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(54) **DIFFUSER-LESS GRAY-TONE LITHOGRAPHY PROCESS, MASK DESIGN, AND FABRICATION METHOD**

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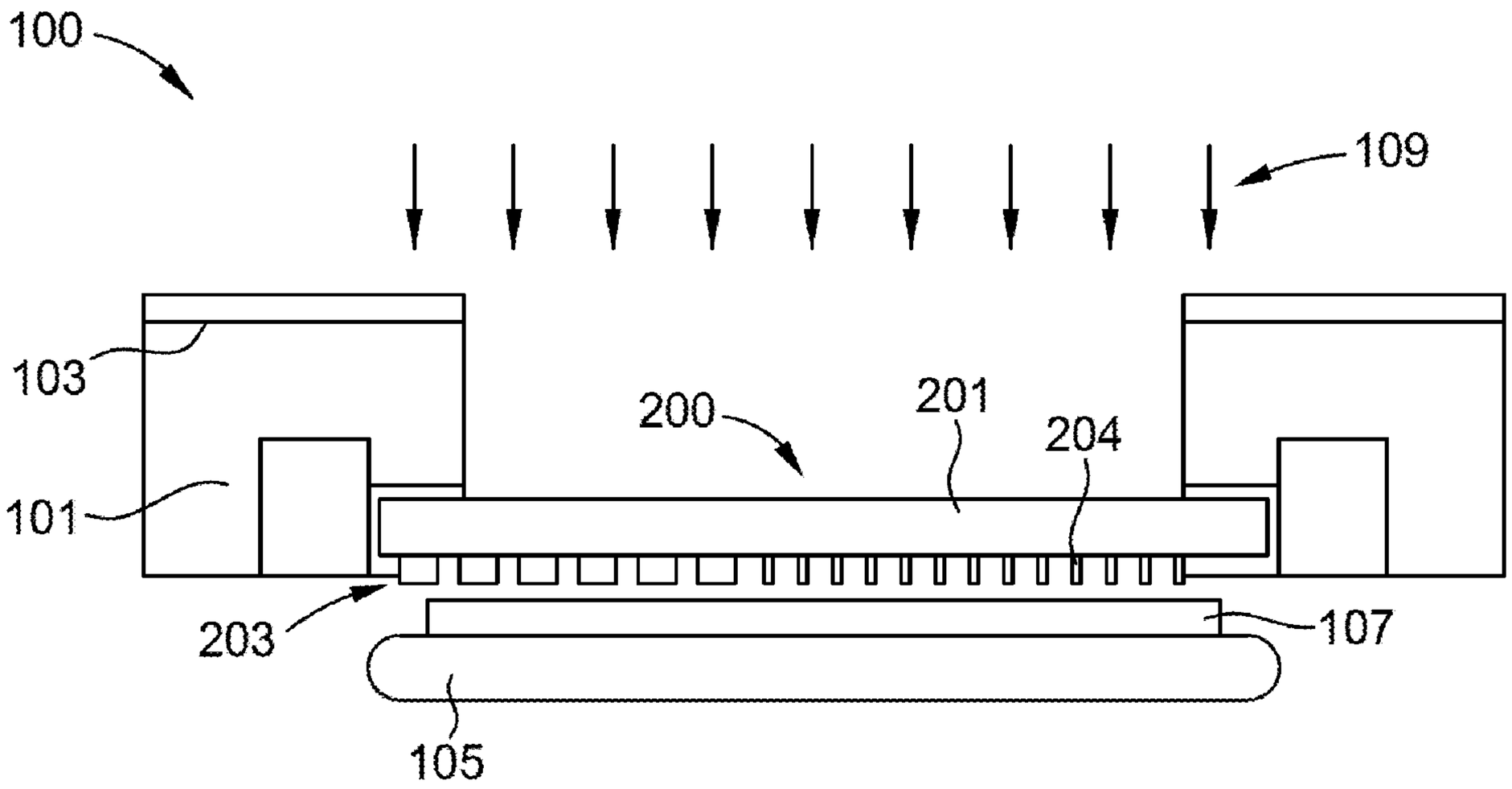
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(57) **ABSTRACT**

The present disclosure generally relates to mask designs and fabrication for gray-tone lithography. More specifically, embodiments described herein relate to masks designed with a specific pitch to avoid the need for a diffuser. In some embodiments, a mask is provided. The mask includes a substrate and a gray-tone pattern grating disposed on the substrate. The gray-tone pattern grating is defined by a plurality of structures disposed on the substrate. The structures include an absorber layer disposed on the substrate. The gray-tone pattern grating has a pitch of less than or equal to an exposure wavelength of light to pass through the structures. The pitch is defined as a distance between a centers of adjacent structures of the plurality of structures.



