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(54) **METHOD FOR DEPOSITION OF DEPTH-VARYING REFRACTIVE INDEX FILMS**

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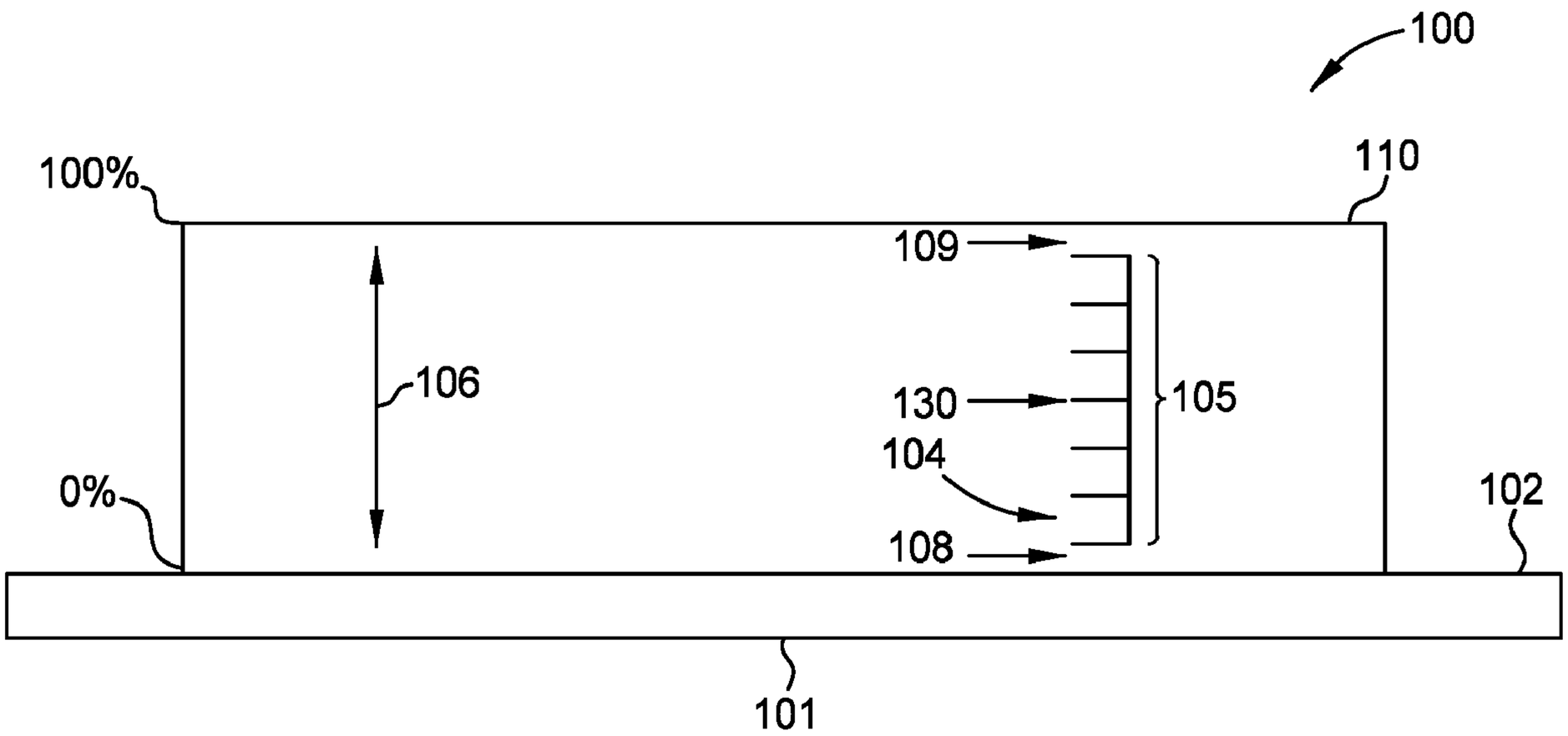
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(57) **ABSTRACT**

Embodiments of the present disclosure relate to optical device films and methods of forming optical device films. Specifically, embodiments described herein provide for an optical device film having a constant oxygen-concentration, a first concentration profile of the first material, and a second concentration profile of the second material. The first material, described and referenced to herein, has a first refractive index about 2.0 or greater and the second material has a second refractive index less than 2.0.



