suspension; and

allowing the liquid suspension to evaporate.

50. The method of claim **49**, wherein the plurality of self-assembled structures are suspended in the liquid suspension on top of the substrate.

51. The method of claim **43**, wherein the method comprises applying the feature material on the substrate and around the self-assembled structure.

52. The method of claim **51**, wherein the feature material is a dielectric material or a metallic material.

53. The method of claim **51**, wherein the feature material is a reflective material having a reflectivity of at least 90%.

54. The method of claim **51**, further comprising applying a reflective coating on the feature material, the reflective coating having a reflectivity of at least 90%.

55. (canceled)

56. The method of claim **43**, wherein the method comprises applying the mold layer on the substrate and around the self-assembled structure, and wherein the method further comprises pplying the feature material within a cavity that is formed in the mold layer, wherein the cavity is formed after the removing the self-assembled structure from the substrate and from the mold layer, and wherein the feature material defines the at least one feature.

57. The method of claim **56**, wherein the applying the feature material within the cavity comprises applying the feature material within the cavity with a conformal deposition process.

58. The method of claim **56**, wherein the applying the feature material within the cavity comprises enclosing the cavity to form a void within the feature material that defines the at least one feature.

59. The method of claim **58**, wherein the void comprises a low-pressure environment.

60. (canceled)

61. (canceled)

62. The method of claim **56**, further comprising positioning or depositing a substance within the at least one feature, wherein the substance is a medicinal substance.

63. (canceled)

64. The method of claim **56**, further comprising forming the cavity in the mold layer that is on the substrate, wherein forming the cavity comprises:

bonding a self-assembled structure on the substrate;

applying the mold layer on the substrate and around the self-assembled structure; and

removing the self-assembled structure from the substrate.

65. (canceled)

66. The method of claim **43**, wherein the at least one feature formed on the substrate is for at least one of a component of an electrical or optical device or a nanoparticle.

67. A component for an electrical or optical device, the component comprising:

a substrate extending along a horizontal plane; and

at least one feature on the substrate, wherein:

the at least one feature comprises a feature material, and

the at least one feature has a varying cross-sectional shape or position along at least two other horizontal planes.

68-90. (canceled)

91. (canceled)

92. (canceled)

93. (canceled)

94. The component of claim **67**, wherein the at least one feature has a plurality of portions that have a concave shape.

95. (canceled)

96. The component of claim **67**, wherein the at least one feature has a spherical shape, wherein the at least one feature defines a void that is positioned within the at least one feature, wherein the at least one feature comprises a substance encapsulated within the at least one feature, and wherein the substance is a medicinal substance.

97. (canceled)
98. (canceled)
99. (canceled)
100. (canceled)
101. (canceled)

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