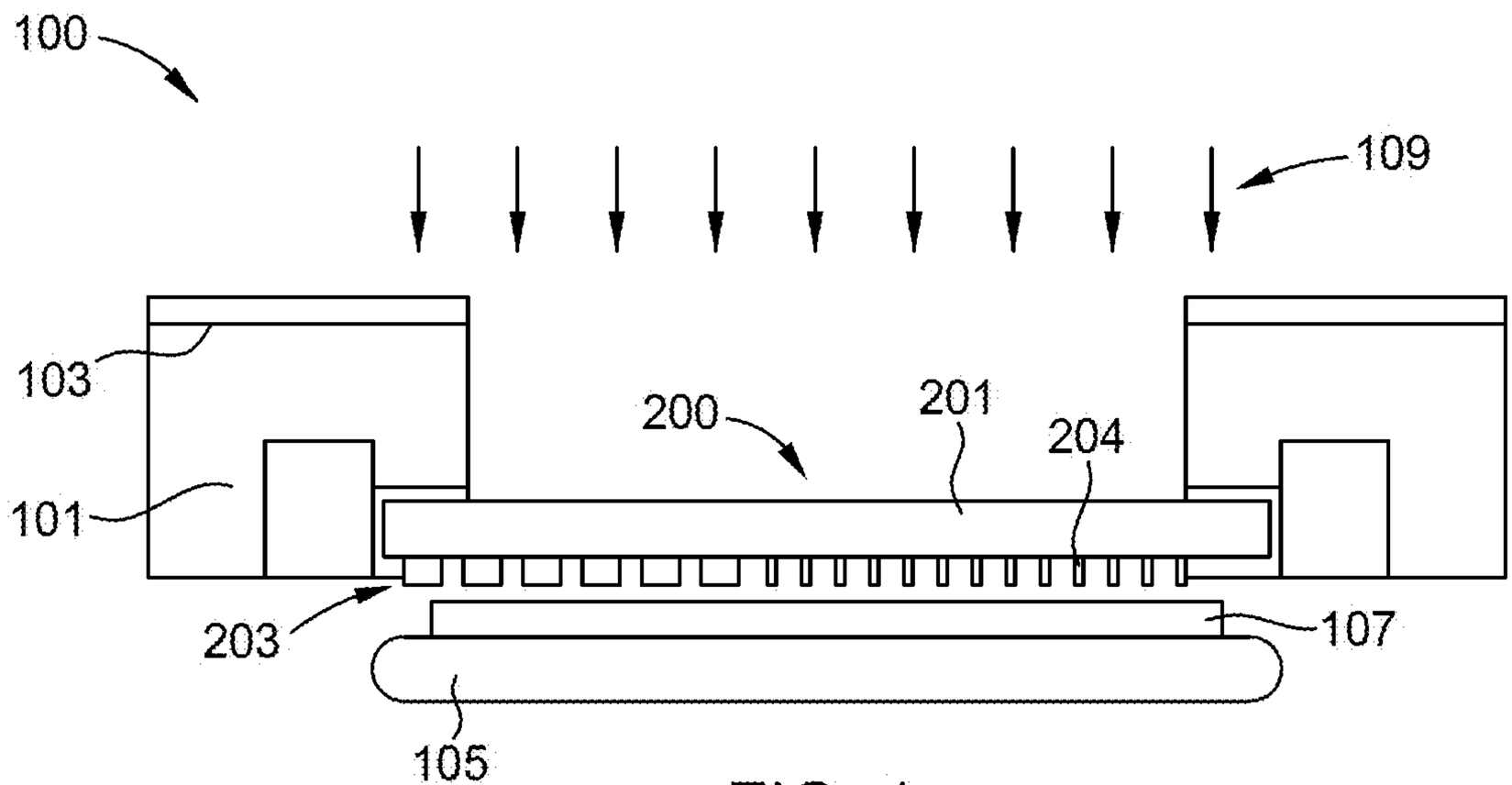


FIG. 1

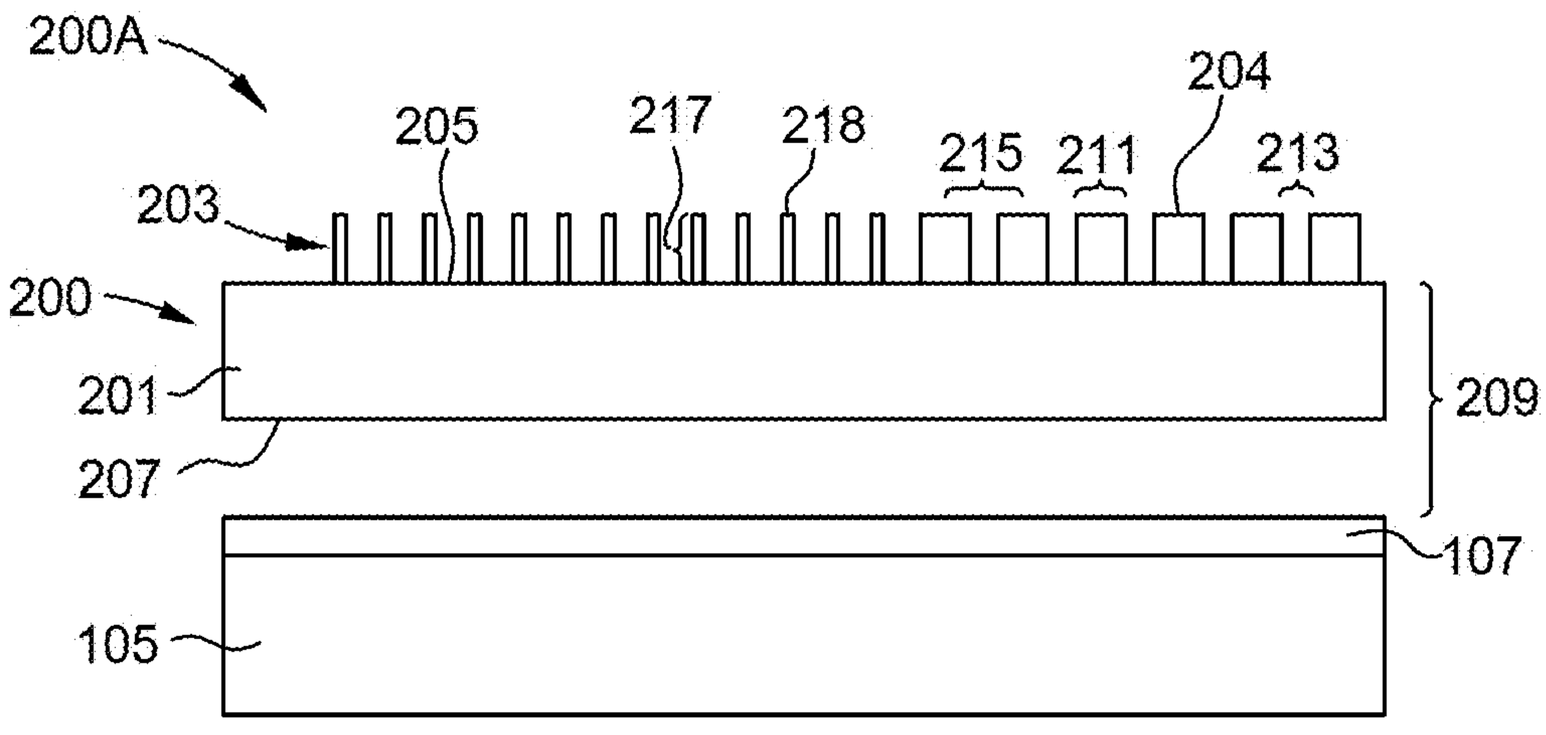


FIG. 2A

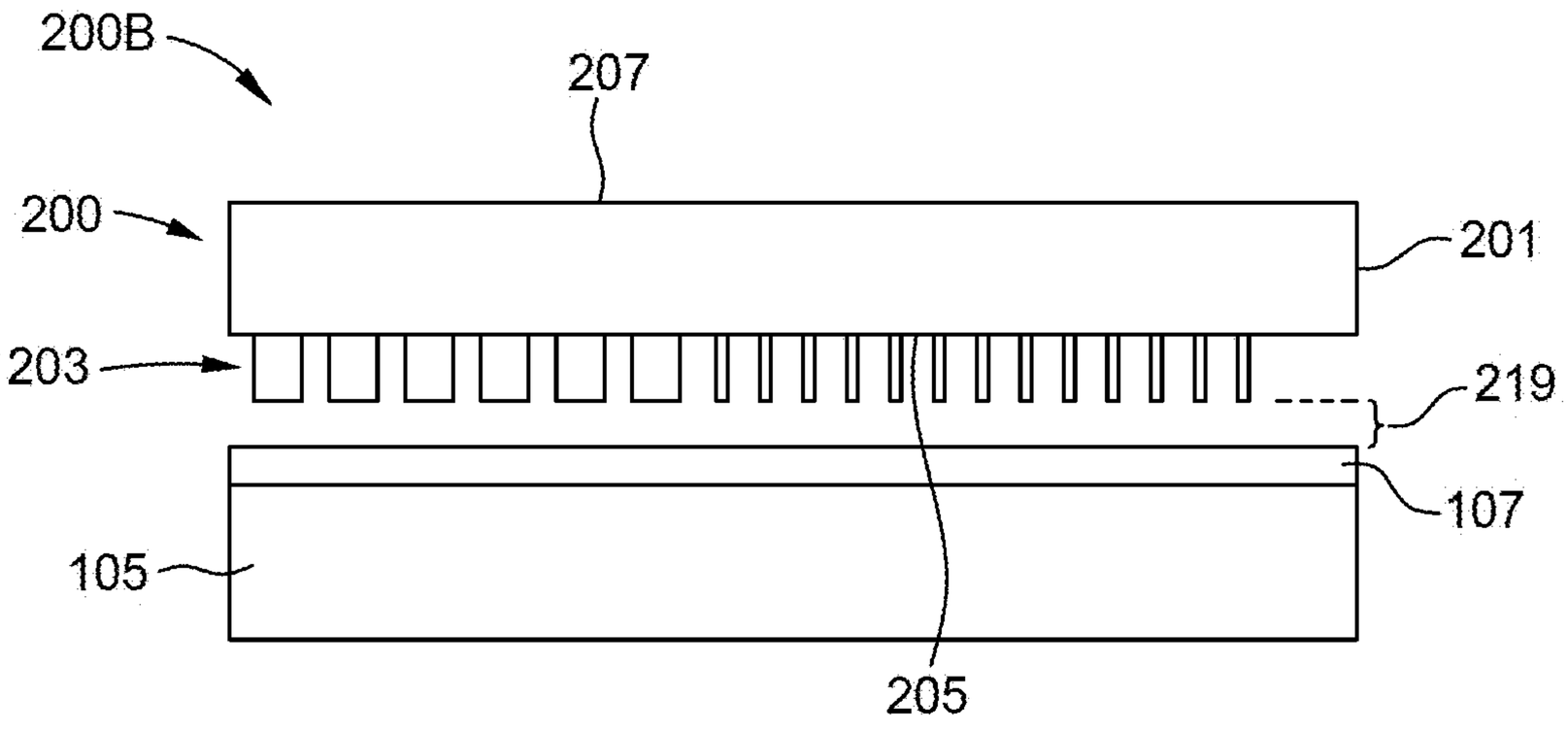


FIG. 2B

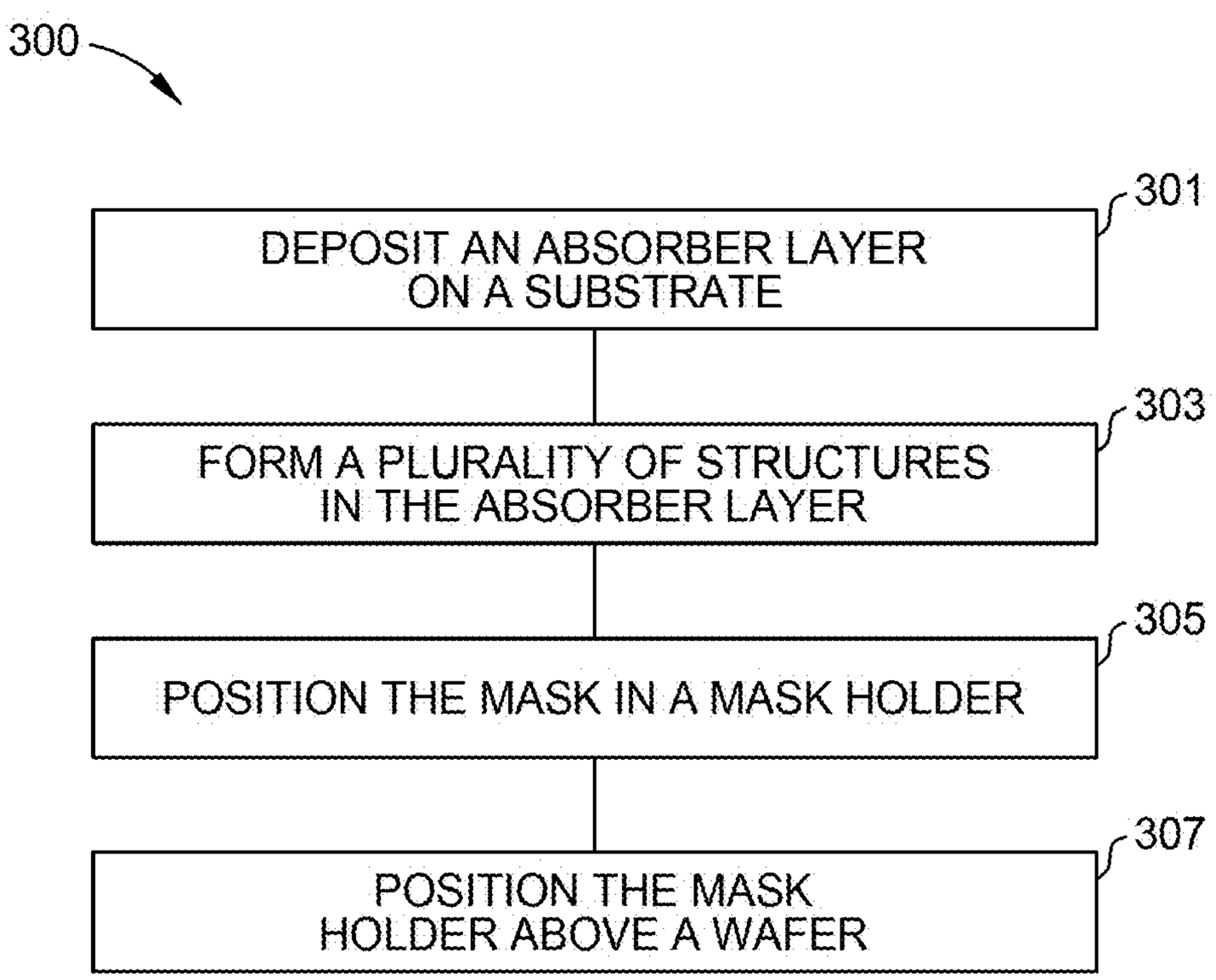

300
DEPOSIT AN ABSORBER LAYER ON A SUBSTRATE
301
FORM A PLURALITY OF STRUCTURES IN THE ABSORBER LAYER
303
POSITION THE MASK IN A MASK HOLDER
305
POSITION THE MASK HOLDER ABOVE A WAFER
307