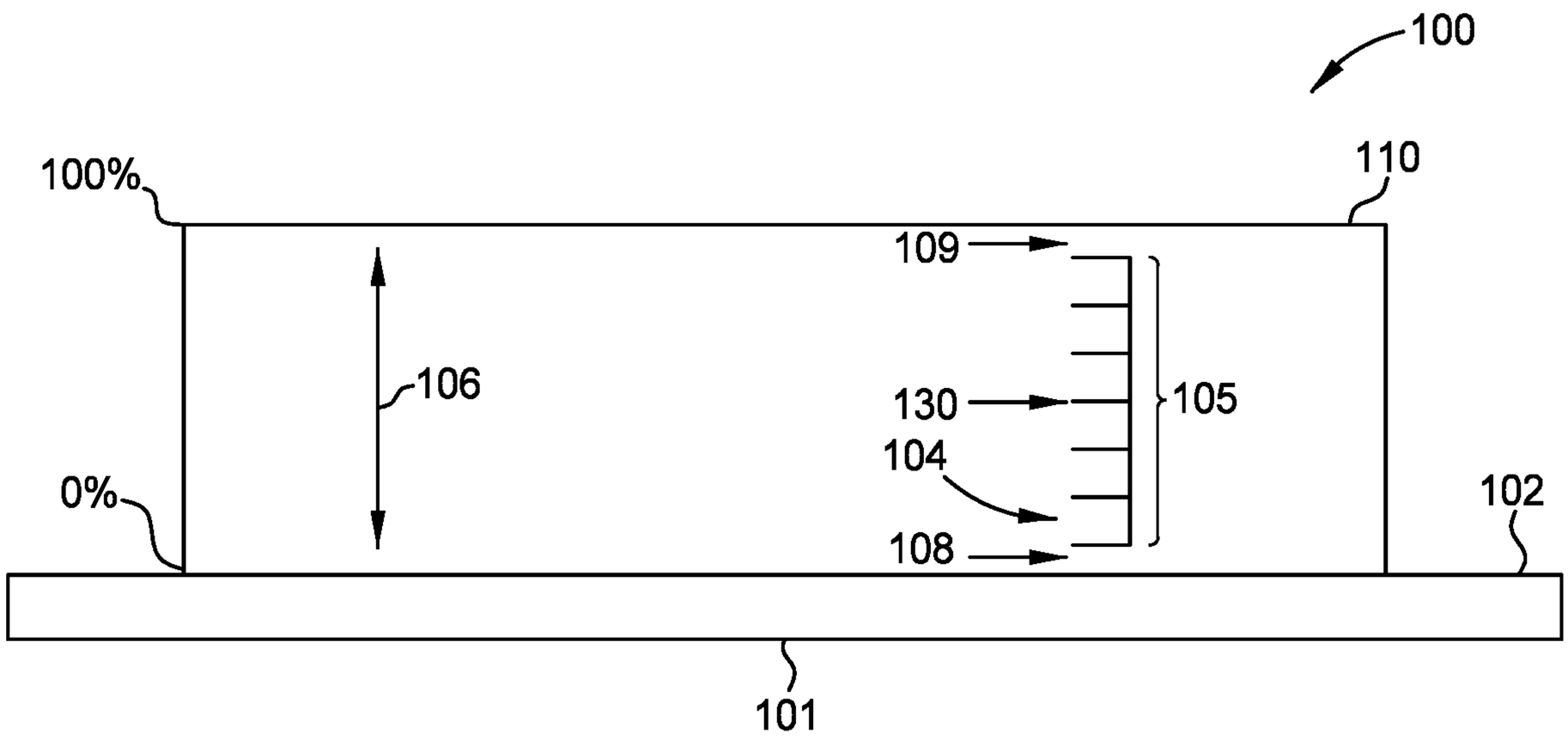


FIG. 1

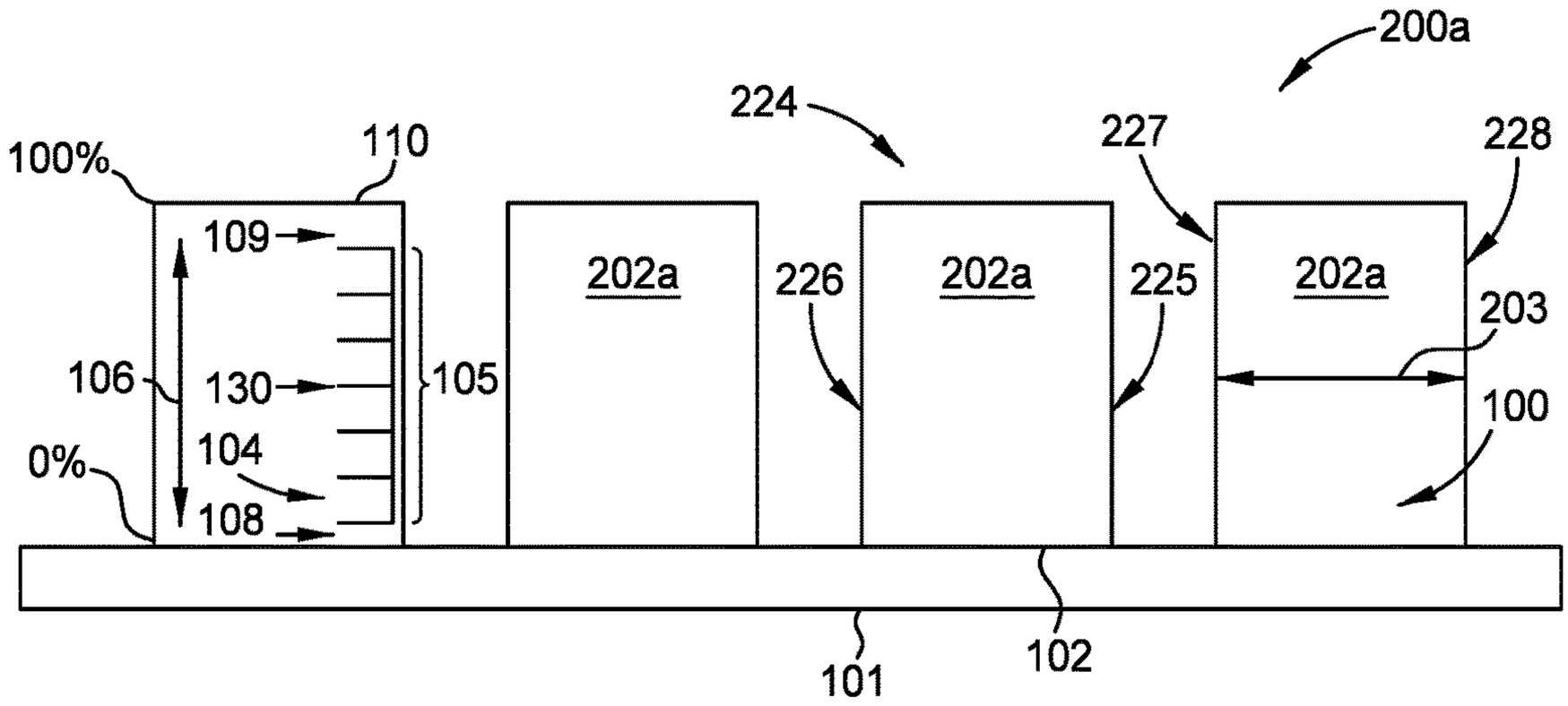

200a
224
227
228
100%
110
109
202a
226
202a
225
202a
203
106
130
105
100
104
0%
108
101
102

FIG. 2A

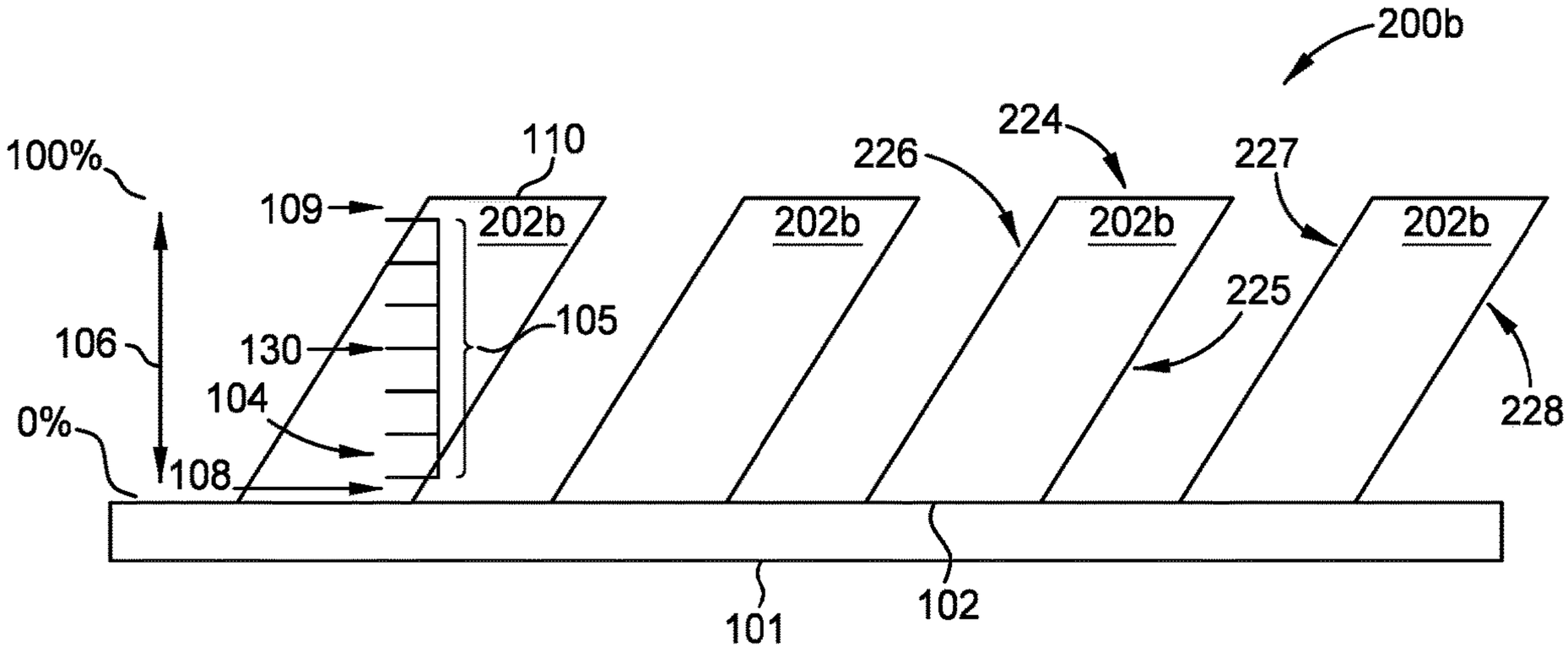

200b
224
100%
110
226
227
109
202b
202b
202b
202b
225
106
130
105
104
0%
228
108
101
102

