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(54) **METROLOGY MEASUREMENTS ON SMALL TARGETS WITH CONTROL OF ZERO-ORDER SIDE LOBES**

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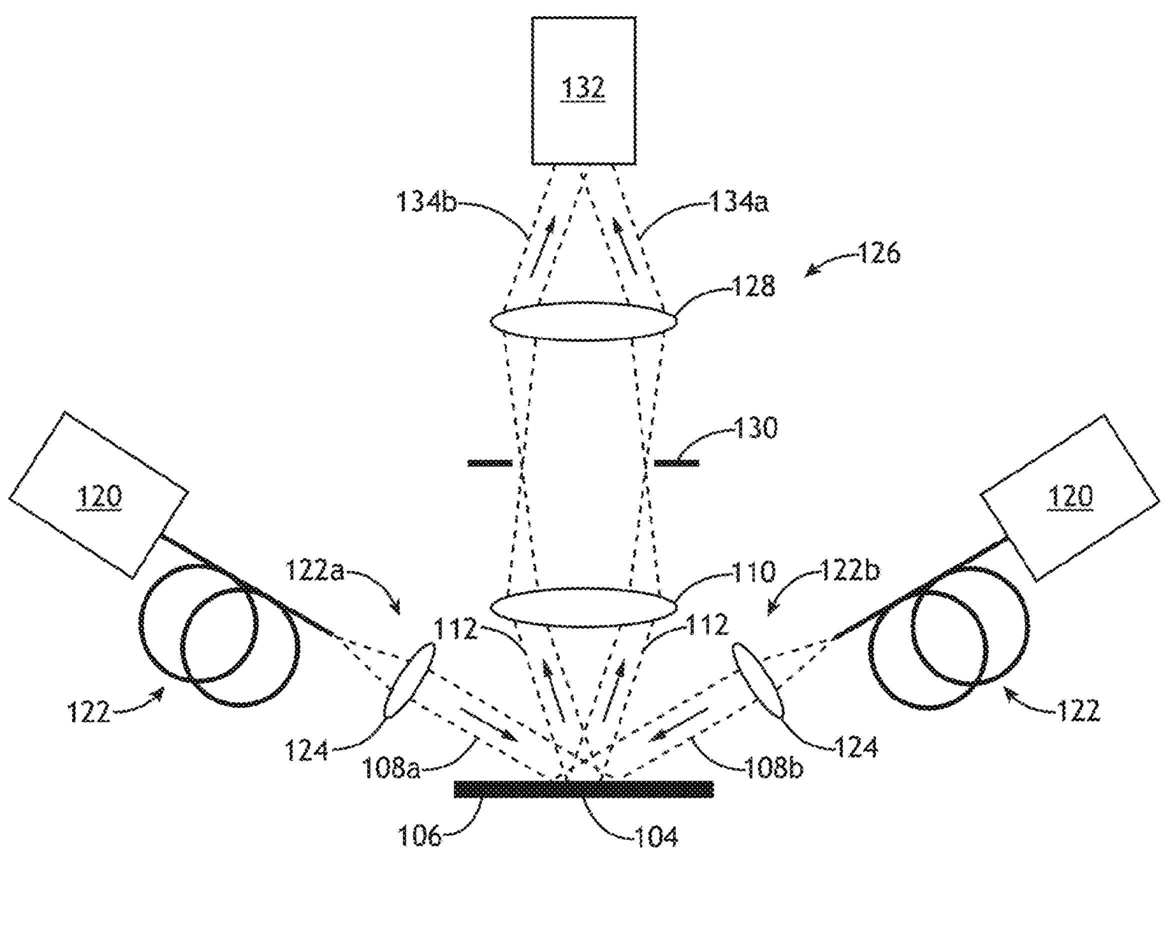
(57) **ABSTRACT**

An optical metrology system may include illumination optics to direct pairs of mutually-coherent illumination beams to an optical metrology target, where the optical metrology target includes sets of periodic features having features with periodicity along different measurement directions. A pair of mutually-coherent illumination beams has opposing azimuth incidence angles and a common altitude incidence angle, where the azimuth incidence angles are rotated with respect to the measurement directions. The system may further generate dark-field images of the optical metrology target, where an image of a periodic structures is formed as a sinusoidal interference pattern generated by interference of a single non-zero diffraction order of light from each of the illumination beams within a pair of mutually-coherent illumination beams. A controller may generate optical metrology measurements along the measurement directions based on the images. The system may mitigate an impact of zero-order side lobes through blocking or image filtering.

102



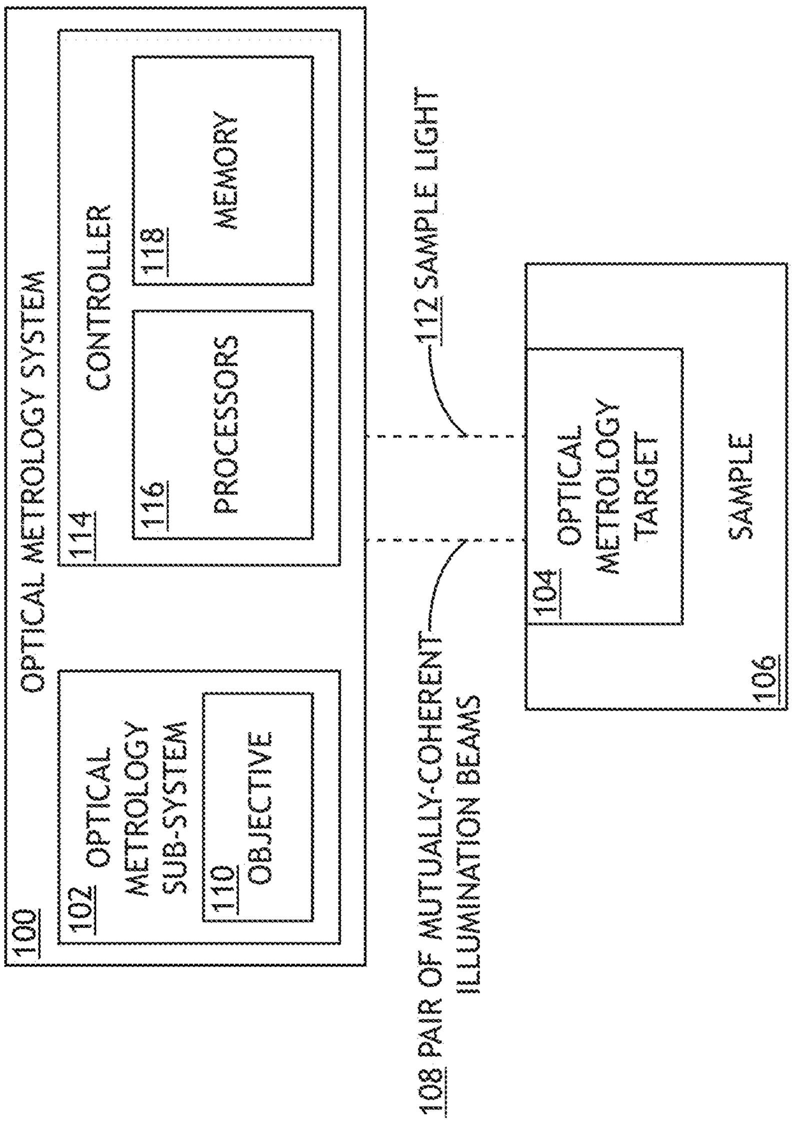
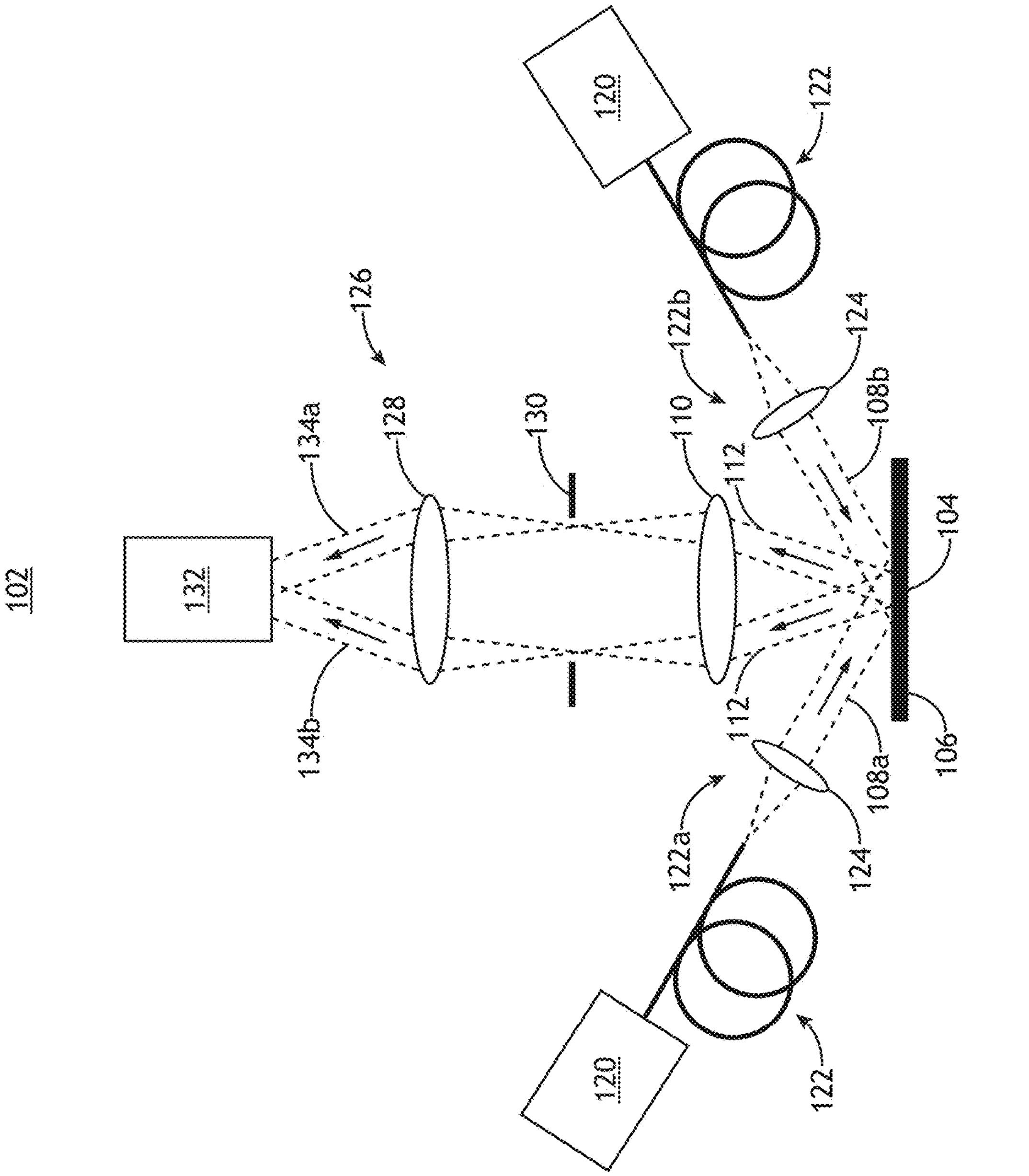

100
OPTICAL METROLOGY SYSTEM
102 OPTICAL METROLOGY SUB-SYSTEM
110 OBJECTIVE
114 CONTROLLER
116 PROCESSORS
118 MEMORY
104 OPTICAL METROLOGY TARGET
106 SAMPLE
108 PAIR OF MUTUALLY-COHERENT ILLUMINATION BEAMS
112 SAMPLE LIGHT

FIG. 1A


102
132
134a
134b
128
126
130
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122b
124
108b
104
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108a
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122a
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122
120
122

