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(54) **MODULATION TRANSFER FUNCTION MEASUREMENT APPARATUS AND METHOD FOR OPTICAL DEVICES**

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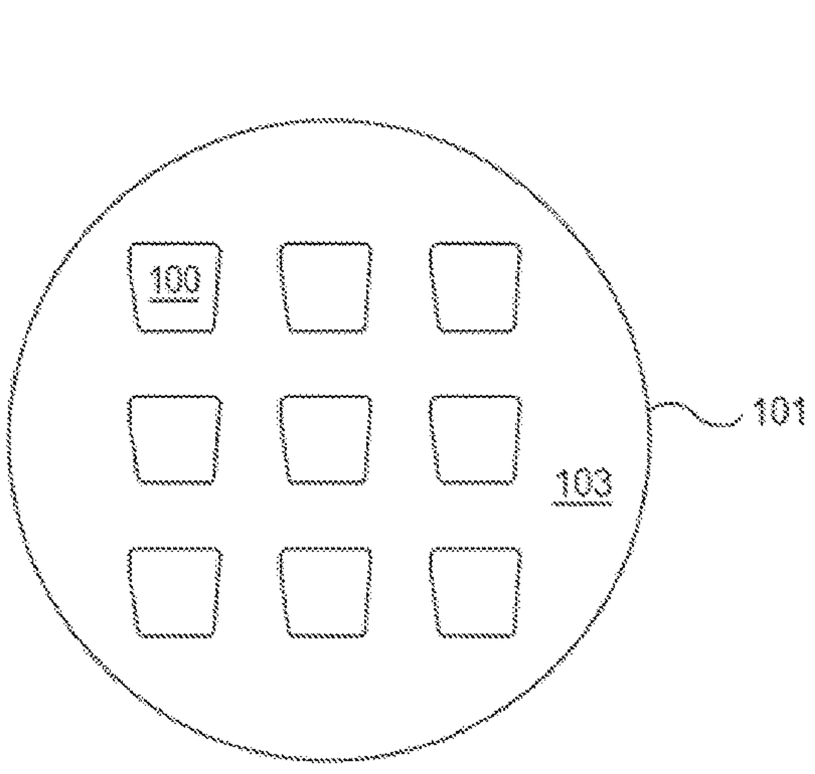
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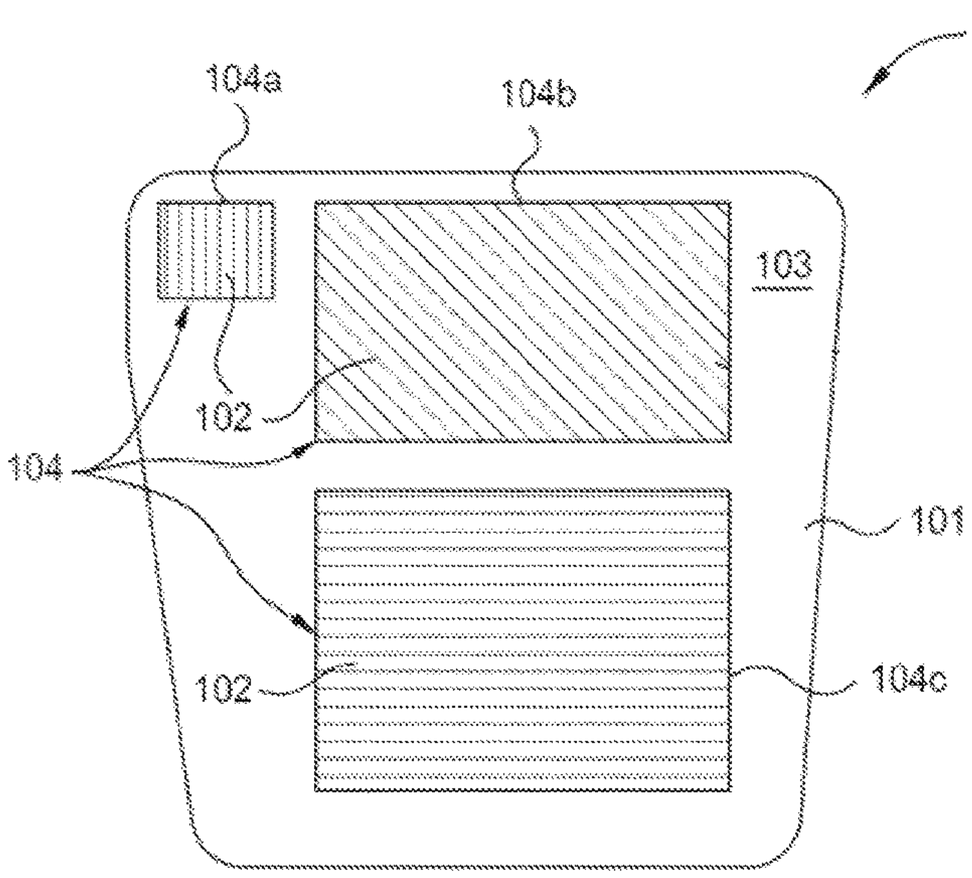
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G01M 11/02 (2006.01)

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(57) **ABSTRACT**

Embodiments herein provide for a measurement system for determining an optical device modulation transfer function (MTF). The measurement system includes a stage operable to retain an optical device or an optical device substrate having at least one optical device disposed thereon. A light engine is disposed above the stage. The light engine includes a light source operable to project a light to the optical device at a range of wavelengths. A reticle is operable to form a pattern from the light projected from the light source. A first lens operable to collimate the light from the light source toward the optical device or optical device substrate. A near field detector is operable to detect the light from the optical device or optical device substrate. A far field detector is operable to detect the light from the optical device of optical device substrate.





