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(54) Title: APPARATUS AND METHODS USING INTERFERENCE IN LIGHT REFLECTED FROM ARTICLES

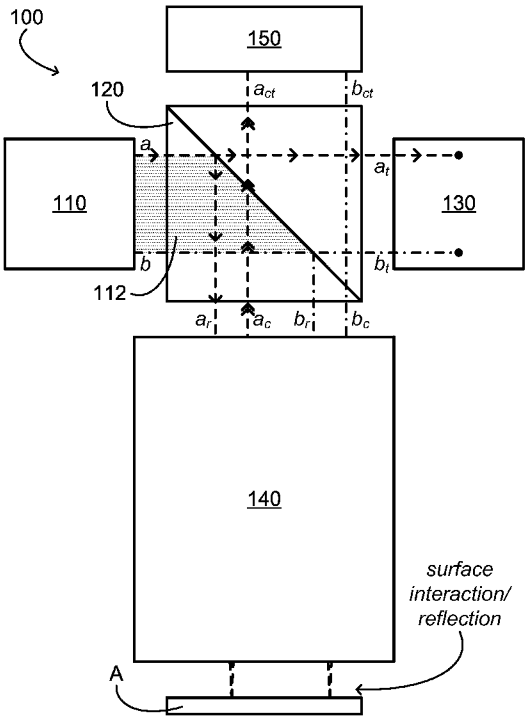

FIG. 1

(57) Abstract: Provided herein are apparatus and methods for inspecting articles for features using interference in light reflected from the articles. The interference may be used to detect, distinguish, and/or map features of articles, which features may include, but are not limited to, surface defects. In at least one embodiment, an apparatus and method includes conveying parallel light along a primary axis through a telecentric lens and a light-splitting device, respectively; illuminating a majority of a surface of an article with the parallel light; conveying reflected light from the surface of the article along the primary axis back through the light-splitting device and the telecentric lens, respectively; and recording interference resulting from a combination of light comprising at least the reflected light from the surface of the article.

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APPARATUS AND METHODS USING INTERFERENCE IN LIGHT REFLECTED FROM ARTICLES

CROSS REFERENCE

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 61/976,496, filed April 7, 2014.

BACKGROUND

[0002] An article may be inspected for defects that might degrade the performance of the article or a system including the article. For example, a hard disk for a hard disk drive may be fabricated and inspected for defects that might degrade the performance of the hard disk or the hard disk drive. Accordingly, apparatus and methods may be used to inspect articles for defects.

SUMMARY

[0003] Provided herein are apparatus and methods for inspecting articles for features using interference in light reflected from the articles. The interference may be used to detect, distinguish, and/or map features of articles, which features may include, but are not limited to, surface defects.

[0004] In at least one embodiment, an apparatus and method includes conveying parallel light along a primary axis through a telecentric lens and a light-splitting device, respectively; illuminating a majority of a surface of an article with the parallel light; conveying reflected light from the surface of the article along the primary axis back through the light-splitting device and the telecentric lens, respectively; and recording interference resulting from a combination of light comprising at least the reflected light from the surface of the article.

[0005] These and various other features will be apparent from a reading of the following description.

DRAWINGS

[0006] **Fig. 1** provides a schematic illustrating an apparatus for inspecting articles for features according to one or more embodiments.

[0007] **Fig. 2** provides a features map for a surface of an article according to one or more embodiments.

[0008] **Fig. 3A** provides a schematic illustrating an apparatus for inspecting articles for features according to one or more embodiments.

[0009] **Fig. 3B** provides a schematic illustrating an apparatus for inspecting articles for features according to one or more embodiments.

[0010] **Fig. 4** provides a digital micromirror device for an apparatus for inspecting articles for features according to one or more embodiments.

[0011] **Fig. 5** provides a schematic illustrating an apparatus for inspecting articles for features according to one or more embodiments.

[0012] **Fig. 6A** provides a mirror array on an XY-positioning stage for an apparatus for inspecting articles for features according to one or more embodiments.

[0013] **Fig. 6B** provides a mirror array on an XY-positioning stage for an apparatus for inspecting articles for features according to one or more embodiments.

[0014] **Fig. 7A** provides a liquid crystal-based mirror array for an apparatus for inspecting articles for features according to one or more embodiments.

[0015] **Fig. 7B** provides a liquid crystal-based mirror array for an apparatus for inspecting articles for features according to one or more embodiments.

[0016] **Fig. 8** provides a schematic illustrating an apparatus for inspecting articles for features according to one or more embodiments.

[0017] **Fig. 9A** provides a schematic illustrating an apparatus for inspecting articles for features according to one or more embodiments.

[0018] **Fig. 9B** provides a schematic illustrating an apparatus for inspecting articles for features according to one or more embodiments.

DESCRIPTION

[0019] Before some particular embodiments are provided in greater detail, it should be understood by persons having ordinary skill in the art that the particular embodiments provided herein do not limit the concepts provided herein, as features in such particular embodiments may vary. It should likewise be understood that a particular embodiment provided herein has features that may be readily separated from the particular embodiment and optionally combined with or substituted for features in any of several other embodiments provided herein.

[0020] It should also be understood by persons having ordinary skill in the art that the terminology used herein is for the purpose of describing some particular embodiments, and the terminology does not limit the concepts provided herein. Unless indicated otherwise, ordinal numbers (e.g., first, second, third, etc.) are used to distinguish or identify different elements or steps in a group of elements or steps, and do not supply a serial or numerical limitation. For example, "first," "second," and "third" elements or steps need not necessarily appear in that order, and embodiments need not be necessarily limited to the three elements or steps. It should also be understood that, unless indicated otherwise, any labels such as "left," "right," "front," "back," "top," "bottom," "forward," "reverse," "clockwise," "counterclockwise," "up," and "down," or other similar terms such as "upper," "lower," "aft," "fore," "vertical," "horizontal," "proximal," and "distal," or the like, are used for convenience and are not intended to imply, for example, any particular fixed location, orientation, or direction. Instead, such labels are used to reflect, for example, relative location, orientation, or direction. It should also be understood that the singular forms of "a," "an," and "the" include plural references unless the context clearly dictates otherwise.

[0021] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by persons having ordinary skill in the art.

[0022] An article may be inspected for features including defects (e.g., surface and/or subsurface defects) that might degrade the performance of the article or a system including the article. The article may include any article of manufacture or a workpiece thereof in any stage of manufacture having one or more surfaces or subsurfaces operable to reflect light. For example, the article may include, but is not limited to, a semiconductor wafer, a magnetic recording medium (e.g., a hard disk for a hard disk drive), a magnetic recording read-write head or slider therefor, or a workpiece thereof in any stage of manufacture.

[0023] A hard disk or a workpiece thereof may be inspected for features including defects (e.g., surface and/or subsurface defects including magnetic defects) that might degrade the performance of the hard disk or the hard disk drive. For example, a hard disk or a workpiece thereof may be inspected for thermal asperities, pits, shallow surface defects, waviness, and/or the like. For example, a hard disk or a workpiece thereof having a lubricant layer may be inspected for lubricant layer inhomogeneity including lubricant layer smears, ripples, bumps, and/or depletion. For example, a hard disk or a workpiece thereof having a carbon overcoat layer may be inspected for carbon overcoat inhomogeneity including carbon overcoat layer voids and/or shadows (e.g., shadows from sputtering clamps).

[0024] It is important to inspect articles for features including performance-degrading defects in order to correct manufacturing trends and to increase product quality.

[0025] Provided herein are apparatus and methods for inspecting articles for features using interference in light reflected from the articles. The interference may be used to detect, distinguish, and/or map features of articles, which features may include, but are not limited to, surface defects. Apparatus and methods for inspecting articles for features using interference in light reflected from the articles will now be provided in some particular, non-limiting embodiments.

[0026] **Fig. 1** provides a schematic illustrating an apparatus **100** including a number of components for inspecting articles for features using interference in light reflected from the articles. As shown in **Fig. 1**, the apparatus **100** may include, but is not limited to, a light source **110**, a light-splitting device **120**, a light trap **130**, an interferometric optical assembly **140**, and a recording device **150**. As further shown in **Fig. 1**, an article **A** may be positioned under the apparatus **100** where light from the apparatus **100** may illuminate, interact with, and be reflected by a surface of the article **A**.

[0027] While not shown in **Fig. 1**, the apparatus **100** may further include a stage configured to support the article **A** and hold the article **A** stationary during inspection without, for example, translation or rotation. However, the stage may be optionally further configured to translate and/or rotate the article **A** during inspection. With respect to translation, the stage may be optionally further configured as a piezoelectric, XY-positioning stage such that article **A** may be translated in any XY-related direction over a distance corresponding to a sub-pixel-sized distance, a pixel-sized distance, or a multiple pixel-sized distance, wherein a pixel-sized distance corresponds to pixel size or pixel pitch in an image sensor of an imaging device. A piezoelectric, XY-positioning stage may be used in combination with any of various embodiments of the mirror array **546** provided herein, for example, to translate the article **A** with respect to the mirror array **546**. With respect to rotation, the stage may be optionally further configured to rotate the article **A** for piecewise inspection of the article **A**; however, it should be understood that piecewise inspection may affect throughput.

[0028] With respect to the light source **110**, the light source **110** may be used alone or in combination with one or more additional optical components provided herein in a light source assembly. As such, it should be understood that any reference to the light source **110** used herein may include the light source **110** alone or the light source **110** in combination with one or more additional optical components provided herein in a light source assembly.

[0029] The light source **110** may be configured to provide parallel light **112**, wherein light rays of the parallel light minimally diverge as the light propagates through the apparatus **100**. The light source **110** may be further configured to provide substantially homogeneous light, wherein the same or about the same radiant energy (e.g., radiant energy as measured in joules or J) is provided to each illuminated surface location at a specific time or over a specific time interval, wherein the same or about the same radiant energy per unit time (e.g., radiant power as measured in watts or W or J/s) is provided to each illuminated surface location, and/or wherein the same or about the same radiant power per unit area (e.g., irradiance as measured in W/m^2) is provided to each illuminated surface location.

[0030] The light source **110** may be configured to provide light including, but not limited to, one or more qualities of light selected from the following: a relatively wide range of wavelengths (e.g., whole spectrum, broad spectrum, ultraviolet-visible, visible, infrared, etc.) of light, a relatively narrow range of wavelengths (e.g., a subdivision of ultraviolet such as UVA, UVB, UVC, etc.; a subdivision of visible such as red, green, blue, etc.; a subdivision of infrared such as near infrared, mid-infrared; etc.) of light, or a particular wavelength (e.g., monochromatic) of light; a relatively wide range of frequencies (e.g., whole spectrum, broad spectrum, ultraviolet-visible, visible, infrared, etc.) of light, a relatively narrow range of frequencies (e.g., a subdivision of ultraviolet such as UVA, UVB, UVC, etc.; a subdivision of visible such as red, green, blue, etc.; a subdivision of infrared such as near infrared, mid-infrared; etc.) of light, or a particular frequency (e.g., monochromatic) of light; unpolarized light or polarized light, wherein the polarized light includes linearly polarized light (e.g., p-polarized light, s-polarized light, q-polarized light, etc.), circularly polarized light, or elliptically polarized light; certain degrees of spatially and/or temporally coherent light ranging from noncoherent light to coherent light (e.g., laser); and collimated or telecentric light .

[0031] The light source **110** may be configured to provide light to illuminate a portion of the surface of the article **A** up to and including an entire surface of the article **A**. As such, the light source **110** may be configured to provide light to illuminate a substantial portion of the surface (e.g., ≥ 10% of the surface) of the article **A**, a major portion of the surface (e.g., > 50% of the surface) of the article **A**, nearly the entire surface (e.g., ~100% of the surface) of the article **A**, or the entire surface (i.e., 100% of the surface) of the article **A**. It should be understood that any reference to the surface of the article **A** used herein may include the foregoing portion of the surface of the article **A** up to and including the entire surface of the article **A**, optionally including one or more subsurfaces.

[0032] With respect to the light-splitting device **120**, the light-splitting device **120** may be used alone or in combination with one or more additional optical components provided herein in a light-splitting assembly. As such, it should be understood that any reference to the light-splitting device **120** used herein may include the light-splitting device **120** alone or the light-splitting device **120** in combination with one or more additional optical components provided herein in a light-splitting assembly.

[0033] The light-splitting device **120** may include, but is not limited to, any light-splitting block, plate, or pellicle operable to split incident light in accordance with at least **Fig. 1**. The light-splitting device **120** may reflect a first portion of the incident light and transmit a second portion of the incident light in accordance with composition, construction, or the composition and construction of the light-splitting device **120**, wherein the composition includes substrate, bonding, and/or coating compositions of the light-splitting device **120**, and wherein the construction includes the manner in which one or more of the foregoing is assembled into the light-splitting device **120**. The composition and/or construction of the light-splitting device **120** may be such that the first and second portions of the incident light are respectively reflected and transmitted in a particular reflection/transmission ("R/T") ratio (e.g., R/T of 10/90, 30/70, 50/50, 70/30, or 90/10). Additionally or alternatively, the composition and/or construction of the light-splitting device **120** may be such that the first and second portions of the incident light are respectively reflected and transmitted with different polarization states. For example, the light-splitting device **120** may reflect s-polarized light and transmit p-polarized light.

[0034] With respect to the light trap **130**, the light trap **130** may be used alone or in combination with one or more additional optical components provided herein in a light-trapping assembly. As such, it should be understood that any reference to the light trap **130** used herein may include the light trap **130** alone or the light trap **130** in combination with one or more additional optical components provided herein in a light-trapping assembly.

[0035] The light trap **130** may include, but is not limited to, any light block or light trap with a sufficiently sized aperture operable to absorb incident light in accordance with at least **Fig. 1**. The light trap **130** may include, but is not limited to, one or more absorptive materials selected from absorptive neutral density glass; blackout fabric; black-flocked paper; black posterboard; black hardboard; light-absorbing foil including black aluminum foil, Metal Velvet™ from Acktar Ltd., Scatter Black™ from Acktar Ltd.; anodized aluminum; graphite; and Vantablack® from Surrey NanoSystems Ltd.

[0036] With respect to the interferometric optical assembly **140**, the interferometric optical assembly **140** may include, but is not limited to, one or more optical components for interferometry selected from the optical components for interferometry provided in **Figs. 3A**, **3B**, **4**, **5**, **6A**, **6B**, **7A**, **7B**, **8**, **9A**, and **9B** and the description therefor.

[0037] With respect to the recording device **150**, the recording device **150** may be used alone or in combination with one or more additional optical components provided herein in a recording assembly. As such, it should be understood that any reference to the recording device **150** used herein may include the recording device **150** alone or the recording device **150** in combination with one or more additional optical components provided herein in a recording assembly.