FIG. 2B

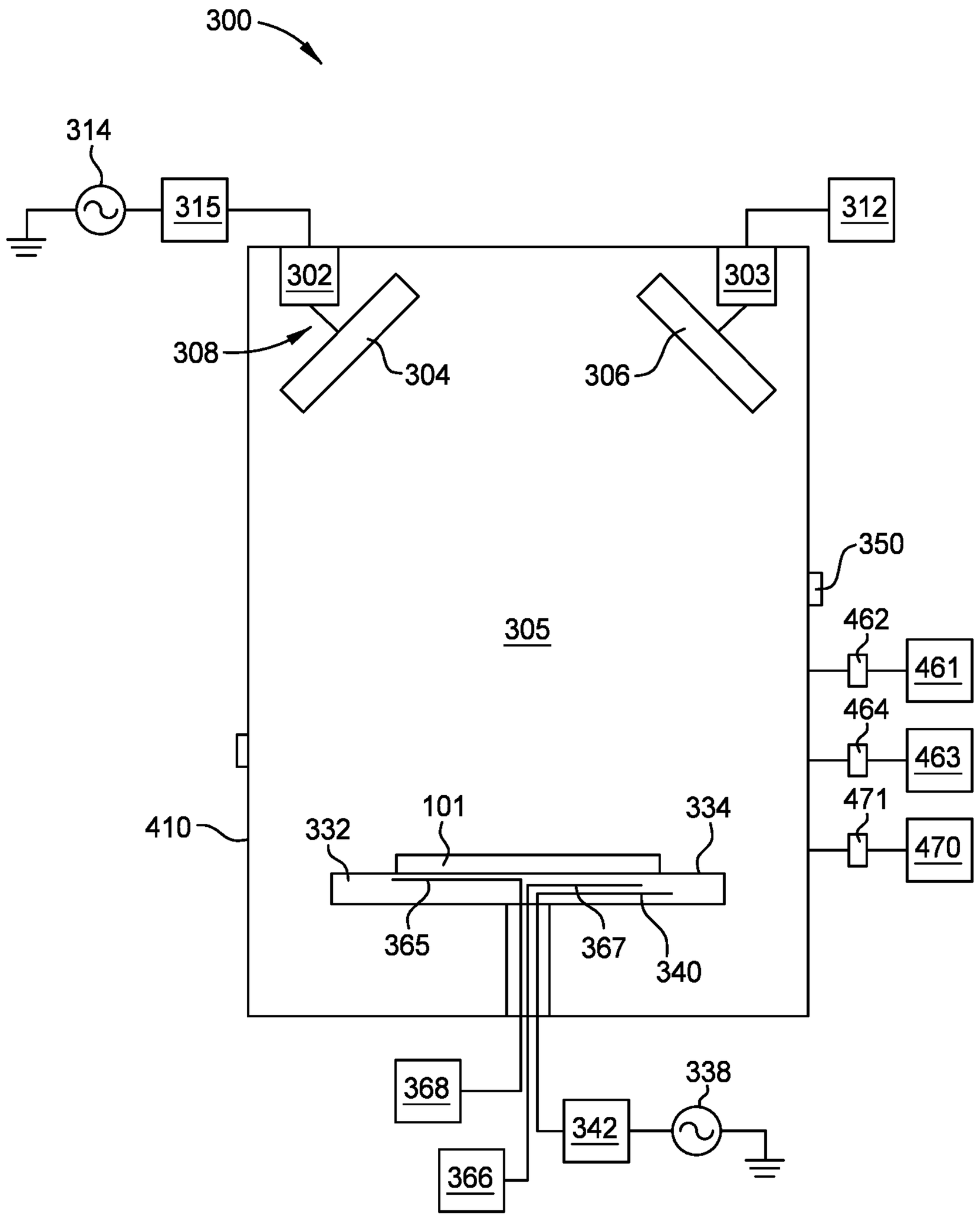

300
314
315
312
302
303
308
304
306
350
305
462
461
464
463
471
470
410
101
332
334
365
367
340
368
338
342
366