FIG. 3

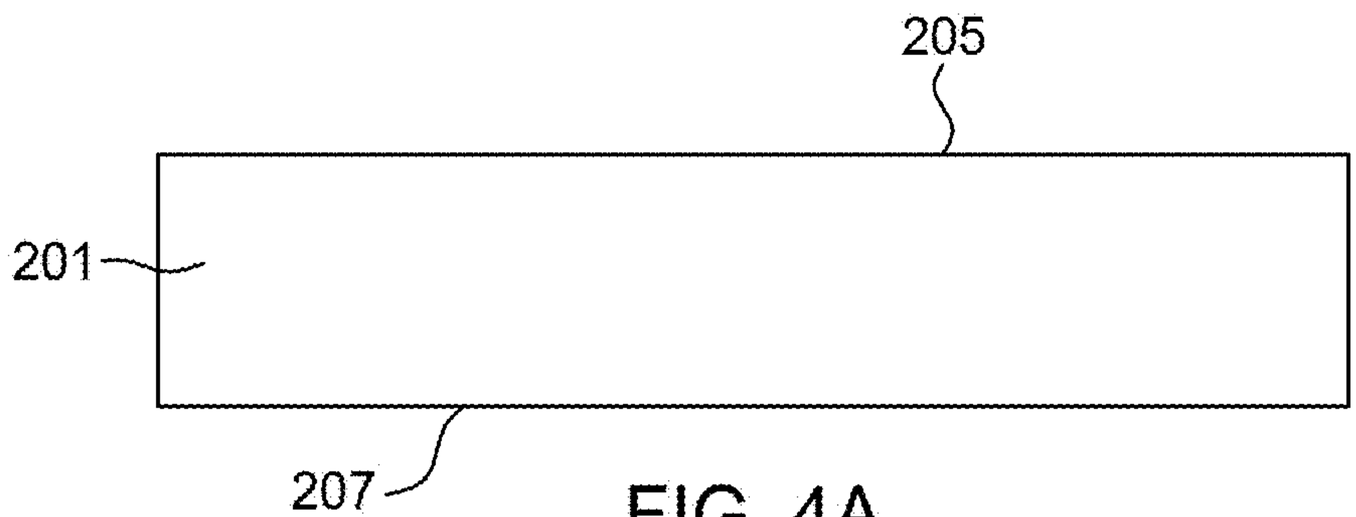


FIG. 4A

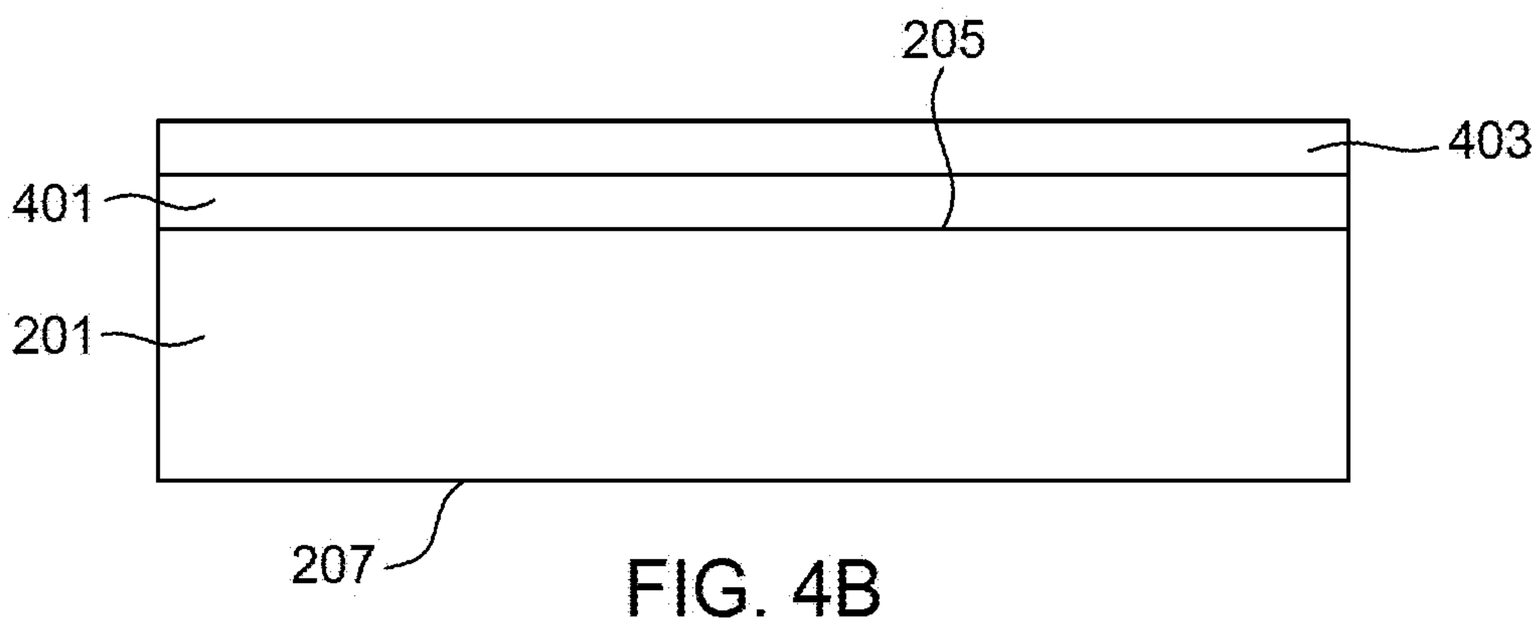


FIG. 4B

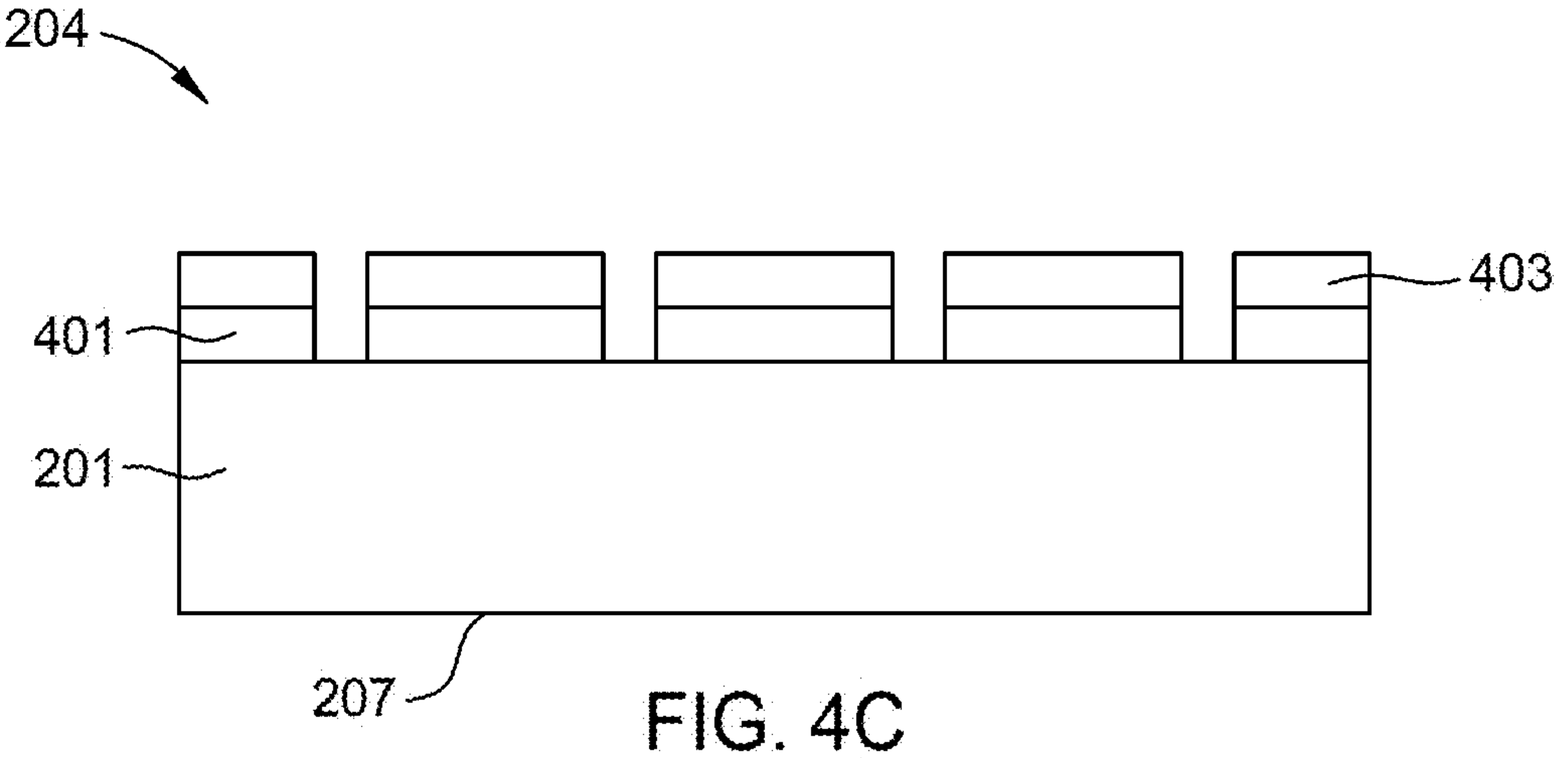


FIG. 4C

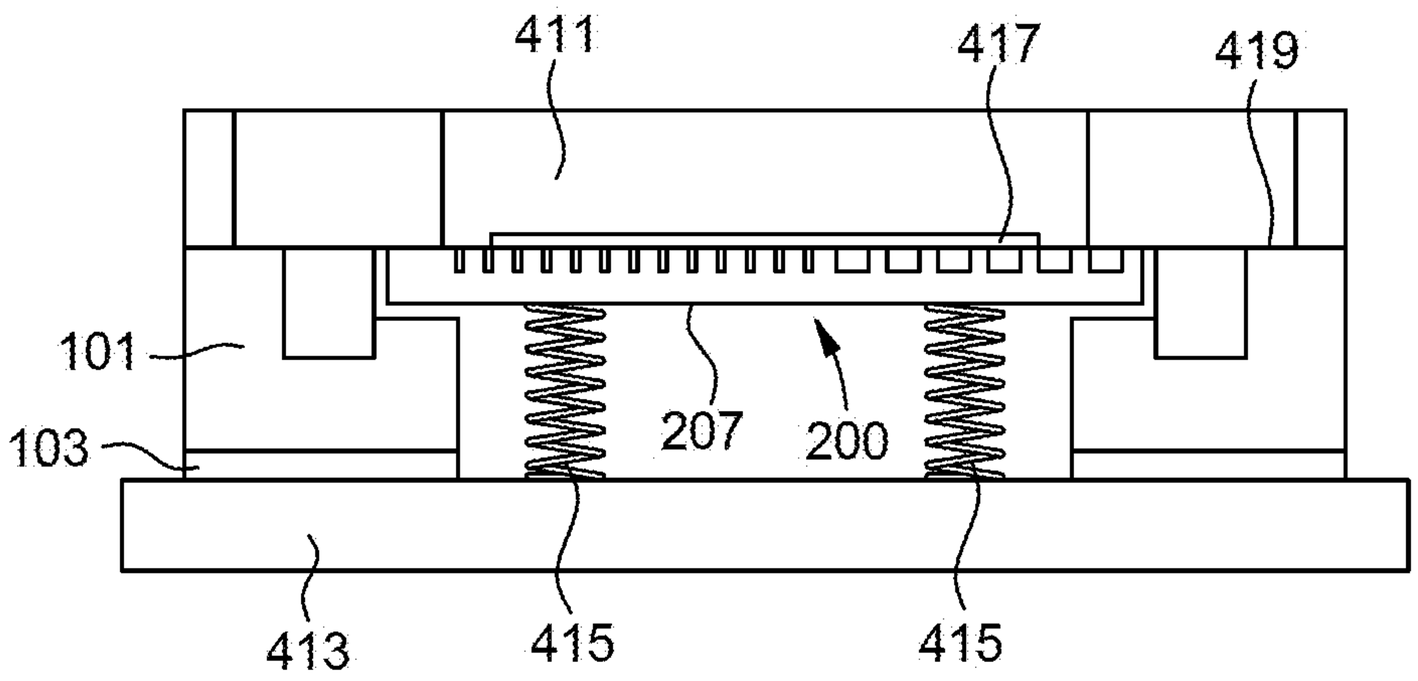


FIG. 4D

DIFFUSER-LESS GRAY-TONE LITHOGRAPHY PROCESS, MASK DESIGN, AND FABRICATION METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This Application claims the benefit of U.S. Provisional Application 63/563,715 filed on Mar. 11, 2024, and entitled "Diffuser-Less Gray-Tone Lithography Process, Mask Design, and Fabrication Method," wherein the entire contents of which are incorporated by reference.

BACKGROUND

Field

[0002] Embodiments of the present disclosure generally relate to mask designs and fabrication for gray-tone lithography. More specifically, embodiments described herein relate to masks designed with a specific pitch to avoid needing diffusers.

Description of the Related Art

[0003] Virtual reality (VR) is generally considered to be a computer-generated simulated environment in which a user has an apparent physical presence. A virtual reality experience can be generated in 3D and viewed with a head-mounted display (HMD), such as glasses or other wearable display devices that have near-eye display panels as lenses to display a virtual reality environment that replaces an actual environment. Augmented reality (AR), enables an experience in which a user can still see through the display lenses of the glasses or other HMD device to view the surrounding environment, yet also see images of virtual objects that are generated to appear as part of the environment. AR can include any type of input, such as audio and haptic inputs, as well as virtual images, graphics, and video that enhance or augment the environment that the user experiences.

SUMMARY

[0004] In one embodiment, which may be combined with other embodiments, a mask for gray-tone lithography is provided. The mask includes a substrate and a gray-tone pattern grating disposed on the substrate. The gray-tone pattern grating is defined by a plurality of structures disposed on the substrate. The structures include an absorber layer disposed on the substrate. The gray-tone pattern grating has a pitch that is less than or equal to an exposure wavelength of light to pass through the structures. The pitch is defined as a distance between a centers of adjacent structures of the plurality of structures.

[0005] In another embodiment, which may be combined with other embodiments, a mask assembly for gray-tone lithography includes a mask, a mask holder, a UV light source, and a substrate support. The mask includes a substrate, and a gray-tone pattern grating with a plurality of grating structures formed from an absorber layer disposed on the substrate. The mask holder is operable to secure the mask, and the mask is inserted in the mask holder. The UV light source is disposed above the mask and is operable to project UV light through the mask. The gray-tone pattern grating has a pitch that is less than or equal to a wavelength of UV light projected by the UV light source. The pitch is defined as a distance between centers of adjacent grating structures of the plurality of grating structures. The substrate support is positioned below the mask.