FIG. 1B

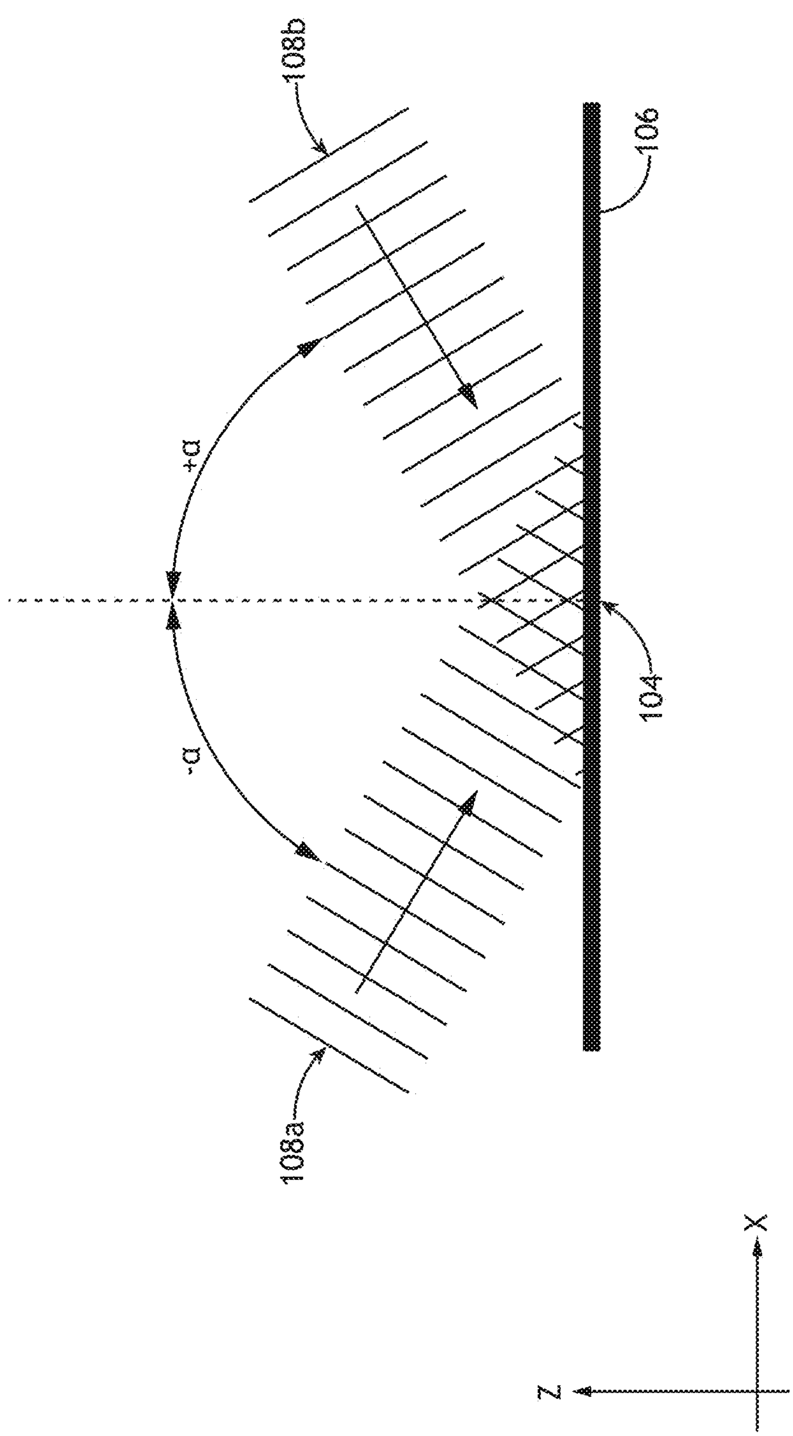


FIG. 2

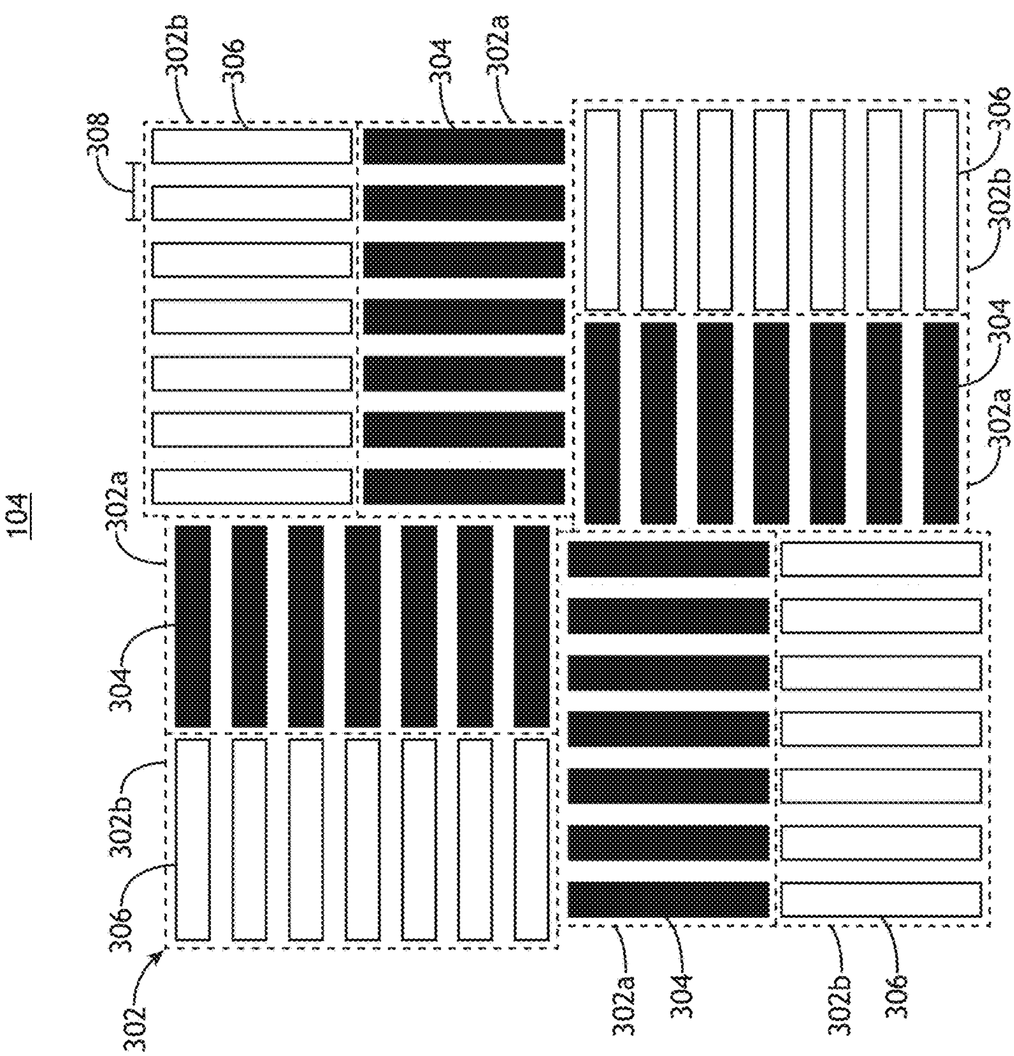

104
308
302b
306
304
302a
302a
304
302b
306
302
302a
304
302b
306
306
302b
304
302a

FIG. 3

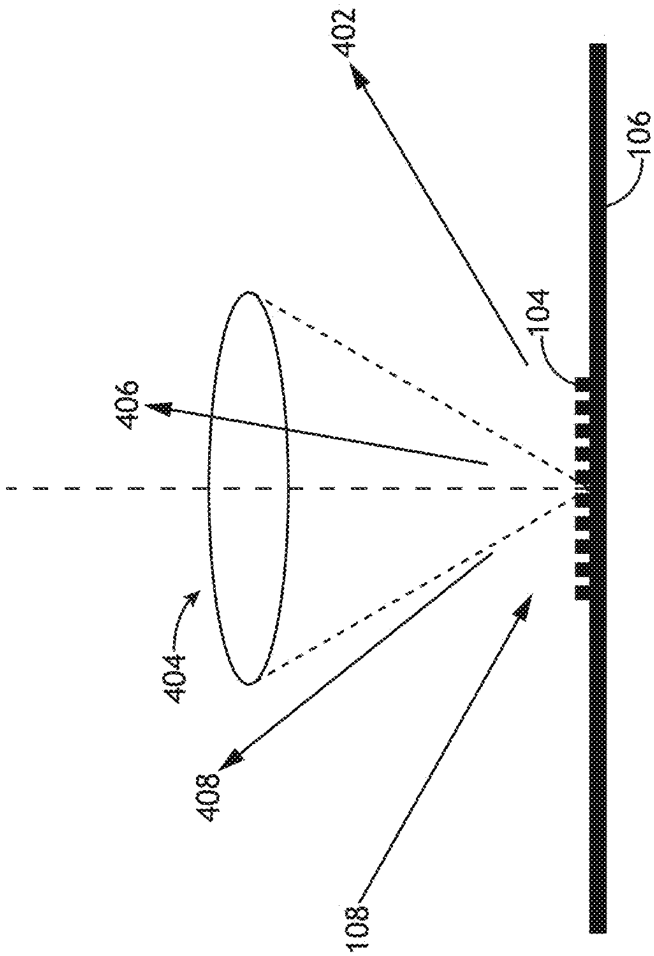
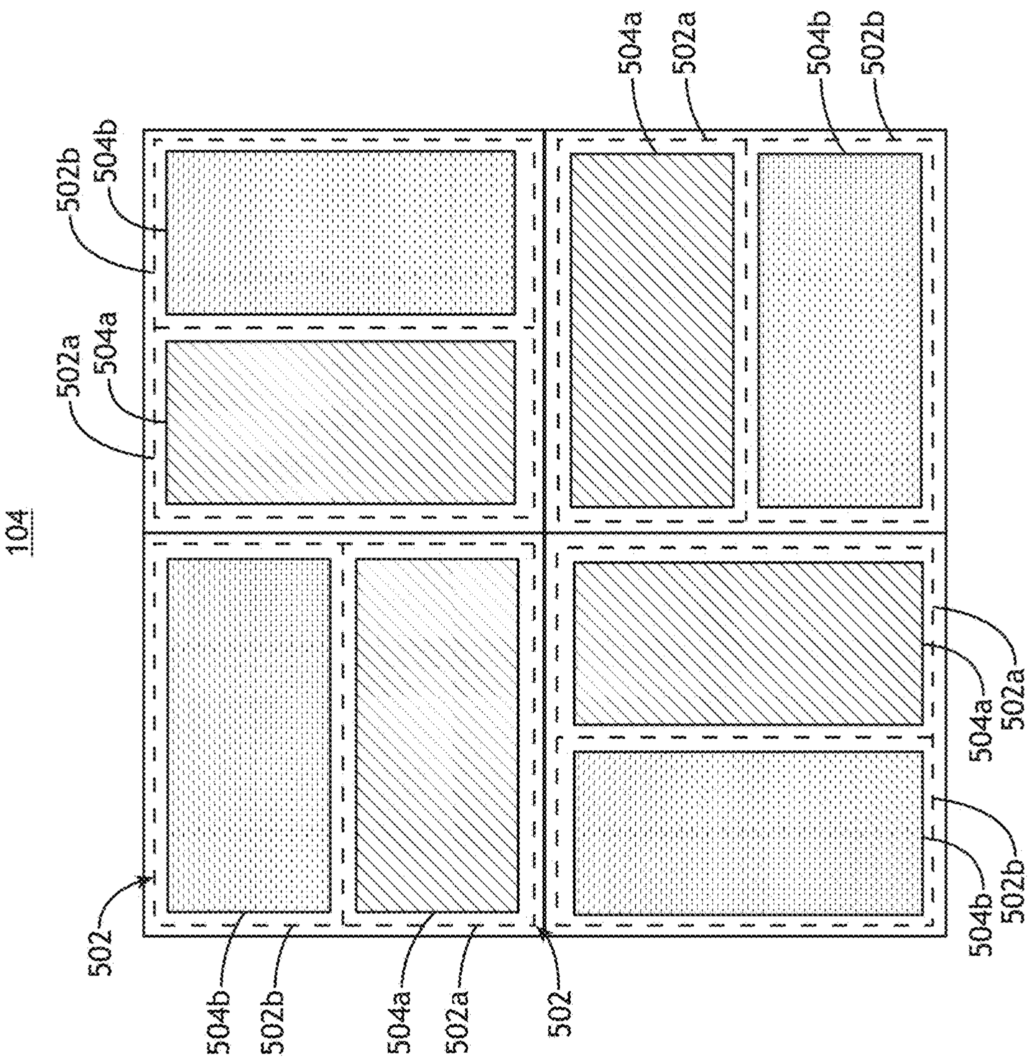


FIG. 4


104
502b
504b
502a
504a
504a
502a
504b
502b
502
504b
502b
504a
502a
502
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502a
504b
502b

FIG.5A

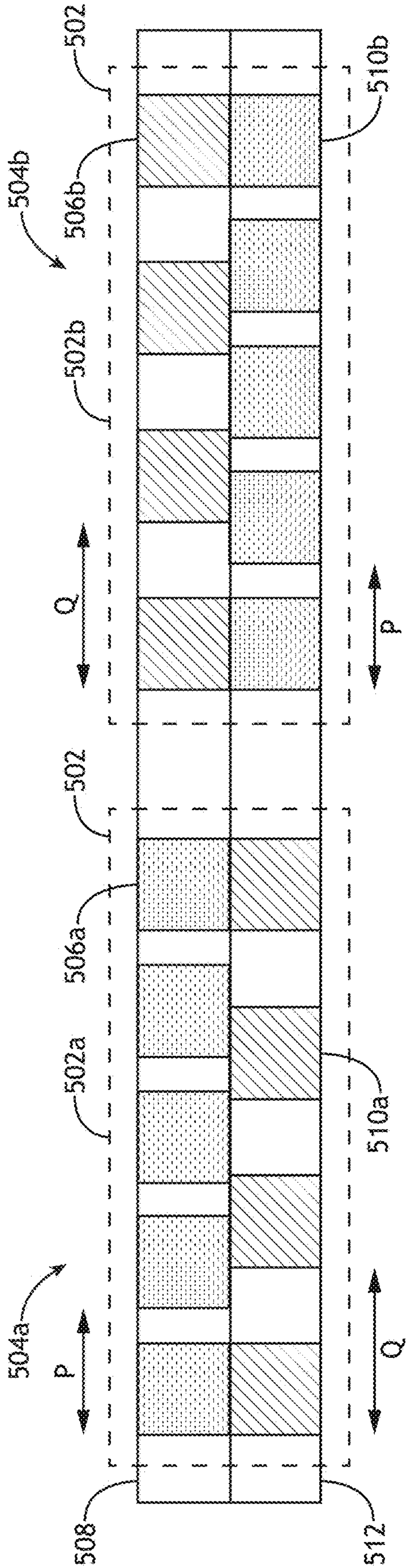


FIG. 5B

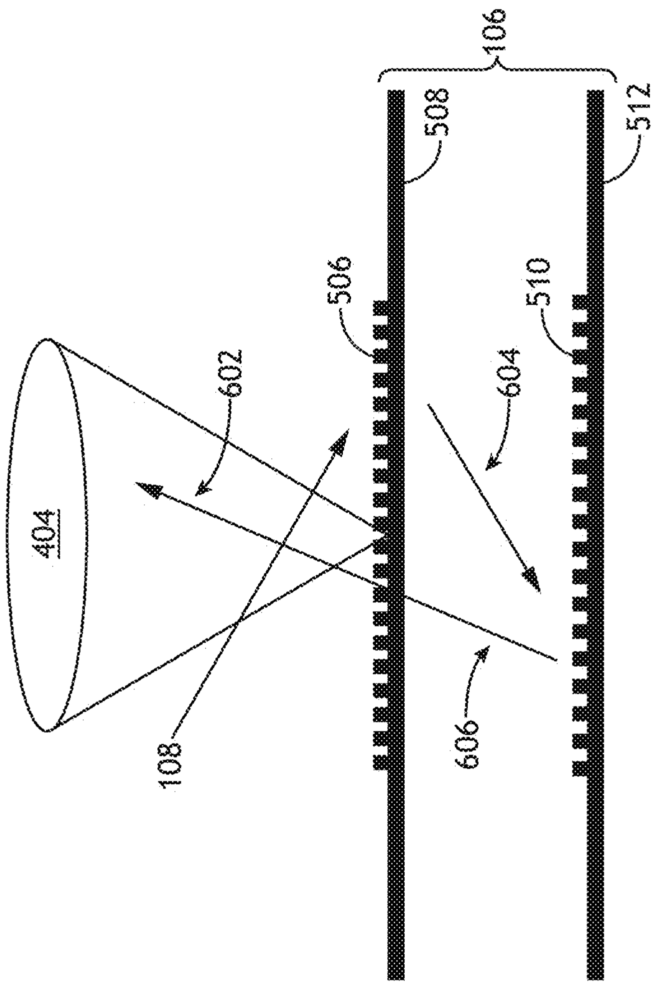
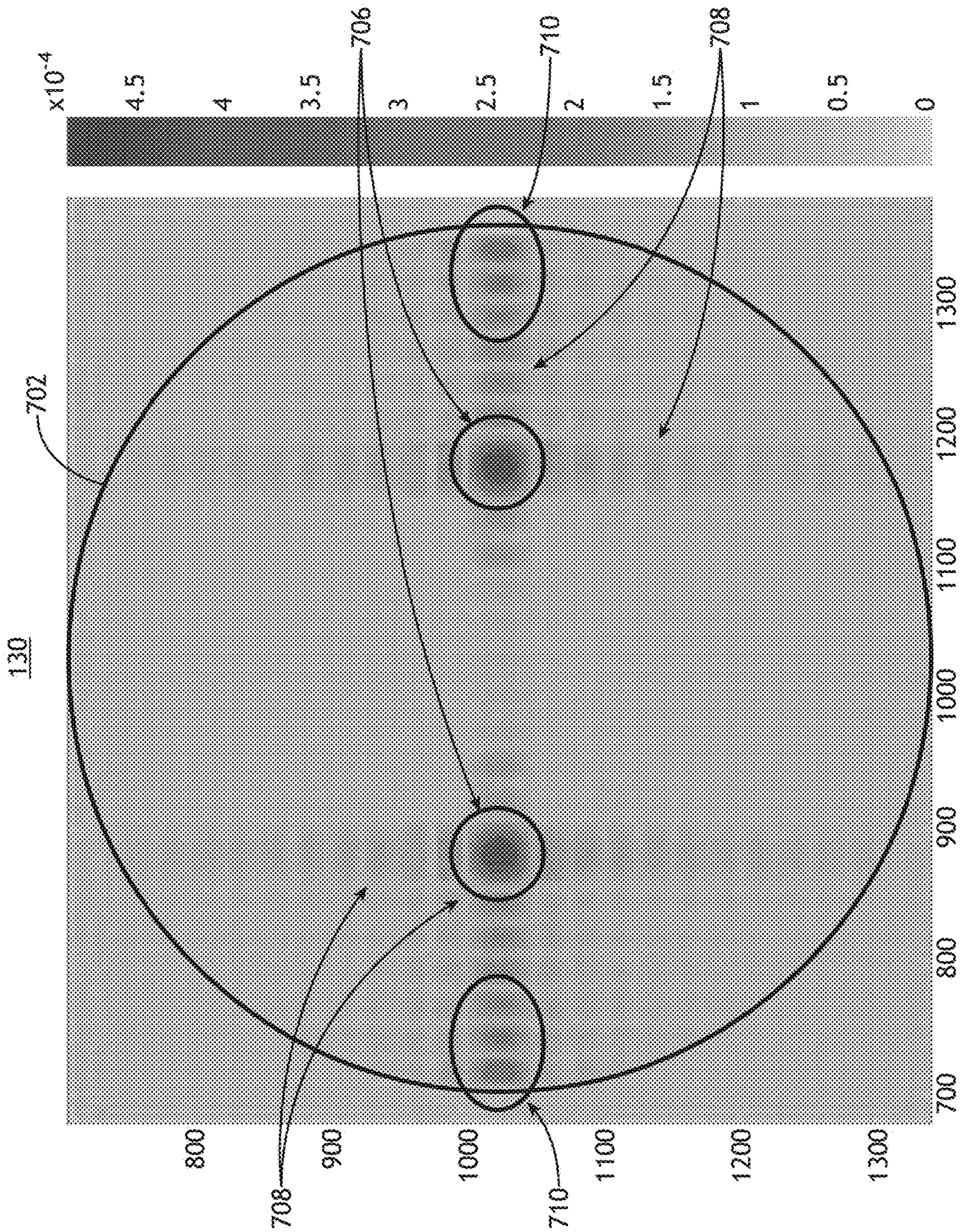