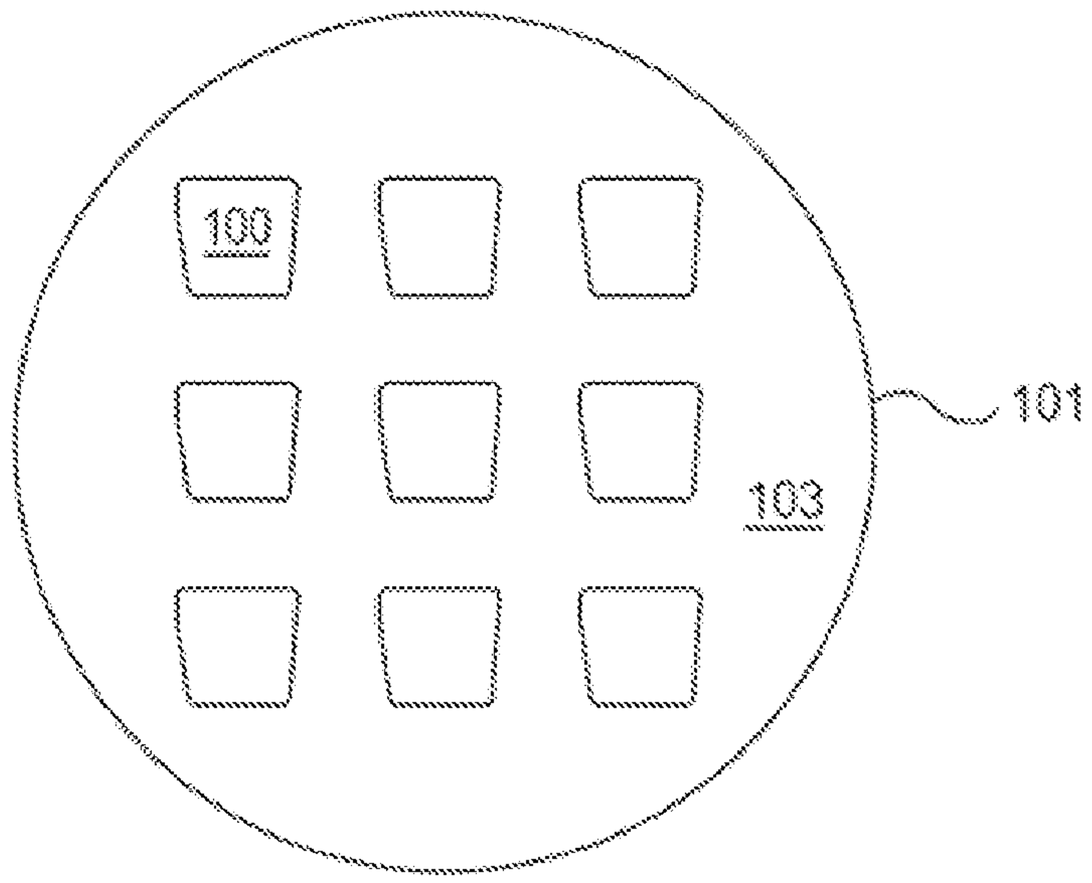


FIG. 1A

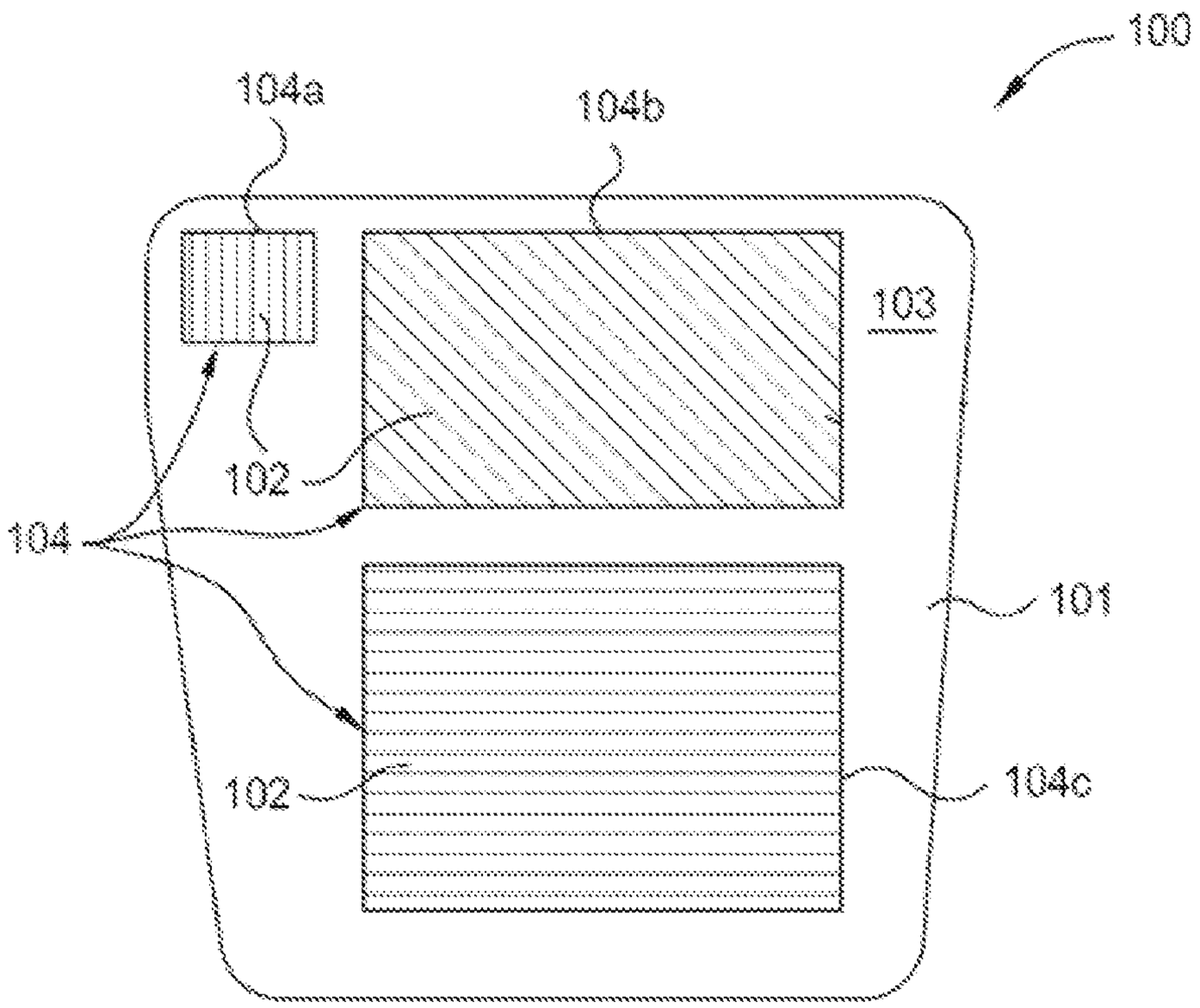


FIG. 1B

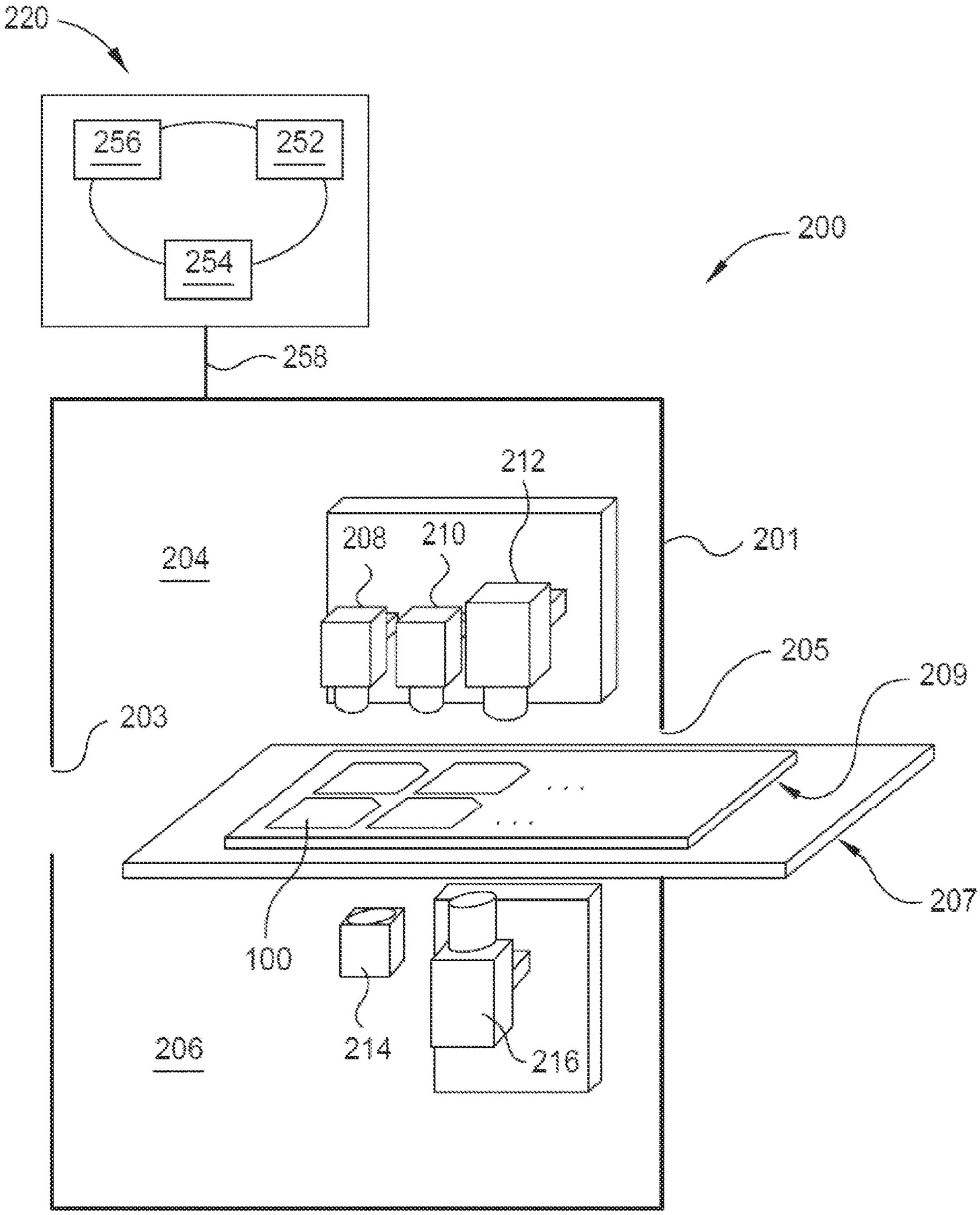

220
256
252
254
258
200
212
208
210
204
201
205
209
203
207
100
214
216
206

FIG. 2

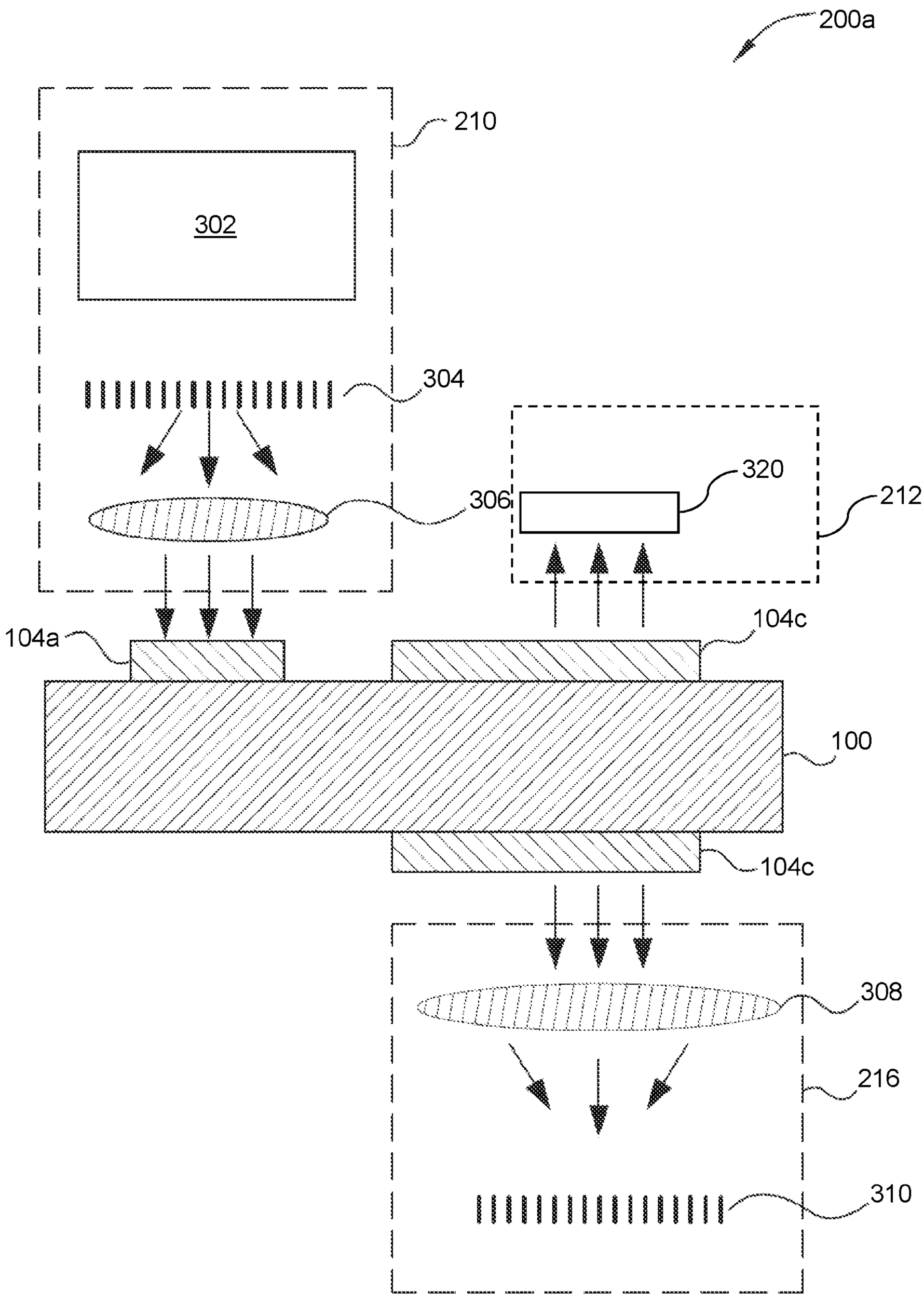


FIG. 3A

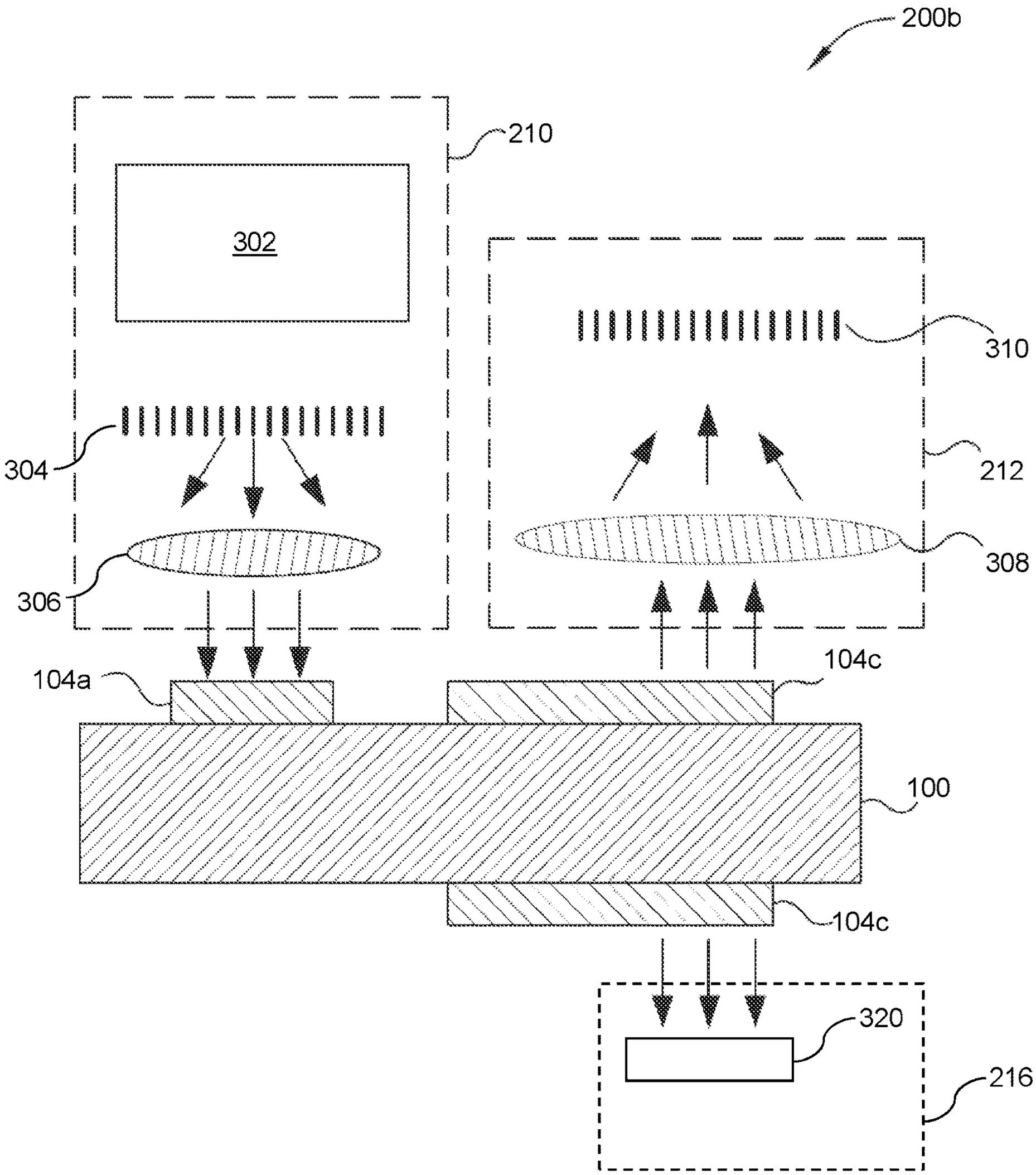


FIG. 3B

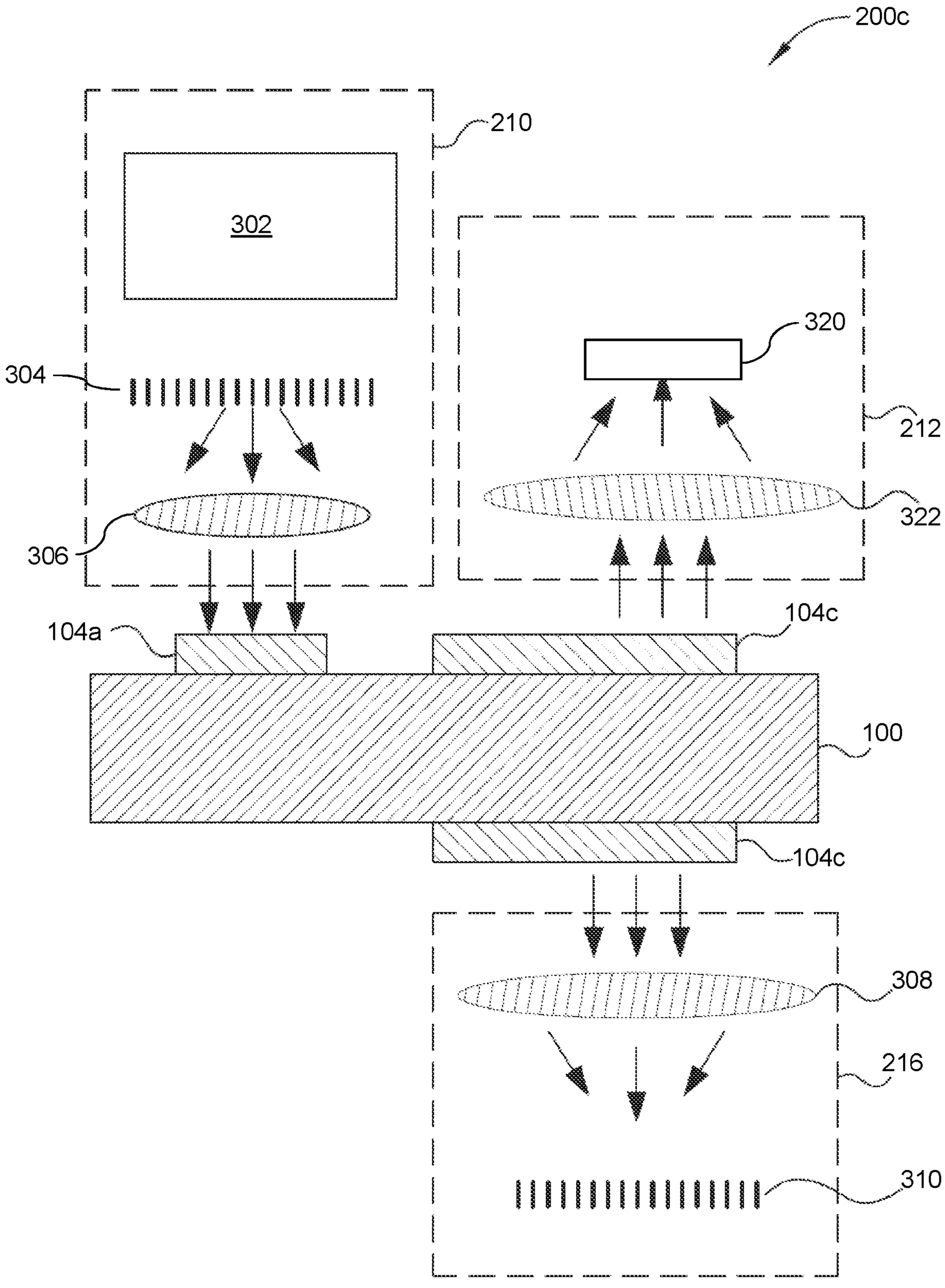


FIG. 3C

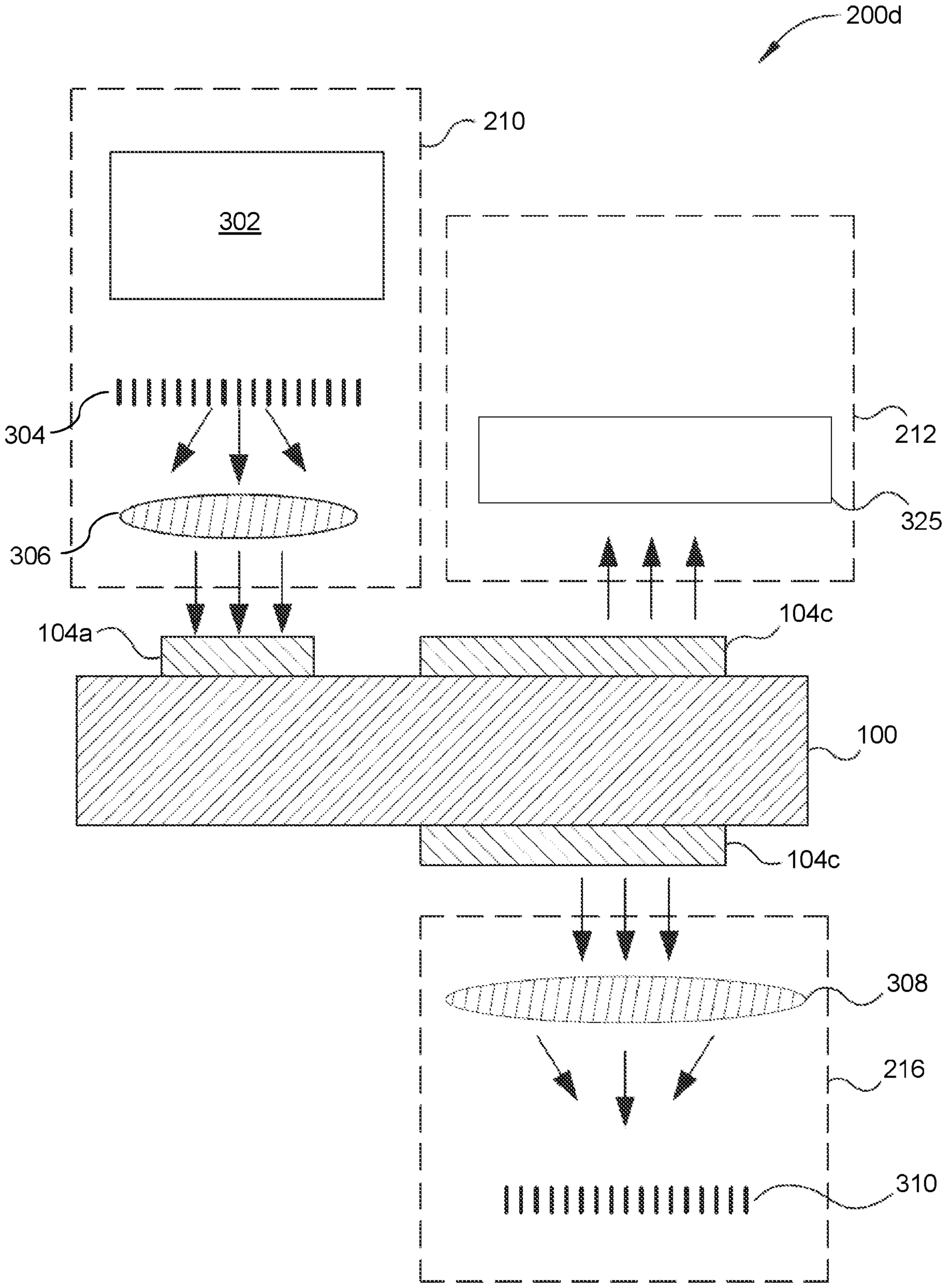


FIG. 3D

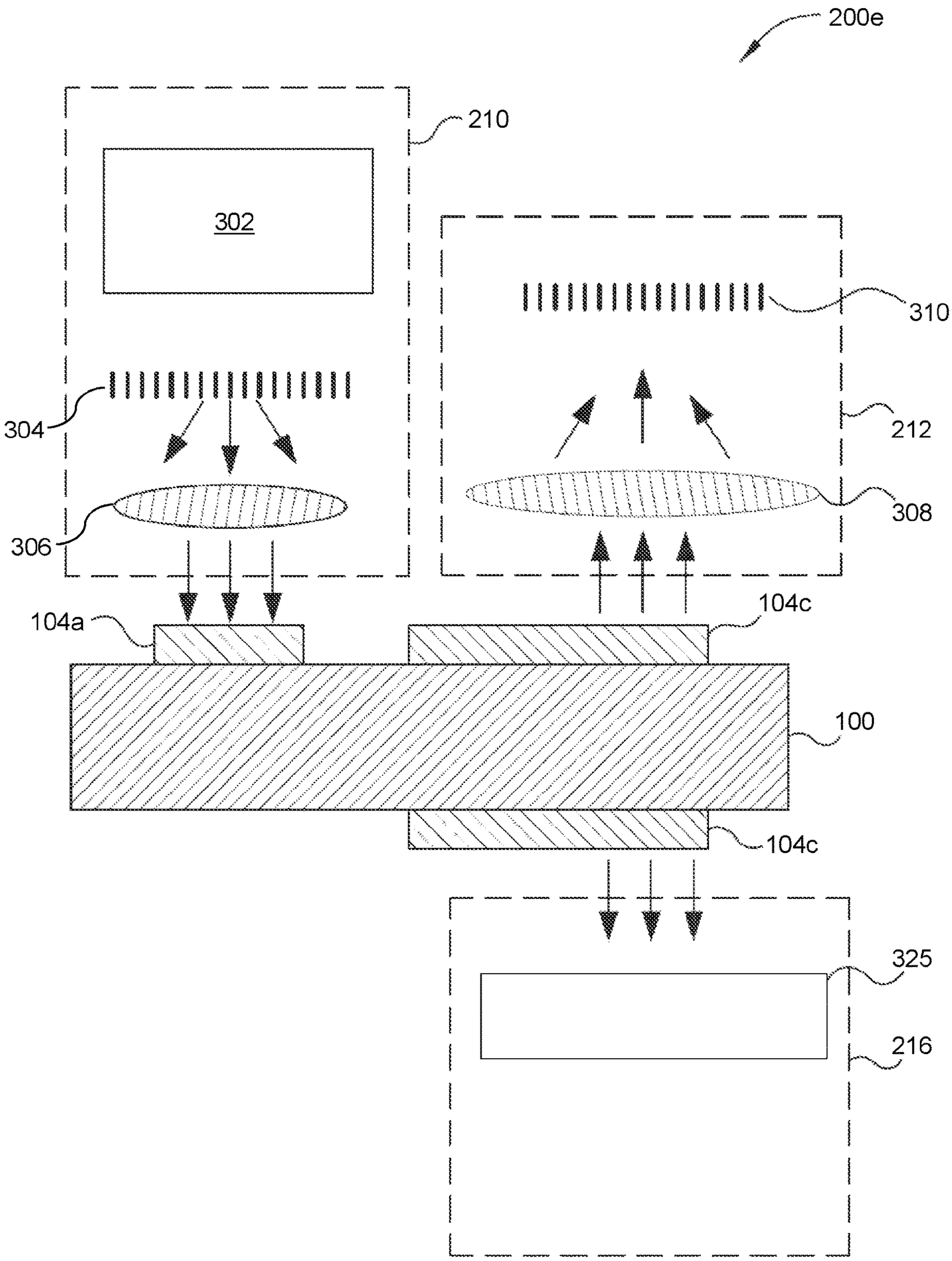


FIG. 3E

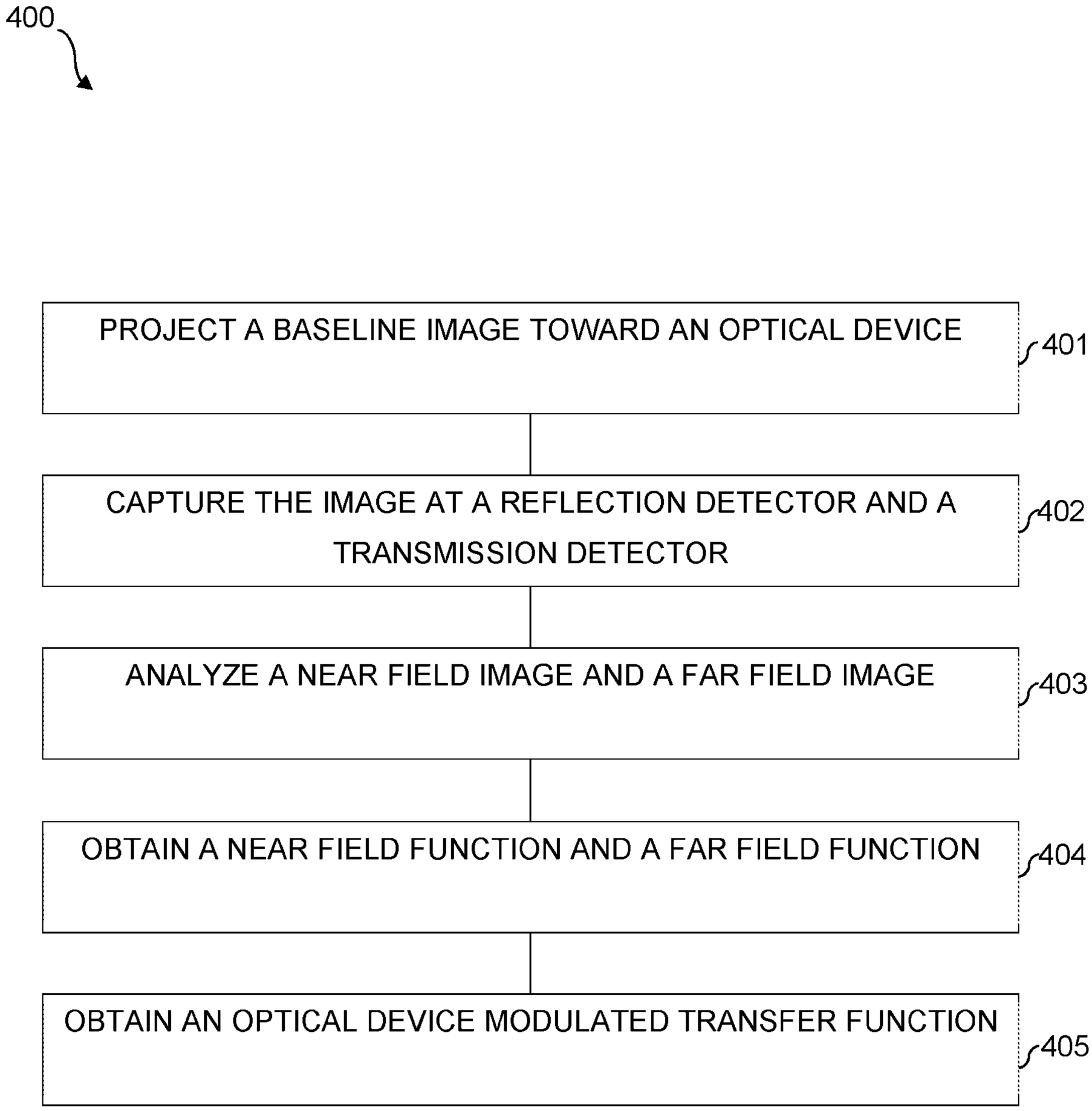

400
PROJECT A BASELINE IMAGE TOWARD AN OPTICAL DEVICE
401
CAPTURE THE IMAGE AT A REFLECTION DETECTOR AND A TRANSMISSION DETECTOR
402
ANALYZE A NEAR FIELD IMAGE AND A FAR FIELD IMAGE
403
OBTAIN A NEAR FIELD FUNCTION AND A FAR FIELD FUNCTION
404
OBTAIN AN OPTICAL DEVICE MODULATED TRANSFER FUNCTION
405

FIG. 4

MODULATION TRANSFER FUNCTION MEASUREMENT APPARATUS AND METHOD FOR OPTICAL DEVICES

BACKGROUND

Field