[0006] In another embodiment, which may be combined with other embodiments, a method of fabricating a mask is provided. The method includes depositing an absorber layer on a first surface of a substrate. The method further includes forming a plurality of structures in the absorber layer by removing sections of the absorber layer. The structures form a grating having a pitch that is less than or equal to an exposure wavelength of light to pass through the structures. The pitch is defined as a distance between centers of adjacent grating structures of the plurality of structures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] 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 the scope of the disclosure, as the disclosure may admit to other equally effective embodiments.

[0008] FIG. **1** is a cross-sectional view of a mask assembly, according to some embodiments.

[0009] FIGS. **2**A and **2**B are cross-sectional views of a mask in different orientations, according to some embodiments.

[0010] FIG. **3** is a flow diagram of a method of forming a mask, according to some embodiments.

[0011] FIGS. **4**A, **4**B, **4**C, and **4**D, are schematic, cross-sectional views of a substrate during a method of forming a mask, according to some embodiments.

[0012] 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

[0013] The present disclosure generally relates to mask designs and fabrication for gray-tone lithography. More specifically, embodiments described herein relate to masks designed with a specific pitch to avoid needing diffusers.

[0014] AR and VR devices may be partially formed though gray-tone lithography using masks. A gray-tone mask modulates the intensity of light that is passed through to adjust the dose exposed on a resist layer. Gray-tone masks for gray-tone lithography may be made using an E-beam writer or laser writer.

[0015] One way to modulate light intensity is by varying the pattern density of opening areas of the mask versus opaque areas of the mask. Current gray-tone masks, due to the limitation of mask writer tool and cost, have patterns that have a critical dimension and a pitch that is larger than the wavelength of light used for the gray-tone lithography. Specifically, current gray-tone masks have a binary design with a pitch ranging from a few micrometers to several tens micrometers. Therefore, the mask pattern may be potentially resolved on a wafer, which one may desire to avoid. Separate

diffusers can be used to scatter the incident light before entering the mask to perform a photolithography process. Scattering the light causes the mask pattern to not be resolved on wafer; however, the diffuser causes transmission loss of light causing throughput delays. The diffuser also causes large transition zones between different thickness targets, which can be a significant issue in small designs. A mask with a diffuser is also complicated to perform optical proximity correction (OPC) to correct errors in the photolithography process. Therefore, what is needed in the art is mask designs that may not require a diffuser.