[0038] The recording device **150** may include, but is not limited to, an imaging device including an image sensor operable to detect the light provided to and subsequently reflected from the surface of the article **A**. The image sensor may include a number of light sensor elements or pixels, each of which may include a photodetector and one or more readout devices (e.g., capacitors, transistors, etc.) operable to convert detected light into electronic signals for processing by a processing means.

[0039] The number of pixels in the image sensor may include, but is not limited to, an arrangement of n rows and m columns of pixels in a two-dimensional array, and the number of pixels may be expressed in a resolution n x m of millions of pixels or megapixels ("MP"). For example, the number of pixels may be in an arrangement of 2048 rows and 2048 columns in a two-dimensional array, and the number of pixels may be expressed in a resolution of 4.2 MP (i.e., 2048 pixels x 2048 pixels = 4.2 x 10^6 pixels or 4.2 MP). For example, the number of pixels may be in an arrangement of 2560 rows and 2160 columns in a two-dimensional array, and the number of pixels may be expressed in a resolution of 5.5 MP (i.e., 2560 pixels x 2160 pixels = 5.5 x 10^6 pixels or 5.5 MP). It should be understood that the image sensor is not limited to the foregoing numbers of pixels as the image sensor may include more or fewer pixels than either of the foregoing numbers of pixels.

[0040] Each pixel of the image sensor may be, but is not limited to, a rectangle or square in shape, and each pixel may be, but is not limited to, micrometer sized (i.e., admits of µm units as measured) in at least one of a length or a width. For example, each pixel may be a rectangle in shape, and each pixel may be about 6.5 µm in at least one of a length or a width. For example, each pixel may be a square in shape, and each pixel may be about 6.5 µm in length and width. It should be understood that the image sensor is not limited to pixels of the foregoing shapes as the image sensor may include pixels of any of a number of shapes different than the foregoing shapes. It should be understood that the image sensor is not limited to pixels of the foregoing size as the image sensor may include pixels of any of a number of sizes (e.g., from about 3 µm to about 15 µm) different than the foregoing size.

[0041] Each pixel of the image sensor may correspond to a particular, fixed area of the surface of the article **A**, and each pixel may respectively correspond to a particular, fixed area of a features map (e.g., features map **M** of **Fig. 2**) of the surface of the article **A**. As such, there may be a one-to-one-to-one correspondence among the particular, fixed area of the surface of the article **A**, the pixel of the image sensor, and the particular, fixed area of the features map of the surface of the article **A**. Such correspondence facilitates identification of a particular feature's coordinates about the surface of the article **A**, optionally for further analysis.

[0042] The image sensor may include, but is not limited to, a charge-coupled device ("CCD"), an intensified charge-coupled device ("ICCD"), an electron-multiplying charge-coupled device ("EMCCD"), a complementary metal-oxide semiconductor ("CMOS"), or a scientific complementary metal-oxide semiconductor ("sCMOS"). And the imaging device may include, but is not limited to, a CCD camera, an ICCD camera, an EMCCD camera, a CMOS camera, or an sCMOS camera.

[0043] While not shown in **Fig. 1**, it should be understood that the apparatus **100** may optionally include any number of additional optical components including, but not limited to, one or more optical components selected from mirrors, lenses, windows, flats, diffusers, filters, collimators, polarizers, prisms, diffraction gratings, beamsplitters, and optical assemblies, any one or more of which may be optionally used in combination with the light source **110**, the light-splitting device **120**, the light trap **130**, the interferometric optical assembly **140**, or the recording device **150**. For example, the apparatus **100** may include one or more polarization-management assemblies or systems for managing polarization of light before and/or after interaction with the surface of the article **A**, as well for optionally managing polarization of reference light. The one or more polarization-management assemblies or systems may include any number of polarization-management components including, but not limited to, one or more polarization-management components selected from polarization filters or polarizers (e.g., linear polarizers), polarization rotators or retarders (e.g., waveplates such as quarter-wave plates and half-wave plates), compensators (e.g., variable compensator), and photoelastic modulators. **Fig. 9B** provides a schematic illustrating an apparatus **900B** optionally including one or more polarization-management systems or components thereof.

[0044] While not shown in **Fig. 1**, it should be understood that the apparatus **100** may include a processing means including, but not limited to, one or more computers or similar apparatus including primary and/or secondary memory and one or more processing elements operable to carry out arithmetic and logical operations. The one or more computers or similar apparatus may be individually selected from servers, workstations, desktop computers, nettops, laptops, netbooks, mobile devices including tablets and smartphones, and apparatus including graphics processing units ("GPU"s), application-specific integrated circuits ("ASIC"s), field-programmable gate arrays ("FPGA"s), or the like.

[0045] The processing means may include or have access to instructions for conveying articles to the apparatus **100**; positioning articles for inspection, optionally including gradationally or continuously rotating articles for inspection; tuning optical components (e.g., piezoelectric-based components in polarization-management assemblies); switching the light source **110** on and off or otherwise between modes for providing light and not providing light; switching the recording device **150** on and off or otherwise between modes for detecting light and not detecting light; and/or synchronizing the light source **110** with the recording device **150**.

[0046] The processing means may include or have access to instructions for processing electronic signals from the recording device **150** or an imaging device and/or image sensor thereof for detecting, distinguishing, and/or mapping features of articles. With respect to mapping features of articles, the processing means may generate a features map **M** corresponding to the electronic signals from the recording device **150** or an imaging device and/or image sensor thereof, an example of which is provided in **Fig. 2**. The features map **M** may provide, but is not limited to, three-dimensional surface imaging for constitutional features (e.g., air bearing surface of a slider) or defects (e.g., thermal asperities, pits, shallow surface defects, waviness, and the like in a hard disk surface), magnetic imaging, and measurements for the foregoing (e.g., thermal asperity height, waviness and the like in a hard disk surface). For example, the processing means may generate the features map **M** of **Fig. 2**, which corresponds to a surface of a hard disk with a lubricant layer defect.

[0047] The processing means may generate any of a number of features maps corresponding to the electronic signals from the recording device **150** or an imaging device and/or image sensor thereof, each of which features maps may provide differentiating or distinguishing information for one or more types of features about the surface of the article **A**. For example, the processing means may generate features maps M_1, M_2, M_3,..., M_n, wherein n indicates the n^{th} features map. The processing means may generate a composite features map from any two or more constituent features maps or the information sufficient to produce them. The composite features map may enhance one or more features common to the two or more constituent features maps. The composite features map may also consolidate one or more features onto the composite features map from any two or more constituent features maps including different features between them. The one-to-one-to-one correspondence provided herein among a particular, fixed area of a surface of an article **A**, a pixel of an image sensor, and a particular, fixed area of a features map **M** facilitates generating the one or more composite features maps.

[0048] The processing means may increase pixel resolution for one or more features maps with pixel interpolation. Pixel interpolation may increase pixel resolution about 10x or more over a native resolution for that of an imaging device and/or image sensor thereof without an increase in physical pixels.

[0049] The apparatus **100** of **Fig. 1** may be configured to inspect articles for features at a rate commensurate with or greater than the rate at which the articles or workpieces thereof are produced. For example, the apparatus 100 may be configured to inspect articles at a rate of at least 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 18, or 20 article(s) per second, or greater. Inspecting articles for features at a rate commensurate with or greater than the rate at which the articles or workpieces thereof are produced is a function of many features of the apparatus including, but not limited to, maintaining the linear and the angular position of articles while inspecting them.

[0050] In addition to the schematic of **Fig. 1** illustrating the apparatus **100** and the number of components thereof, the schematic of **Fig. 1** also illustrates methods for inspecting articles for features using interference in light reflected from the articles.

[0051] As shown in **Fig. 1**, the light source **110** may provide parallel light **112**, of which outermost light rays ***a*** and ***b*** of **Fig. 1** are representative. Focusing on light ray ***a*** with the understanding that light ray ***b*** follows an analogous path, light ray ***a*** may be conveyed to the light-splitting device **120**, where a first portion of light ray ***a*** may be reflected to yield light ray a_r, and where a second portion of light ray ***a*** may be transmitted to yield light ray a_t. As further shown in **Fig. 1**, light ray a_t may subsequently terminate in the light trap **130** while light ray a_r may be conveyed through the interferometric optical assembly **140** to the surface of the article **A** where light ray a_r or a derivative thereof may interact with and/or reflect from the surface of the article **A**. Depending upon the interferometric optical assembly **140**, different embodiments for which are provided in reference to **Figs. 3A**, **3B**, **5**, **8**, **9A**, and **9B**, light ray a_r may subsequently combine with a reference light ray in accordance with the superposition principle to yield light ray a_c. As further shown in **Fig. 1**, light ray a_c may be subsequently conveyed back to and transmitted through the light-splitting device **120** to yield light ray a_{ct}. Light ray a_{ct} may be subsequently conveyed to the recording device **150** where it may be converted to an electronic signal and processed by the processing means for generating a features map such as the features map **M** of **Fig. 2**.

[0052] In view of the apparatus **100** and the components thereof provided in reference to **Fig. 1**, some particular embodiments of the apparatus **100** will now be provided with some non-limiting, interferometric optical assemblies corresponding to the interferometric optical assembly **140**.

[0053] **Figs. 3A** and **3B** provide schematics illustrating an apparatus **300** including a number of components for inspecting articles for features using interference in light reflected from the articles. Like the apparatus **100** shown in **Fig. 1**, the apparatus **300** shown in **Figs. 3A** and **3B** may include, but is not limited to, a light source **110**, a light-splitting device **120**, a light trap **130**, an interferometric optical assembly **140**, and a recording device **150**. As further shown in **Figs. 3A** and **3B**, an article **A** may be positioned, for example, on a stage under the apparatus **300** where light from the light source **110** may illuminate, interact with, and reflect from a surface of the article **A**.

[0054] With respect to the interferometric optical assembly **140** of the apparatus **300**, the interferometric optical assembly **140** may include, but is not limited to, a lens **342**, a light-splitting device **344**, and a mirror **346**.

[0055] With respect to the lens **342**, the lens **342** may include, but is not limited to, a telecentric lens, which reduces optical aberrations and feature-position errors for features in features maps such as the features map **M** of **Fig. 2**. The telecentric lens may include, but is not limited to, an object-space telecentric lens (i.e., entrance pupil at infinity), an image-space telecentric lens (i.e., exit pupil at infinity), or a bi-telecentric or double telecentric lens (i.e., entrance and exit pupils at infinity). For example, the lens **342** may be a bi-telecentric lens. It should be understood that the lens **342** is not limited to the foregoing, and any reference to the lens **342** used herein may include the lens **342** alone or the lens **342** in combination with one or more additional optical components provided herein in a lens assembly.

[0056] With respect to the light-splitting device **344**, the light-splitting device **344** may include, but is not limited to, a light-splitting device such as the light-splitting device **120** provided in reference to **Fig. 1**. For example, the light-splitting device **344** may be a light-splitting cube as shown in **Figs. 3A** and **3B**. It should be understood that the light-splitting device **344** is not limited to the foregoing, and any reference to the light-splitting device **344** used herein may include the light-splitting device **344** alone or the light-splitting device **344** in combination with one or more additional optical components provided herein in a light-splitting assembly.

[0057] With respect to the mirror **346**, the mirror **346** may include, but is not limited to, any optically coated flat or mirror operable to reflect incident light back toward the light-splitting device **344**. For example, the mirror **346** may be a first-surface mirror, wherein a first surface of a mirror substrate facing the light-splitting device **344** may be optically coated with an optical coating to minimize energy loss to the mirror substrate, and wherein the optical coating may be optionally a broadband (e.g., 400-750 nm) coating with an average reflectance of at least 99% for one or more polarization states of light (e.g., p-polarized light and s-polarized light). The mirror **346** may be optionally mounted on an adjustable mount or stage such that the distance and/or angle of the mirror **346** to the light-splitting device **344** may be adjusted. It should be understood that the mirror **346** is not limited to the foregoing, and any reference to the mirror **346** used herein may include the mirror **346** alone or the mirror **346** in combination with one or more additional optical components provided herein in a mirror assembly.

[0058] In an alternative, the mirror **346** may include a digital micromirror device ("DMD") such as the DMD **446** of **Fig. 4**. The DMD **446** may include, but is not limited to, a mirror level **447** including a number of individually adjustable micrometer-sized (i.e., admits of µm units as measured in at least one dimension) mirrors or microscopic mirrors; a yoke-and-hinge level **448** including a number of yokes on torsion hinges onto which the microscopic mirrors may be respectively mounted; a yoke-address electrode level **449** including a number of yoke address electrodes in pairs respectively corresponding to the number of microscopic mirrors; and a substrate level including a number of CMOS-based, static random-access memory ("SRAM") cells respectively corresponding to the number of microscopic mirrors. The yoke-and-hinge level **448** may also include a number of mirror address electrodes in pairs respectively corresponding to the number of microscopic mirrors. A bias may be created among a pair of mirror address electrodes and a pair of yoke address electrodes to electrostatically lock a corresponding microscopic mirror in an initial position. The bias may be removed to tilt (e.g., ±10-12° or increments thereof) the microscopic mirror into a subsequent position in accordance with a charge in an underlying SRAM cell. The bias may be subsequently restored among the pair of mirror address electrodes and the pair of yoke address electrodes to electrostatically lock the microscopic mirror in the subsequent position.

[0059] In yet another alternative, the mirror **346** may include a spatial light modulator array ("SLMA") for selectably phase shifting light reflected therefrom.

[0060] Each microscopic mirror of the DMD **446** or element of the SLMA may have a one-to-one correspondence with a pixel of an image sensor of an imaging device. As provided herein, a pixel of an image sensor such as the foregoing pixel may also correspond to a particular, fixed area of a surface of an article **A** and a particular, fixed area of a features map **M** of the surface of the article **A**. In view of the foregoing, adjustment of a microscopic mirror of the DMD **446** or element of the SLMA may phase shift light (e.g., reference light) reflected therefrom, which, in turn, may result in a modification when the phase-shifted light combines with light reflected from the surface of the article **A** in a combination at the foregoing pixel of the image sensor. The modification in the combination may, in turn, result in a modification of the particular, fixed area of the features map **M** to which the foregoing pixel corresponds. As such, each individually adjustable microscopic mirror or any group of microscopic mirrors up to an including the entire DMD **446** provides a phase-shifting or phase-locking means for detailed inspection of a corresponding location on a surface of an article **A** through a corresponding features map **M** of the surface of the article **A**. Likewise, each individually adjustable element or any group of elements up to an including the entire SLMA provides a phase-shifting or phase-locking means for detailed inspection of a corresponding location on a surface of an article **A** through a corresponding features map **M** of the surface of the article **A**.