FIG. 6


130
702
706
710
708
x10^-4
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
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800
900
1000
1100
1200
1300
800
900
1000
1100
1200
1300
708
710

FIG. 7A

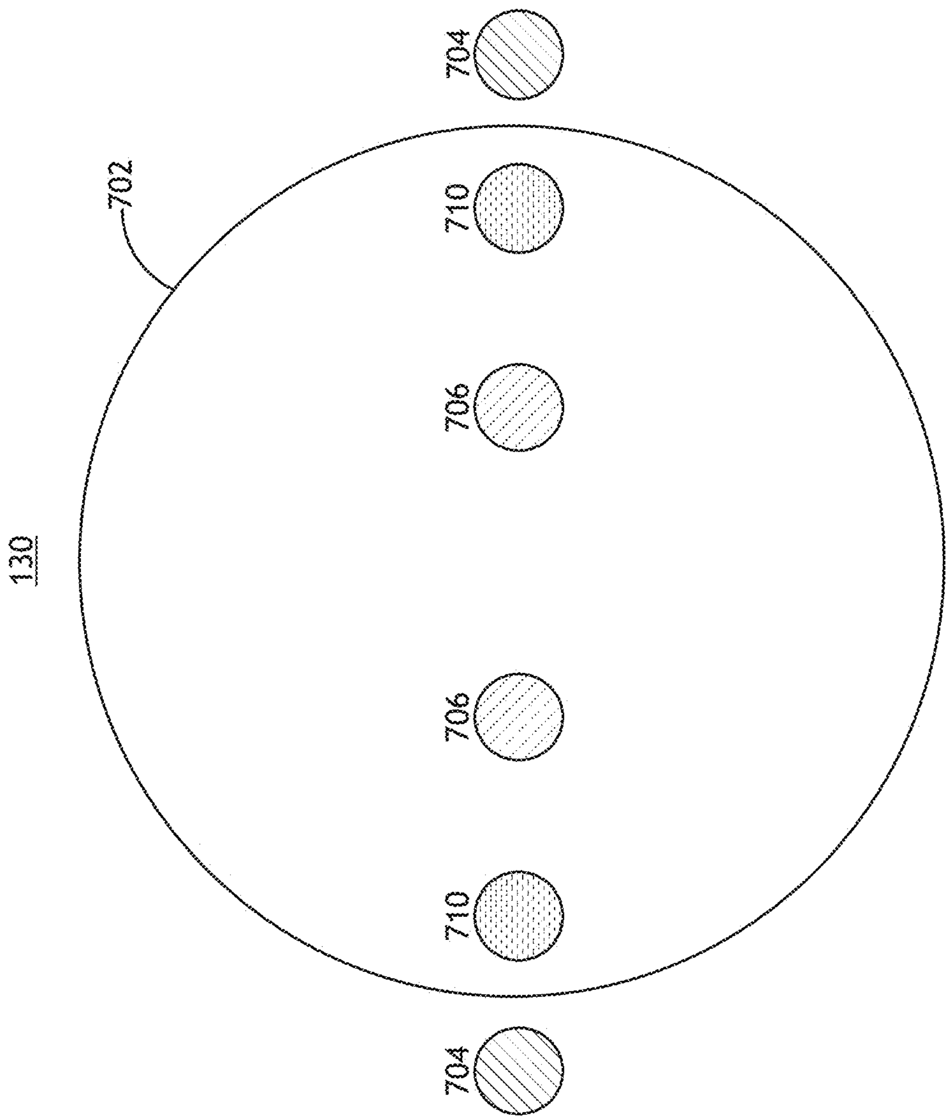

FIG.7B

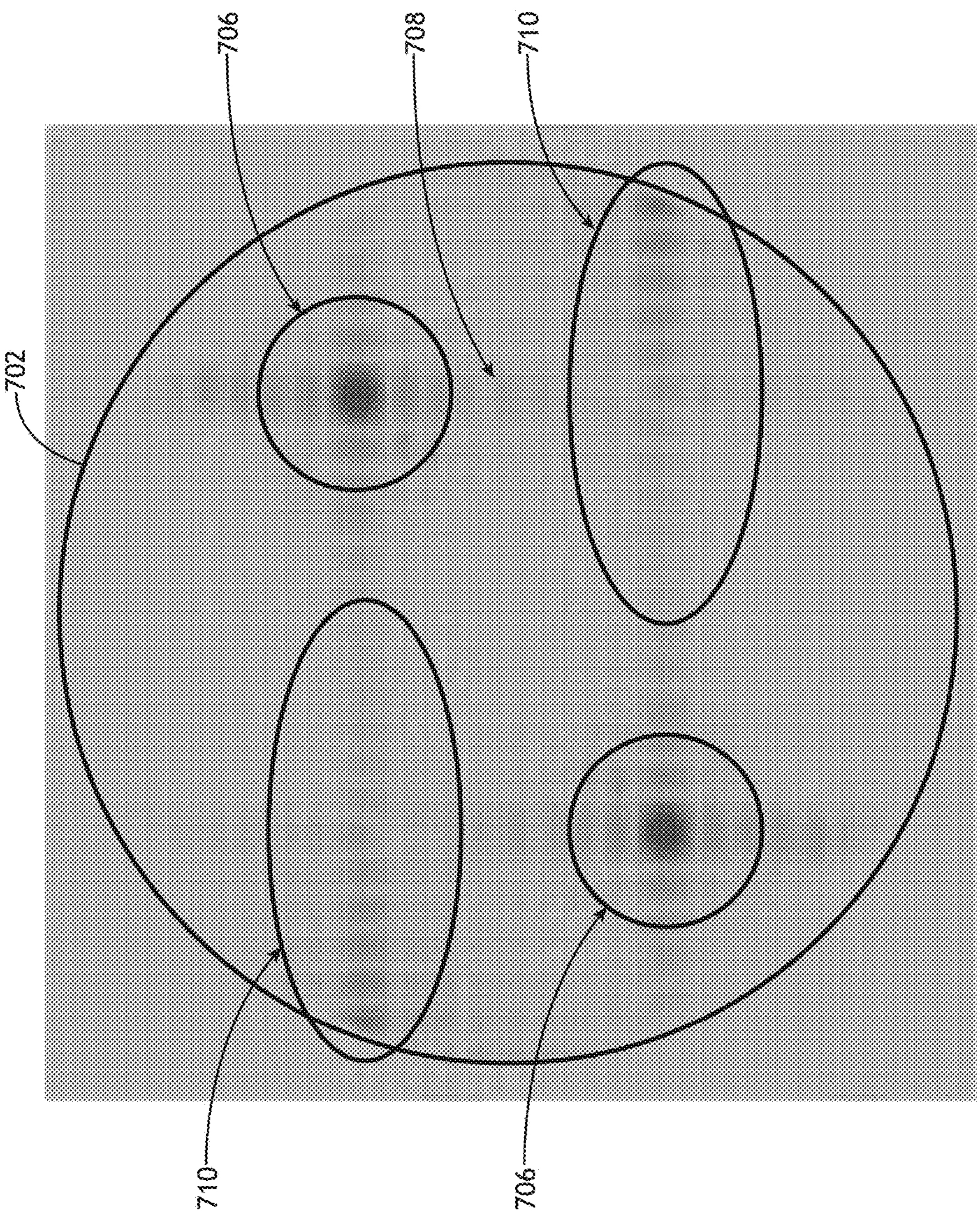

FIG.8A

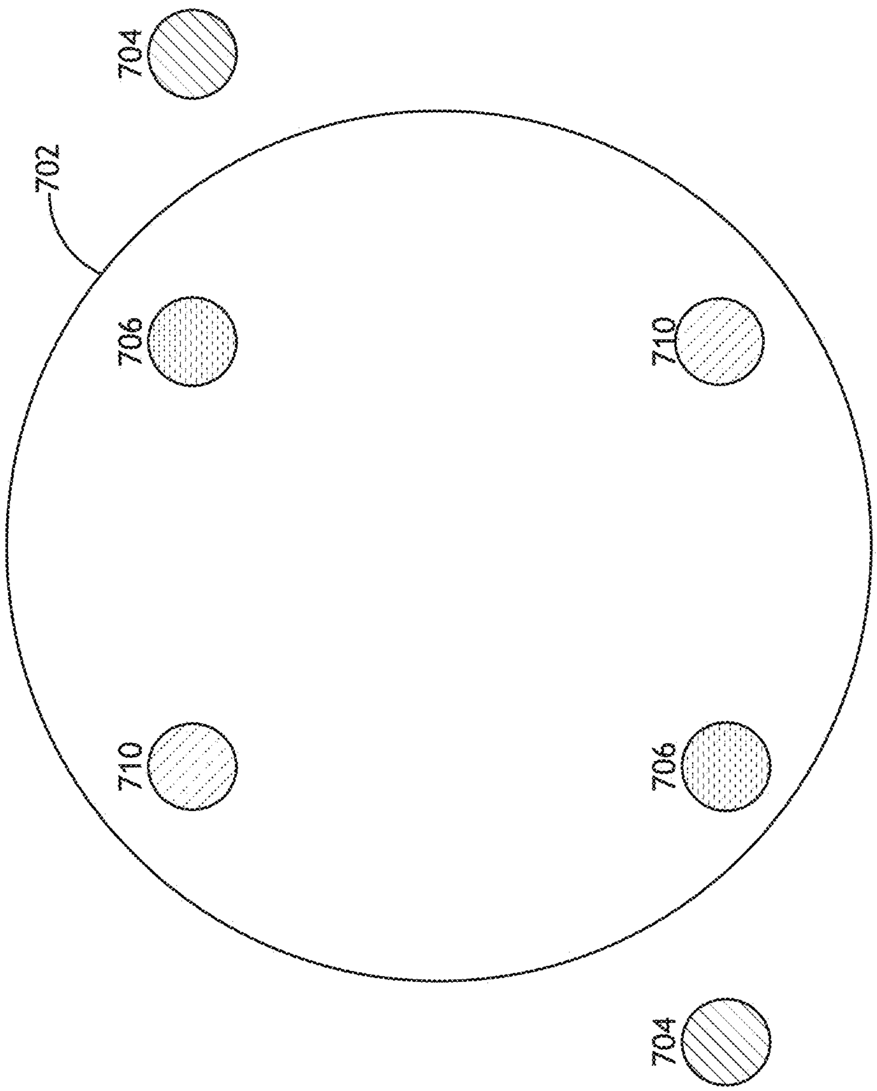

FIG.8B

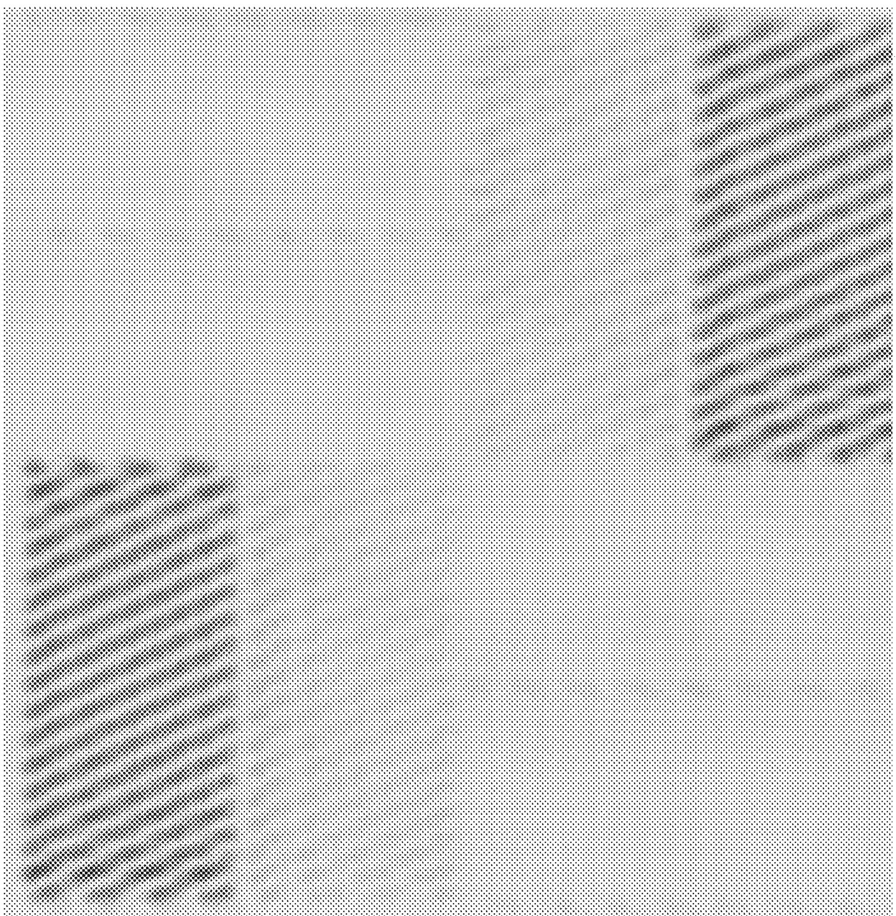

FIG.8C

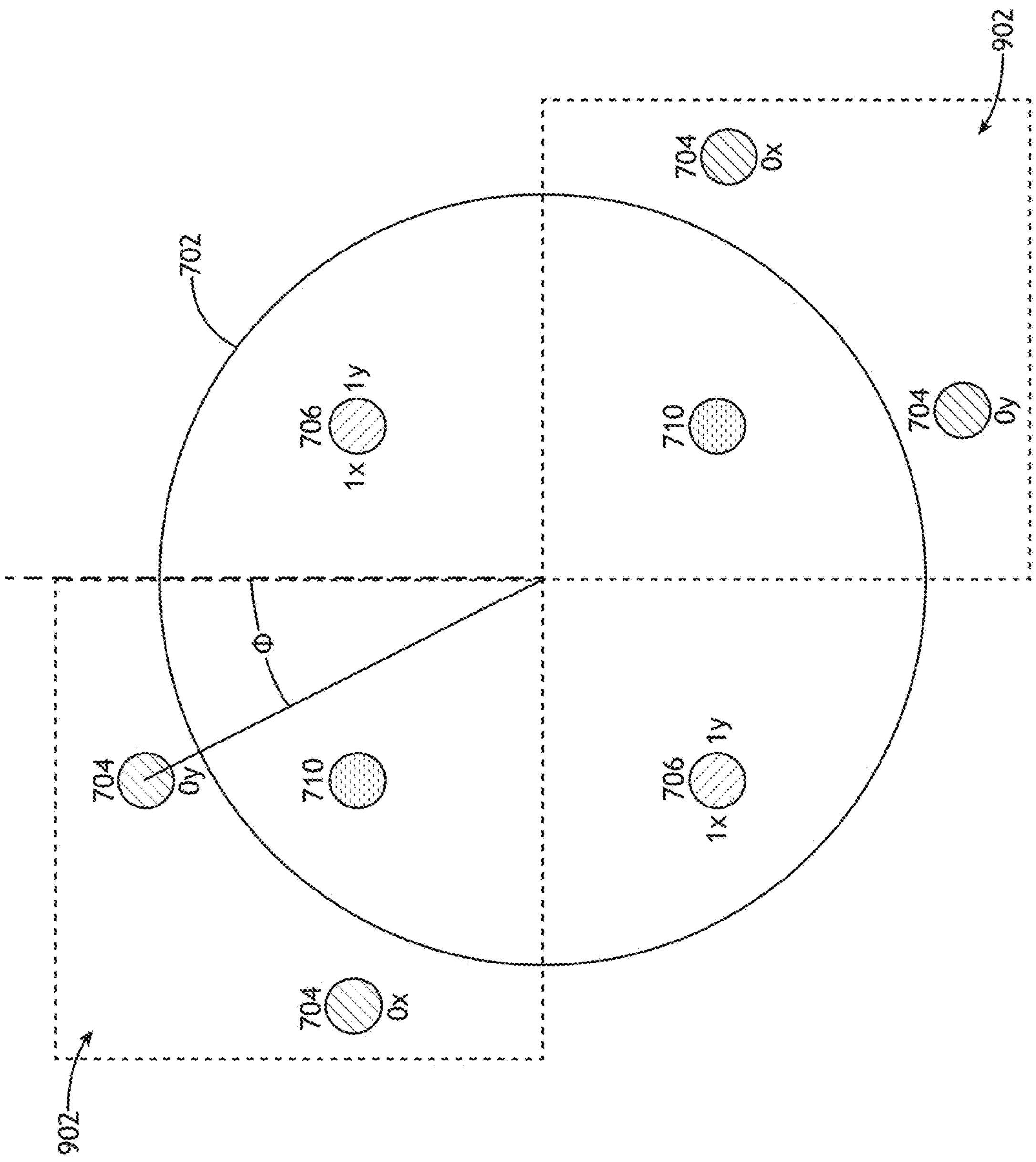
902
704
0x
702
706
1x
1y
710
704
0y
Φ
704
0y
710
706
1x
1y
704
0x
902

FIG.9

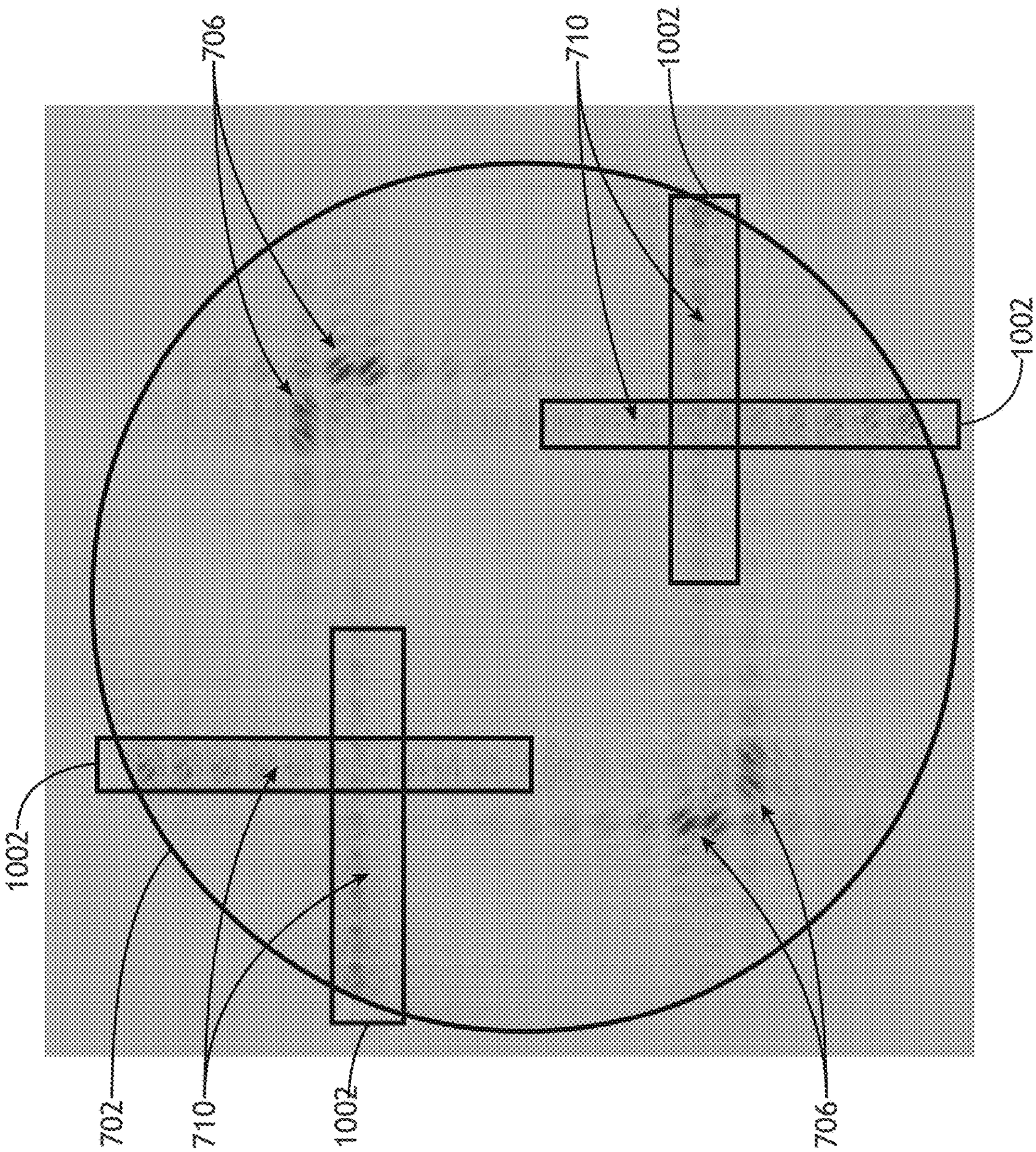

FIG. 10

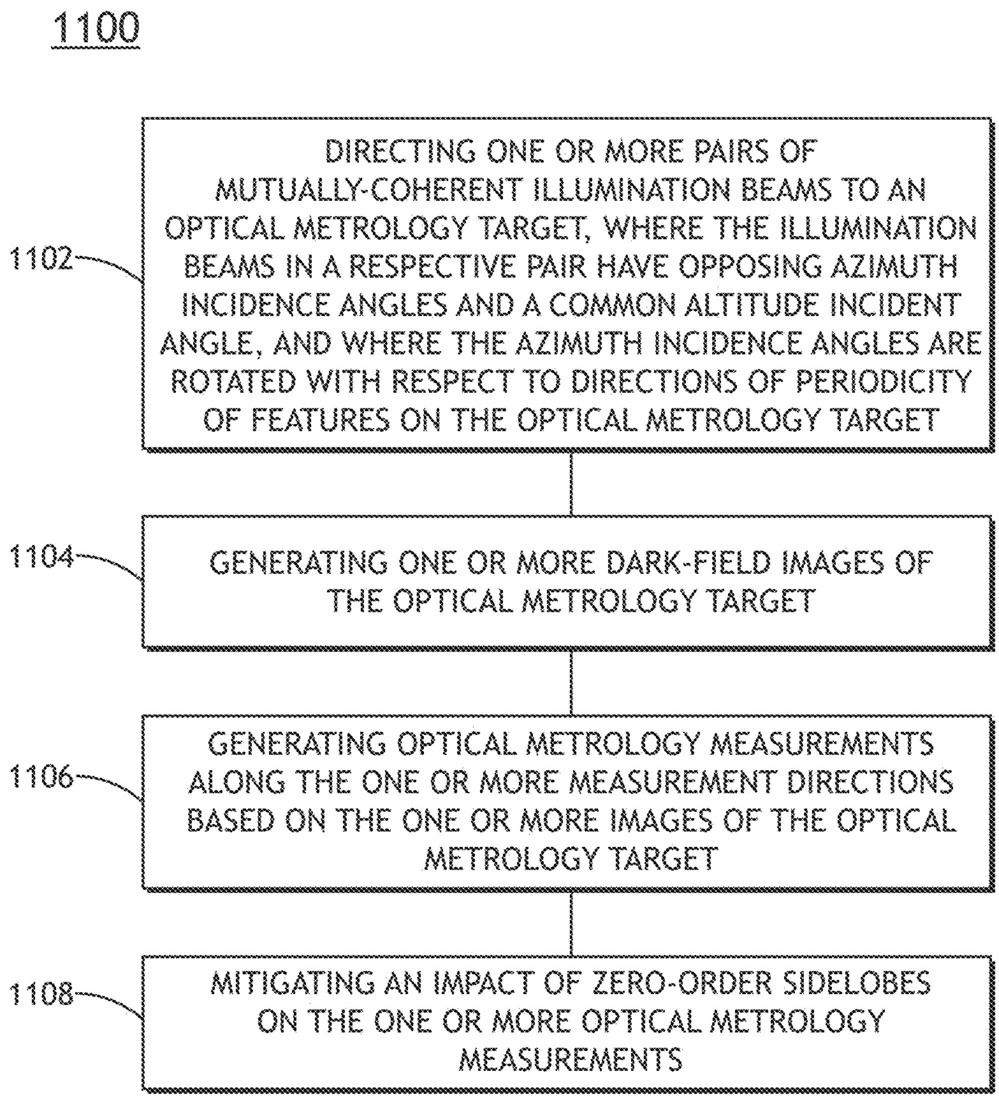
1100
1102
DIRECTING ONE OR MORE PAIRS OF MUTUALLY-COHERENT ILLUMINATION BEAMS TO AN OPTICAL METROLOGY TARGET, WHERE THE ILLUMINATION BEAMS IN A RESPECTIVE PAIR HAVE OPPOSING AZIMUTH INCIDENCE ANGLES AND A COMMON ALTITUDE INCIDENT ANGLE, AND WHERE THE AZIMUTH INCIDENCE ANGLES ARE ROTATED WITH RESPECT TO DIRECTIONS OF PERIODICITY OF FEATURES ON THE OPTICAL METROLOGY TARGET
1104
GENERATING ONE OR MORE DARK-FIELD IMAGES OF THE OPTICAL METROLOGY TARGET
1106
GENERATING OPTICAL METROLOGY MEASUREMENTS ALONG THE ONE OR MORE MEASUREMENT DIRECTIONS BASED ON THE ONE OR MORE IMAGES OF THE OPTICAL METROLOGY TARGET
1108
MITIGATING AN IMPACT OF ZERO-ORDER SIDELOBES ON THE ONE OR MORE OPTICAL METROLOGY MEASUREMENTS

FIG. 11

METROLOGY MEASUREMENTS ON SMALL TARGETS WITH CONTROL OF ZERO-ORDER SIDE LOBES

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims the benefit under 35 U.S.C. § 119 (e) of U.S. Provisional Application Ser. No. 63/553,137, filed Feb. 14, 2024, entitled OVERLAY MEASUREMENT ON SMALL TARGETS, naming Vladimir Levinskim Nireekshan Reddy, Andrew Hill, David Koprivica, Oren Lahav, Daria Negri, and Yonatan Vaknin as inventors, which is incorporated herein by reference in the entirety.

TECHNICAL FIELD

[0002] The present disclosure relates generally to optical metrology and, more particularly, to dark-field imaging optical metrology with mutually-coherent oblique illumination and control of zero-order side lobes.

BACKGROUND

[0003] It is generally desirable to minimize the size of an optical metrology targets (e.g., overlay metrology targets, scanner acquisition targets, or the like) in order to maximize the area on a sample available for creating devices. In the case of a target design incorporating periodic features, reducing the optical metrology target size generally requires reducing the pitch of the periodic