[0016] Accordingly, as described herein, a transparent wafer (such as a 30 millimeter (mm) wafer) can be used to form a gray-tone lithography mask that does not require a diffuser to operate. In some embodiments, which may be combined with other embodiments, the wafer mask has a sub-resolution pattern to have a pitch less than the wavelength of light. As a result, the wafer mask scatters light, and makes a diffuser unnecessary. The wafer mask can be attached to a mask holder and used as a standard mask. In some embodiments, which may be combined with other embodiments, the wafer mask has the benefits of a maximum mask size fit up to 300 mm, better pattern density control, lower cost, and design freedom. The wafer mask is easy to clean and perform metrology using standard clean and metrology tools. The wafer mask also allows for OPC to be performed.

[0017] FIG. **1** is a cross-sectional view of a mask assembly **100** according to some embodiments. The mask assembly **100** includes a mask **200**, a mask holder **101**, and an opaque layer **103**. The mask assembly **100** is positioned over a wafer **105** having a resist layer **107** disposed thereon. The mask assembly **100** is operable to secure the mask **200** in position. In some embodiments, which may be combined with other embodiments, the mask holder **101** has a similar shape to traditional photo masks used in photolithography processes. The wafer **105** is disposed on a substrate support (not shown). The substrate support may be aligned below the mask **200** and may be operable to hold the wafer **105** under the mask assembly **100** and mask **200**. Ultraviolet (UV) light **109** is projected above the mask assembly **100** through the mask **200**. For instance, a UV light source (not shown) may be disposed above the mask **200** that is configured to generate the UV light **109** such that the UV light **109** is projected through the mask **200**. The mask **200** partially blocks portions on the UV light **109** so that the UV light **109** patterns the resist layer **107** through photolithography. The more UV light **109** that interacts with a portion of the resist layer **107** the more of the resist layer **107** is removed in the photolithography process.

[0018] The mask **200** includes a mask substrate **201** and a mask grating **203**. The mask substrate **201** includes at least one of fused silica, soda-lime glass, or other similar materials. In some embodiments, which may be combined with other embodiments, the mask substrate **201** may have a thickness that is in a range of about 700 micrometers (μm) to about 850 μm, such as about 750 μm to about 800 μm, or such as about 775 μm. The mask grating **203** is disposed on the mask substrate **201**. The mask grating **203** includes grating structures **204**. The grating structures **204** define a gray-tone pattern.

[0019] FIGS. **2**A-**2**B are cross-sectional views of the mask **200** in different orientations according to some embodiments. FIG. **2**A shows the mask **200** in a first orientation **200**A that illustrates the mask grating **203** disposed on a first surface **205** of the mask substrate **201**. A second surface **207** of the mask substrate **201** opposes the first surface **205** and faces the wafer **105**. In FIG. **2**A, the mask grating **203** is shown spaced at a first distance **209** away from the resist layer **107** of the wafer **105**. In some embodiments, which may be combined with other embodiments, the first distance **209** may range from a thickness of the mask **200** to about 8 mm, such as about 800 microns to about 6000 μm, or such as 1000 μm. The first distance **209** includes the thickness of the mask substrate **201** and the distance from second surface **207** of the mask substrate **201** to the resist layer **107**. An edge transition zone is caused by the mask assembly **100** having an opening diameter equal to or smaller than a diameter of the wafer **105** and the distance from the mask **200** to the resist layer **107**. Scattering of UV light **109** at the top surface of mask holder **101** will cause unwanted light exposed beyond the edge of the wafer **105** (FIG. **1**). An exclusion zone in design or optical proximity correction is needed to achieve thickness on target. The opaque layer **103** may be deposited on the top surface of the mask holder **101** to simplify the optical scattering scenario. The width of the edge transition zone depends on the property of the illuminated UV light **109** and the distance between the opaque layer **103** and the surface of the resist layer **107**. Since the edge transition zone may only affect areas close to the edge of the wafer **105**, when the edge transition zone is controlled to be within the Edge-Bead-Removal (EBR) region, the edge transition zone will not affect the active device area. An edge transition zone of less than 200 microns is achievable.

[0020] The grating structures **204** may be defined by a critical dimension **211**, a space width **213**, a pitch **215**, and a thickness **217**. The critical dimension **211** is defined as the width of the grating structures **204**. The space width **213** is defined as the distance between adjacent grating structures **204**. The pitch **215** is defined by a distance between the center of a single grating structure **204** and the center of an adjacent grating structure **204**. The thickness **217** is defined as the distance from the first surface **205** to a top surface **218** of the grating structures **204**. The thickness **217** may be dependent on the material used in the grating structures and generally is in a range from about 30 nanometers (nm) to about 150 nm, such as about 60 nm to about 120 nm, or such as about 80 nm to about 100 nm. In some embodiments, which may be combined with other embodiments, adjusting the amount of UV light **109** passing through the mask **200** is performed by adjusting the critical dimension **211** while keeping the pitch **215** constant or adjusting the pitch **215** while keeping the critical dimension **211** constant. In some embodiments, which may be combined with other embodiments, both the critical dimension **211** and the pitch **215** are adjusted to control the amount of UV light **109** passing through the mask **200**. The grating structures **204** may be oriented in a line and space pattern or a two-dimensional pattern, such as a contact holes and pillar pattern.

[0021] The pitch **215** may vary or remain constant across the mask grating **203** as described above. In some embodiments, which may be combined with other embodiments, the pitch **215** is less than or equal to the exposure wavelength of the UV light **109** at all points across the mask grating **203**. For instance, in some embodiments, which may be combined with other embodiments, the UV light **109** is about 425 nm or less and the pitch **215** is less than or equal to about 425 nm. For example, the pitch **215** is less than or equal to

365 nm when the UV light **109** has a wavelength of 365 nm. The UV light **109** is therefore scattered from a collimated state that the UV light **109** has from a UV light source. In some embodiments, which may be combined with other embodiments, the pitch **215** is equal to the wavelength of the UV light **109** and the UV light **109** is scattered from the collimated state. The mask **200** does not require a diffuser to scatter the UV light **109** since the mask **200** grating has sub-wavelength pitch **215** and the mask pattern will not be resolved due to a diffraction limit.

[0022] The critical dimension **211** of the mask grating **203** affects the transmission rate of the UV light **109** through the mask **200**. The critical dimension **211** may be in a range of about 25 nm to about 25 nm less than the pitch **215**. When the pitch **215** is constant, the critical dimension **211** modulates the transmission rate of UV light **109** through the mask **200**. Lowering the critical dimension **211** increases the transmission rate of UV light **109**, which in turn causes more of the resist layer **107** to be removed during the photolithography process. Conversely, increasing the critical dimension **211** decreases the transmission rate of UV light **109** which in turn causes less of the resist layer **107** to be removed during the photolithography process. In some embodiments, which may be combined with other embodiments, the critical dimension **211** may vary across the mask grating **203** to tune the remaining resist thickness on wafer **105** (FIG. **1**).

[0023] FIG. **2**B shows the mask **200** in a second orientation **200**B. The second orientation **200**B of the mask **200** shows the mask grating **203** disposed on the first surface **205** of the mask substrate **201**; however, in the second orientation **200**B, the first surface **205** of the mask substrate **201** opposes the second surface **207** and faces the wafer **105**. Thus, in FIG. **2**B, the mask grating **203** is spaced at a second distance **219** away from the resist layer **107** of the wafer **105**. The second distance **219** may be in a range from greater than 0 μm to about 6 mm, such as about 20 μm to about 1 mm, or such as about 250 μm.

[0024] FIG. **3** is a flow diagram of a method **300** of forming the mask **200** according to some embodiments. In addition, FIGS. **4**A-**4**D are schematic, cross-sectional views of the mask substrate **201** during the method **300** of forming the mask **200** according to some embodiments.