[0001] Embodiments of the present disclosure generally relate to optical devices. More specifically, embodiments described herein provide for a method and apparatus for determining a modulation transfer function (MTF) of an optical device.

Description of the Related Art

[0002] Virtual reality is generally considered to be a computer generated simulated environment in which a user has an apparent physical presence. A virtual reality experience can be generated in 3D and viewed with a head-mounted display (HMD), such as glasses or other wearable display devices that have near-eye display panels as lenses to display a virtual reality environment that replaces an actual environment. Augmented reality, however, enables an experience in which a user can still see through the display lenses of the glasses or other HMD device to view the surrounding environment, yet also see images of virtual objects that are generated for display and appear as part of the environment. Augmented reality can include any type of input, such as audio and haptic inputs, as well as virtual images, graphics, and video that enhances or augments the environment that the user experiences. As an emerging technology, there are many challenges and design constraints with augmented reality.

[0003] One such challenge is determining the optical resolution of the optical devices to ensure that image quality standards are met. Current measurement systems for optical devices generally have low sampling rates across a large field of view as well as low throughput and fail to properly compensate for imperfections in image quality caused by cameras and image projectors within the measurement systems. Additionally, the measurement systems may be bulky and are susceptible to imperfections associated with the image projectors of the measurement system. Therefore, it is desirable to have a system and method for optical resolution measurement that will not be affected by imperfections associated with the image projector or camera and will have an improved throughput. Accordingly, what is needed in the art is a method of determining a MTF of an optical device.