[0061] The DMD **446** may be optionally mounted on an adjustable mount or stage such that the distance and/or angle of the DMD **446** to the light-splitting device **344** may be adjusted. It should be understood that the DMD **446** is not limited to the foregoing, and any reference to the DMD **446** used herein may include the DMD **446** alone or the DMD **446** in combination with one or more additional optical components provided herein in a DMD assembly.

[0062] In addition to the schematics of **Figs. 3A** and **3B** illustrating the apparatus **300** and the number of components thereof, the schematics of **Figs. 3A** and **3B** also illustrate methods for inspecting articles for features using interference in light reflected from the articles.

[0063] As shown in **Fig. 3A**, the light source **110** may provide parallel light **112**, of which outermost light rays ***a*** and ***b*** of **Fig. 3A** are representative. Focusing on light ray ***a***, light ray ***a*** may be conveyed to the light-splitting device **120**, where a first portion of light ray ***a*** may be reflected to yield light ray a_r, and where a second portion of light ray ***a*** may be transmitted to yield light ray a_t provided in reference to **Fig. 1**. Light ray a_r may be subsequently conveyed to the lens **342** where light ray a_r may be illustratively refracted as shown in a direction away from the light source **110** and toward the light trap **130**. It should be understood that the foregoing direction is for a non-limiting, illustrative purpose. Light ray a_r may be subsequently conveyed to the light-splitting device **344**, where a first portion of light ray a_r may be reflected to yield light ray $a_{r'}$, and where a second portion of light ray a_r may be transmitted to yield light ray a_{rt}. Light ray $a_{r'}$, which corresponds to a reference light ray, may be subsequently conveyed to and reflected from the mirror **346** or DMD **446** to yield light ray $a_{r''}$. Meanwhile, light ray a_{rt} may be conveyed to the surface of the article **A** where the light ray a_{rt} may interact with and/or reflect from the surface of the article **A** to yield light ray $a_{r't}$. As further shown in **Fig. 3A**, each of light rays $a_{r''}$ and $a_{r't}$ may be subsequently conveyed back to the light-splitting device **344** where light rays $a_{r''}$ and $a_{r't}$ may combine in accordance with the superposition principle to yield light ray

$\boldsymbol{a}_c$. Light ray $\boldsymbol{a}_c$ may be subsequently conveyed back to and transmitted through the light-splitting device **120** to yield light ray $\boldsymbol{a}_{ct}$. Light ray $\boldsymbol{a}_{ct}$ may be subsequently conveyed to the recording device **150** where it may be converted to an electronic signal and processed by the processing means for generating a features map such as the features map **M** of **Fig. 2**.

[0064] As shown in **Fig. 3B**, the light source **110** may provide parallel light **112**, of which outermost light rays $\boldsymbol{a}$ and $\boldsymbol{b}$ of **Fig. 3B** are representative. Focusing on light ray $\boldsymbol{b}$, light ray $\boldsymbol{b}$ may be conveyed to the light-splitting device **120**, where a first portion of light ray $\boldsymbol{b}$ may be reflected to yield light ray $\boldsymbol{b}_r$, and where a second portion of light ray $\boldsymbol{b}$ may be transmitted to yield light ray $\boldsymbol{b}_t$ provided in reference to **Fig. 1**. Light ray $\boldsymbol{b}_r$ may be subsequently conveyed to the lens **342** (e.g., bi-telecentric lens) where light ray $\boldsymbol{b}_r$ may be illustratively refracted as shown in a direction toward the light source **110** and away from the light trap **130**. It should be understood that the foregoing direction is for a non-limiting, illustrative purpose, and the foregoing direction is a different direction than that provided in reference to **Fig. 3A**. Light ray $\boldsymbol{b}_r$ may be subsequently conveyed to the light-splitting device **344**, where a first portion of light ray $\boldsymbol{b}_r$ may be reflected to yield light ray $\boldsymbol{b}_{r'}$, and where a second portion of light ray $\boldsymbol{b}_r$ may be transmitted to yield light ray $\boldsymbol{b}_{rt}$. Light ray $\boldsymbol{b}_{r'}$, which corresponds to a reference light ray, may be subsequently conveyed to and reflected from the mirror **346** or DMD **446** to yield light ray $\boldsymbol{b}_{r''}$. Meanwhile, light ray $\boldsymbol{b}_{rt}$ may be conveyed to the surface of the article **A** where the light ray $\boldsymbol{b}_{rt}$ may interact with and/or reflect from the surface of the article **A** to yield light ray $\boldsymbol{b}_{r't}$. As further shown in **Fig. 3B**, each of light rays $\boldsymbol{b}_{r''}$ and $\boldsymbol{b}_{r't}$ may be subsequently conveyed back to the light-splitting device **344** where light rays $\boldsymbol{b}_{r''}$ and $\boldsymbol{b}_{r't}$ may combine in accordance with the superposition principle to yield light ray $\boldsymbol{b}_c$. Light ray $\boldsymbol{b}_c$ may be subsequently conveyed back to and transmitted through the light-splitting device **120** to yield light ray $\boldsymbol{b}_{ct}$. Light ray $\boldsymbol{b}_{ct}$ may be subsequently conveyed to the recording device **150** where it may be converted to an electronic signal and processed by the processing means for generating a features map such as the features map **M** of **Fig. 2**, which may be the same features map **M** provided in reference to **Fig. 3A**.

[0065] **Fig. 5** provides a schematic illustrating an apparatus **500** including a number of components for inspecting articles for features using interference in light reflected from the articles. Like the apparatus **100** shown in **Fig. 1**, the apparatus **500** shown in **Fig. 5** may include, but is not limited to, a light source **110**, a light-splitting device **120**, a light trap **130**, an interferometric optical assembly **140**, and a recording device **150**. As further shown in **Fig. 5**, an article **A** may be positioned, for example, on a stage under the apparatus **500** where light from the light source **110** may illuminate, interact with, and reflect from a surface of the article **A**.

[0066] With respect to the interferometric optical assembly **140** of the apparatus **500**, the interferometric optical assembly **140** may include, but is not limited to, a lens **342**, a light-splitting device **544**, and a mirror array **546**.

[0067] With respect to the lens **342**, the lens **342** may include, but is not limited to, a telecentric lens such as the telecentric lens provided in reference to **Figs. 3A** and **3B**. For example, the lens **342** may be a bi-telecentric lens. It should be understood that the lens **342** is not limited to the foregoing, and any reference to the lens **342** used herein may include the lens **342** alone or the lens **342** in combination with one or more additional optical components provided herein in a lens assembly.

[0068] With respect to the light-splitting device **544**, the light-splitting device **544** may include, but is not limited to, a light-splitting device such as the light-splitting device **120** provided in reference to **Fig. 1**. For example, the light-splitting device **544** may be a light-splitting plate as shown in **Fig. 5**. It should be understood that the light-splitting device **544** is not limited to the foregoing, and any reference to the light-splitting device **544** used herein may include the light-splitting device **544** alone or the light-splitting device **544** in combination with one or more additional optical components provided herein in a light-splitting assembly.

[0069] With respect to the mirror array **546**, the mirror array **546** may include, but is not limited to, a mirror array substrate including an array of reflective elements in the mirror array substrate and/or on the mirror array substrate, wherein the mirror array substrate is operable to transmit light therethrough, and wherein the array of reflective elements is operable to reflect incident light back toward the light-splitting device **544**. The mirror array **546** may be optionally mounted on an adjustable mount or stage such that the distance and/or angle of the mirror array **546** to the light-splitting device **544** may be adjusted. It should be understood that the mirror array **546** is not limited to the foregoing, and any reference to the mirror array **546** used herein may include the mirror array **564** alone or the mirror array **546** in combination with one or more additional optical components provided herein in a lens assembly.

[0070] The mirror array **546** may include, but is not limited to, an array of micrometer-sized (i.e., admits of μm units as measured in at least one dimension) mirrors **547** on the mirror array substrate. The array of mirrors **547** may include first-surface mirrors at a first surface of the mirror array substrate facing the light-splitting device **544**; second-surface mirrors at a second surface of the mirror array substrate behind the first surface with respect to the light-splitting device **544**; or a combination of first-surface mirrors and second-surface mirrors. For example, the array of mirrors **547** may be an array of second-surface mirrors as shown in **Fig. 5**.

[0071] The array of mirrors **547** may include a patterned optical coating on the first-surface of the mirror array substrate and/or the second surface of the mirror array substrate, wherein the optical coating may be optionally a broadband (e.g., 400-750 nm) coating with an average reflectance of at least 99% for one or more polarization states of light (e.g., p-polarized light and s-polarized light). The patterned optical coating may provide any of a number of differently shaped mirrors in the array of mirrors **547** including, but not limited to, rectangle-shaped mirrors, square-shaped mirrors, or hexagon-shaped mirrors. For example, **Fig. 6A** provides a schematic illustrating a mirror array **646A** including an array of mirrors **547** in which each mirror is a rectangle-shaped or square-shaped mirror **647A**. For example, **Fig. 6B** provides a schematic illustrating a mirror array **646B** including an array of mirrors **547** in which each mirror is a hexagon-shaped mirror **647B**.

[0072] As provided herein, the mirror array **546** may be optionally mounted on an adjustable mount or stage such that the distance and/or angle of the mirror array **546** to the light-splitting device **544** may be adjusted. Additionally or alternatively, the mirror array **546** may be optionally mounted on a piezoelectric, XY-positioning stage such that the mirror array **546** may be translated in any XY-related direction over a distance corresponding to a sub-pixel-sized distance, a pixel-sized distance, or a multiple pixel-sized distance, wherein a pixel-sized distance corresponds to pixel size or pixel pitch in an image sensor of an imaging device. **Figs. 6A** and **6B** provide schematics illustrating translation of mirror arrays **646A** and **646B**, respectively. The processing means provided herein may be configured to generate a features map corresponding to each position into which the mirror array **546** is translated. The processing means may subsequently generate a composite features map from any two or more constituent features maps to enhance one or more features common to the two or more constituent features maps or consolidate one or more different features between the constituent features maps.

[0073] In an alternative, the mirror array **546** may include a liquid crystal-based mirror array such as the liquid crystal-based mirror array **746** of **Figs. 7A** and **7B**. The mirror array **746** may include, but is not limited to, an array of micrometer-sized (i.e., admits of μm units as measured in at least one dimension) liquid crystal cells **747**. The array of cells **747** may include any of a number of differently shaped cells including, but not limited to, rectangle-shaped cells, square-shaped cells, or hexagon-shaped cells. For example, **Figs. 7A** and **7B** provide schematics illustrating the mirror array **746** including an array of cells **747** in which each cell is a hexagon-shaped cell as exemplified by cells **647A**, **647B**, and **647C**.

[0074] The mirror array **746** may to be configured to electrically switch between any of a number of configurations in which the array of cells **747** includes cells of mixed reflective and transmissive states. For example, as shown in **Fig. 7A**, the mirror array **746** may be in a first configuration, wherein a first portion of the array of cells **747** may be in a reflective state as exemplified by the cell **747A**, and wherein a second portion of the array of cells **747** may be in a transmissive state as exemplified by the cells **747B** and **747C**. As shown in **Fig. 7B**, the mirror array **746** may be electrically switched into a second configuration, wherein the first portion of the array of cells **747** may be in a transmissive state as exemplified by the cell **747A**, wherein some of the second portion of the array of cells **747** may be in a reflective state as exemplified by the cell **747B**, and wherein some of the second portion of the array of cells **747** may remain in the transmissive state as exemplified by the cell **747C**. The processing means provided herein may be configured to generate a features map corresponding to each configuration into which the mirror array **746** is electrically switched. The processing means may subsequently generate a composite features map from any two or more constituent features maps to enhance one or more features common to the two or more constituent features maps or consolidate one or more different features between the constituent features maps.

[0075] In addition to the schematic of **Fig. 5** illustrating the apparatus **500** and the number of components thereof, the schematic of **Fig. 5** also illustrates methods for inspecting articles for features using interference in light reflected from the articles.

[0076] As shown in **Fig. 5**, the light source **110** may provide parallel light **112**, of which outermost light rays a and b of **Fig. 5** are representative. Focusing on light ray a, light ray a may be conveyed to the light-splitting device **120**, where a first portion of light ray a may be reflected to yield light ray a_r, and where a second portion of light ray a may be transmitted to yield light ray a_t provided in reference to **Fig. 1**. Light ray a_r may be subsequently conveyed to the lens **342** where light ray a_r may be illustratively refracted as shown in a direction away from the light source **110** and toward the light trap **130**. It should be understood that the foregoing direction is for a non-limiting, illustrative purpose, and the foregoing direction may be a different direction such as that shown in **Fig. 5** for light ray b. Light ray a_r may be subsequently conveyed to and transmitted through the mirror array substrate of the mirror array **546** to the light-splitting device **544**, where a first portion of light ray a_r may be reflected to yield light ray $a_{r'}$, and where a second portion of light ray a_r may be transmitted to yield light ray a_{rt}. Light ray $a_{r'}$, which corresponds to a reference light ray, may be subsequently conveyed to and reflected from a mirror **547** of the mirror array **546** to yield light ray $a_{r''}$. Meanwhile, light ray a_{rt} may be conveyed to the surface of the article **A** where the light ray a_{rt} may interact with and/or reflect from the surface of the article **A** to yield light ray $a_{r't}$. As further shown in **Fig. 5**, each of light rays $a_{r''}$ and $a_{r't}$ may be subsequently conveyed back to the light-splitting device **544** where light rays $a_{r''}$ and $a_{r't}$ may combine in accordance with the superposition principle to yield light ray a_c. Light ray a_c may be subsequently conveyed back to and transmitted through the light-splitting device **120** to yield light ray a_{ct}. Light ray a_{ct} may be subsequently conveyed to the recording device **150** where it may be converted to an electronic signal and processed by the processing means for generating a features map such as the features map **M** of **Fig. 2**.

[0077] **Fig. 8** provides a schematic illustrating an apparatus **800** including a number of components for inspecting articles for features using interference in light reflected from the articles. Like the apparatus **100** shown in **Fig. 1**, the apparatus **800** shown in **Fig. 8** may include, but is not limited to, a light source **110**, a light-splitting device **120**, a light trap **130**, an interferometric optical assembly **140**, and a recording device **150**. As further shown in **Fig. 8**, an article **A** may be positioned, for example, on a stage under the apparatus **800** where light from the light source **110** may illuminate, interact with, and reflect from a surface of the article **A**.