[0025] As shown in FIGS. **3**, **4**A, and **4**B, at operation **301**, an absorber layer **401** is deposited on the mask substrate **201**. The absorber layer **401** is deposited on the first surface **205** of the mask substrate **201**. In some embodiments, which may be combined with other embodiments, the absorber layer **401** is deposited by physical vapor deposition (PVD), chemical vapor deposition (CVD), atomic layer deposition (ALD) or spin on. In some embodiments, which may be combined with other embodiments, the absorber layer **401** includes at least one of chromium (Cr), silicon (Si), tungsten (W), tungsten carbide (WC),titanium nitride (TiN), nickel (Ni), gold (Au), molybdenum silicide ($MoSi_2$), tantalum (Ta), tantalum nitride (TaN), or ruthenium (Ru). The thickness of the absorber layer **401** may be dependent on the material used in the absorber layer **401**. In some embodiments, which may be combined with other embodiments, the absorber layer **401** has a thickness in a range of about 60 nm to about 100 nm when Cr is used. In some embodiments, which may be combined with other embodiments, the absorber layer **401** forms the mask grating **203**. In other embodiments, which may be combined with other embodiments, the mask grating **203** includes the absorber layer **401** and a protective layer **403**. Thus, in some embodiments, which may be combined with other embodiments, the protective layer **403** may be deposited on the absorber layer **401**. The protective layer **403** may be deposited by PVD, chemical vapor deposition (CVD), or atomic layer deposition (ALD). In some embodiments, which may be combined with other embodiments, the protective layer **403** includes at least one of silicon oxide (SiO, SiO_2), silicon nitride (SiN), titanium nitride (TiN), or a similar material. The protective layer **403** may have a thickness in a range of about 5 nm to about 50 nm.

[0026] As shown in FIGS. **3** and **4**C, at operation **303**, the plurality of grating structures **204** are formed in the absorber layer **401** and protective layer **403**. The grating structures **204** may be etched in the absorber layer **401** and protective layer **403**. The grating structures **204** may be patterned using litho-etch process. In some embodiments, which may be combined with other embodiments, each of the grating structures **204** have an absorber section and a protective section. The protective layer **403** may improve the process window leading to a higher yield. Space widths **213** may be formed by the etching. The etching exposes sections of the first surface **205** of the mask substrate **201**. The grating structures may also have the critical dimensions **211**. The critical dimension **211** may be in a range of about 25 nm to about 25 nm less than the pitch **215**. The pitch **215** may vary across the mask grating **203** or may be constant. In addition, the pitch **215** may be less than or equal to the wavelength of the light to be used with the mask **200**.

[0027] The mask grating **203** may be formed with a designed mask with a variable mask critical dimension based on the design target. The patterns can also be generated by image stitching. Image stitching uses multiple or a single pattern on the scanner/stepper mask and images the pattern at different locations on the absorber layer **401** to form a larger pattern in the absorber layer **401**. Each location can use the same or different exposure conditions (such as dose and focus). Therefore, the pattern can be varying and larger than the design on the scanner/stepper mask. Image stitching is a useful tool to reduce the cost of scanner/stepper masks used to make the mask **200** when die size is large enough to require multiple scanner/stepper masks. Since the scanner/stepper masks are smaller than the mask substrate **201**, image stitching increases the size of the pattern of the mask grating **203**.

[0028] The pitch **215** and the critical dimension **211** may have better pattern dimension control than a mask written using the same mask writer tool due to imaging reduction by the scanner/stepper and a mature semiconductor process which transfers and defines the pattern of the grating structures **204** on the absorber layer **401**. The reduction ratio can be different depending on what kind of lithography tool used.

[0029] A mask density transition boundary on the grating structures **204** may also generate a transition zone on the wafer **105** during the gray tone lithography due to diffraction. This transition zone means the thickness will not change from one design to another design immediately. Since the transition zone is caused by diffraction and interference, the larger the distance between the grating structures **204** and the surface of the resist layer **107**, the larger the transition zone. This relationship with the transition zone is true for both diffuser-less masks and masks with a diffuser

for gray tone lithography. However, sub-wavelength pitch in the mask **200** eliminates the need for the diffuser. The mask **200** can use collimated light directly as illumination and the proximity gap between mask **200** and wafer **105** may be small since the mask pattern will not be resolved due to the diffraction limit. Typically, the transition zone may be less than 30 μm when the proximity gap for exposure is set to a few hundred μm. This transition zone is far less than traditional masks with diffuser, which have typically have density transition zones of 50 μm or larger.

[0030] As shown in FIGS. **3** and **4**D, at operation **305**, the mask **200** is positioned in the mask assembly **100**. The mask **200** is formed from a substrate **201**. The mask **200** is put in the mask holder **101** to be used in a photolithography device. In some embodiments, which may be combined with other embodiments, standard masks are square shaped. As described above, in some embodiments, which may be combined with other embodiments, the mask **200** is formed on a wafer with a diameter of about 290 mm to about 310 mm, such as about 299.5 mm to about 300.5 mm. The mask **200** is therefore put in a mask assembly **100** to become the standard size. In some embodiments, which may be combined with other embodiments, the mask assembly **100** is square shaped and has a length and width of 14 inches. The mask **200** is properly aligned in the mask assembly **100**. In one embodiment, which may be combined with other embodiments, a second surface **417** of the mask **200** is flush to a second surface **419** of the mask holder **101**. In this configuration, the mask **200** can be used without any process change on the lithography tool. When the mask **200** is protruded or recessed from the mask holder **101**, the gray tone lithography process may be performed, but may introduce risk for the lithography tool and the operation procedure or recipe may need to be adjusted. The mask **200** is aligned in the mask assembly **100** using aligning objects. The aligning objects include a cover glass **411** and a flat surface **413** with springs **415**. FIG. **4**D shows the cover glass **411** placed on top of the mask grating **203** and the springs **415** are positioned on the second surface **207** of the mask substrate **201**. The springs **415** are connected to the flat surface **413**. The flat surface **413** are also connected to the opaque layer **103**. The aligning objects ensure the mask **200** is properly positioned in the mask assembly **100**.

[0031] At operation **307**, the mask assembly **100** is removed from the aligning objects. The mask assembly **100** may now be inserted into a photolithography chamber. FIG. **1** shows the mask assembly **100** ready to be used in a photolithography process.

[0032] As explained above and reiterated below, the present disclosure includes, without limitation, the following example implementations.

[0033] Clause 1: A mask, comprising: a substrate; and a gray-tone pattern grating disposed on the substrate, the gray-tone pattern grating defined by a plurality of structures disposed on the substrate, the structures comprising: an absorber layer disposed on the substrate, wherein the gray-tone pattern grating has a pitch that is less than or equal to an exposure wavelength of light to pass through the structures, the pitch defined as a distance between centers of adjacent structures of the plurality of structures.

[0034] Clause 2: The mask of any of the clauses, wherein the structures have a critical dimension defined as a width of the structures, the critical dimension in a range from about 25 nanometers (nm) to about 25 nm less than the pitch.

[0035] Clause 3: The mask of any of the clauses, wherein the structures have a thickness defined as a distance from a first surface of the substrate to a top surface of the structures, the thickness in a range from about 30 nm to about 150 nm.

[0036] Clause 4: The mask of any of the clauses, wherein the structures are oriented in a two-dimensional pattern that comprises a contact holes and pillar pattern.

[0037] Clause 5: The mask of any of the clauses, wherein the structures are oriented in a line and space pattern.

[0038] Clause 6: The mask of any of the clauses, wherein the substrate has a thickness in a range of about 750 micrometer (μm) to about 800 μm.