FIG. 3

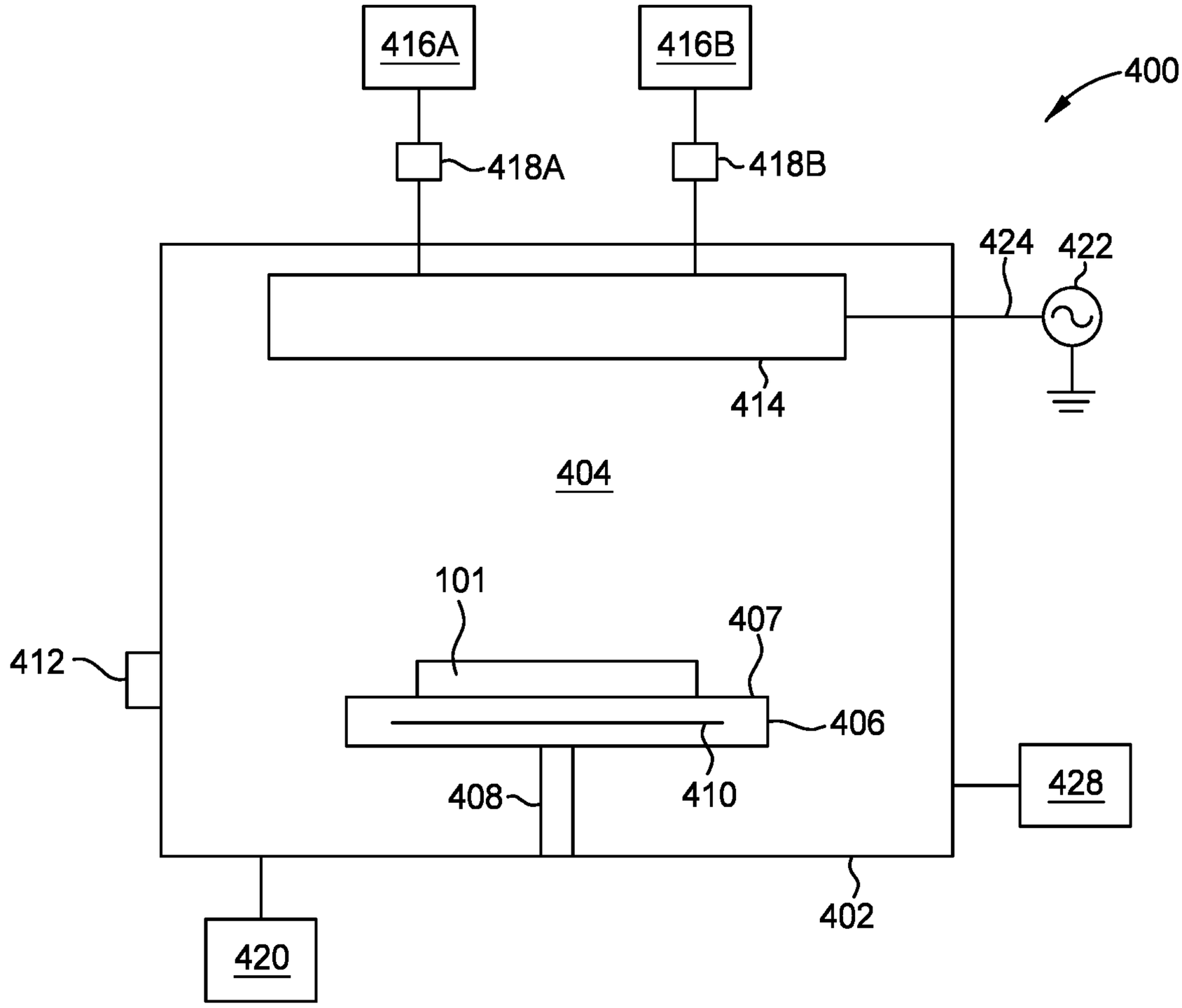

416A
416B
400
418A
418B
424
422
414
404
101
407
412
406
410
408
428
420
402

FIG. 4

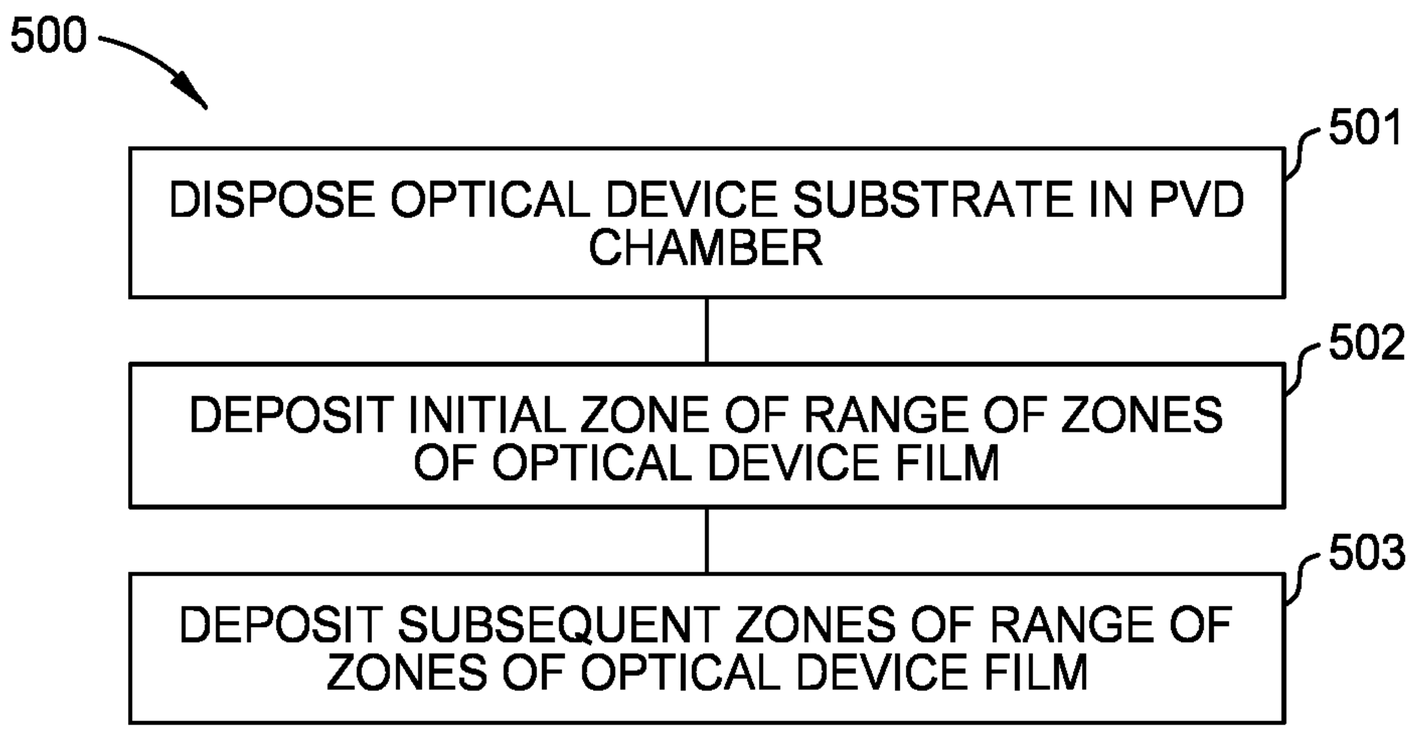


FIG. 5

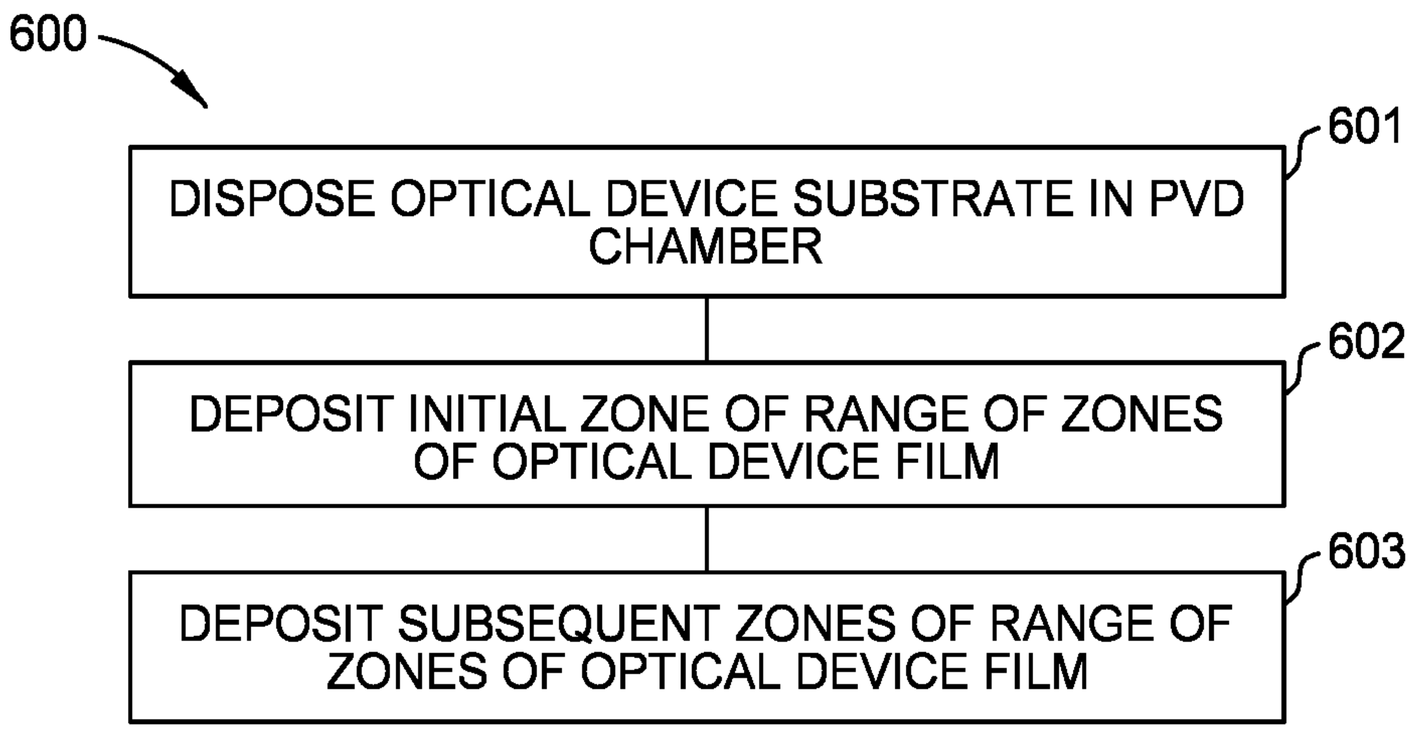


FIG. 6

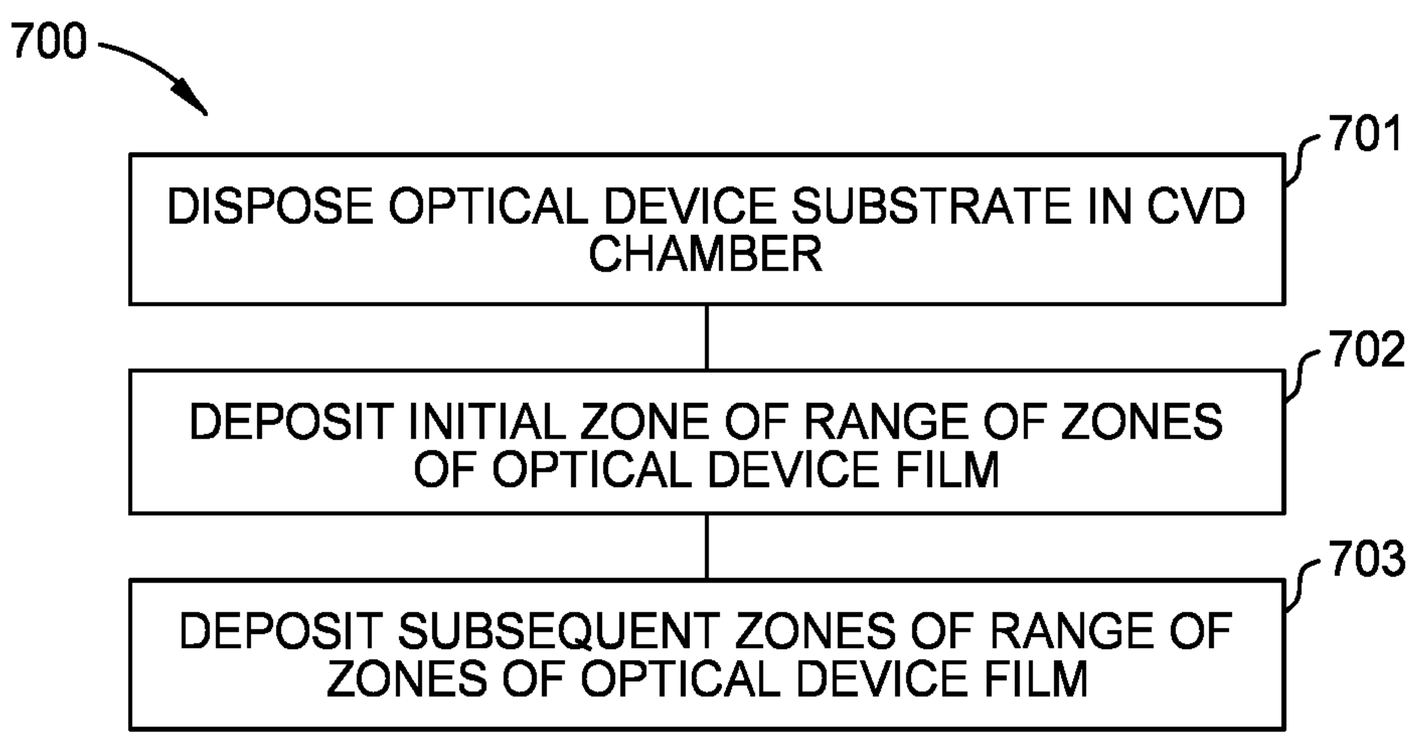


FIG. 7

METHOD FOR DEPOSITION OF DEPTH-VARYING REFRACTIVE INDEX FILMS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 63/055,160, filed on Jul. 22, 2020, the contents of which are herein incorporated by reference.

BACKGROUND

Field

[0002] Embodiments of the present disclosure relate to optical device films and methods of forming optical device films.

Description of the Related Art

[0003] Optical devices, such as waveguides, flat optical devices, metasurfaces, color-filters, and anti-reflective coatings, are engineered to exhibit a high refractive index and low absorption loss properties. Metal oxide containing materials, e.g., titanium dioxide (TiO2) have a high refractive index and low absorption loss that enable efficient, large-scale fabrication of optical devices.

[0004] Graded-index optical device films are used to control light interacting at the surface or within the film. In conventional optical device films, it is difficult to realize continuous tunability of index over a large range by changing deposition conditions for a single material, and using multiple materials necessitates approximating a continuous profile with a stepped profile.

[0005] Conventional optical device films typically include multiple, distinct layers of materials that possess different refractive index properties, such as a step-index waveguide. For example, an optical film is formed with a TiO_2 layer deposited on a surface of the optical device substrate and a silicon dioxide (SiO_2) layer is formed above the TiO_2 layer, where the TiO_2 layer has an index of refraction of about 2.4 (n=2.4) and the SiO_2 layer has an index of refraction of about 1.5 (n=1.5). The difference between the indices of refraction of the TiO_2 layer and the SiO_2 layer is approximately 0.9, which represents a sudden shift for light passing between the layers. This sudden shift may be characterized as a non-continuous step between optical materials, which diminishes the desired optical device properties, such as light reflectivity and light transmissivity, for light passing between the distinct layers. Conventional optical device films often include multiple, distinct layers of more than two materials to reduce the shift of refractive indices between the layers, and thus improve the desired optical properties between layers. However, the refractive indices for these conventional optical device films are non-continuous and optical aberrations may exist in such conventional optical device films.