[0078] With respect to the interferometric optical assembly **140** of the apparatus **800**, the interferometric optical assembly **140** may include, but is not limited to, a first lens **342**, a polarizer **844**, and a second lens **842**.

[0079] With respect to the first lens **342**, the first lens **342** may include, but is not limited to, a telecentric lens such as the telecentric lens provided in reference to **Figs. 3A** and **3B**. For example, the first lens **342** may be a bi-telecentric lens. It should be understood that the first lens **342** is not limited to the foregoing, and any reference to the first lens **342** used herein may include the first lens **342** alone or the first lens **342** in combination with one or more additional optical components provided herein in a lens assembly.

[0080] With respect to the polarizer **844**, the polarizer **844** may include, but is not limited to, any light-splitting, light-polarizing device operable to split incident light into one or more different polarization states in one or more directions, respectively. The polarizer **844** may be optionally mounted on an adjustable mount or stage such that the distance and/or angle of the polarizer **844** to the first lens **342**, the second lens **842**, or both the first lens **342** and the second lens **842** may be adjusted. It should be understood that the polarizer **844** is not limited to the foregoing, and any reference to the polarizer **844** used herein may include the polarizer **844** alone or the polarizer **844** in combination with one or more additional optical components provided herein in a polarizer assembly.

[0081] The polarizer **844** may split incident light into a first portion with a first polarization state and a second portion with a second, different polarization state, and the polarizer **844** may simultaneously transmit the first portion in a first direction and the second portion in a second, optionally different direction. For example, the polarizer **844** may split the incident light into orthogonal, linearly polarized light including s-polarized light and p-polarized light, and the polarizer **844** may transmit the s-polarized light and the p-polarized light parallel to each other in the same direction, or the polarizer **844** may transmit the s-polarized light and the p-polarized light oblique (e.g., 15-45°) to each other in different directions. The composition, construction, or the composition and construction of the polarizer **844** determines the polarization states and directions into which the incident light is split, wherein the composition includes substrate, bonding, and/or coating compositions of the polarizer **844**, and wherein the construction includes the manner in which one or more of the foregoing is assembled into the polarizer **844**. The polarizer **844** may include, but is not limited to, a beam displacer (e.g., calcite-based prism optionally with one or more anti-reflective coatings), a Wollaston prism (e.g., two calcite-based prisms bonded together optionally with one or more anti-reflective coatings), or a number of beam displacers or Wollaston prisms in an array as provided in **Figs. 9A** and **9B**.

[0082] With respect to the second lens **842**, the second lens **842** may be the same as or different than the first lens **342**. The second lens **842** may include, but is not limited to, a telecentric lens such as the telecentric lens provided in reference to **Figs. 3A** and **3B**. For example, the second lens **842** may be a bi-telecentric lens. It should be understood that the second lens **842** is not limited to the foregoing, and any reference to the second lens **842** used herein may include the second lens **842** alone or the second lens **842** in combination with one or more additional optical components provided herein in a lens assembly.

[0083] In addition to the schematic of **Fig. 8** illustrating the apparatus **800** and the number of components thereof, the schematic of **Fig. 8** also illustrates methods for inspecting articles for features using interference in light reflected from the articles.

[0084] As shown in **Fig. 8**, the light source **110** may provide parallel light **112**, of which inner light ray ***a*** of **Fig. 8** is representative. Light ray ***a*** may be conveyed to the light-splitting device **120**, where a first portion of light ray ***a*** may be reflected to yield light ray a_r, and where a second portion of light ray ***a*** may be transmitted to yield light ray a_t provided in reference to **Fig. 1**. Light ray a_r may be subsequently conveyed to the lens **342** where light ray a_r may be illustratively refracted as shown in a direction away from the light source **110** and toward the light trap **130**. It should be understood that the foregoing direction is for a non-limiting, illustrative purpose, and the foregoing direction may be a different direction such as that provided herein. Light ray a_r may be subsequently conveyed to the polarizer **844**, where a first portion of light ray a_r may be split to yield light ray a_p, and where a second portion of light ray a_r may be split to yield light ray $a_{p'}$, which corresponds to a reference light ray orthogonal to light ray a_p. Light rays a_p and $a_{p'}$ may be subsequently refracted through the lens **842** and conveyed to the surface of the article **A** where the light rays a_p and $a_{p'}$ may interact with and/or reflect from adjacent locations on the surface of the article **A** to yield light rays a_{pr} and $a_{p'r}$. As further shown in **Fig. 8**, light rays a_{pr} and $a_{p'r}$ may be subsequently refracted through the lens **842** and conveyed to the polarizer **844** where the light rays a_{pr} and $a_{p'r}$ may combine in accordance with the superposition principle to yield light ray a_c. Light ray a_c may be subsequently conveyed back to and transmitted through the light-splitting device **120** to yield light ray a_{ct}. Light ray a_{ct} may be subsequently conveyed to the recording device **150** where it may be converted to an electronic signal and processed by the processing means for generating a features map such as the features map **M** of **Fig. 2**.

[0085] **Figs. 9A** and **9B** provide schematics respectively illustrating an apparatus **900A** and an apparatus **900B**, each of which includes a number of components for inspecting articles for features using interference in light reflected from the articles. Like the apparatus **100** shown in **Fig. 1**, each of the apparatus **900A** and the apparatus **900B** may individually include, but is not limited to, a light source **110**, a light-splitting device **120**, a light trap **130**, an interferometric optical assembly **140**, and a recording device **150**. As further shown in **Figs. 9A** and **9B**, an article **A** may be positioned, for example, on a stage under the apparatus **900A** or the apparatus

900B where light from the light source **110** may illuminate, interact with, and reflect from a surface of the article **A**.

[0086] With respect to the interferometric optical assembly **140**, each of the apparatus **900A** and the apparatus **900B** individually includes a non-limiting combination of components for the interferometric optical assembly **140** provided in reference to at least **Figs. 3A**, **3B**, and **8**. As shown in **Figs. 9A** and **9B**, the interferometric optical assembly **140** may include, but is not defined by or limited to, a lens **342**, a light-splitting device **344**, a polarizer **844**, a second lens **842**, and a mirror **346**.

[0087] With respect to the first lens **342**, the first lens **342** may include, but is not limited to, a telecentric lens such as the telecentric lens provided in reference to **Figs. 3A** and **3B**. For example, the first lens **342** may be a bi-telecentric lens. It should be understood that the first lens **342** is not limited to the foregoing, and any reference to the first lens **342** used herein may include the first lens **342** alone or the first lens **342** in combination with one or more additional optical components provided herein in a lens assembly.

[0088] With respect to the light-splitting device **344**, the light-splitting device **344** may include, but is not limited to, a light-splitting device such as the light-splitting device **120** provided in reference to **Fig. 1**. For example, the light-splitting device **344** may be a light-splitting cube as shown in **Figs. 9A** and **9B**. It should be understood that the light-splitting device **344** is not limited to the foregoing, and any reference to the light-splitting device **344** used herein may include the light-splitting device **344** alone or the light-splitting device **344** in combination with one or more additional optical components provided herein in a light-splitting assembly.

[0089] With respect to the polarizer **844**, the polarizer **844** may include, but is not limited to, the polarizer **844** provided in reference to **Fig. 8**. For example, the polarizer **844** may be a beam displacer, a Wollaston prism, or a number of beam displacers or Wollaston prisms in an array as provided in **Figs. 9A** and **9B**. It should be understood that the polarizer **844** is not limited to the foregoing, and any reference to the polarizer **844** used herein may include the polarizer **844** alone or the polarizer **844** in combination with one or more additional optical components provided herein in a polarizer assembly.

[0090] With respect to the second lens **842**, the second lens **842** may be the same as or different than the first lens **342**. The second lens **842** may include, but is not limited to, a telecentric lens such as the telecentric lens provided in reference to **Figs. 3A** and **3B**. For example, the second lens **842** may be a bi-telecentric lens. It should be understood that the second lens **842** is not limited to the foregoing, and any reference to the second lens **842** used herein may include the second lens **842** alone or the second lens **842** in combination with one or more additional optical components provided herein in a lens assembly.

[0091] With respect to the mirror **346**, the mirror **346** may include, but is not limited to, the mirror **346** provided in reference to **Figs. 3A** and **3B**. For example, the mirror **346** may be a first-surface mirror or a DMD. It should be understood that the mirror **346** is not limited to the foregoing, and any reference to the mirror **346** used herein may include the mirror **346** alone or the mirror **346** in combination with one or more additional optical components provided herein in a mirror assembly.

[0092] As provided in reference to the apparatus **100** of **Fig. 1**, apparatus provided herein may include one or more polarization-management assemblies or systems for managing polarization of light before and/or after interaction with the surface of the article **A**, as well for optionally managing polarization of reference light. The one or more polarization-management assemblies or systems may include any number of polarization-management components including, but not limited to, one or more polarization-management components selected from polarization filters or polarizers (e.g., linear polarizers), polarization rotators or retarders (e.g., waveplates such as quarter-wave plates and half-wave plates), compensators (e.g., variable compensator), and photoelastic modulators. It should be understood that the polarization-management assemblies or systems are not limited to the foregoing, and any reference to the polarization-management assemblies or systems used herein may include one or more additional optical components provided herein in the polarization-management assemblies or systems.

[0093] **Fig. 9B** provides a schematic illustrating an apparatus **900B** optionally including one or more polarization-management systems or components thereof. As shown in **Fig. 9B**, the apparatus **900B** may optionally include a first polarization-management system for managing polarization of light before interaction with the surface of the article **A**, wherein the first polarization-management system includes a polarization rotator **952**. As further shown in **Fig. 9B**, the apparatus **900B** may optionally include a second polarization-management system for managing polarization of reference light, wherein the second polarization-management system includes a polarization rotator **954** and/or polarization filter **956**. As further shown in **Fig. 9B**, the apparatus **900B** may optionally include a third polarization-management system for managing polarization of light after interaction with the surface of the article **A**, wherein the third polarization-management system includes a polarization filter **958**. It should be understood that the foregoing polarization-management systems and/or the components thereof are not limited to the apparatus **900B**, and any apparatus provided herein may include one or more of the polarization-management systems and/or the components thereof.

[0094] While the schematics of **Figs. 9A** and **9B** respectively illustrate the apparatus **900A** and **900B** and the number of components thereof, the schematics do not expressly illustrate methods for inspecting articles for features using interference in light reflected from the articles. However, the methods for inspecting articles for features using interference in light reflected from the articles may be provided with reference to **Figs. 3A**, **3B**, and **8**.

[0095] As shown in **Fig. 9**, the light source **110** may provide parallel light **112**, of which light ray ***a*** of **Figs. 3A**, **3B**, and **8** is representative. Focusing on light ray ***a*** of **Figs. 3A** and **3B**, light ray ***a*** may be conveyed to the light-splitting device **120**, optionally through the polarization rotator **952** first, where a first portion of light ray ***a*** may be reflected to yield light ray $\boldsymbol{a_r}$, and where a second portion of light ray ***a*** may be transmitted to yield light ray $\boldsymbol{a_t}$ provided in reference to **Fig. 1**. Light ray $\boldsymbol{a_r}$ may be subsequently conveyed to the lens **342** where light ray $\boldsymbol{a_r}$ may be illustratively refracted as shown in a direction away from the light source **110** and toward the light trap **130**. It should be understood that the foregoing direction is for a non-limiting, illustrative purpose. Light ray $\boldsymbol{a_r}$ may be subsequently conveyed to the light-splitting device **344**, where a first portion of light ray a_r may be reflected to yield light ray $a_{r'}$, and where a second portion of light ray a_r may be transmitted to yield light ray a_{rt}. Light ray $a_{r'}$ may be subsequently conveyed to the mirror **346** or DMD **446**, optionally through the polarization rotator **954** and the polarization filter **956** first, and reflected from the mirror **346** or DMD **446** to yield light ray $a_{r''}$. Meanwhile, light ray a_{rt} may be conveyed to the polarizer **844** shown in **Figs. 9A** and **9B**, where a first portion of light ray a_{rt} may be split to yield light ray a_p shown in **Fig. 8**, and where a second portion of light ray a_{rt} may be split to yield orthogonal light ray $a_{p'}$ shown in **Fig. 8**. Focusing on light rays a_p and $a_{p'}$ of **Fig. 8**, light rays a_p and $a_{p'}$ may be subsequently refracted through the lens **842** and conveyed to the surface of the article **A** where the light rays a_p and $a_{p'}$ may interact with and/or reflect from adjacent locations on the surface of the article **A** to yield light rays a_{pr} and $a_{p'r}$. Light rays a_{pr} and $a_{p'r}$ may be subsequently refracted through the lens **842** and conveyed to the polarizer **844** where the light rays a_{pr} and $a_{p'r}$ may combine in accordance with the superposition principle to yield light ray a_c. Each of light rays a_c (**Fig. 8**) and $a_{r''}$ (**Figs. 3A** and **3B**) may be subsequently conveyed back to the light-splitting device **344** where light rays a_c and $a_{r''}$ may combine in accordance with the superposition principle. The combination of light ray a_c and light ray $a_{r''}$ may be subsequently conveyed back to and transmitted through the light-splitting device **120** to yield light ray a_{ct}. Light ray a_{ct} may be subsequently conveyed to the recording device **150**, optionally through the polarization filter **958** first, where it may be converted to an electronic signal and processed by the processing means for generating a features map such as the features map **M** of **Fig. 2**.

[0096] As such, provided herein is a method comprising conveying parallel light along a primary axis through a telecentric lens and a light-splitting device, respectively; illuminating a majority of a surface of an article with the parallel light; conveying reflected light from the surface of the article along the primary axis back through the light-splitting device and the telecentric lens, respectively; and recording interference resulting from a combination of light comprising at least the reflected light from the surface of the article. In some embodiments, the telecentric lens is a bi-telecentric lens. In some embodiments, the light-splitting device produces orthogonal, linearly polarized light from the parallel light. In some embodiments, the method further comprises conveying the polarized light along the primary axis through another telecentric lens before illuminating the majority of the surface of the article. In some embodiments, height differences in one or more surface features of the surface of the article provide different path lengths for the polarized light and produce phase differences in the reflected light from the surface of the article. In some embodiments, recording interference resulting from the combination of light comprises imaging the interference from the phase differences in the reflected light from the surface of the article. In some embodiments, the light-splitting device transmits a first portion of the parallel light and reflects a second portion the parallel light. In some embodiments, the method further comprises reflecting the second portion of the parallel light from one or more mirrors placed along the primary axis or one or more mirrors placed along a secondary axis at an angle to the primary axis. In some embodiments, the combination of light comprising at least the reflected light from the surface of the article further comprises the second portion of the parallel light after reflecting the second portion of the parallel light from the one or more mirrors. In some embodiments, recording interference resulting from the combination of light comprises imaging the interference from phase differences in the combination of the reflected light from the surface of the article and the second portion of the parallel light after reflecting the second portion of the parallel light from the one or more mirrors.