[0039] Clause 7: The mask of any of the clauses, wherein the structures further comprise a protective layer disposed on the absorber layer, the protective layer comprising silicon oxide, or silicon nitride.

[0040] Clause 8: The mask of any of the clauses, wherein the absorber layer comprises chromium, titanium nitride, nickel, gold, molybdenum silicide, tantalum, tantalum nitride, or ruthenium.

[0041] Clause 9: A mask assembly for gray-tone lithography, comprising: a mask, comprising: a substrate; and a gray-tone pattern grating with a plurality of grating structures comprising an absorber layer disposed on the substrate; a mask holder operable to secure the mask, the mask being inserted in the mask holder; a UV light source disposed above the mask operable to project UV light through the mask, wherein the gray-tone pattern grating has a pitch that is less than or equal to a wavelength of UV light projected by the UV light source, the pitch defined as a distance between centers of adjacent grating structures of the plurality of grating structures; and a substrate support positioned below the mask.

[0042] Clause 10: The mask assembly of any of the clauses, wherein the grating structures have a critical dimension defined as a width of the grating structures, wherein the critical dimension is in a range from about 25 nanometers (nm) to about 25 nm less than the pitch.

[0043] Clause 11: The mask assembly of any of the clauses, wherein the substrate has a thickness in a range of 750 micrometers (μm) to 800 μm.

[0044] Clause 12: The mask assembly of any of the clauses, wherein the mask has a diameter in a range of about 299.5 millimeters (mm) to about 300.5 mm.

[0045] Clause 13: The mask assembly of any of the clauses, wherein the gray-tone pattern grating of the mask is facing away from the substrate support and the mask is positioned in the mask holder.

[0046] Clause 14: The mask assembly of any of the clauses, wherein the gray-tone pattern grating of the mask is facing the substrate support and the mask is positioned in the mask holder.

[0047] Clause 15: A method of fabricating a mask, comprising: depositing an absorber layer on a first surface of a substrate; and forming a plurality of structures in the absorber layer by removing sections of the absorber layer, the structures forming a grating having a pitch that is less than or equal to an exposure wavelength of light to pass through the structures, the pitch defined as a distance between centers of adjacent grating structures of the plurality of structures.

[0048] Clause 16: The method of any of the clauses, further comprising: positioning the mask in a mask holder; and positioning the mask holder above a wafer for a photolithography process.

[0049] Clause 17: The method of any of the clauses, further comprising: passing light through the mask to perform a photolithography process on the wafer.

[0050] Clause 18: The method of any of the clauses, wherein a scanner/stepper mask imaged at different locations on the substrate forms the plurality of structures.

[0051] Clause 19: The method of any of the clauses, wherein the structures have a thickness in a range of about 30 nanometers (nm) to about 150 nm, and a critical dimension of in a range of about 25 nm to about 25 nm less than the pitch, wherein the critical dimension is defined as a width of the structures.

[0052] Clause 20: The method of any of the clauses, wherein a modulation of the thickness, the critical dimension, and the pitch of the structures in the grating is configured to affect a transmission rate of UV light through the mask.

[0053] In summation, the present disclosure generally relates to mask designs and fabrication for gray-tone lithography. More specifically, embodiments described herein relate to masks designed with a specific pitch to avoid needing diffusers. The mask is made by normal semiconductor process on a wafer such as film deposition, lithography or other similar processes. Benefits of the mask include a maximum mask size fit up to 300 mm in some embodiments. The mask has better pattern density control allowing a four times reduction in size by a scanner and lower transition zones for gray-tone process. The mask has a lower cost due to not requiring a high-end E-Beam writer in fabrication of the large format mask. The mask has design freedom by adjusting scanner recipe and is easy to clean and perform metrology. The wafer mask also allows for OPC to be performed.

[0054] While the foregoing is directed to embodiments of the present disclosure, other and further embodiments 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. A mask, comprising:

a substrate; and

a gray-tone pattern grating disposed on the substrate, the gray-tone pattern grating defined by a plurality of structures disposed on the substrate, the structures comprising:

an absorber layer disposed on the substrate, wherein the gray-tone pattern grating has a pitch that is less than or equal to an exposure wavelength of light to pass through the structures, the pitch defined as a distance between centers of adjacent structures of the plurality of structures.

2. The mask of claim **1**, wherein the structures have a critical dimension defined as a width of the structures, the critical dimension in a range from about 25 nanometers (nm) to about 25 nm less than the pitch.

3. The mask of claim **2**, wherein the structures have a thickness defined as a distance from a first surface of the substrate to a top surface of the structures, the thickness in a range from about 30 nm to about 150 nm.

4. The mask of claim **3**, wherein the structures are oriented in a two-dimensional pattern that comprises a contact holes and pillar pattern.

5. The mask of claim **3**, wherein the structures are oriented in a line and space pattern.

6. The mask of claim **1**, wherein the substrate has a thickness in a range of about 750 micrometer (μm) to about 800 μm.

7. The mask of claim **1**, wherein the structures further comprise a protective layer disposed on the absorber layer, the protective layer comprising silicon oxide, or silicon nitride.

8. The mask of claim **1**, wherein the absorber layer comprises chromium, titanium nitride, nickel, gold, molybdenum silicide, tantalum, tantalum nitride, or ruthenium.

9. A mask assembly for gray-tone lithography, comprising:

a mask, comprising:

a substrate; and

a gray-tone pattern grating with a plurality of grating structures comprising an absorber layer disposed on the substrate;

a mask holder operable to secure the mask, the mask being inserted in the mask holder;

a UV light source disposed above the mask operable to project UV light through the mask, wherein the gray-tone pattern grating has a pitch that is less than or equal to a wavelength of UV light projected by the UV light source, the pitch defined as a distance between centers of adjacent grating structures of the plurality of grating structures; and

a substrate support positioned below the mask.

10. The mask assembly of claim **9**, wherein the grating structures have a critical dimension defined as a width of the grating structures, wherein the critical dimension is in a range from about 25 nanometers (nm) to about 25 nm less than the pitch.

11. The mask assembly of claim **9**, wherein the substrate has a thickness in a range of 750 micrometers (μm) to 800 μm.

12. The mask assembly of claim **9**, wherein the mask has a diameter in a range of about 299.5 millimeters (mm) to about 300.5 mm.

13. The mask assembly of claim **12**, wherein the gray-tone pattern grating of the mask is facing away from the substrate support and the mask is positioned in the mask holder.

14. The mask assembly of claim **12**, wherein the gray-tone pattern grating of the mask is facing the substrate support and the mask is positioned in the mask holder.

15. A method of fabricating a mask, comprising:

depositing an absorber layer on a first surface of a substrate; and

forming a plurality of structures in the absorber layer by removing sections of the absorber layer, the structures forming a grating having a pitch that is less than or equal to an exposure wavelength of light to pass through the structures, the pitch defined as a distance between centers of adjacent grating structures of the plurality of structures.

16. The method of claim **15**, further comprising:

positioning the mask in a mask holder; and

positioning the mask holder above a wafer for a photolithography process.

17. The method of claim **16**, further comprising:

passing light through the mask to perform a photolithography process on the wafer.

18. The method of claim **15**, wherein a scanner/stepper mask imaged at different locations on the substrate forms the plurality of structures.

19. The method of claim **15**, wherein the structures have a thickness in a range of about 30 nanometers (nm) to about 150 nm, and a critical dimension of in a range of about 25 nm to about 25 nm less than the pitch, wherein the critical dimension is defined as a width of the structures.

20. The method of claim **19**, wherein a modulation of the thickness, the critical dimension, and the pitch of the structures in the grating is configured to affect a transmission rate of UV light through the mask.

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