features, minimizing interactions between neighboring target cells, and/or minimizing the influence of features in the periphery of the target. However, the presence of zero-order side lobes (e.g., side lobes associated with zero-order diffraction) may negatively impact an optical metrology measurement, particularly as the optical metrology target size is reduced. Accordingly, it is desirable to develop systems and methods to address these deficiencies.

SUMMARY

[0004] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not necessarily restrictive of the invention as claimed. The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention and together with the general description, serve to explain the principles of the invention.

BRIEF DESCRIPTION OF DRAWINGS

[0005] The numerous advantages of the disclosure may be better understood by those skilled in the art by reference to the accompanying figures.

[0006] FIG. **1**A is a conceptual view of an optical metrology system, in accordance with one or more embodiments of the present disclosure.

[0007] FIG. **1**B is a simplified schematic view of an optical metrology sub-system suitable for illuminating an optical metrology target with one or more pairs of mutually-coherent illumination beams and imaging the optical metrology target based on a single non-zero diffraction order from each illumination beam, in accordance with one or more embodiments of the present disclosure.

[0008] FIG. **2** illustrates a conceptual diagram of illuminating an optical metrology target with a pair of mutually-coherent illumination beams, in accordance with one or more embodiments of the present disclosure.

[0009] FIG. **3** illustrates a top view of an advanced imaging metrology (AIM) optical metrology target, in accordance with one or more embodiments of the present disclosure.

[0010] FIG. **4** illustrates a conceptual schematic illustrating the collection of a single non-zero diffraction order from an AIM optical metrology target, in accordance with one or more embodiments of the present disclosure.

[0011] FIG. **5**A illustrates a top view of a robust AIM (r-AIM) optical metrology target, in accordance with one or more embodiments of the present disclosure.

[0012] FIG. **5**B illustrates a side view of two adjacent cells including Moiré structures that may form a quadrant of an r-AIM optical metrology target as depicted in FIG. **5**A, in accordance with one or more embodiments of the present disclosure.