[0097] Also provided herein is a method, comprising conveying parallel light through a telecentric lens and a light-splitting device, respectively, wherein the light-splitting device transmits a surface-interactive portion of the parallel light and reflects a reference portion of the parallel light toward a mirror array; illuminating a majority of a surface of an article with the surface-interactive portion of the parallel light; conveying reflected light from the surface of the article back through the light-splitting device and the telecentric lens, respectively; and recording interference resulting from a combination of the reflected light from the surface of the article and the reference portion of the parallel light subsequent to reflection from the mirror array. In some embodiments, the telecentric lens is a bi-telecentric lens, and the light-splitting device is a beam splitter plate. In some embodiments, the mirror array comprises an array of rectangle-shaped mirrors mounted on a piezoelectric, XY-positioning stage. In some embodiments, the mirror array comprises an array of hexagonal-shaped mirrors mounted on a piezoelectric, XY-positioning stage. In some embodiments, the mirror array comprises an array of liquid crystal cells configured to electrically switch between reflective and transmissive states.

[0098] Also provided herein is a method, comprising conveying parallel light along a primary axis through a telecentric lens and a light-splitting device, respectively, wherein the light-splitting device transmits a surface-interactive portion of the parallel light and reflects a reference portion of the parallel light toward a tilted mirror; illuminating a majority of a surface of an article with the surface-interactive portion of the parallel light; conveying reflected light from the surface of the article back through the light-splitting device and the telecentric lens, respectively; and recording interference resulting from a combination of the reflected light from the surface of the article and the reference portion of the parallel light subsequent to reflection from the tilted mirror. In some embodiments, the telecentric lens is a bi-telecentric lens. In some embodiments, the light-splitting device is a beam splitter cube. In some embodiments, the tilted mirror comprises an array of individually adjustable, rectangle-shaped mirrors. In some embodiments, each of the rectangle-shaped mirrors may be locked in position for phase locking with respect to a corresponding location on the surface of the article.

[0099] While some particular embodiments have been provided herein, and while these particular embodiments have been provided in considerable detail, it is not the intention for these particular embodiments to limit the scope of the concepts provided herein. Additional adaptations and/or modifications may appear to persons having ordinary skill in the art, and, in broader aspects, these adaptations and/or modifications may be encompassed as well. Accordingly, departures may be made from the foregoing embodiments without departing from the scope of the concepts provided herein.

CLAIMS

What is claimed is:

1. A method, comprising:

conveying parallel light along a primary axis through a telecentric lens and a light-splitting device, respectively;

illuminating a majority of a surface of an article with the parallel light;

conveying reflected light from the surface of the article along the primary axis back through the light-splitting device and the telecentric lens, respectively; and

recording interference resulting from a combination of light comprising at least the reflected light from the surface of the article.

2. The method of Claim 1,

wherein the telecentric lens is a bi-telecentric lens.

3. The method of Claim 2,

wherein the light-splitting device produces orthogonal, linearly polarized light from the parallel light.

4. The method of Claim 3, further comprising

conveying the polarized light along the primary axis through another telecentric lens before illuminating the majority of the surface of the article.

5. The method of Claim 3,

wherein height differences in one or more surface features of the surface of the article provide different path lengths for the polarized light and produce phase differences in the reflected light from the surface of the article.

6. The method of Claim 5,

wherein recording interference resulting from the combination of light comprises imaging the interference from the phase differences in the reflected light from the surface of the article.

7. The method of Claim 2,

wherein the light-splitting device transmits a first portion of the parallel light and reflects a second portion the parallel light.

8. The method of Claim 7, further comprising

reflecting the second portion of the parallel light from one or more mirrors placed along the primary axis or one or more mirrors placed along a secondary axis at an angle to the primary axis.

9. The method of Claim 8,

wherein the combination of light comprising at least the reflected light from the surface of the article further comprises the second portion of the parallel light after reflecting the second portion of the parallel light from the one or more mirrors.

10. The method of Claim 9,

wherein recording interference resulting from the combination of light comprises imaging the interference from phase differences in the combination of the reflected light from the surface of the article and the second portion of the parallel light after reflecting the second portion of the parallel light from the one or more mirrors.

11. A method, comprising:

conveying parallel light through a telecentric lens and a light-splitting device, respectively,

wherein the light-splitting device transmits a surface-interactive portion of the parallel light and reflects a reference portion of the parallel light toward a mirror array;

illuminating a majority of a surface of an article with the surface-interactive portion of the parallel light;

conveying reflected light from the surface of the article back through the light-splitting device and the telecentric lens, respectively; and recording interference resulting from a combination of the reflected light from the surface of the article and the reference portion of the parallel light subsequent to reflection from the mirror array.

12. The method of Claim 11,

wherein the telecentric lens is a bi-telecentric lens, and

wherein the light-splitting device is a beam splitter plate.

13. The method of Claim 11,

wherein the mirror array comprises an array of rectangle-shaped mirrors mounted on a piezoelectric, XY-positioning stage.

14. The method of Claim 11,

wherein the mirror array comprises an array of hexagonal-shaped mirrors mounted on a piezoelectric, XY-positioning stage.

15. The method of Claim 11,

wherein the mirror array comprises an array of liquid crystal cells configured to electrically switch between reflective and transmissive states.

16. A method, comprising:

conveying parallel light along a primary axis through a telecentric lens and a light-splitting device, respectively,

wherein the light-splitting device transmits a surface-interactive portion of the parallel light and reflects a reference portion of the parallel light toward a tilted mirror;

illuminating a majority of a surface of an article with the surface-interactive portion of the parallel light;

conveying reflected light from the surface of the article back through the light-splitting device and the telecentric lens, respectively; and

recording interference resulting from a combination of the reflected light from the surface of the article and the reference portion of the parallel light subsequent to reflection from the tilted mirror.

17. The method of Claim 16,

wherein the telecentric lens is a bi-telecentric lens.

18. The method of Claim 16,

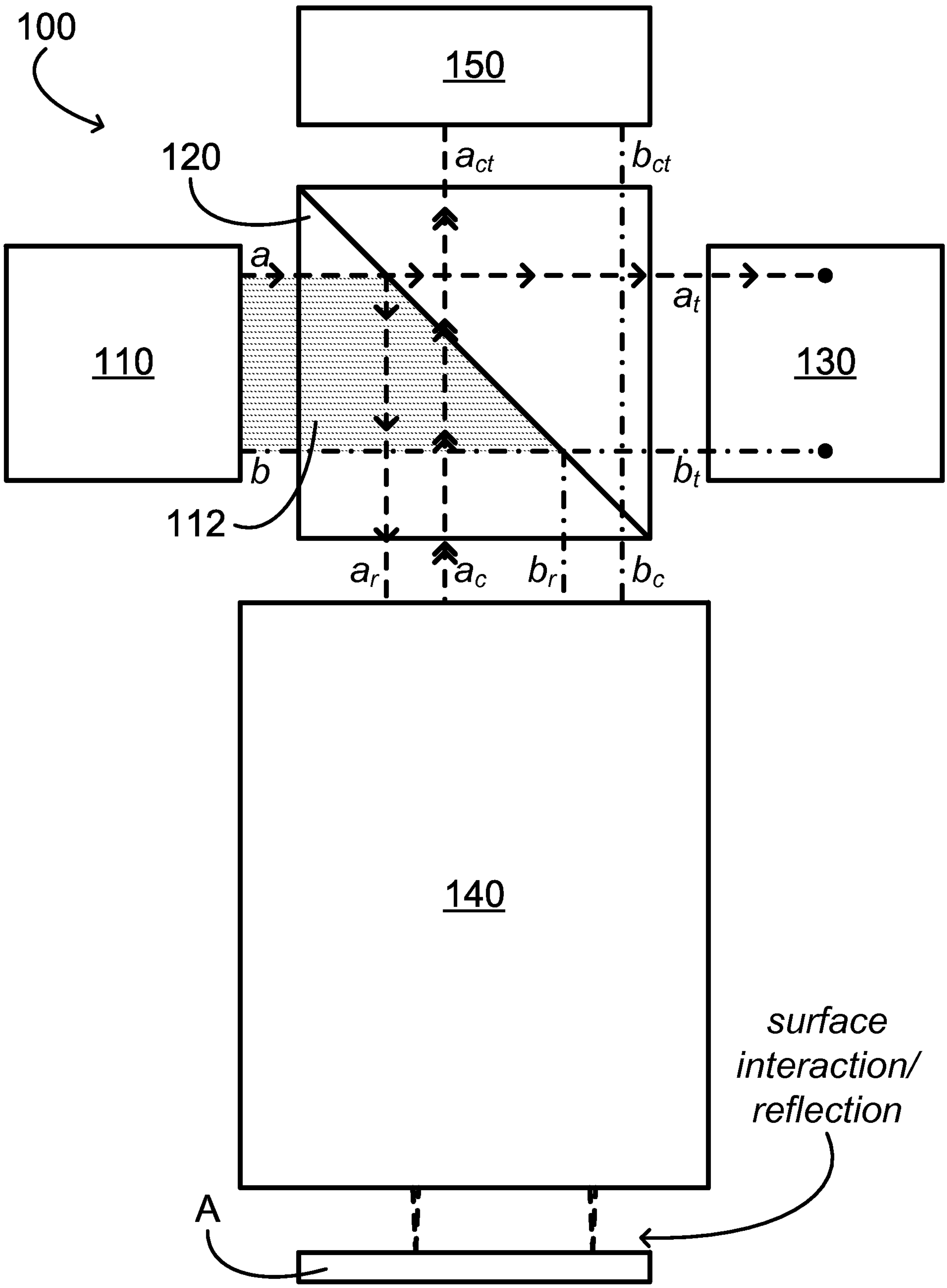
wherein the light-splitting device is a beam splitter cube.

19. The method of Claim 16,

wherein the tilted mirror comprises an array of individually adjustable, rectangle-shaped mirrors.

20. The method of Claim 16,

wherein each of the rectangle-shaped mirrors may be locked in position for phase locking with respect to a corresponding location on the surface of the article.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150
a_{ct}
b_{ct}
120
a
110
130
a_t
b
b_t
112
a_r
a_c
b_r
b_c
140
surface interaction/ reflection
A

FIG. 1

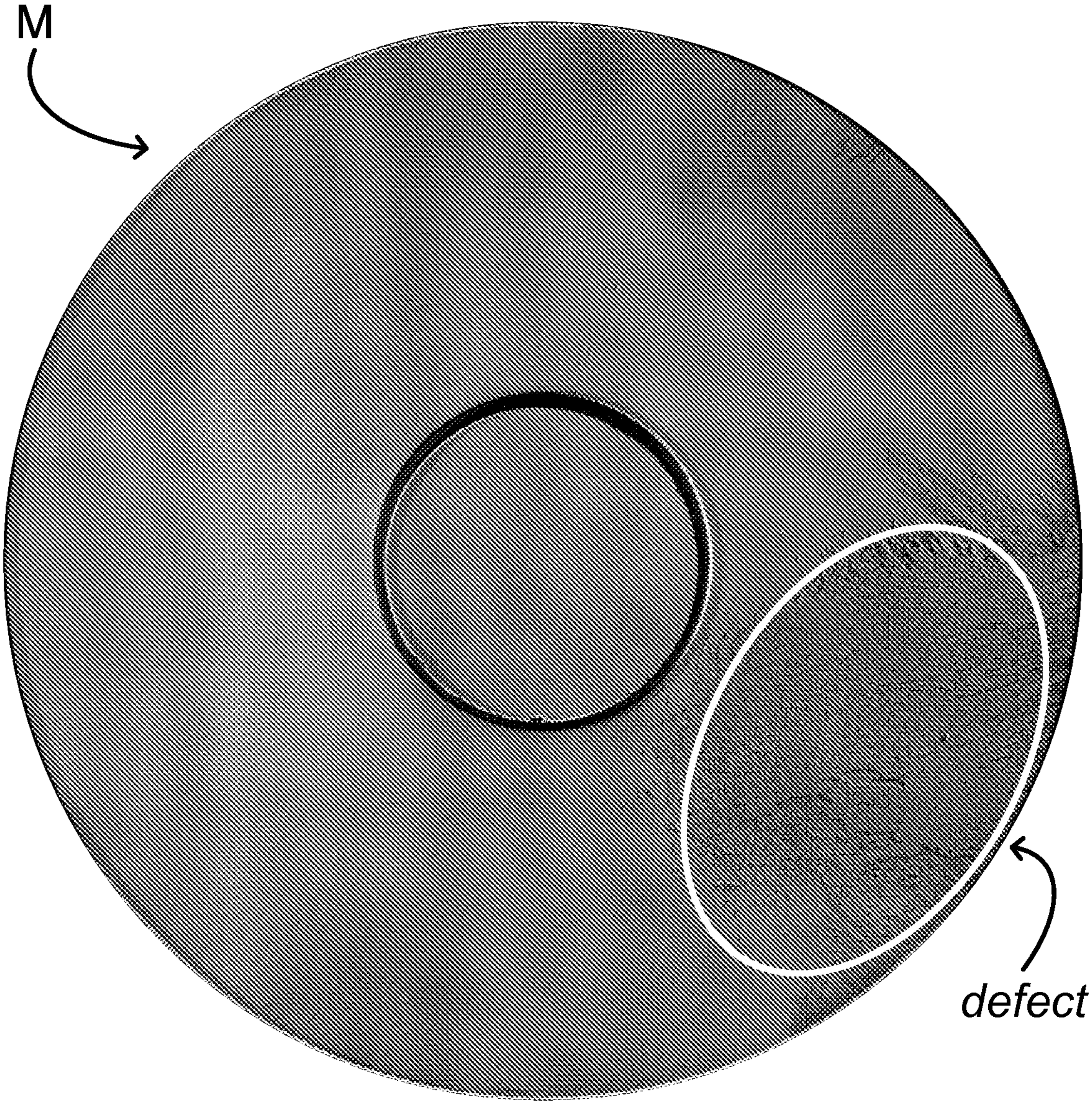
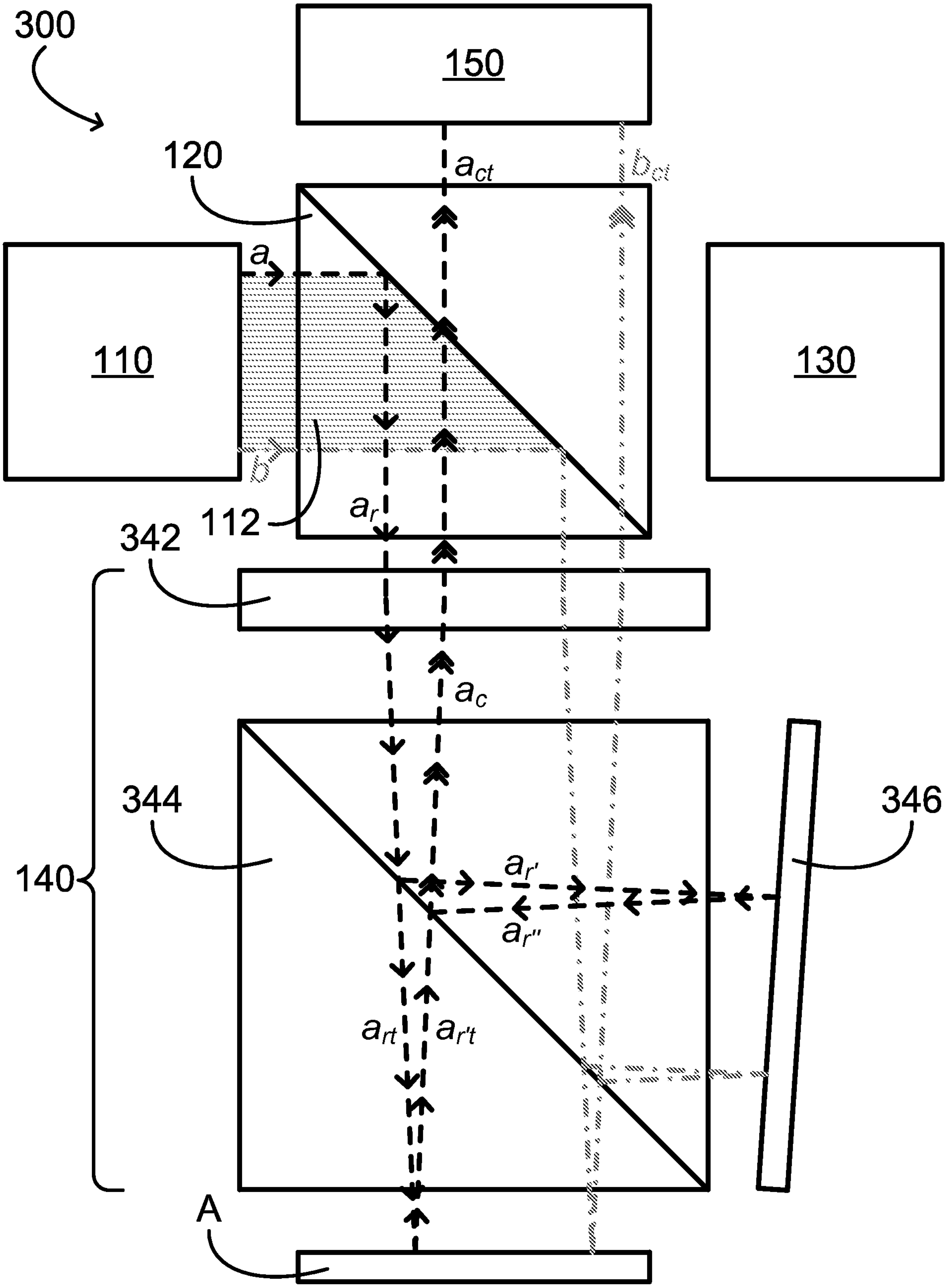