[0006] Accordingly, what is needed in the art are improved optical device films and methods of forming optical device films.

SUMMARY

[0007] In one embodiment, an optical device film is provided. The optical device film includes a thickness divided into a range of zones from a first surface corresponding to 0% of the thickness to a second surface corresponding to 100% of the thickness. Each zone of the range of zones has a zone thickness. The optical device film has an oxygen concentration or a nitrogen concentration in each zone of the range of zones. The optical device film also includes a first material having a first refractive index of about 2.0 or greater and a second material having a second refractive index of less than 2.0. The first material has a first concentration profile throughout the range of zones. The second material has a second concentration profile throughout the range of zones. The second concentration profile is different from the first concentration profile.

[0008] In another embodiment, a method is provided. The method includes disposing an optical device substrate on a substrate support. The substrate support is disposed in a chamber. The chamber includes a first target and a second target disposed in the chamber. The first target includes a first material and a second target includes a second material. An optical device film on the optical device substrate is deposited by depositing the first material with a first concentration profile and depositing the second material with a second concentration profile. The depositing the first material includes providing a first power level to the first target. The first concentration profile of the first material is controlled by at least one of increasing or decreasing the first power level provided to the first target. The depositing the second material includes providing a second power level to the second target. The second concentration profile of the second material is controlled by at least one of increasing or decreasing the second power level provided to the second target.

[0009] In another embodiment, a method is provided. The method includes disposing an optical device substrate on a substrate support. The substrate support is disposed in a chamber. The chamber includes a first target and a gas source. The first target includes a first material. The gas source is operable to flow a precursor gas comprising a second material. An optical device film on the optical device substrate is deposited by depositing the first material with a first concentration profile and depositing the second material with a second concentration profile. The depositing the first material includes providing a first power level to the first target. The first concentration profile of the first material is controlled by at least one of increasing or decreasing the first power level provided to the first target. The depositing the second material includes providing a precursor gas at a flow rate. The second concentration profile of the second material is controlled by at least one of increasing or decreasing a flow rate of the precursor.

[0010] In yet another embodiment, a method is provided. The method includes disposing an optical device substrate in a chamber, flowing a first gas comprising a first material into the chamber at a first flow rate, and flowing a second gas comprising a second material into the chamber at a second flow rate. A first concentration profile of the first material of a deposited optical device film is controlled by at least one of increasing or decreasing the first flow rate during the flowing of the first gas. A second concentration profile of the second material of the deposited optical device film is controlled by at least one of increasing or decreasing the second flow rate during the flowing of the second gas.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] So that the manner in which the above-recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only exemplary embodiments and are therefore not to be considered limiting of its scope, and may admit to other equally effective embodiments.

[0012] FIG. **1** is a schematic, cross-sectional view of an optical device film according to embodiments described herein.

[0013] FIG. **2**A and FIG. **2**B are schematic, cross-sectional views of optical devices formed from the optical device film.

[0014] FIG. **3** is a schematic, cross-sectional view of a physical vapor deposition (PVD) chamber according to embodiments described herein.

[0015] FIG. **4** is a schematic, cross-sectional view of a chemical vapor deposition (CVD) chamber according to embodiments described herein.

[0016] FIGS. **5-7** are flow diagrams of methods for fabricating an optical device film according to embodiments described herein.

[0017] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.

DETAILED DESCRIPTION

[0018] Embodiments of the present disclosure relate to optical device films and methods of forming optical device films. Specifically, embodiments described herein provide for an optical device film having an oxygen-concentration or nitrogen-concentration, a first concentration profile of a first material, and a second concentration profile of a second material. The optical device film includes the first material at a first concentration and the second material at a second concentration throughout the thickness of the film. The first material, described and referenced to herein, has a first refractive index of about 2.0 or greater. The second material, described and referenced to herein, has a second refractive index of less than 2.0. The first material includes, but is not limited to, oxides or nitrides of titanium (Ti), tantalum (Ta), zirconium (Zr), indium (In), or niobium (Nb). The second material includes, but is not limited to, oxides or nitrides of silicon (Si), aluminum (Al), hafnium (Hf), scandium (Sc), Tin (Sn), yttrium (Y), praseodymium (Pr), or magnesium (Mg).

[0019] FIG. **1** is a schematic, cross-sectional view of an optical device film **100**. The optical device film **100** is disposed on an optical device substrate **101** according to embodiments described herein. The optical device substrate **101** is any suitable optical device substrate on which an optical device may be formed. In one embodiment, the optical device substrate **101** is a silicon (Si) containing optical device substrate. In one embodiment, the optical device substrate **101** is a silicon oxide-based glass or a metal oxide-based glass. In one embodiment, the optical device substrate **101** includes, but is not limited to, silicon (Si), silicon nitride (SiN), silicon dioxide (SiO_2), fused silica, quartz, silicon carbide (SiC), germanium (Ge), silicon germanium (SiGe), indium phosphide (InP), gallium arsenide (GaAs), gallium oxide (GaO), diamond, lithium niobate ($LiNbO_3$), gallium nitride (GaN), sapphire, tantalum oxide (Ta_2O_5), titanium dioxide (TiO_2) or combinations thereof. The optical device substrate **102** may include a perovskite material that is optically transparent. In another embodiment, the optical device substrate **101** is a layered optical device substrate, for example a thin glass bonded to a silicon carrier. The layered optical device substrate may be a substrate with optical device stacks disposed on the substrate (e.g., patterned optical device films for gratings, waveguides, optoelectronics, monolithically-integrated CMOS-photonic device, heterogeneously-integrated CMOS-photonic devices). In yet another embodiment, the optical device substrate **101** is a laminated substrate comprising multiple layers of bonded glass.

[0020] The optical device film **100** has a first surface **102**, a second surface **110**, and a thickness **106**. The thickness **106** of the optical device film **100** is divided into a range of zones **105** measured from the first surface **102** corresponding to 0% of the thickness **106** to the second surface **110** corresponding to 100% of the thickness **106**. In one embodiment, which can be combined with other embodiments described herein, the thickness **106** has a constant or substantially constant oxygen or nitrogen concentration throughout the range of zones **105** of the optical device film **100**. In one embodiment, the difference in oxygen or nitrogen concentration between each zone **104** of range of zones **105** is an atomic percentage of 10% (e.g., plus or minus 5%). In one embodiment, the oxygen concentration of an optical device film **100** of a first material of TiO_2 and a second material of SiO_2 is about 66.67 atomic percent at plus or minus 10%. Each zone **104** has a zone thickness of about 0.001% to about 50% of the thickness **106**. Each zone **104** includes a first material at a first concentration and a second material at a second concentration. The first material, described and referenced to herein, has a first refractive index of about 2.0 or greater. The second material, described and referenced to herein, has a second refractive index of less than 2.0. The first material and the second material may be a metal-containing or a semiconductor material. For example, the first material includes, but is not limited to, oxides or nitrides of titanium (Ti), tantalum (Ta), zirconium (Zr), indium (In), or niobium (Nb). For example, the second material includes, but is not limited to, oxides or nitrides of silicon (Si), aluminum (Al), hafnium (Hf), scandium (Sc), Tin (Sn), yttrium (Y), praseodymium (Pr), or magnesium (Mg).

[0021] Introducing the first material and the second material at different concentrations continuously during deposition will allow for the modification of the optical properties i.e., the refractive index, of the optical device film **100**. In one embodiment, each zone **104** has a zone thickness of about 0.001% to about 50% of the thickness **106**. The first concentration of the first material through the range of zones **105** of the thickness **106** has a first concentration profile, and the second concentration of the second material through the range of zones **105** of the thickness **106** has a second concentration profile. In one embodiment, the first concentration has a maximum concentration at an initial zone **108** of the range of zones **105** adjacent to the first surface **102** and a minimum concentration at a final zone **109** of the range of zones **105** adjacent to the second surface **110**. The second concentration has the minimum concentration at the initial

zone **108** and a maximum concentration at the final zone **109** of the range of zones **105**. In the embodiments where the oxygen concentration is about 66.67 atomic percent at plus or minus 10% (e.g., of a first material of TiO_2 and a second material of SiO_2), the minimum concentration is about 0 atomic percent and the maximum concentration is about 33.3 atomic percent. In the embodiment, the first concentration of each zone **104** deposited immediately over a prior zone is not greater than the first concentration of the prior zone, and the second concentration of each zone **104** deposited immediately over a prior zone is not less than the second concentration of the prior zone.

[0022] In another embodiment, the first concentration has the minimum concentration at the initial zone **108** and a maximum concentration at the final zone **109**. The second concentration has the maximum concentration at the initial zone **108** and the minimum concentration at the final zone **109**. In the embodiment, the first concentration of each zone **104** deposited immediately over a prior zone is not less than the first concentration of the prior zone, and the second concentration of each zone **104** deposited immediately over a prior zone is not greater than the second concentration of the prior zone.