SUMMARY

[0004] In one embodiment, a measurement system is provided. The measurement system includes a stage operable to retain an optical device or an optical device substrate having at least one optical device disposed thereon, a light engine, a near field detector, and a far field detector. The light engine is disposed above the stage and includes a light source, a reticle operable to form a pattern from the light projected from the light source, and a first lens operable to collimate the light from the light source toward the optical device or optical device substrate. The light source is operable to project a light to the optical device at a range of wavelengths. The first lens is operable to collimate the light from the light source toward the optical device or optical device substrate. The near field detector operable to detect the light from the optical device or optical device substrate. The far field detector operable to detect the light from the optical device of optical device substrate.

[0005] In another embodiment, a method is disclosed. The method includes projecting an image of a pattern, the image projected from a light engine of a measurement system, capturing a near field image at the near field detector, capturing a far field image at the far field detector, analyzing the near field image and far field image to locate a first plurality of points on the near field image and far field image, the first plurality of points converted into a near field function and far field function, obtaining a near field fast Fourier transform (FFT) of the near field function and far field FFT of the far field function, and determining an optical device modulation transfer function (MTF) of the one or more optical devices, the optical device MTF determined by comparing the near field FFT to the far field FFT corresponding to the image. The measurement system includes a stage disposed under the light engine, the stage operable