[0013] FIG. **6** illustrates a conceptual schematic illustrating the collection of a single non-zero diffraction order from an r-AIM optical metrology target, in accordance with one or more embodiments of the present disclosure.

[0014] FIG. **7**A illustrates an image of a collection pupil of an optical metrology sub-system associated with imaging an optical metrology target using a mutually-coherent pair of illumination beams with azimuth angles aligned with a direction of periodicity of features on the optical metrology target, in accordance with one or more embodiments of the present disclosure.

[0015] FIG. **7**B illustrates a simplified schematic of the collection pupil associated with FIG. **7**A, in accordance with one or more embodiments of the present disclosure.

[0016] FIG. **8**A illustrates an image of a collection pupil of an optical metrology sub-system associated with imaging an optical metrology target using a mutually-coherent pair of illumination beams with azimuth angles rotated with respect to a direction of periodicity of features on the optical metrology target, in accordance with one or more embodiments of the present disclosure.

[0017] FIG. **8**B illustrates a simplified schematic of the collection pupil associated with FIG. **8**A, in accordance with one or more embodiments of the present disclosure.

[0018] FIG. **8**C illustrates an image of an optical metrology target **104** generated with a rotated pair of illumination beams **108** as shown in FIGS. **8**A-**8**B, in accordance with one or more embodiments of the present disclosure.

[0019] FIG. **9** illustrates a simplified schematic of a collection pupil of an optical metrology sub-system having features with periodicity along both the X and Y directions imaged with two pairs of mutually-coherent illumination beams, in accordance with one or more embodiments of the present disclosure.

[0020] FIG. **10** illustrates a pupil image of an optical metrology sub-system depicting localized blocking of zero-order side lobes associated with the collection pupil configuration of FIG. **9**, in accordance with one or more embodiments of the present disclosure.

[0021] FIG. **11** illustrates a flow diagram illustrating steps performed in a method **1100** for optical metrology with mutually-coherent illumination beams **108**, in accordance with one or more embodiments of the present disclosure.

DETAILED DESCRIPTION

[0022] Reference will now be made in detail to the subject matter disclosed, which is illustrated in the accompanying drawings. The present disclosure has been particularly shown and described with respect to certain embodiments and specific features thereof. The embodiments set forth herein are taken to be illustrative rather than limiting. It should be readily apparent to those of ordinary skill in the art that various changes and modifications in form and detail may be made without departing from the spirit and scope of the disclosure.

[0023] Embodiments of the present disclosure are directed to systems and methods for optical metrology with pairs of mutually-coherent illumination beams (e.g., mutually-coherent illumination beam pairs) oriented with common polar incidence angles and opposing azimuth incidence angles, where zero-order side lobes are controlled to reduce or eliminate an impact on a measurement. In particular, optical metrology along a particular measurement direction may be performed based on imaging an overlay target based on interference of a single non-zero diffraction order from each illumination beam in a mutually-coherent pair and zero-order side lobes associated with zero-order light is blocked and/or algorithmically filtered from an image.

[0024] As used herein, light associated with a particular diffraction order from an optical metrology target having periodic features may be characterized as having a pole (e.g., a central peak) and potentially side lobes. For example, side lobes may be associated with diffraction effects from edges or other features of the optical metrology target (or constituent cells therein) having different spatial frequencies than the periodic features and are primarily due to a finite extent of a grating within the overlay target (e.g., a finite cell size).

[0025] In particular, embodiments of the present disclosure are directed to illuminating an optical metrology target with a pair of mutually-coherent illumination beams at symmetric azimuth angles for each measurement direction of interest. As used herein, a pair of mutually-coherent illumination beams includes a pair of illumination beams that are both temporally and spatially coherent with respect to each other. However, each illumination beam need not necessarily be individually spatially coherent. In other words, the illumination beams in a mutually-coherent pair may be individually spatially incoherent across respective beam profiles, but light at azimuthally opposing points at common polar incidence angles is mutually temporally coherent.

[0026] An optical metrology measurement for a single measurement direction may utilize one pair of mutually-coherent illumination beams, while an optical metrology measurement for two measurement directions (e.g., two orthogonal measurement directions) may utilize two pairs of mutually-coherent illumination beams. Further, although illumination beams within each pair are mutually coherent, it is not necessary for beams in different pairs to be mutually coherent. Rather, it may be beneficial but not required that the pairs of illumination beams are incoherent with respect to each other.

[0027] Optical metrology with mutually coherent illumination beams is described generally in U.S. Pat. No. 12,032,300 titled IMAGING OVERLAY WITH MUTUALLY COHERENT OBLIQUE ILLUMINATION issued on Jul. 9, 2024, which is incorporated herein by reference in its entirety. However, it is contemplated herein that the presence of zero-order side lobes (e.g., side lobes associated with zero-order diffraction that may surround a zero-order pole) may negatively impact an optical metrology measurement generated using such a technique and further contemplated herein that the impacts of the zero-order side lobes may increase as a size of an optical metrology target is reduced.

[0028] Embodiments of the present disclosure are directed to various techniques to mitigate, reduce, or eliminate the impact of zero-order side lobes associated with an optical metrology measurement based on mutually-coherent oblique illumination. The systems and methods disclosed herein may be suitable for any type of optical metrology measurement based on periodic targets such as, but not limited to, overlay metrology or scanner acquisition (e.g., scanner alignment). In this way, an overlay metrology target may correspond to an overlay metrology target, a scanner acquisition target (e.g., an alignment target), or any other type of target.

[0029] In some embodiments, a pair of mutually-coherent illumination beams used to generate measurements for a particular measurement direction are azimuthally rotated relative to a direction of periodicity associated with the particular measurement direction. For example, an optical metrology target may include one or more cells designed for measurement along a particular measurement direction (e.g., an X direction) that include features with periodicity along the particular measurement direction. In some embodiments, a pair of mutually-coherent illumination beams used to illuminate the target is rotated relative to the particular measurement direction.

[0030] In this configuration, an optical metrology subsystem may provide a dark-field image since zero-order diffraction of the illumination beams does not contribute to image formation. Further, since each pair of illumination beams is mutually coherent, the single diffraction lobe associated with each illumination beam in the pair interfere to form a sinusoidal interference pattern in the image (e.g., a pattern of sinusoidal interference fringes). In particular, the periodicity of sinusoidal interference does not correspond to a periodicity of features on the overlay target, but rather will be dependent on multiple factors including, but not limited to, a pitch of grating structures in the optical metrology target, wavelength of the illumination beams, polar incidence angle of the illumination beams, and the azimuthal incidence angle (e.g., a difference between the azimuth incidence angle of the illumination beams relative to a characterized direction of periodicity). As a result, the various grating structures in the optical metrology target may be imaged with high contrast as pure sinusoids such that optical metrology measurements may be generated based on comparisons of relative phases of the neighboring cell images in accordance with a metrology recipe.

[0031] Further, this configuration may allow for the control of the impact of zero-order side lobes using various techniques. For example, this configuration may result in fringes associated with interference between the zero-order side lobes and first-order diffraction oriented along different directions compared to fringes associated with interference between first-order diffraction of different illumination beams, which may allow for algorithmic isolation and filtering of the impact of the zero-order side lobes. As another example, this configuration may separate zero-order side lobes from first-order diffraction in a collection pupil plane, which may enable physical blocking of at least a portion of the zero-order side lobes in the collection pupil. Further, both physical blocking and algorithmic filtering techniques may be combined.

[0032] In some embodiments, two pairs of mutually-coherent illumination beams are used to generate measurements along two measurement directions (e.g., orthogonal X and Y measurement directions). In this configuration, each pair of mutually-coherent illumination beams is rotated relative to the associated measurement direction (or both measurement directions) to provide for the mitigation of the impact of the zero-order side lobes on the measurements.

[0033] Further, in some embodiments, the pairs of mutually-coherent illumination beams are rotated to be in common quadrants an illumination pupil. Put another way, an angular separation between pairs of mutually-coherent illumination beams may be less than 45 degrees. Such a configuration may beneficially constrain zero-order side lobes to opposing quadrants in a collection pupil plane relative to first-order diffraction, which may enable convenient blocking of the zero-order side lobes in the collection pupil plane.

[0034] It is contemplated herein that various optical metrology target designs are suitable for optical metrology measurements with mutually-coherent illumination beam pairs. In some embodiments, an optical metrology target is an advanced imaging metrology (AIM) target. In this configuration, each cell of the optical metrology target may include grating structures from different lithographic exposures in non-overlapping regions on one or more layers, where the grating structures from the different lithographic exposures have the same pitch. In some embodiments, an optical metrology target is a Moiré target. In this configuration, each cell may include grating structures from different lithographic exposures in overlapping regions on two layers to form grating-over-grating structures or Moiré structures, where the grating structures from the different lithographic exposures have different pitches. Further, a cell may include a pair of Moiré structures in which the pitches on the constituent layers are reversed relative to each other. For example, a first Moiré structure may have a first pitch (P) on a first layer and a second pitch (Q) on a second layer, while a second Moiré structure may have the first pitch (P) on the second layer and the second pitch (Q) on the first layer. Such an optical metrology target may be referred to as a robust AIM (r-AIM) optical metrology target and provides that an optical metrology measurement may be determined based on relative phases between the two Moiré structures.

[0035] It is further contemplated herein that the intensity of zero-order side lobes may increase as a size of an optical metrology target decreases. In this way, mitigation of the impacts of zero-order side lobes using the systems and methods disclosed herein may enable the shrinking of optical metrology targets without sacrificing performance. In some cases, the systems and methods disclosed herein may enable a size reduction of optical metrology target size (e.g., a length of a side of an optical metrology target) to 20 micrometers, 8 micrometers, or less.

[0036] Referring now to FIGS. **1A-11**, systems and methods for optical metrology based on mutually-coherent illumination beam pairs are described in greater detail, in accordance with one or more embodiments of the present disclosure.

[0037] FIG. **1**A illustrates a conceptual view of an optical metrology system **100**, in accordance with one or more embodiments of the present disclosure.

[0038] In some embodiments, the optical metrology system **100** includes an optical metrology sub-system **102** configured to image an optical metrology target **104** on a sample **106** based on illumination of the optical metrology target **104** with a pair of mutually-coherent illumination beams **108** per measurement direction of interest. In particular, each of the illumination beams **108***a,b* may fully illuminate the entirety of an optical metrology target **104**. In this way, each cell of the optical metrology target **104** receives common illumination conditions to promote matched image brightness for all of the cells. The optical metrology sub-system **102** may then include an objective lens **110** to collect light from the optical metrology target **104**, which is referred to herein as sample light **112**. At least a portion of this sample light **112** may then be used to image the optical metrology target **104**.

[0039] In some embodiments, an image of periodic features of an optical metrology target **104** is generated based on a single non-zero diffraction order from each illumination beam **108** in a pair of mutually-coherent illumination beams **108**. Further, each pair of mutually-coherent illumination beams **108** may be azimuthally rotated relative to a direction of periodicity of features in the optical metrology target **104**. In this way, the impact of zero-order side lobes (e.g., side lobes surrounding a peak of zero-order diffraction) may be mitigated, reduced, or eliminated through any combination of physical blocking of the zero-order side lobes in a collection pupil of the optical metrology sub-system **102** or algorithmic filtering of generated images (e.g., post-processing of the generated images).

[0040] The optical metrology system **100** may then generate optical metrology measurements for the sample **106** based on one or more of these images.

[0041] In some embodiments, the optical metrology system **100** includes a controller **114** communicatively coupled to the optical metrology sub-system **102**, where the controller **114** includes one or more processors **116**. For example, the one or more processors **116** may be configured to execute a set of program instructions maintained in a memory **118**, or memory device.

[0042] The one or more processors **116** of a controller **114** may include any processing element known in the art. In this sense, the one or more processors **116** may include any microprocessor-type device configured to execute algorithms and/or instructions. Further, the memory **118** may include any storage medium known in the art suitable for storing program instructions executable by the associated one or more processors **116**. For example, the memory **118** may include a non-transitory memory medium. As an additional example, the memory **118** may include, but is not limited to, a read-only memory, a random-access memory, a magnetic or optical memory device (e.g., disk), a magnetic tape, a solid-state drive and the like. It is further noted that the memory **118** may be housed in a common controller housing with the one or more processors **116**.

[0043] The one or more processors **116** of the controller **114** may be configured to execute program instructions causing the one or more processors **116** to perform various process steps disclosed herein either directly or indirectly. For example, the program instructions may cause the one or more processors **116** to generate control signals for any additional components (e.g., the optical metrology sub-system **102**, or any components therein) to perform various actions such as, but not limited to, generating images of an optical metrology target **104**. As another example, the program instructions may cause the one or more processors **116** to generate one or more optical metrology measurements based on the acquired images.

[0044] Referring now to FIG. **1**B, various aspects of the optical metrology sub-system **102** are described in greater detail, in accordance with one or more embodiments of the present disclosure. FIG. **1**B illustrates a simplified schematic view of an optical metrology sub-system **102** suitable for illuminating an optical metrology target **104** with one or more pairs of mutually-coherent illumination beams **108** and imaging the optical metrology target **104** based on a single non-zero diffraction order from each illumination beam **108**, in accordance with one or more embodiments of the present disclosure.

[0045] The optical metrology target **104** and/or the optical metrology sub-system **102** may be configured to according to a metrology recipe suitable for generating optical metrology measurements based on a desired technique. More generally, the optical metrology sub-system **102** may be configurable according to a variety of metrology recipes to perform optical metrology measurements using a variety of techniques and/or perform optical metrology measurements on a variety of different designs of an optical metrology target **104**.

[0046] For example, a metrology recipe may include various aspects of an optical metrology target **104** or a design of an optical metrology target **104** including, but not limited to, a layout of target features on one or more sample layers, feature sizes, or feature pitches. As another example, a metrology recipe may include parameters of illumination beams **108** such as, but not limited to, an illumination wavelength, an illumination pupil distribution (e.g., a distribution of illumination angles and associated intensities of illumination at those angles), a polarization of incident illumination, a spatial distribution of illumination, or a sample height. By way of another example, a metrology recipe may include collection parameters such as, but not limited to, a collection pupil distribution (e.g., a desired distribution of angular light from the sample to be used for a measurement and associated filtered intensities at those angles), collection field stop settings to select portions of the sample of interest, polarization of collected light, or wavelength filters.

[0047] In some embodiments, the optical metrology sub-system **102** is configured (e.g., according to a metrology recipe) to image an optical metrology target **104** having periodic structures using a single non-zero diffraction order from each illumination beam **108** in a pair of mutually-coherent illumination beams **108**. In this configuration, the optical metrology sub-system **102** may provide a dark-field image since zero-order diffraction of the illumination beams **108** does not contribute to image formation. Further, since each pair of illumination beams **108** is mutually coherent, the single diffraction lobe associated with each illumination beam **108** in the pair interfere to form a sinusoidal interference pattern in the image (e.g., a pattern of sinusoidal interference fringes). In particular, the periodicity of sinusoidal interference does not correspond to a periodicity of features on the overlay target, but rather will be dependent on multiple factors including, but not limited to, a pitch of grating structures in the optical metrology target **104** (e.g., first-layer gratings **304** and/or second-layer gratings **306**), wavelength of the illumination beams **108**, polar incidence angle of the illumination beams **108**, and the azimuthal incidence angle (e.g., a difference between the azimuth incidence angle of the illumination beams **108** relative to a characterized direction of periodicity).