[0023] In another embodiment, the first concentration profile and the second concentration profile have sinusoidal profiles. In one embodiment with the first concentration profile and the second concentration profile having sinusoidal profiles, the first concentration has the maximum concentration at the initial zone **108** that decreases to the minimum concentration at a midpoint of the range of zones **105** and that increases to the maximum concentration at the final zone **109**. The second concentration has the minimum concentration at the initial zone **108** that increases to the maximum concentration at a midpoint of the range of zones **105** and that decreases to the minimum concentration at the final zone **109**. In another embodiment with the first concentration profile and the second concentration profile having sinusoidal profiles, the first concentration has the minimum concentration at the initial zone **108** that increases to the maximum concentration at a midpoint of the range of zones **105** and that decreases to the minimum concentration at the final zone **109**. The second concentration has the maximum concentration at the initial zone **108** that decreases to the minimum concentration at a midpoint of the range of zones **105** and that increases to the maximum concentration at the final zone **109**.

[0024] In yet another embodiment, the first concentration profile of the first material and the second concentration profile of the second material of the optical device film **100** are controlled by the embodiments of the method **500**, **600**, **700** such that any profile may be obtained. In embodiments of the method **500** of forming the optical device film **100** described herein, the first concentration and second concentration may be controlled by at least one of increasing or decreasing a first power level provided to a first target of the first material or increasing or decreasing a second power level provided to a second target of the second material. In embodiments of the method **600** of forming the optical device film **100** described herein, the first concentration and second concentration may be controlled by at least one of increasing or decreasing a first power level provided to a first target of the first material and increasing or decreasing a flow rate of a precursor gas including the second material. In embodiments of the method **700** of forming the optical device film **100** described herein, the first concentration and second concentration may be controlled by at least one of increasing or decreasing a first flow rate of a first gas including the first material and increasing or decreasing a second flow rate of a second gas including the second material. Therefore, the optical device film **100** having the concentration of oxygen or nitrogen may include any desired profile of the first material and the second material.

[0025] The optical device film **100** of the methods **500**, **600**, **700** described herein formed from the first material and the second material may include one or more of oxides or nitrides of titanium (Ti), tantalum (Ta), zirconium (Zr), indium (In), or niobium (Nb), and one or more of oxides or nitrides of silicon (Si), aluminum (Al), hafnium (Hf), scandium (Sc), Tin (Sn), yttrium (Y), praseodymium (Pr), or magnesium (Mg).

[0026] FIG. **2**A and FIG. **2**B are schematic, cross-sectional views of optical devices **200***a*, **200***b* formed from the optical device film **100**. The optical devices **200***a*, **200***b* include optical device structures **202***a*, **202***b* disposed on the optical device substrate **101**. The optical device structures **202***a*, **202***b* include sub-micron critical dimensions, e.g., nanosized dimensions, corresponding to the widths **203** of the optical device structures **202***a*, **202***b*. The optical device structures **202***a* may be binary structures with top surface **224** of the optical device structures **202***a* parallel to the surface **102** of the optical device substrate **101**. A first sidewall **225** and a second sidewall **226** are parallel to a third sidewall **227** and a fourth sidewall **228**. The sidewalls **225**, **226**, **227**, and **228** are oriented normal to a major axis of the optical device substrate **101**. The optical device structures **202***b* may be angled structures with the sidewalls **225**, **226**, **227**, and **228** slanted relative to the surface **102** of the optical device substrate **101**. The optical devices **200***a*, **200***b* are formed form the optical device film **100** having the first concentration profile of the first material, the second concentration profile of the second material, and a concentration of oxygen or nitrogen throughout the thickness **106** of the optical device film **100**.

[0027] FIG. **3** is a schematic, cross-sectional view of a PVD chamber **300**. The PVD chamber **300** may be used for the methods **500** and **600** described herein. It is to be understood that the PVD chamber **300** described below is an exemplary PVD chamber and other PVD chambers, including PVD chambers from other manufacturers, may be used with or modified to accomplish aspects of the present disclosure.

[0028] The PVD chamber **300** includes a plurality of cathodes **302**, **303** having a corresponding plurality of targets (at least one first target **304** and at least one second target **306**), attached to the chamber body **310** (e.g., via a chamber body adapter **308**). The first target **304** includes at least one first material described herein and the second target **306** includes at least one second material described herein. Each cathode (e.g., the first target **304** and second target **306**) may be coupled to a DC power source **312** or an RF power source **314** and matching network **316**.

[0029] The PVD chamber **300** is configured to include a substrate support **332** having a support surface **334** to support the optical device substrate **101**. The PVD chamber **300** includes an opening **350** (e.g., a slit valve) through which an end effector (not shown) extends to place an

optical device substrate **101** onto lift pins (not shown) for lowering the optical device substrate **101** onto a support surface **334**.

[0030] The PVD chamber **300** includes a sputter gas source **361** operable to supply a sputter gas, such as argon (Ar) to a process volume **305**. A gas flow controller **362** is disposed between the sputter gas source **361** and the process volume **305** to control a flow of the sputter gas from the sputter gas source **361** to the process volume **305**. The PVD chamber **300** includes a reactive gas source **363** operable to supply a reactive gas, such as an oxygen-containing gas or nitrogen-containing gas to the process volume **305**. A gas flow controller **364** is disposed between the reactive gas source **363** and the process volume **305** to control a flow of the reactive gas from the reactive gas source **363** to the process volume **305**. The PVD chamber **300** may include a precursor gas source **370** operable to supply a precursor gas to the process volume **305**. A gas flow controller **371** is disposed between the precursor gas source **370** and the process volume **305** to control a flow of the precursor gas from the precursor gas source **370** to the process volume **305**.

[0031] In the embodiment shown in FIG. **3**, the substrate support **332** includes an RF bias power source **338** coupled to a bias electrode **340** disposed in the substrate support **332** via a matching network **342**. The substrate support **332** includes a mechanism (not shown) that retains the optical device substrate **101** on a support surface **334** of the substrate support **332**, such as an electrostatic chuck, a vacuum chuck, a substrate retaining clamp, or the like. The substrate support **332** includes a cooling conduit **365** disposed in the substrate support **332** where the cooling conduit **365** controllably cools the substrate support **332** and the optical device substrate **101** positioned thereon to a predetermined temperature, for example between about −20° C. to 300° C. The cooling conduit **365** is coupled to a cooling fluid source **368** to provide cooling fluid (not shown). The substrate support **332** also includes a heater **367** embedded therein. The heater **367**, such as a resistive element, disposed in the substrate support **332** is coupled to an optional heater power source **366** and controllably heats the substrate support **332** and the optical device substrate **101** positioned thereon to a predetermined temperature, for example between about −20° C. to 300° C.

[0032] While FIG. **3** depicts one first target **304** and one second target **306**, the PVD chamber **300** may include one or more first targets **304** and/or one or more second targets **306**. For example, 3-5 targets selected from at least one of the first targets **304** or the second targets **306** may be included in the PVD chamber **300**. Each first target **304** is operable to deposit a different material. For example, 3-5 second targets **306** may be included in the PVD chamber. Each optical device material target **306** is operable to deposit a different material. In embodiments with the one or more first targets **304** and the one or more second **306**, each first target **304** is operable to deposit a different first material and/or each second target **306** is operable to deposit a different second material.

[0033] FIG. **4** is a schematic, cross-sectional view of a CVD chamber **400** that may be used for the method **700** described herein. It is to be understood that the CVD chamber **400** described herein is an exemplary CVD chamber and other CVD chambers, including CVD chambers from other manufacturers, may be used with or modified to accomplish aspects of the present disclosure.

[0034] The CVD chamber **400** has a chamber body **402** that includes a processing volume **404** having a substrate support **406** disposed therein to support an optical device substrate **101** thereon. The substrate support **406** includes a heating/cooling conduit **410** and a mechanism that retains the optical device substrate **101** on a support surface **407** of the substrate support **406**, such as an electrostatic chuck, a vacuum chuck, a substrate retaining clamp, or the like. The substrate support **406** is coupled to and movably disposed in the processing volume **404** by a stem **408** connected to a lift system (not shown) that moves the substrate support **406** between an elevated processing position and a lowered position that facilitates transfer of the optical device substrate **101** to and from the CVD chamber **400** through an opening **412**.

[0035] The CVD chamber **400** includes a flow controller **418**A disposed between a first gas source **416**A and a chamber body **402** to control the first flow rate of the first process gas of the first material from the first gas source **416**A to a showerhead **414**. The CVD chamber **400** includes a flow controller **418**B disposed between a second gas source **416**B and the chamber body **402** to control the second flow rate of the second process gas of the second material from the second gas source **416**B to a showerhead **414**. The showerhead **414** is connected to an RF power source **422** by an RF feed **424** for generating a plasma in the processing volume **404** from the first process gas and/or second process gas. The RF power source **422** provides RF energy to the showerhead **414** to facilitate generation of a plasma between the showerhead **414** and the substrate support **406**. A vacuum pump **420** is coupled to the chamber body **402** for controlling the pressure within the processing volume **404**. A controller **428** is coupled to the CVD chamber **400** and configured to control aspects of the CVD chamber **400** during processing.