FIG. 2



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120
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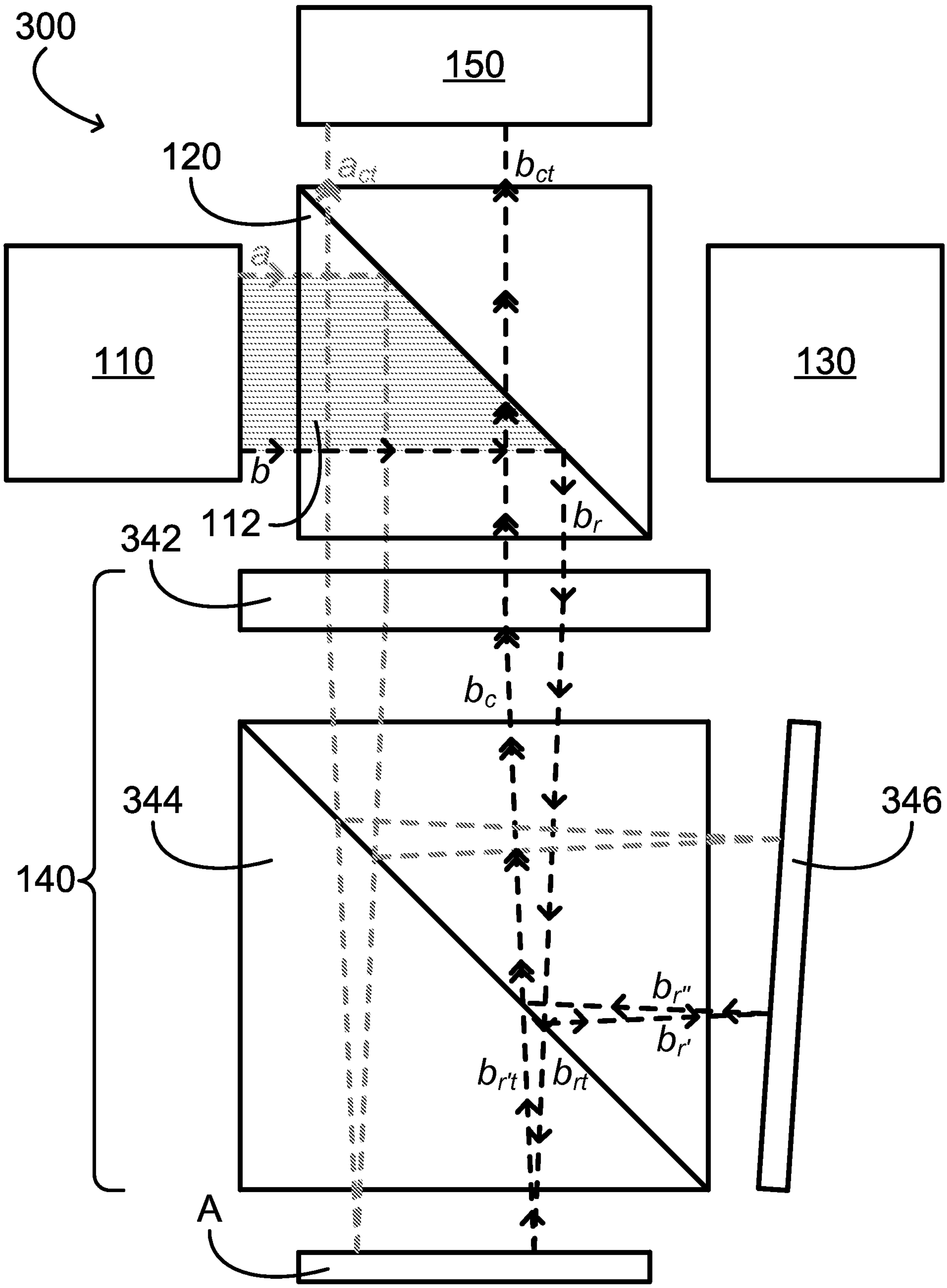
b_{ct}
a
110
130
b
112
a_r
342
a_c
344
346
140
$a_{r'}$
$a_{r''}$
a_{rt}
$a_{r't}$
A

FIG. 3A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$b_{r'}$
$b_{r't}$
b_{rt}
A

FIG. 3B

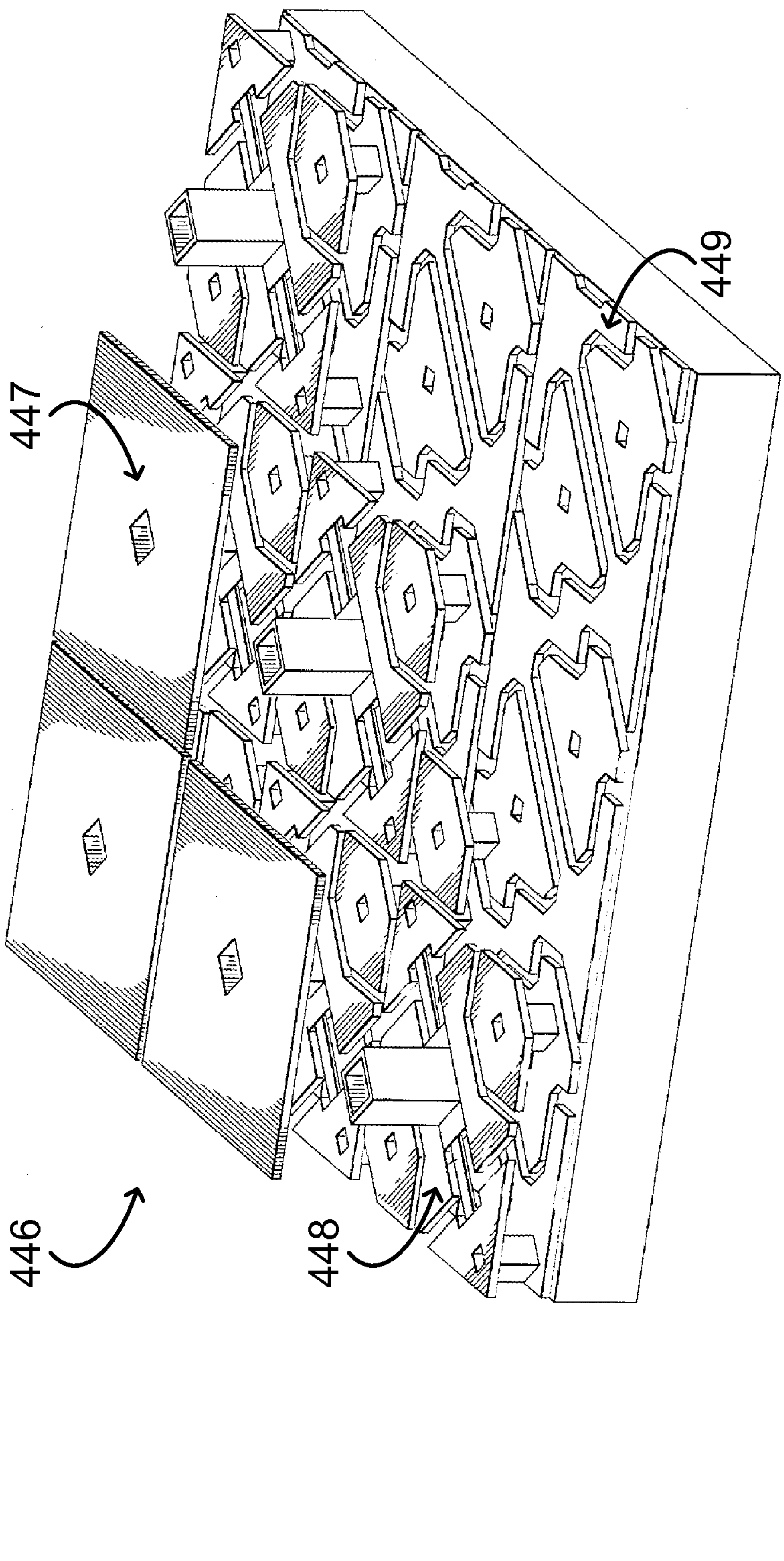
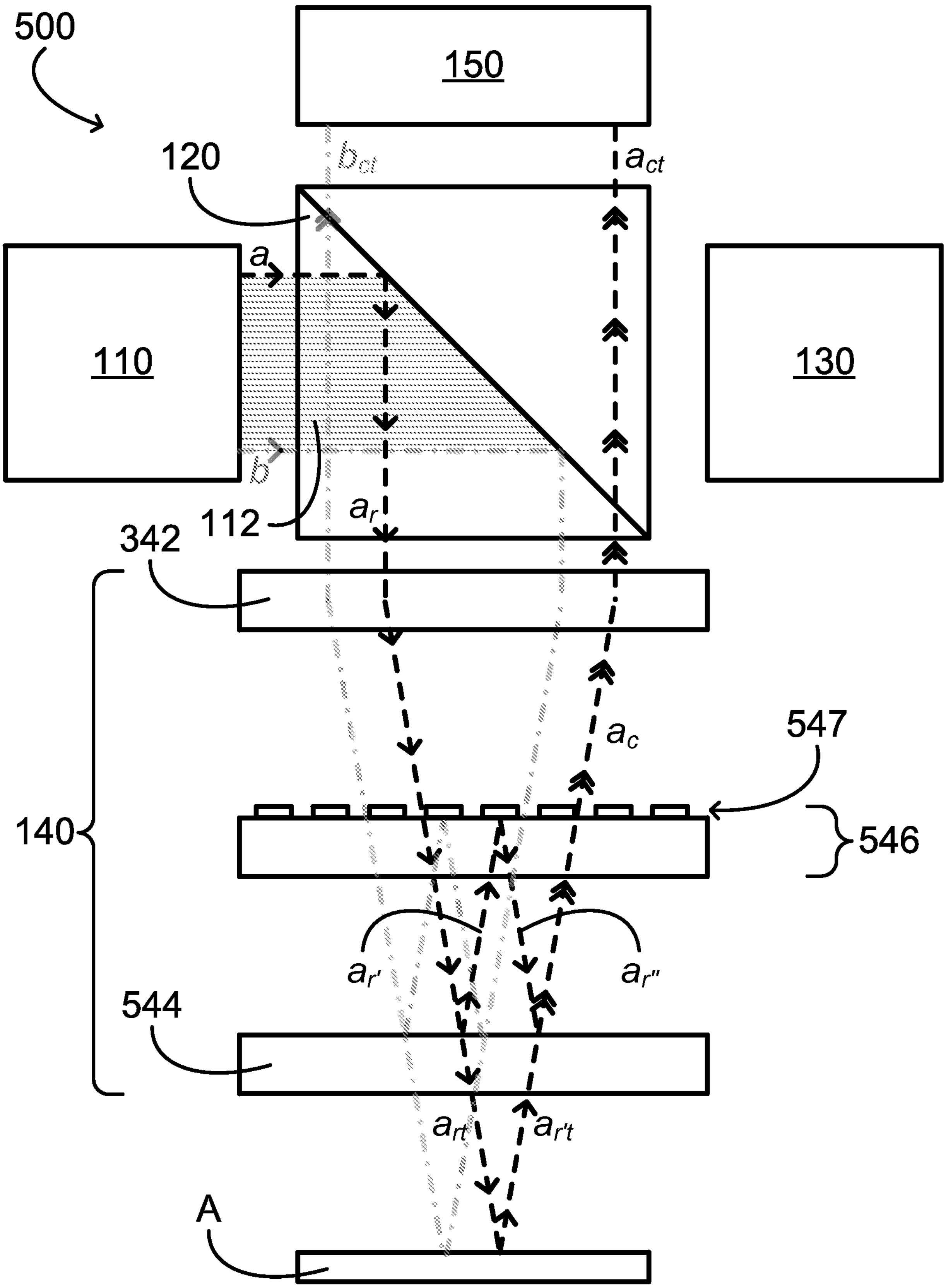