[0048] As a result, the various grating structures in the optical metrology target **104** may be imaged with high contrast as pure sinusoids such that optical metrology measurements may be generated based on comparisons of relative phases of the neighboring cell images in accordance with a metrology recipe.

[0049] In some embodiments, the optical metrology sub-system **102** includes at least one illumination source **120** configured to generate the one or more pairs of mutually-coherent illumination beams **108**. For example, the illumination beams **108** in a pair may have sufficient temporal and/or spatial coherence such that diffraction orders from different illumination beams **108** in the pair they may interfere at the detector **132** to form a high-contrast sinusoidal image of periodic features on the optical metrology target **104**.

[0050] Each illumination beam **108** may include one or more selected wavelengths of light including, but not limited to, ultraviolet (UV) radiation, visible radiation, or infrared (IR) radiation.

[0051] The illumination source **120** may include any type of illumination source suitable for providing at least one pair of mutually-coherent illumination beams **108**. In some embodiments, the illumination source **120** includes at least one laser source. For example, the illumination source **120** may include, but is not limited to, one or more narrowband laser sources, a broadband laser source, a supercontinuum laser source, a white light laser source, or the like. In this regard, the illumination source **120** may provide an illumination beam **108** having high coherence (e.g., high temporal coherence and/or spatial coherence).

[0052] In some embodiments, the optical metrology sub-system **102** includes illumination optics to direct the various illumination beams **108** to an optical metrology target **104** on the sample **106** through one or more illumination channels **122** (e.g., illumination channel **122***a* and illumination channel **122***b* in FIG. **1**B). Further, the sample **106** may be disposed on a sample stage (not shown) suitable for securing the sample **106** and further configured to position the optical metrology target **104** with respect to the illumination beams **108**.

[0053] It is noted that FIG. **1**B illustrates the illumination of an optical metrology target **104** with a single pair of mutually-coherent illumination beams **108**. In some embodiments, the optical metrology sub-system **102** illuminates an optical metrology target **104** with two pairs of mutually-coherent illumination beams **108**. In this configuration, the optical metrology sub-system **102** may include an additional pair of illumination channels providing illumination beams **108** with different opposing azimuth incidence angles.

[0054] Each of the illumination channels **122** may include one or more optical components suitable for modifying and/or conditioning an illumination beam **108** as well as directing the illumination beam **108** to the optical metrology target **104**. For example, each of the illumination channels **122** may include, but is not required to include, one or more illumination lenses **124** (e.g., to control a spot size of the illumination beam **108** on the optical metrology target **104**, to relay pupil and/or field planes, or the like), one or more polarizers to adjust the polarization of the illumination beam **108** in the channel, one or more filters, one or more beam splitters, one or more diffusers, one or more homogenizers, one or more apodizers, one or more beam shapers, or one or more mirrors (e.g., static mirrors, translatable mirrors, scanning mirrors, or the like).

[0055] In some embodiments, the optical metrology sub-system **102** includes imaging optics within a collection pathway **126** for the collection of light from the sample light **112**. In some embodiments, the collection pathway **126** includes an objective lens **110** to collect diffracted or scattered light from the optical metrology target **104**. For example, the objective lens **110** may collect one or more diffracted orders of radiation from the optical metrology target **104** in response to the illumination beams **108**.

[0056] The collection pathway **126** may further include multiple optical elements to direct and/or modify illumination collected by the objective lens **110** including, but not limited to one or more lenses **128**, one or more filters, one or more polarizers, one or more beam blocks, or one or more beamsplitters. Such elements may be located in any suitable location in the collection pathway **126** including, but not limited to, a collection pupil **130**.

[0057] In some embodiments, the collection pathway **126** includes a detector **132** configured to generate an image (e.g., a dark-field image) of the optical metrology target **104**. For example, a detector **132** may receive an image of the sample **106** provided by elements in the collection pathway **126** (e.g., the objective lens **110**, the one or more lenses **128**, or the like).

[0058] For example, FIG. **1**B illustrates generating a dark-field image of an optical metrology target **104** with a single non-zero diffraction order (e.g., light associated with a single first diffraction order) from each illumination beam **108** of a pair of mutually-coherent illumination beams **108**. In particular, FIG. **1**B illustrates the collection of a first non-zero diffraction order **134***a* associated with a first illumination beam **108***a* and the collection of a second non-zero diffraction order **134***b* associated with a second illumination beam **108***b*, where illumination beams **108***a,b* are mutually coherent.

[0059] It is contemplated herein that optical metrology based on dark-field imaging using mutually-coherent pairs of illumination beams **108** as disclosed herein may provide multiple advantages relative to existing image-based optical metrology techniques based on spatially-incoherent illumination including, but not limited to, support of fine grating pitches, high image contrast, high image brightness, matched brightness between cells of an optical metrology target, insensitivity to monochromatic aberrations (e.g., defocus, or the like), minimal encroachment of cell edges, and/or minimal stray light.

[0060] For example, image contrast of periodic features is high (maximized in some cases) when generating an image by interfering wavefronts from only two non-zero diffracted orders with equal amplitudes. As another example, image brightness is high (maximized in some cases) based on the use of spatially coherent laser illumination, which avoids light loss related to removing coherence for incoherent imaging with high-brightness laser sources. As another example in the case of an r-AIM optical metrology target **104**, image brightness is matched between target cells since only grating pitches differ between cells. As another example, optical metrology measurements are insensitive to monochromatic aberrations and defocus due to the sampling of only two points in a pupil by the collected diffraction orders and further due to the sampling of the same points by cells from different layers. As another example, the use of oblique illumination (and OTL (outside-the-lens) illumination in some cases) mitigates cell edge ringing in generated images. As another example, the use of OTL configurations in particular may further limit light loss of the mutually-coherent illumination beams **108** since they do not propagate through the objective lens. Such configurations also limit a number of ghost reflections or scattering sites since relatively fewer optical surfaces are used as well as mitigate back-scattered illumination onto an imaging detector.

[0061] It is contemplated herein that the illumination channels **122** and the collection pathway **126** of the optical metrology sub-system **102** may be oriented in a wide range of configurations suitable for generating a dark-field image of the optical metrology target **104**. For example, FIG. **1**B illustrates an OTL configuration in which the various illumination beams **108** are directed to the optical metrology target **104** outside of a NA of the objective lens **110**. In some embodiments, the optical metrology sub-system **102** directs the illumination beams **108** to the optical metrology target **104** within the NA of the objective lens **110** in a TTL (through-the-lens) configuration. For example, the optical metrology sub-system **102** may include one or more components common to the collection pathway **126** and the illumination channels **122** to simultaneously provide the illumination beams **108** to the objective lens **110** for illumination of the optical metrology target **104** and direct a single non-zero diffraction order to the detector **132** to contribute to an image of the optical metrology target **104**. As a non-limiting illustration, the optical metrology sub-system **102** may include an annular mirror located at or near a pupil plane common to both the collection pathway **126** (e.g., conjugate to the collection pupil **130**) and the illumination channels **122** (e.g., conjugate to an illumination pupil (not explicitly shown)). Such an annular mirror may direct the various illumination beams **108** to the objective lens **110**. Such an annular mirror may further block zero-order diffraction of the illumination beams **108** while passing non-zero diffraction orders through a central opening to provide dark-field imaging with high contrast as described herein.

[0062] Referring now to FIGS. **2**-**6**, optical metrology with pairs of mutually-coherent illumination beams **108** is described, in accordance with one or more embodiments of the present disclosure.

[0063] FIG. **2** illustrates a conceptual diagram of illuminating an optical metrology target **104** with a pair of mutually-coherent illumination beams **108**, in accordance with one or more embodiments of the present disclosure. FIG. **2** depicts two illumination beams **108***a,b* as a pair of mutually-coherent illumination beams **108**, where each illumination beam **108** is depicted as providing a planar wavefront. In some embodiments, the optical metrology sub-system **102** directs a pair of mutually-coherent illumination beams **108** at symmetric incidence angles. For example, the illumination beams **108***a,b* have symmetric polar incidence angles ($\pm\alpha$) and symmetric (e.g., opposing) azimuth incidence angles. In FIG. **2**, this is illustrated by the two illumination beams **108***a,b* propagating in opposite azimuth directions in a plane of the figure.

[0064] FIGS. **3-6** depict imaging with a single non-zero diffraction order from each of the illumination beams **108** for various non-limiting designs of an optical metrology target **104**. In particular, FIGS. **3-4** depict AIM targets and FIGS. **5A-6** depict r-AIM targets.

[0065] FIG. **3** illustrates a top view of an AIM optical metrology target **104**, in accordance with one or more embodiments of the present disclosure. In one embodiment, the optical metrology target **104** includes various cells **302**, each including a single grating located on a single layer of the sample **106**. For example, the optical metrology target **104** may include one or more cells **302*a*** with first-layer gratings **304** on a first layer of the sample **106** and one or more cells **302*b*** second-layer gratings **306** on a second layer of the sample **106**. Further, each of the first-layer gratings **304** and the second-layer gratings **306** are formed from features having a common pitch **308**. In this regard, diffraction orders from the first-layer gratings **304** and the second-layer gratings **306** may be collocated in the collection pupil **130**. Such an optical metrology target **104** may be suitable for, but not limited to, overlay measurements based on a relative shift between the first-layer gratings and the second-layer gratings.

[0066] FIG. **4** illustrates a conceptual schematic illustrating the collection of a single non-zero diffraction order from an AIM optical metrology target **104**, in accordance with one or more embodiments of the present disclosure. FIG. **4** depicts an illumination beam **108** directed to an optical metrology target **104** using an OTL configuration such as that depicted in FIG. 1B. In this configuration, a zero-order diffraction pole **402** (e.g., specular reflection) from the sample **106** naturally lies outside a collection NA **404** (e.g., a NA of the objective lens **110**). FIG. **4** further depicts a first-order diffraction pole **406** within the collection NA **404**, while a second-order diffraction pole **408** lies outside the collection NA **404** and thus does not contribute to image formation.

[0067] It is noted that FIG. **4** depicts illumination and collection based on only one illumination beam **108** of a pair of mutually-coherent illumination beams **108** for clarity. It is to be understood illumination with the other illumination beam **108** in the pair of mutually-coherent illumination beams **108** produces a similar result based on the illumination symmetry.

[0068] It is to be understood that although FIG. **4** depicts an OTL configuration, a similar result may be achieved with a TTL configuration when the zero-order diffraction pole **402** (e.g., specular reflection and zero-order diffraction) is blocked in the collection pathway **126** (e.g., by an element in the collection pupil **130**). Further, a metrology recipe may be configured to provide a combination of grating pitch **308** and wavelength of the illumination beams **108** that satisfies the requirement of collecting only a single non-zero diffraction order (e.g., the first-order diffraction pole **406**) for each illumination beam **108** using an AIM optical metrology target **104**.

[0069] FIGS. **5**A and **5**B illustrate an r-AIM optical metrology target **104**, in accordance with one or more embodiments of the present disclosure. FIG. **5**A illustrates a top view of an r-AIM optical metrology target **104**, in accordance with one or more embodiments of the present disclosure. FIG. **5**B illustrates a side view of two adjacent cells **502** (e.g., cell **502*a*** and cell **502*b***) including Moiré structures (e.g., Moiré structure **504*a*** and Moiré structure **504*b***) that may form a quadrant of an r-AIM optical metrology target **104** as depicted in FIG. **5**A, in accordance with one or more embodiments of the present disclosure.

[0070] A Moiré structure **504*a,b*** may include two gratings in overlapping regions of the sample **106**, where the two gratings have different pitches. In some embodiments, a r-AIM optical metrology target **104** includes adjacent Moiré structures **504** having opposite pitches in the corresponding layers. In this way, a measurement error on the sample **106** may cause Moiré diffraction orders associated with a Moiré pitch to move in opposite directions for the two adjacent Moiré structures **504**.

[0071] For example, FIG. **5**B illustrates a first Moiré structure **504*a*** having an upper grating **506*a*** with a first pitch (P) on a first layer **508** of the sample **106** and a lower grating **510*a*** with a second pitch (Q) on a second layer **512** of the sample **106**. FIG. **5**B also illustrates a second Moiré structure **504*b*** having an upper grating **506*b*** with the second pitch (Q) on the first layer **508** of the sample **106** and a lower grating **510*b*** with the first pitch (P) on the second layer **512** of the sample **106**.

[0072] FIG. **6** illustrates a conceptual schematic illustrating the collection of a single non-zero diffraction order from an r-AIM optical metrology target **104**, in accordance with one or more embodiments of the present disclosure. FIG. **6** depicts an illumination beam **108** directed to an optical metrology target **104** using an OTL configuration such as that depicted in FIG. 1B. As with FIG. **4**, a zero-order diffraction pole (not shown in FIG. **6** for clarity) lies outside the collection NA **404** (e.g., a NA of the objective lens **110**).

[0073] FIG. **6** further depicts a Moiré diffraction pole **602** (e.g., from a Moiré diffraction order) associated with first-order diffraction from both gratings entering the collection NA **404**. For example, the Moiré diffraction pole **602** is formed from a first-order diffraction pole **604** from the upper grating **506** that serves as the basis of a first-order diffraction pole **606** from the lower grating **510**.

[0074] It is noted that FIG. **6** depicts illumination and collection based on only one illumination beam **108** of a pair of mutually-coherent illumination beams **108** for clarity. It is to be understood illumination with the other illumination beam **108** in the pair of mutually-coherent illumination beams **108** produces a similar result based on the illumination symmetry.

[0075] It is to be understood that although FIG. **6** depicts an OTL configuration, a similar result may be achieved with a TTL configuration when zero-order diffraction poles are blocked in the collection pathway **126** (e.g., by an element in the collection pupil **130**). In some embodiments, a metrology recipe provides the conditions under which all light diffracted from one of the gratings of a Moiré structure **504** fall outside the collection NA **404** and only one Moiré diffraction order associated with diffraction of light by each of the gratings of the Moiré structure **504** falls within the collection NA **404**.

[0076] Referring now to FIGS. **7A-10**, control over zero-order side lobes in optical metrology is described in greater detail, in accordance with one or more embodiments of the present disclosure.

[0077] FIG. **7**A illustrates an image of a collection pupil **130** (e.g., a pupil image) of an optical metrology sub-system **102** associated with imaging an optical metrology target **104** using a mutually-coherent pair of illumination beams **108** with azimuth angles aligned with a direction of periodicity of features on the optical metrology target **104**, in accordance with one or more embodiments of the present disclosure. FIG. **7**B illustrates a simplified schematic of the collection pupil **130** associated with FIG. **7**A, in accordance with one or more embodiments of the present disclosure.

[0078] In particular, FIGS. **7**A-**7**B depict an OTL configuration with an optical metrology target **104** having outer dimensions of 8 μm based on illumination beams **108** having an NA of 0.93 and a collection NA of 0.8. The collection NA is shown as a circular collection pupil boundary **702** in FIGS. **7**A-**7**B. In this OTL configuration, two zero-order diffraction poles **704** (e.g., poles associated with specular reflection of the illumination beams **108**) are depicted outside the collection pupil boundary **702** in FIG. **7**B and not shown in FIG. **7**A since they are not collected by the objective lens **110**.