[0036] While FIG. **4** depicts a first gas source **416**A and a second gas source **416**B, the CVD chamber **400** may include one or more first gas sources **416**A and/or one or more second gas sources **416**B. For example, 3-5 gas sources selected from at least one of the first gas sources **416**A or the second gas sources **416**B may be included in the CVD chamber **400**. In embodiments with the one or more first gas sources **416**A and the one or more second gas sources **416**B, each first gas source **416**A is operable to deposit a different first material and/or each second gas source **416**B is operable to deposit a different second material.

[0037] FIG. **5** is a flow diagram of a method **500** of forming an optical device film **100**. The optical device film **100** may be utilized in subsequent processes to form the devices **200***a*, **200***b*. To facilitate explanation, FIG. **5** will be described with reference to the PVD chamber **300** of FIG. **3**. However, it is to be noted that a PVD chamber other than the PVD chamber **300** of FIG. **3** may be utilized in conjunction with method **500**.

[0038] At operation **501**, the optical device substrate **101** is disposed on a substrate support in the PVD chamber **300**. At operation **502**, an initial zone **108** of the range of zones **105** of the optical device film **100** is deposited. The first target **304** having the first material is set to a first power level and the second target **306** having the second material is set to a second power level. In one embodiment, the first material of the first target **304** and/or the second material of

the second target **306** includes an oxygen-containing material or a nitrogen-containing material. The first material, described and referenced to herein, has a first refractive index about 2.0 or greater. The second material, described and referenced to herein, has a second refractive index less than 2.0. The first material includes, but is not limited to, oxides or nitrides of titanium (Ti), tantalum (Ta), zirconium (Zr), indium (In), or niobium (Nb). The second material includes, but is not limited to, oxides or nitrides of silicon (Si), aluminum (Al), hafnium (Hf), scandium (Sc), Tin (Sn), yttrium (Y), praseodymium (Pr), or magnesium (Mg). In another embodiment, an oxygen-containing gas or a nitrogen-containing gas is supplied to the process volume **305**. In the embodiment, the deposited first material and the second material react with the oxygen-containing gas or nitrogen-containing gas to form the initial zone **108** of the optical device film **100**. In another embodiment, the optical device substrate **101** is maintained at a predetermined temperature between −20° C. to 300° C.

[0039] In one embodiment, a first concentration of the first material has a maximum concentration in the initial zone **108** of the range of zones **105** by applying the first power level at the upper limit of the first power level to the first target **304**. The upper limit of the first power level corresponding to the highest power level is supplied to the first target **304** during the method **500**. In the embodiment, a second concentration of the second material has the minimum concentration at the initial zone **108** not applying the second power level or applying the second power level at the lower limit of the second power level to the second target **306**. The lower limit of the second power level corresponding to the lowest power level is supplied to the second target **306** during the method **500**. In another embodiment, the first concentration of the first material has a minimum concentration in the initial zone **108** of the range of zones **105** by not applying the first power level or applying the first power level at the lower limit of the first power level to the first target **304**. The lower limit of the first power level corresponding to the lowest power level is supplied to the first target **304** during the method **500**. In the embodiment, the second concentration of the second material has the maximum concentration at the initial zone **108** by applying the second power level at the upper limit of the second power level to the second target **306**. The upper limit of the second power level corresponding to the highest power level is supplied to the second target **306** during the method **500**. In yet another embodiment, the first concentration and second concentration may be controlled by at least one of setting the first power level provided to the first target **304** of the first material and setting a second power provided to the second target **306** of the second material at different power levels between the upper limit and lower limit of the first and second power levels.

[0040] At operation **503**, subsequent zones of the optical device film **100** are deposited until the final zone **109** of the range of zones **105** is deposited. The deposition of the subsequent zones includes at least one of setting the first power level provided to the first target **304** of the first material and setting a second power level provided to the second target **306** of the second material at different power levels to form the optical device film **100**. The optical device film **100** includes an oxygen concentration or nitrogen concentration, the first concentration profile of the first material, and the second concentration profile of the second material. In one embodiment, which can be combined with other embodiments described herein, the thickness **106** has a constant or substantially constant oxygen or nitrogen concentration throughout the range of zones **105** of the optical device film **100**.

[0041] FIG. **6** is a flow diagram of a method **600** of forming an optical device film **100**. The optical device film **100** may be utilized in subsequent processes to form the devices **200***a*, **200***b*. To facilitate explanation, FIG. **6** will be described with reference to the PVD chamber **300** of FIG. **3**. However, it is to be noted that a PVD chamber other than the PVD chamber **300** of FIG. **3** may be utilized in conjunction with method **600**.

[0042] At operation **601**, the optical device substrate **101** is disposed on a substrate support in the PVD chamber **300**. At operation **602**, an initial zone **108** of the range of zones **105** of the optical device substrate **101** is deposited. The first target **304** having the first material is set to a first power level and the precursor gas including the second material is provided at a precursor flow rate. In one embodiment, the first material of the first target **304** and/or the precursor gas of the second material includes an oxygen-containing material or a nitrogen-containing material. The first material, described and referenced to herein, has a first refractive index about 2.0 or greater. The second material, described and referenced to herein, has a second refractive index less than 2.0. The first material includes, but is not limited to, oxides or nitrides of titanium (Ti), tantalum (Ta), zirconium (Zr), indium (In), or niobium (Nb). The second material includes, but is not limited to, oxides or nitrides of silicon (Si), aluminum (Al), hafnium (Hf), scandium (Sc), Tin (Sn), yttrium (Y), praseodymium (Pr), or magnesium (Mg). In another embodiment, an oxygen-containing gas is supplied to the process volume **305**. In another embodiment, an oxygen-containing gas or a nitrogen-containing gas is supplied to the process volume **305**. In the embodiment, the deposited first material and the second material react with the oxygen-containing gas or the nitrogen-containing gas to form the initial zone **108** of the optical device film **100**. In another embodiment, the optical device substrate **101** is maintained at a predetermined temperature between about −20° C. to 300° C.

[0043] In one embodiment, a first concentration of the first material has a maximum concentration in the initial zone **108** of the range of zones **105** by applying the first power level at the upper limit of the first power level to the first target **304**. The upper limit of the first power level corresponding to the highest power level is supplied to the first target **304** during the method **600**. In the embodiment, a second concentration of the second material has the minimum concentration at the initial zone **108** by not flowing the precursor gas or flowing the precursor gas at the lowest flow rate during the method **600**. In another embodiment, the first concentration of the first material has a minimum concentration in the initial zone **108** of the range of zones **105** by not applying the first power level or applying the first power level at the lower limit of the first power level to the first target **304**. The lower limit of the first power level corresponding to the lowest power level is supplied to the first target **304** during the method **600**. In the embodiment, the second concentration of the second material has the maximum concentration at the initial zone **108** by flowing the precursor gas at the highest flow rate during the method **600** during the method **500**. In yet another embodiment, the first

concentration and second concentration may be controlled by at least one of varying the first power level provided to the first target **304** of the first material and varying the flow rate of precursor gas during the method **600**.

[0044] At operation **603**, subsequent zones of the optical device film **100** are deposited until the final zone **109** of the range of zones **105** is deposited. The deposition of the subsequent zones includes at least one of increasing or decreasing a first power level provided to a first target of the first material and increasing or decreasing a flow rate of a precursor gas including the second material to form the optical device film **100** having an oxygen concentration or nitrogen concentration, the first concentration profile of the first material, and the second concentration profile of the second material. In one embodiment, which can be combined with other embodiments described herein, the thickness **106** has a constant or substantially constant oxygen or nitrogen concentration throughout the range of zones **105** of the optical device film **100**.

[0045] FIG. **7** is a flow diagram of a method **700** of forming an optical device film **100**. The optical device film **100** may be utilized in subsequent processes to form the devices **200***a*, **200***b*. To facilitate explanation, FIG. **7** will be described with reference to the CVD chamber **400** of FIG. **4**. However, it is to be noted that a CVD chamber other than the CVD chamber **400** of FIG. **4** may be utilized in conjunction with method **700**.

[0046] At operation **701**, the optical device substrate **101** is disposed on a substrate support in the CVD chamber **400**. At operation **702**, an initial zone **108** of the range of zones **105** of the optical device substrate **101** is deposited. The first gas has a first gas flow rate and the second gas has a second gas flow rate. The first material of the first gas, described and referenced to herein, has a first refractive index about 2.0 or greater. The second material of the second gas, described and referenced to herein, has a second refractive index less than 2.0. In one embodiment, the first material of the first target **304** and/or the precursor gas of the second material includes an oxygen-containing material or a nitrogen-containing material. In one embodiment, the optical device substrate **101** is maintained at a predetermined temperature between about −20° C. to 300° C.