FIG. 4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120
b_{ct}
a_{ct}
a
110
130
b
112
a_r
342
a_c
547
140
546
$a_{r'}$
$a_{r''}$
544
a_{rt}
$a_{r't}$
A

FIG. 5

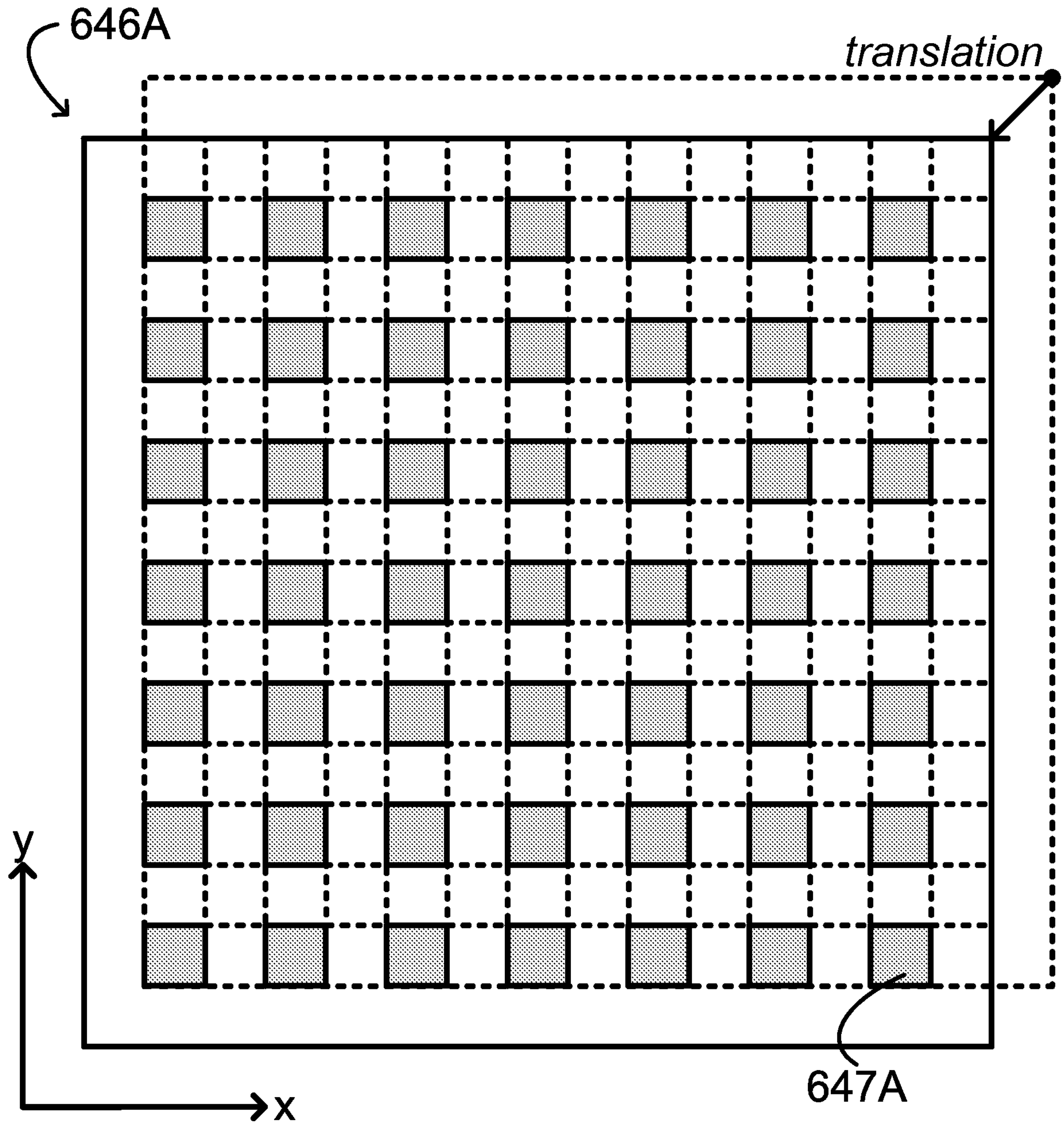

FIG. 6A

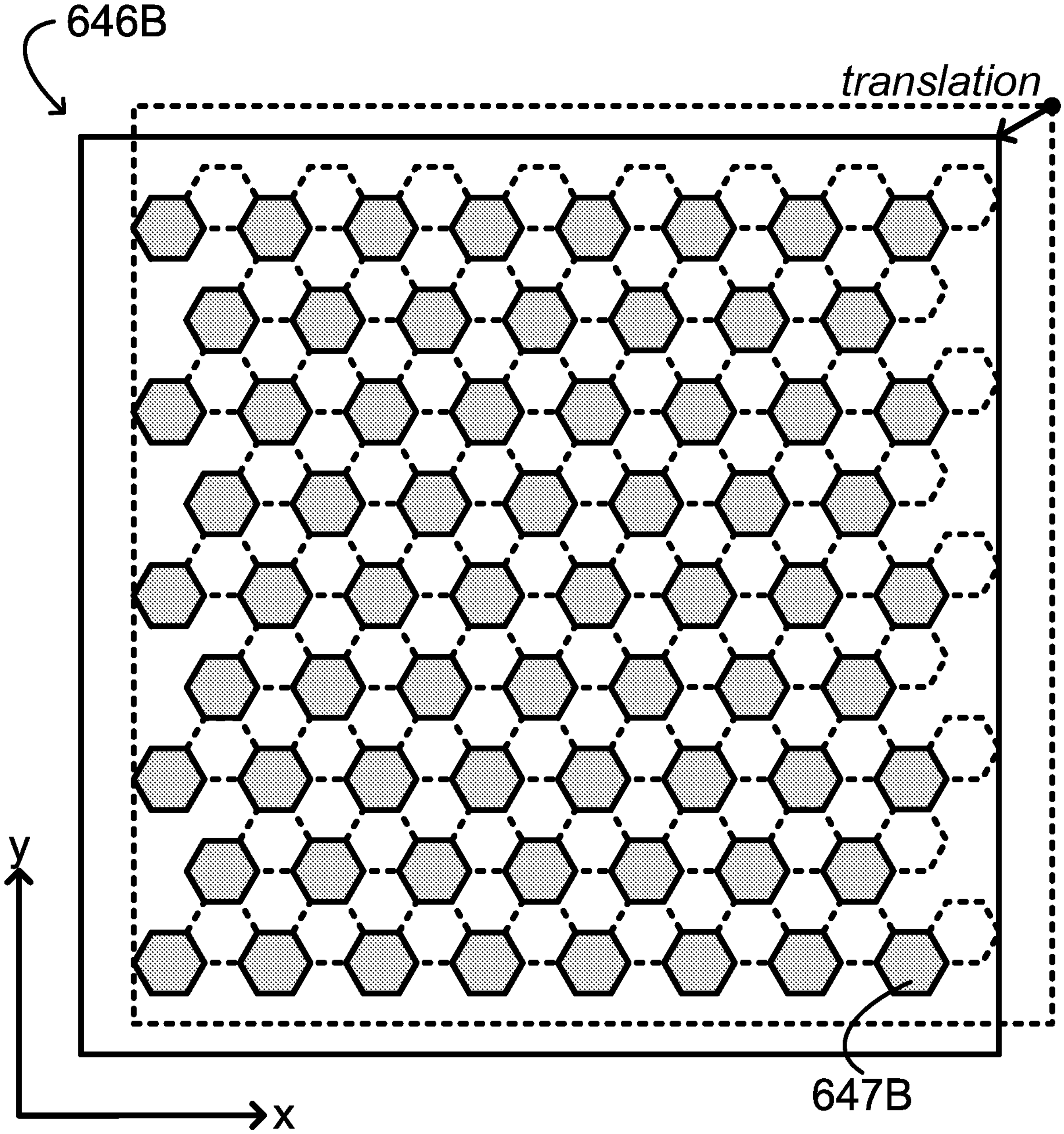

FIG. 6B

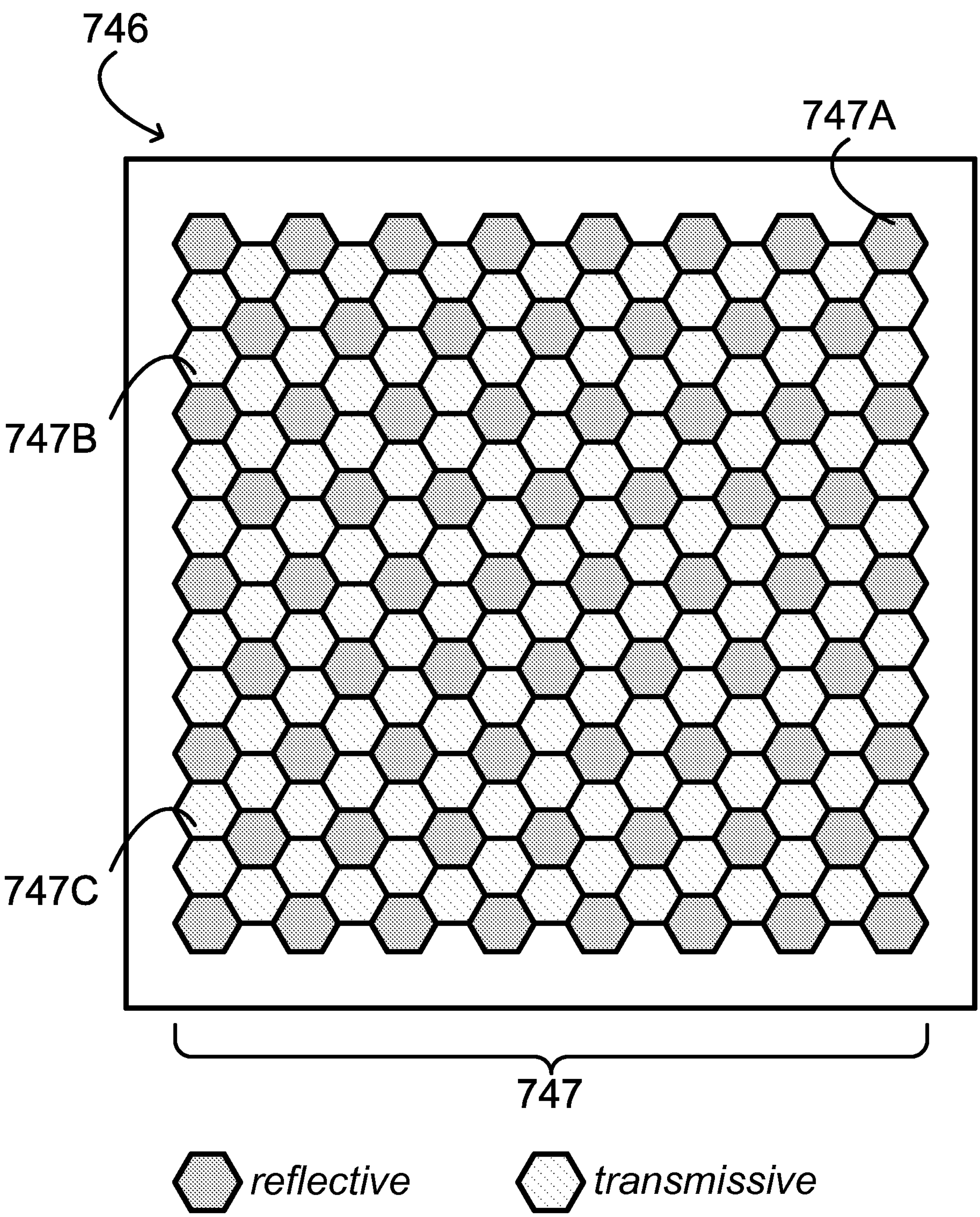

FIG. 7A

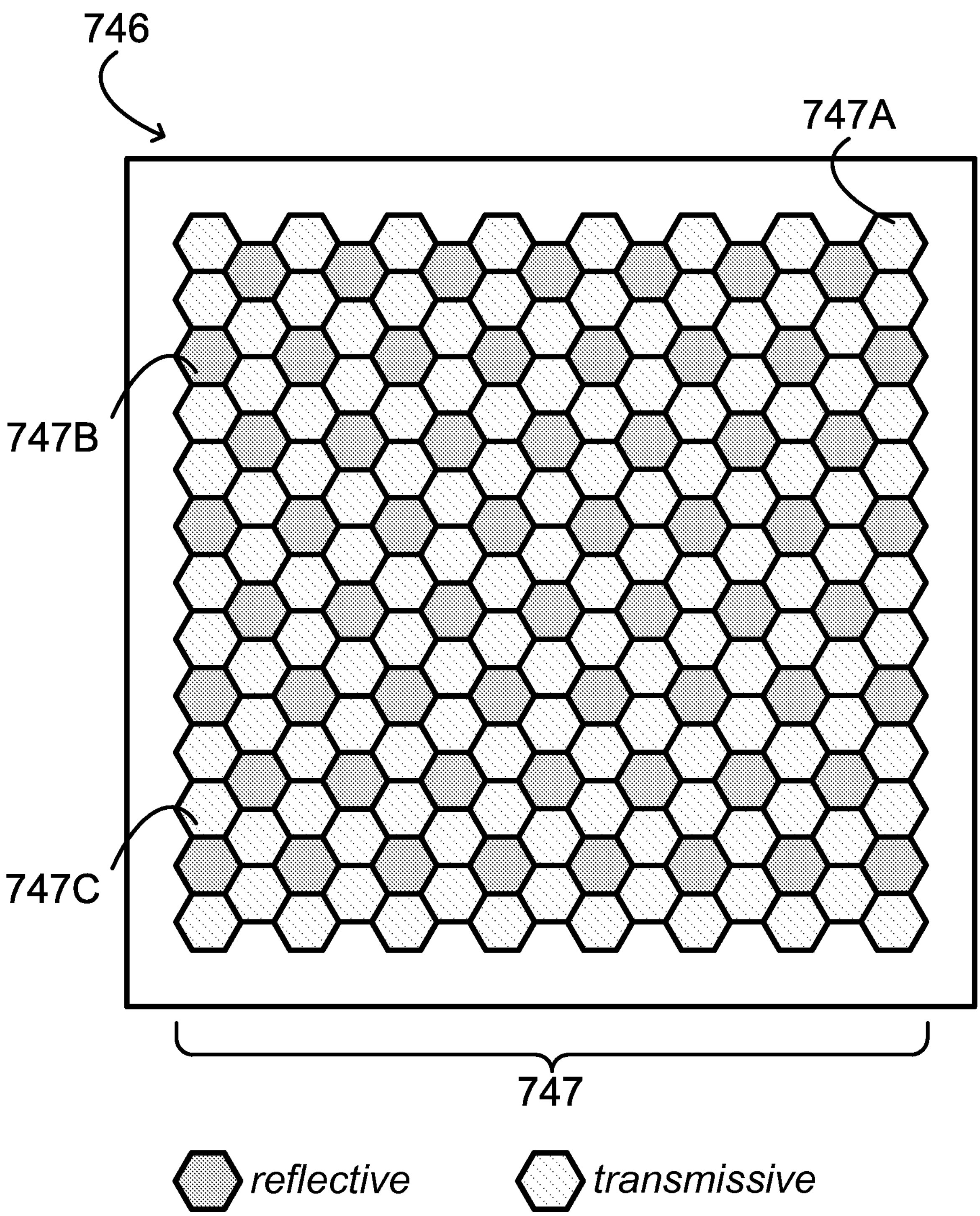

FIG. 7B

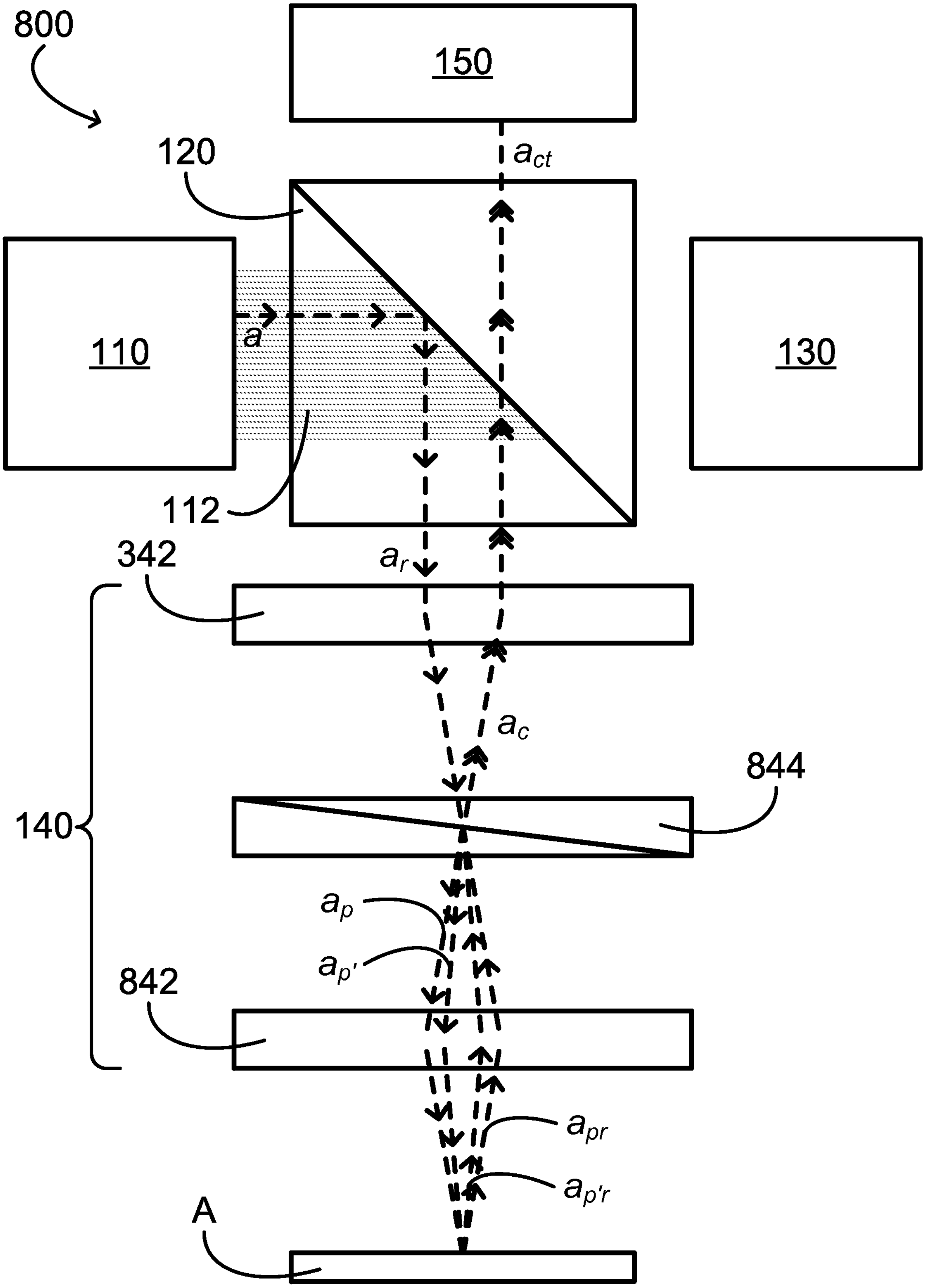

FIG. 8

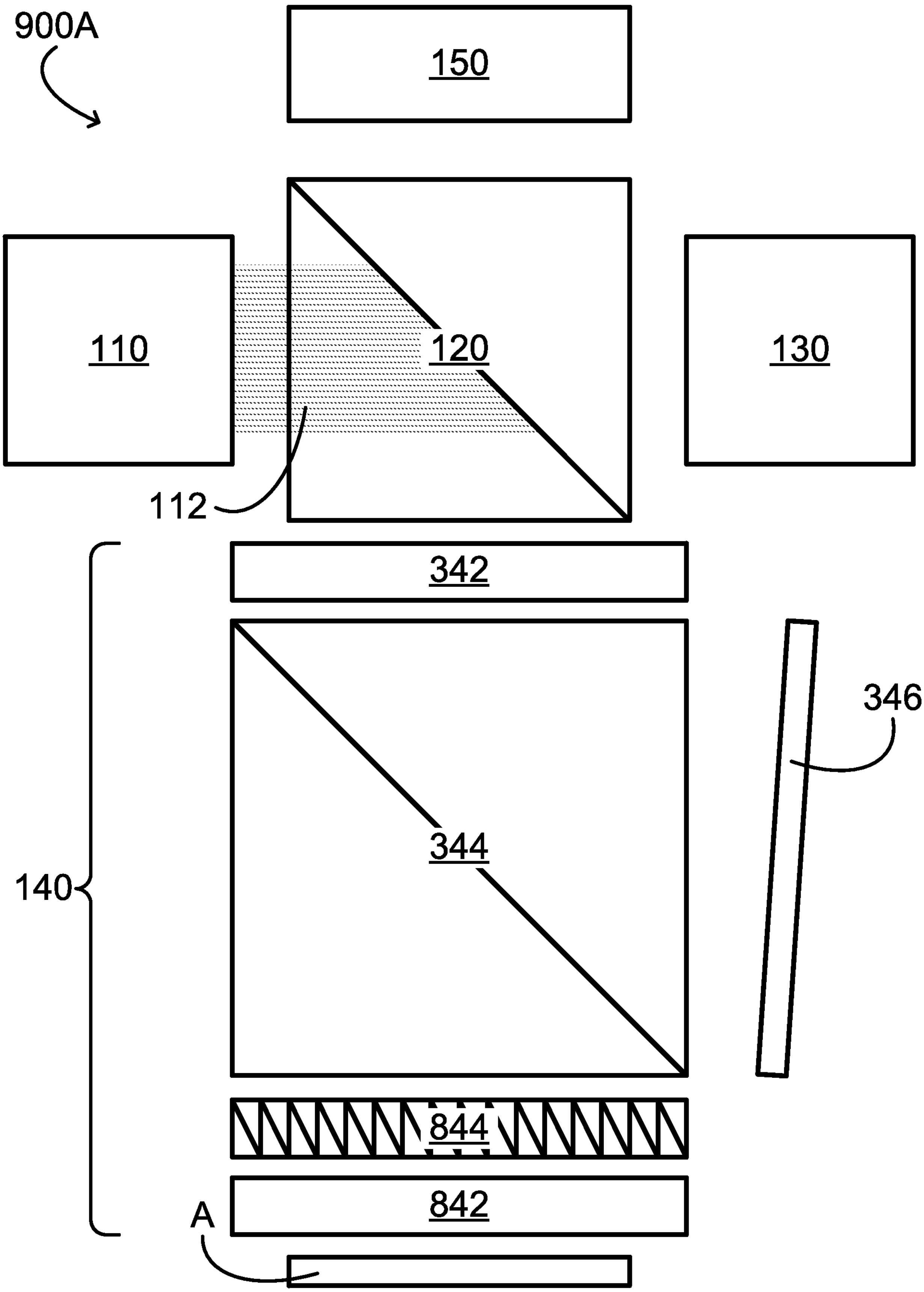

FIG. 9A

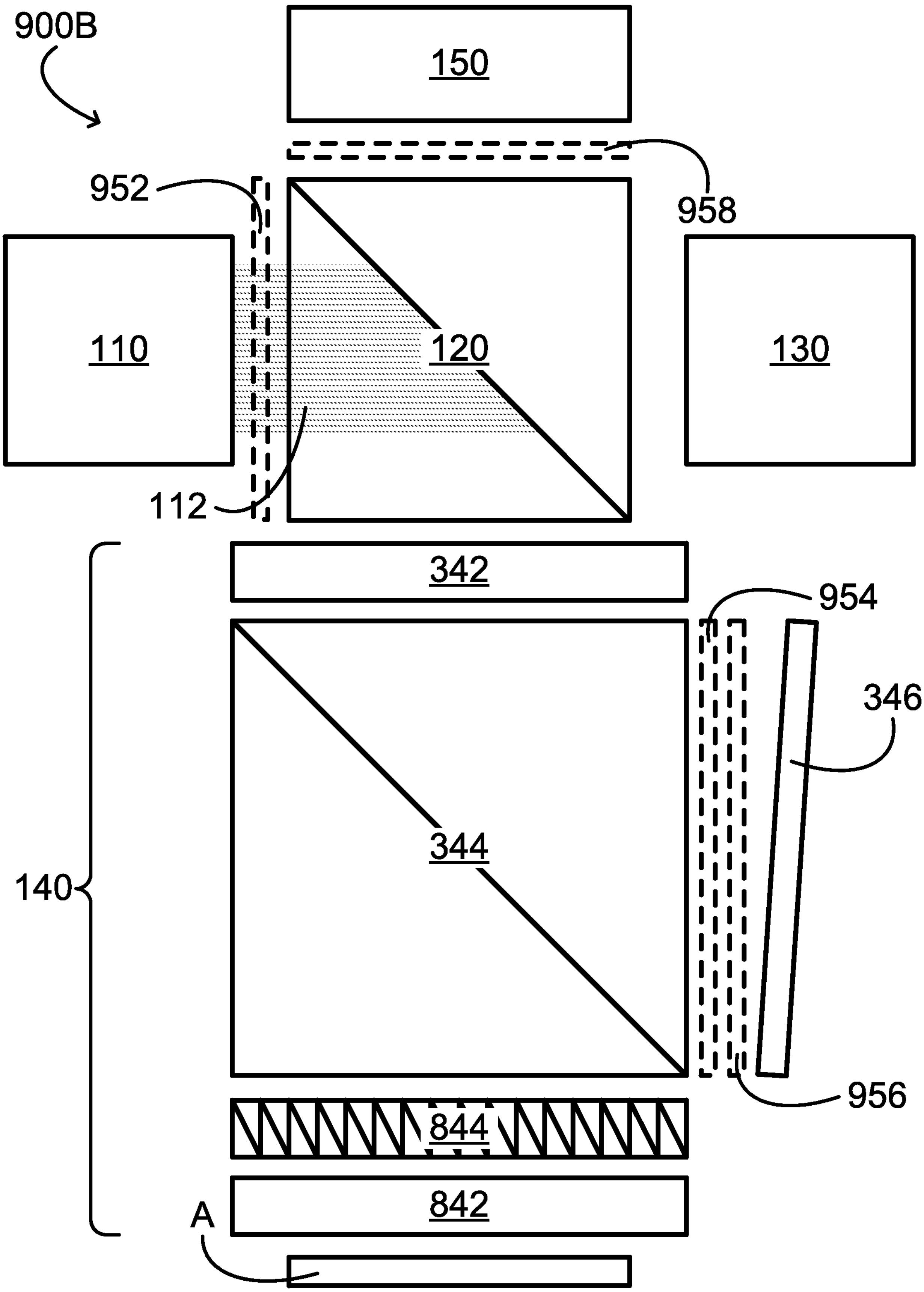
900B
150
958
952
110
120
130
112
342
954
346
344
140
956
844
842
A

FIG. 9B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/024580

A. CLASSIFICATION OF SUBJECT MATTER

G11B 19/04(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G11B 19/04; G02B 27/10; G01B 11/24; G01N 21/88; G01N 21/00; G03B 27/32; G01B 9/02; G01N 21/86

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: DMD (Digital Micromirror device), disk, inspect, defect, telecentric lens, interferometric, splitter, mirror, and similar terms.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 2011-0075151 A1 (HWAN J. JEONG) 31 March 2011 See paragraphs [0010], [0113], [0191], [0207], [0228]; claims 143, 145; and figure 29.	1-7 8-20
A	US 2012-0224183 A1 (MARTIN FAY et al.) 06 September 2012 See paragraphs [0067]-[0084]; claim 1; and figures 1, 10(b).	1-20
A	US 7041998 B2 (ADAM WEISS et al.) 09 May 2006 See column 9, line 41 - column 12, line 34; claim 1; and figures 5B-5C.	1-20
A	US 2012-0206703 A1 (KAUSTUVE BHATTACHARYYA et al.) 16 August 2012 See paragraphs [0056]-[0062]; claim 18; and figure 4.	1-20
A	US 6169631 B1 (JIALUO JACK XUAN et al.) 02 January 2001 See column 5, line 6 - column 6, line 30; claim 7; and figure 2A.	1-20

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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

Date of the actual completion of the international search	Date of mailing of the international search report
17 June 2015 (17.06.2015)	**18 June 2015 (18.06.2015)**

Name and mailing address of the ISA/KR
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Telephone No. +82-42-481-8262

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2015/024580

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