[0079] FIGS. **7**A-**7**B further depict two non-zero-order diffraction poles **706** inside the collection pupil boundary **702**. For example, one non-zero-order diffraction pole **706** may be collected for each illumination beam **108** in a pair. As an illustration, the non-zero-order diffraction poles **706** may correspond to first-order diffraction poles from, Moiré diffraction poles, or poles associated with non-zero diffraction from any type of optical metrology target **104**.

[0080] FIGS. **7**A-**7**B further depict various side lobes surrounding the diffraction poles. As described previously herein, side lobes may be associated with any phenomenon such as, but not limited to, diffraction from edges of the optical metrology target **104** or cells therein.

[0081] For example, FIG. **7**A depicts non-zero-order side lobes **708** extending along both X and Y directions from the non-zero-order diffraction poles **706**. FIG. **7**A further depicts zero-order side lobes **710** extending inward from the collection pupil boundary **702** that are associated with the uncollected zero-order diffraction poles **704**. In FIG. **7**A, the non-zero-order side lobes **708** and the zero-order side lobes **710** are depicted a series of peaks with decreasing intensity surrounding the central pole. In FIG. **7**B, the locations of zero-order side lobes **710** are simply depicted as circles.

[0082] It is contemplated herein that in the configuration depicted in FIGS. **7**A-**7**B, there may be uncontrolled phase differences between plane waves associated with the first-order light that may arise from various conditions such as, but not limited to, mechanical vibrations). When no zero-order side lobes **710** are collected, such phase differences may be the same for different layers of the sample **106** and should thus not impact an optical metrology measurement.

[0083] However, when zero-order side lobes **710** overlap with first-order light (e.g., non-zero-order side lobes **708** and/or non-zero-order diffraction poles **706** as depicted in FIG. **7**A), the associated interference may produce a signal modulation that depends on the phase between the associated plane waves, which may impact the accuracy of an optical metrology measurement. Further, a strength of the various side lobes (e.g., the non-zero-order side lobes **708** and the zero-order side lobes **710**) may increase as the size of the optical metrology target **104** decreases. Put another way, edge diffraction effects associated with the generation of side lobes increase with smaller target sizes. As a result, the presence of side lobes may pose a practical constraint when reducing target size when using typical techniques.

[0084] Referring now to FIGS. **8**A-**10**, the mitigation of the impact of zero-order side lobes **710** by azimuthally rotating mutually-coherent pairs of illumination beams **108** relative to directions of periodicity of features on the optical metrology target **104** is described in greater detail, in accordance with one or more embodiments of the present disclosure.

[0085] FIG. **8**A illustrates an image of a collection pupil **130** of an optical metrology sub-system **102** associated with imaging an optical metrology target **104** using a mutually-coherent pair of illumination beams **108** with azimuth angles rotated with respect to a direction of periodicity of features on the optical metrology target **104**, in accordance with one or more embodiments of the present disclosure. FIG. **8**B illustrates a simplified schematic of the collection pupil **130** associated with FIG. **8**A, in accordance with one or more embodiments of the present disclosure. FIGS. **8**A-**8**B depict the same configuration of the optical metrology target **104** and the optical metrology sub-system **102** as in FIGS. **7**A-**7**B, except that the illumination beams **108** are rotated.

[0086] It is contemplated herein that rotating a pair of mutually-coherent illumination beams **108** relative to a direction of periodicity of features on an optical metrology target **104** may provide numerous benefits that enable accurate measurements on small optical metrology targets **104**.

[0087] For example, as shown in FIGS. **8**A-**8**B, rotating a pair of mutually-coherent illumination beams **108** relative to a direction of periodicity of features on an optical metrology target **104** may spatially separate zero-order side lobes **710** from non-zero-order diffraction (e.g., non-zero-order side lobes **708** and/or non-zero-order diffraction poles **706**) in the collection pupil plane, which substantially reduces the interference of such light and any associated impact on an optical metrology measurement. For example, FIG. **8**A depicts clear separation between zero-order side lobes **710** and non-zero-order diffraction poles **706**, as well as reduced overlap of zero-order side lobes **710** with non-zero-order side lobes **708** (e.g., overlap in regions of relatively low intensity).

[0088] Rotating a pair of mutually-coherent illumination beams **108** relative to a direction of periodicity of features on an optical metrology target **104** may further enable the use of a higher collection NA than typical techniques while maintaining desired image properties (e.g., image contrast, image brightness, or the like). In particular, the NA of the objective lens **110** may be increased such that the collection pupil boundary **702** is closer to the zero-order diffraction poles **704** without meaningfully degrading the image of the optical metrology target **104**. Even though increasing the NA of the objective lens **110** increases the signal strength of collected zero-order side lobes **710**, this additional portion of the zero-order side lobes **710** does not overlap with non-zero diffraction (or the non-zero diffraction has negligible intensity in these regions).

[0089] Additionally, this rotated illumination configuration enables various techniques for further mitigating any residual impact of the zero-order side lobes **710**.

[0090] In some embodiments, remaining interference between zero-order side lobes **710** and non-zero-order light (e.g., the low-intensity non-zero-order side lobes **708**) is at least partially filtered from an image of the optical metrology target **104** based on fringe orientation. For example, fringes in an image of the optical metrology target **104** associated with interference between zero-order side lobes **710** and non-zero-order light (e.g., the low-intensity non-zero-order side lobes **708**) may be oriented at a different angle than fringes associated with interference between non-zero-order diffraction from a pair of mutually-coherent illumination beams **108**. Accordingly, one or more image processing techniques (e.g., algorithmic techniques) such as, but not limited to, spatial Fourier Transform filtering techniques, may be utilized to filter out signals associated with the zero-order side lobes **710** from an image of the optical metrology target **104**.

[0091] As an illustration, FIG. **8**C illustrates an image of an optical metrology target **104** generated with a rotated pair of illumination beams **108** as shown in FIGS. **8**A-**8**B, in accordance with one or more embodiments of the present disclosure. In FIG. **8**C, the image includes relatively strong diagonal fringes associated with the mutually-coherent pair of illumination beams **108** and relatively weak vertical fringes associated with interference between zero-order side lobes **710** and non-zero-order side lobes **708** as shown in FIG. **8**A. Such vertical fringes may be removed to further mitigate the impact of the zero-order side lobes **710** on an optical metrology measurement.

[0092] In some embodiments, at least a portion of the zero-order side lobes **710** is blocked from reaching a detector **132** and thus blocked from contributing to forming an image of the optical metrology target **104**. For example, the optical metrology sub-system **102** may include one or more components in the collection pathway **126** (e.g., in the collection pupil **130**) to selectively block at least a portion of the zero-order diffraction poles **704**.

[0093] As an illustration, the optical metrology sub-system **102** may include one or more blockers (e.g., beam blocks) in upper-left and lower-right portions of the collection pupil **130** to block the zero-order side lobes **710** shown in FIGS. **8**A-**8**B.

[0094] It is noted that although FIGS. **7**A-**8**C depict conditions for imaging with a single pair of mutually-coherent illumination beams **108**, this is merely an illustration. In a general sense, an optical metrology system **100** may image an optical metrology target **104** with multiple pairs of mutually-coherent illumination beams **108**.

[0095] For example, an optical metrology sub-system **102** may include a first pair of mutually-coherent illumination beams **108** to image features of an optical metrology target **104** with periodicity along a first direction (e.g., an X direction) and may further include a second pair of mutually-coherent illumination beams **108** to image features of an optical metrology target **104** with periodicity along a second direction (e.g., a Y direction). In these configurations, the different pairs of mutually-coherent illumination beams **108** may be directed to the optical metrology target **104** either sequentially or simultaneously. For instance, the azimuth incidence angles of the first pair of mutually-coherent illumination beams **108** may be selected (e.g., in accordance with a metrology recipe) such that only a single non-zero diffraction order along the X direction is collected (or passed to the detector **132**). Similarly, the azimuth incidence angles of the second pair of mutually-coherent illumination beams **108** may be selected (e.g., in accordance with a metrology recipe) such that only a single non-zero diffraction order along the Y direction is collected (or passed to the detector **132**).

[0096] FIGS. **9**-**10** depict non-limiting configurations for blocking zero-order side lobes **710** in configurations with two pairs of mutually-coherent illumination beams **108**, in accordance with one or more embodiments of the present disclosure.

[0097] FIG. **9** illustrates a simplified schematic of a collection pupil **130** of an optical metrology sub-system **102** having features with periodicity along both the X and Y directions imaged with two pairs of mutually-coherent illumination beams **108**, in accordance with one or more embodiments of the present disclosure. For example, one pair of mutually-coherent illumination beams **108** may provide imaging of features with periodicity along the X direction and another pair of mutually-coherent illumination beams **108** may provide imaging of features with periodicity along the Y direction.

[0098] FIG. **9** depicts a first pair of zero-order diffraction poles **704** (**0**x) associated with a first pair of mutually-coherent illumination beams **108** (not shown) that have azimuth angles rotated to provide imaging of features with periodicity along the X direction based on non-zero-order diffraction poles **706** (**1**x) associated with diffraction of the first pair of mutually-coherent illumination beams **108** (not shown) along the X direction.

[0099] FIG. **9** further depicts a second pair of zero-order diffraction poles **704** (**0**y) associated with a second pair of mutually-coherent illumination beams **108** (not shown) that have azimuth angles rotated to provide imaging of features with periodicity along the Y direction based on non-zero-order diffraction poles **706** (**1**y) associated with diffraction of the second pair of mutually-coherent illumination beams **108** (not shown) along the Y direction.

[0100] FIG. **9** also depicts zero-order side lobes **710** associated with the various zero-order diffraction poles **704**.

[0101] It is to be understood that the arrangement of various diffraction lobes in FIG. **9** is merely illustrative and should not be interpreted as limiting the scope of the present disclosure. For example, FIG. **9** depicts the zero-order side lobes **710** associated with the various zero-order diffraction poles **704** along X and Y directions as overlapping (or close together in the collection pupil **130**. However, this is merely illustrative and the positions of the zero-order side lobes **710** are generally determined by the azimuth angles of the associated illumination beams **108**. As another example, FIG. **9** depicts the non-zero-order diffraction poles **706** associated with X and Y diffraction as overlapping (or are close together) in the collection pupil **130**. This is also merely illustrative and the positions of the non-zero-order diffraction poles **706** may generally depend on the specific azimuth angles of a corresponding pair of mutually-coherent illumination beams **108** as well as the pitch of the corresponding features on an optical metrology target **104** and may generally be located anywhere in the collection pupil **130**.

[0102] In some embodiments, an optical metrology sub-system **102** includes one or more blockers **902** (e.g., at a collection pupil **130**) oriented to selectively block at least a portion of zero-order side lobes **710**. As described previously herein, the impact of zero-order side lobes **710** on an optical metrology measurement may be mitigated through any combination of physical blocking of at least portions of the zero-order side lobes **710** or image processing techniques.

[0103] As shown in FIG. **9**, zero-order side lobes **710** may be grouped together through appropriate selection of the azimuth angles of the pairs of mutually-coherent illumination beams **108**. For example, FIG. **9** illustrates a configuration in which the non-zero-order diffraction poles **706** are arranged within a first set of diagonal quadrants of the collection pupil boundary **702** and in which the zero-order side lobes **710** may be arranged within a second set of diagonal quadrants. As a result, blockers **902** in this second set of diagonal quadrants may effectively block the zero-order side lobes **710** and pass the desired non-zero-order diffraction poles **706** (and associated non-zero-order side lobes **708**). This configuration is achieved by rotating the two pairs of mutually-coherent illumination beams **108** to be within diagonal quadrants of an illumination pupil plane.

[0104] However, there are some limitations of this configuration that provide sufficient separation between the zero-order side lobes **710** and the non-zero-order diffraction poles **706** (and associated non-zero-order side lobes **708**). For example, only a certain range of rotation angles ϕ may result in the collection of a single non-zero-order diffraction pole **706** per illumination beam **108** as depicted in FIG. **9**. In some embodiments, the maximum rotation angle ϕ may be governed by the expression:

$$\cos\phi < \frac{NA_{coll}}{NA_{illum}} \tag{1}$$

where NA_{coll} is a collection NA (e.g., a NA of the objective lens **110**) and NA_{illum} is an illumination NA (e.g., associated with a size of an illumination beam **108** in an illumination pupil and thus a size of diffraction poles in the collection pupil **130**). As an example in the case of an illumination NA of 0.93 and a collection NA of 0.8, the maximum rotation angle (ϕ) is approximately 25°.

[0105] Another consideration related to the selection of a rotation angle ϕ is the separation distance D between the zero-order side lobes **710** and the non-zero-order diffraction poles **706**. In a general sense, it may be desirable to maximize this distance D in all directions to effectively isolate the zero-order side lobes **710** and provide sufficient physical space for the blockers **902**. For example, it may be desirable to have the distance D (e.g., in units of NA) be greater than or equal to a threshold value such as, but not limited to, 0.3, 0.5, 0.6, or any suitable value. Equation (2) may be, but is not required to be, used to relate a rotation angle ϕ to a threshold value DTH:

$$\sin\phi > \frac{D_{TH}}{NA_{illum}} \tag{2}$$

[0106] As an example in the case of an illumination NA of 0.93 and a threshold value DTH of 0.3, the minimum desirable value of the rotation angle ϕ is approximately 20 degrees.

[0107] In some embodiments, an optical metrology sub-system **102** includes one or more blockers tailored to shape of expected zero-order side lobes **710** (e.g., in accordance with a metrology recipe), which may be referred to as localized blocking. In this configuration, the shape and/or location of a blocker (e.g., in a collection pupil **130**) may be selected to block zero-order side lobes **710**.

[0108] FIG. **10** illustrates a pupil image of an optical metrology sub-system **102** depicting localized blocking of zero-order side lobes **710** associated with the collection pupil **130** configuration of FIG. **9**, in accordance with one or more embodiments of the present disclosure. For example, FIG. **10** depicts the non-zero-order diffraction poles **706** (1_X, 1_Y) along both the X and Y directions from the two pairs of mutually-coherent illumination beams **108** schematically depicted in FIG. **9**. FIG. **10** further depicts zero-order side lobes **710** extending from the illumination beams **108** along both X and Y directions (e.g., associated with edge diffraction along Y and X directions, respectively) and may be at least partially blocked using blockers **1002**. It is contemplated herein that the positions of the zero-order side lobes **710** and thus the positions of the blockers **1002** may be determined by the azimuth incidence angles and intensity of the various illumination beams **108**, but may be independent of the wavelength of the illumination beams **108** as well as the pitch of the features on the optical metrology target **104**.

[0109] Further, the blockers **1002** may be implemented in a variety of ways within the spirit and scope of the present disclosure. For example, the blockers **1002** may be implemented as an aperture with fixed opaque portions forming the blockers **1002**. As another example, the blockers **1002** may be provided by a programmable pixelated device such as, but not limited to, a micro-electro-mechanical system (MEMS) mirror or a spatial light modulator (SLM).

[0110] Referring now to FIG. **11**, FIG. **11** illustrates a flow diagram illustrating steps performed in a method **1100** for optical metrology with mutually-coherent illumination beams **108**, in accordance with one or more embodiments of the present disclosure. Applicant notes that the embodiments and enabling technologies described previously herein in the context of the optical metrology system **100** should be interpreted to extend to the method **1100**. It is further noted, however, that the method **1100** is not limited to the architecture of the optical metrology system **100**.