[0047] In one embodiment, a first concentration of the first material has a maximum concentration in the initial zone **108** of the range of zones **105** by flowing the first gas at the highest flow rate during the method **700**. In the embodiment, a second concentration of the second material has the minimum concentration at the initial zone **108** by not flowing the second gas or flowing the second gas at the lowest flow rate during the method **700**. In another embodiment, the first concentration of the first material has a minimum concentration in the initial zone **108** of the range of zones **105** by not flowing the first gas or flowing the first gas at the lowest flow rate during the method **700**. In the embodiment, the second concentration of the second material has the maximum concentration at the initial zone **108** by flowing the second gas at the highest flow rate during the method **700**. In yet another embodiment, the first concentration and second concentration may be controlled by at least one of varying the first gas flow rate and varying the second gas flow rate during the method **700**.

[0048] At operation **703**, subsequent zones of the optical device film **100** are deposited until the final zone **109** of the range of zones **105** is deposited. The deposition of the subsequent zones includes at least one of increasing or decreasing a first flow rate of a first gas including the first material and increasing or decreasing a second flow rate of a second gas including the second material to form the optical device film **100** having a oxygen concentration or a nitrogen concentration, the first concentration profile of the first material, and the second concentration profile of the second material. In one embodiment, which can be combined with other embodiments described herein, the thickness **106** has a constant or substantially constant oxygen or nitrogen concentration throughout the range of zones **105** of the optical device film **100**.

[0049] In summation, optical device films and methods of forming optical device films having an oxygen-concentration or a nitrogen concentration, the first concentration profile of the first material, and the second concentration profile of the second material are described herein. Introducing the first material and the second material at different concentrations continuously during deposition will allow for the modification of the optical properties i.e., the refractive index, of the optical device film. In one embodiment, a method includes controlling the first concentration profile and the second concentration profile by at least one of increasing or decreasing a first power level provided to a first target of the first material or increasing or decreasing a second power provided to a second target of the second material. In another embodiment, a method includes controlling the first concentration profile and the second concentration profile by at least one of increasing or decreasing a first power level provided to a first target of the first material and increasing or decreasing a flow rate of a precursor gas including the second material. In yet another embodiment, a method includes controlling the first concentration profile and the second concentration profile by at least one of increasing or decreasing a first flow rate of a first gas including the first material and increasing or decreasing a second flow rate of a second gas including the second material.

[0050] While the foregoing is directed to examples of the present disclosure, other and further examples of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

1. An optical device film, comprising:

a thickness divided into a range of zones from a first surface substantially corresponding to 0% of the thickness to a second surface substantially corresponding to 100% of the thickness, each zone of the range of zones having a zone thickness;

an oxygen concentration or a nitrogen concentration in each zone of the range of zones of the optical device film;

a first material having a first refractive index of about 2.0 or greater, the first material having a first concentration profile throughout the range of zones; and

a second material having a second refractive index of less than 2.0, the second material having a second concentration profile throughout the range of zones, the second concentration profile different from the first concentration profile.

2. The optical device film of claim **1**, wherein the zone thickness is about 0.001% to about 50% of the thickness.

3. The optical device film of claim 1, wherein the first material includes oxides or nitrides of titanium (Ti), tantalum (Ta), zirconium (Zr), indium (In), or niobium (Nb).

4. The optical device film of claim 1, wherein the second material includes oxides or nitrides of silicon (Si), aluminum (Al), hafnium (Hf), scandium (Sc), Tin (Sn), yttrium (Y), praseodymium (Pr), or magnesium (Mg).

5. The optical device film of claim 1, wherein the oxygen concentration is about 66.67 atomic percent at plus or minus 10%.

6. The optical device film of claim 1, wherein:

an initial zone of the range of zones adjacent to the first surface, comprises:

a maximum concentration of the first material; and

a minimum concentration of 0 atomic percent of the second material; and

a final zone of the range of zones adjacent to the second surface, comprises:

a minimum concentration of 0 atomic percent of the first material; and

a maximum concentration of the second material.

7. The optical device film of claim 6, wherein:

the first concentration profile has a first concentration of each zone disposed immediately over a prior zone not greater than the first concentration of the prior zone; and

the second concentration profile has a second concentration of each zone disposed immediately over the prior zone not less than the second concentration of the prior zone.

8. The optical device film of claim 6, wherein:

the first concentration profile has the maximum concentration at the initial zone of the range of zones, the first concentration profile has the minimum concentration at a midpoint of the range of zones, the first concentration profile has the maximum concentration at the final zone of the range of zones; and

the second concentration profile has the minimum concentration at the initial zone of the range of zones, the second concentration profile has the maximum concentration at the midpoint of the range of zones, the second concentration profile has the minimum concentration at the final zone of the range of zones.

9. The optical device film of claim 1, wherein:

an initial zone of the range of zones adjacent to the first surface, comprises:

a maximum concentration of the second material; and

a minimum concentration of 0 atomic percent of the first material; and

a finial zone of the range of zones adjacent to the second surface, comprises:

a minimum concentration of 0 atomic percent of the second material; and

a maximum concentration of the first material.

10. The optical device film of claim 9, wherein:

the first concentration profile has a first concentration of each zone disposed immediately over a prior zone not less than the first concentration of the prior zone; and

the second concentration profile has a second concentration of each zone disposed immediately over the prior zone not greater than the second concentration of the prior zone.

11. The optical device film of claim 9, wherein:

the first concentration profile has the minimum concentration at the initial zone of the range of zones, the first concentration profile has the maximum concentration at a midpoint of the range of zones, the first concentration profile has the minimum concentration at the final zone of the range of zones; and

the second concentration profile has the maximum concentration at the initial zone of the range of zones, the second concentration profile has the minimum concentration at the midpoint of the range of zones, the second concentration profile has the maximum concentration at the final zone of the range of zones.

12. The optical device film of claim 1, wherein the optical device film comprises a plurality of optical device structures disposed therein.

13. The optical device film of claim 12, wherein the plurality of optical device structures are slanted relative to the first surface of the optical device film.

14. The optical device film of claim 12, wherein the difference in the oxygen or the nitrogen concentration between each zone of the range of zones is an atomic percentage of 10%.

15. A method, comprising:

disposing an optical device substrate on a substrate support, the substrate support disposed in a chamber, the chamber comprising:

a first target disposed in the chamber, the first target comprising a first material; and

a second target disposed in the chamber, the second target comprising a second material; and

depositing an optical device film on the optical device substrate, comprising:

depositing the first material with a first concentration profile, the depositing the first material comprising providing a first power level to the first target, wherein the first concentration profile of the first material is controlled by at least one of increasing or decreasing the first power level provided to the first target; and

depositing the second material with a second concentration profile, the depositing the second material comprising providing a second power level to the second target, wherein the second concentration profile of the second material is controlled by at least one of increasing or decreasing the second power level provided to the second target.

16. The method of claim 15, wherein the first material includes oxides or nitrides of titanium (Ti), tantalum (Ta), zirconium (Zr), indium (In), or niobium (Nb).

17. The method of claim 15, wherein the second material includes oxides or nitrides of silicon (Si), aluminum (Al), hafnium (Hf), scandium (Sc), Tin (Sn), yttrium (Y), praseodymium (Pr), or magnesium (Mg).

18. A method, comprising:

disposing an optical device substrate on a substrate support, the substrate support disposed in a chamber, the chamber comprising:

a first target disposed in the chamber, the first target comprising a first material; and

a gas source operable to flow a precursor gas comprising a second material; and

depositing an optical device film on the optical device substrate, comprising:

depositing the first material with a first concentration profile, the depositing the first material comprising providing a first power level to the first target, wherein the first concentration profile of the first material is controlled by at least one of increasing or decreasing the first power level provided to the first target; and

depositing the second material with a second concentration profile, the depositing the second material comprising providing a precursor gas at a flow rate, wherein the second concentration profile of the second material is controlled by at least one of increasing or decreasing a flow rate of the precursor gas.

19. The method of claim **18**, wherein the second material includes oxides or nitrides of silicon (Si), aluminum (Al), hafnium (Hf), scandium (Sc), Tin (Sn), yttrium (Y), praseodymium (Pr), or magnesium (Mg).

20. A method, comprising:

disposing an optical device substrate in a chamber;

flowing a first gas comprising a first material into the chamber at a first flow rate, wherein a first concentration profile of the first material of a deposited optical device film is controlled by at least one of increasing or decreasing the first flow rate during the flowing of the first gas; and

flowing a second gas comprising a second material into the chamber at a second flow rate, wherein a second concentration profile of the second material of the deposited optical device film is controlled by at least one of increasing or decreasing the second flow rate during the flowing of the second gas.

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