[0111] In some embodiments, the method **1100** includes a step **1102** of directing one or more pairs of mutually-coherent illumination beams **108** to an optical metrology target **104**, where the illumination beams **108** in a respective pair have opposing azimuth incidence angles and a common altitude incidence angle (e.g., polar incidence angle), and where the azimuth incidence angles are rotated with respect to directions of periodicity of features on the optical metrology target **104** (e.g., corresponding to measurement directions). For example, the optical metrology target **104** may include one or more sets of periodic features associated with two or more different lithographic exposures, where the one or more sets of periodic features have periodicity along one or more measurement directions. Further, the illumination beams **108** in a respective pair of mutually-coherent illumination beams **108** may have opposing azimuth incidence angles and a common altitude incidence angle, where the azimuth incidence angles are rotated with respect to the one or more measurement directions.

[0112] In some embodiments, the method **1100** includes a step **1104** of generating one or more dark-field images of the optical metrology target **104**. For example, an image of a particular one of the one or more sets of periodic structures may include a sinusoidal interference pattern generated by interference of a single non-zero diffraction order of light from each of the illumination beams **108** within a particular pair mutually-coherent illumination beams **108**. For example, the single non-zero diffraction order may correspond to a first diffraction order (e.g., first-order diffraction), a Moiré diffraction order, or any other non-zero diffraction order.

[0113] In some embodiments, the method **1100** includes a step **1106** of generating optical metrology measurements along the one or more measurement directions based on the one or more images of the optical metrology target **104**. Any suitable technique may be used to generate optical metrology measurements based on the images. For example, the optical metrology measurements may be generated based on differences of centers of symmetry of sets of periodic features from different lithographic exposures.

[0114] In some embodiments, the method **1100** includes a step **1108** of mitigating an impact of zero-order side lobes on the one or more optical metrology measurements. As described throughout the present disclosure, interference between zero-order side lobes and non-zero-order light may negatively impact an accuracy, sensitivity, and/or precision of optical metrology measurements. Further, an intensity of zero-order side lobes may increase as a size of the optical metrology target **104** decreases such that zero-order side lobes may present a constraint on target size reduction.

[0115] Zero-order side lobes may be mitigated in step **1108** through any combination of physical blocking or image processing techniques.

[0116] For example, step **1108** may include blocking at least a portion of zero-order side lobes from reaching a detector generating the one or more images. In this way, interference between zero-order side lobes and non-zero-order light may be prevented.

[0117] As another example, step **1108** may include filtering one or more signals associated with interference between the zero-order side lobes and any of the first-order diffraction lobes from the one or more images to generate one or more filtered images. For example, undesirable interference between the zero-order side lobes and any of the first-order diffraction lobes may have a fringe direction and/or spatial frequency compared to desirable interference between non-zero diffraction from a pair of mutually-coherent illumination beams **108**. In this configuration, any type of filtering technique may be used such as, but not limited to, spatial Fourier Transform filtering.

[0118] The herein described subject matter sometimes illustrates different components contained within, or connected with, other components. It is to be understood that such depicted architectures are merely exemplary, and that in fact many other architectures can be implemented which achieve the same functionality. In a conceptual sense, any arrangement of components to achieve the same functionality is effectively "associated" such that the desired functionality is achieved. Hence, any two components herein combined to achieve a particular functionality can be seen as "associated with" each other such that the desired functionality is achieved, irrespective of architectures or intermedial components. Likewise, any two components so associated can also be viewed as being "connected" or "coupled" to each other to achieve the desired functionality, and any two components capable of being so associated can also be viewed as being "couplable" to each other to achieve the desired functionality. Specific examples of couplable include but are not limited to physically interactable and/or physically interacting components and/or wirelessly interactable and/or wirelessly interacting components and/or logically interactable and/or logically interacting components.

[0119] It is believed that the present disclosure and many of its attendant advantages will be understood by the foregoing description, and it will be apparent that various changes may be made in the form, construction, and arrangement of the components without departing from the disclosed subject matter or without sacrificing all of its material advantages. The form described is merely explanatory, and it is the intention of the following claims to encompass and include such changes. Furthermore, it is to be understood that the invention is defined by the appended claims.

What is claimed:

1. An optical metrology system, comprising:

one or more illumination optics configured to direct one or more pairs of mutually-coherent illumination beams to an optical metrology target on a sample in accordance with a metrology recipe, wherein the optical metrology target in accordance with the metrology recipe includes one or more sets of periodic features associated with two or more different lithographic exposures, wherein the one or more sets of periodic features have periodicity along one or more measurement directions, wherein the illumination beams in a respective pair of the mutually-coherent illumination beams are directed to the sample with opposing azimuth incidence angles and a common altitude incidence angle, wherein the opposing azimuth incidence angles of the one or more pairs of the mutually-coherent illumination beams are azimuthally rotated with respect to the one or more measurement directions;

an imaging sub-system including an objective lens configured to provide dark-field imaging of the optical metrology target on a detector located at a field plane conjugate to the optical metrology target in accordance with the metrology recipe, wherein an image of a particular one of the one or more sets of periodic features includes a sinusoidal interference pattern generated by interference of a single non-zero diffraction order of light from each of the illumination beams within a particular pair of the one or more pairs of the mutually-coherent illumination beams; and

a controller including one or more processors configured to execute program instructions causing the one or more processors to generate one or more optical metrology measurements along the one or more measurement directions based on one or more images of the optical metrology target received from the detector.

2. The optical metrology system of claim **1**, wherein the objective lens collects at least some zero-order side lobes from the one or more pairs of the mutually-coherent illumination beams, wherein the imaging sub-system further includes one or more blockers to prevent at least some of the zero-order side lobes collected by the objective lens from reaching the detector.

3. The optical metrology system of claim **2**, wherein the one or more blockers are located in opposing quadrants of a pupil plane of the imaging sub-system.

4. The optical metrology system of claim **1**, wherein the objective lens collects at least some zero-order side lobes from the one or more pairs of the mutually-coherent illumination beams, wherein the program instructions are further configured to cause the one or more processors to generate the one or more optical metrology measurements by:

filtering one or more signals associated with interference between the zero-order side lobes collected by the objective lens and any of the non-zero diffraction orders from the one or more images to generate one or more filtered images; and

generating the one or more optical metrology measurements based on the one or more filtered images.

5. The optical metrology system of claim **4**, wherein the one or more signals in the one or more images associated with interference between the zero-order side lobes collected by the objective lens and any of the non-zero diffraction orders include interference fringes along a different direction than interference between the non-zero diffraction orders, wherein filtering the one or more signals comprises filtering the one or more signals based on fringe direction.

6. The optical metrology system of claim **1**, wherein the one or more sets of periodic features on the optical metrology target comprise:

a first-layer grating on a first layer of the sample; and

a second-layer grating on a second layer of the sample, wherein the first and second-layer gratings are in non-overlapping regions of the sample, wherein the first and second-layer gratings have a common pitch, wherein a corresponding one of the one or more optical metrology measurements is based on a relative imaged shift between the first and second-layer gratings.

7. The optical metrology system of claim **6**, wherein the optical metrology target comprises:

an advanced imaging metrology (AIM) target.

8. The optical metrology system of claim **6**, wherein the single non-zero diffraction order of light from each of the mutually-coherent illumination beams comprises:

first-order diffraction from each of the mutually-coherent illumination beams.

9. The optical metrology system of claim **1**, wherein the one or more sets of periodic features on the optical metrology target comprise:

a first Moiré structure comprising:

a first-layer grating with a first pitch on a first layer of the sample; and

a second-layer grating with a second pitch on a second layer of the sample, wherein the first and second-layer gratings are formed in a first overlapping region of the sample; and

a second Moiré structure comprising:

a third grating with the second pitch on the first layer of the sample; and

a fourth grating with the first pitch on the second layer of the sample, wherein the third and fourth gratings are formed in a second overlapping region of the sample.

10. The optical metrology system of claim **9**, wherein the optical metrology target comprises:

a robust advanced imaging metrology (r-AIM) target.

11. The optical metrology system of claim **9**, wherein the single non-zero diffraction order of light from each of the mutually-coherent illumination beams comprises:

a Moiré diffraction order of light from each of the mutually-coherent illumination beams associated with sequential diffraction from the first-layer grating and the second-layer grating.

12. The optical metrology system of claim **1**, wherein a number of the one or more pairs of the mutually-coherent illumination beams is equal to a number of the one or more sets of periodic features in accordance with the metrology recipe.

13. The optical metrology system of claim **1**, wherein illumination beams in a respective one of the one or more pairs of the mutually-coherent illumination beams are directed to the optical metrology target simultaneously.

14. The optical metrology system of claim **1**, wherein the illumination beams in a respective one of the one or more pairs of the mutually-coherent illumination beams are directed to the optical metrology target sequentially.

15. The optical metrology system of claim **1**, wherein the optical metrology target has outer dimensions smaller than 20 micrometers.

16. The optical metrology system of claim **1**, wherein the optical metrology target has outer dimensions smaller than 8 micrometers.

17. The optical metrology system of claim **1**, wherein the one or more optical metrology measurements comprise:

overlay measurements.

18. The optical metrology system of claim **1**, wherein the one or more optical metrology measurements comprise:

scanner alignment measurements.

19. An optical metrology method, comprising:

directing one or more pairs of mutually-coherent illumination beams to an optical metrology target on a sample, wherein the optical metrology target includes one or more sets of periodic features associated with two or more different lithographic exposures, wherein the one or more sets of periodic features have periodicity along one or more measurement directions, wherein the illumination beams in a respective pair of the mutually-coherent illumination beams are directed to the sample with opposing azimuth incidence angles and a common altitude incidence angle, wherein the azimuth incidence angles of the one or more pairs of the mutually-coherent illumination beams are azimuthally rotated with respect to the one or more measurement directions;

generating one or more images of the optical metrology target with a detector, wherein the one or more images are dark-field images, wherein an image of a particular one of the one or more sets of periodic features includes a sinusoidal interference pattern generated by interference of a single non-zero diffraction order of light from each of the illumination beams within a particular pair of the one or more pairs of the mutually-coherent illumination beams; and

generating one or more optical metrology measurements along the one or more measurement directions based on the one or more images of the optical metrology target received from the detector.

20. The optical metrology method of claim **19**, further comprising:

collecting at least some zero-order side lobes from the one or more pairs of the mutually-coherent illumination beams; and

preventing, with one or more blockers at least some of the zero-order side lobes from reaching the detector.

21. The optical metrology method of claim **20**, wherein the one or more blockers are located in opposing quadrants of a pupil plane of an imaging sub-system including the detector.

22. The optical metrology method of claim **19**, further comprising:

collecting at least some zero-order side lobes from the one or more pairs of the mutually-coherent illumination beams; and

generating the one or more optical metrology measurements by:

filtering one or more signals associated with interference between the zero-order side lobes and any of the non-zero diffraction orders from the one or more images to generate one or more filtered images; and

generating the one or more optical metrology measurements based on the one or more filtered images.

23. The optical metrology method of claim **22**, wherein the one or more signals in the one or more images associated with interference between the zero-order side lobes and any of the non-zero diffraction orders include interference fringes along a different direction than interference between the non-zero diffraction orders, wherein filtering the one or more signals comprises filtering the one or more signals based on fringe direction.

24. The optical metrology method of claim **19**, wherein the one or more sets of periodic features on the optical metrology target comprise:

a first-layer grating on a first layer of the sample; and

a second-layer grating on a second layer of the sample, wherein the first and second-layer gratings are in non-overlapping regions of the sample, wherein the first and second-layer gratings have a common pitch, wherein a corresponding one of the one or more optical metrology measurements is based on a relative shift between the first and second-layer gratings in the one or more images.

25. The optical metrology method of claim **24**, wherein the optical metrology target comprises:

an advanced imaging metrology (AIM) target.

26. The optical metrology method of claim **24**, wherein the single non-zero diffraction order of light from each of the mutually-coherent illumination beams comprises:

first-order diffraction from each of the mutually-coherent illumination beams.

27. The optical metrology method of claim **19**, wherein the one or more sets of periodic features on the optical metrology target comprise:

a first Moiré structure comprising:

a first-layer grating with a first pitch on a first layer of the sample; and

a second-layer grating with a second pitch on a second layer of the sample, wherein the first and second-layer gratings are formed in a first overlapping region of the sample; and

a second Moiré structure comprising:

a third grating with the second pitch on the first layer of the sample; and

a fourth grating with the first pitch on the second layer of the sample, wherein the third and fourth gratings are formed in a second overlapping region of the sample.

28. The optical metrology method of claim **27**, wherein the optical metrology target comprises:

a robust advanced imaging metrology (r-AIM) target.

29. The optical metrology method of claim **27**, wherein the single non-zero diffraction order of light from each of the mutually-coherent illumination beams comprises:

a Moiré diffraction order of light from each of the mutually-coherent illumination beams associated with sequential diffraction from the first-layer grating and the second-layer grating.

30. The optical metrology method of claim **19**, wherein a number of the one or more pairs of the mutually-coherent illumination beams is equal to a number of the one or more sets of periodic features.

31. The optical metrology method of claim **19**, wherein illumination beams in a respective one of the one or more pairs of the mutually-coherent illumination beams are directed to the optical metrology target simultaneously.

32. The optical metrology method of claim **19**, wherein illumination beams in a respective one of the one or more pairs of the mutually-coherent illumination beams are directed to the optical metrology target sequentially.

33. The optical metrology method of claim **19**, wherein the optical metrology target has outer dimensions smaller than 20 micrometers.

34. The optical metrology method of claim **19**, wherein the optical metrology target has outer dimensions smaller than 8 micrometers.

35. The optical metrology method of claim **19**, wherein the one or more optical metrology measurements comprise:

overlay measurements.

36. The optical metrology method of claim **19**, wherein the one or more optical metrology measurements comprise:

scanner alignment measurements.

37. An optical metrology system, comprising:

a controller including one or more processors configured to execute program instructions causing the one or more processors to implement a metrology recipe by:

generating one or more optical metrology measurements along one or more measurement directions based on one or more images of an optical metrology target, wherein the optical metrology target includes one or more sets of periodic features associated with two or more different lithographic exposures, wherein the one or more sets of periodic features have periodicity along the one or more measurement directions, wherein the one or more images are generated by:

directing one or more pairs of mutually-coherent illumination beams to the optical metrology target on a sample, wherein the illumination beams in a respective pair of the mutually-coherent illumination beams are directed to the sample with opposing azimuth incidence angles and a common altitude incidence angle, wherein the opposing azimuth incidence angles of the one or more pairs of the mutually-coherent illumination beams are azimuthally rotated with respect to the one or more measurement directions, wherein an image of a particular one of the one or more sets of periodic features includes a sinusoidal interference pattern generated by interference of a single non-zero diffraction order of light from each of the illumination beams within a particular pair of the one or more pairs of the mutually-coherent illumination beams;

filtering one or more signals associated with interference between collected zero-order side lobes and any of the non-zero diffraction orders from the one or more images to generate one or more filtered images; and

generating the one or more optical metrology measurements based on the one or more filtered images.

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