to have one or more optical devices disposed thereon. The light engine is disposed above the stage projects the baseline image to the one or more optical devices. The near field detector is operable to detect the light from the optical device. The far field detector operable to detect the light from the optical device.

[0006] In yet another embodiment, a controller of a measurement system is disclosed. The controller stores instructions that, when executed by a processor, causes the measurements system to measure optical properties of an optical device of optical device substrate disposed in a measurement system. The optical properties of the optical device or optical device substrate include projecting a baseline image of a pattern. The baseline image is projected from a light engine of a measurement system. A near field image is captured at a near field detector of the measurement system. A far field image is captured at a far field detector of the measurement system. The near field image and far field image are analyzed to locate a first plurality of points on the near field image and far field image. The first plurality of points are converted into a near field function and far field function. A near field fast Fourier transform (FFT) of the near field function and far field FFT of the far field function are obtained. An optical device modulation transfer function (MTF) of the one or more optical devices is determined. The optical device MTF is determined by comparing the near field FFT to the far field FFT corresponding to the baseline image.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only exemplary embodiments and are therefore not to be considered limiting of its scope, and may admit to other equally effective embodiments.

[0008] FIG. **1**A is a perspective, frontal view of a substrate according to embodiments described herein.

[0009] FIG. **1**B is a perspective, frontal view of an optical device according to embodiments described herein.

[0010] FIG. **2** is a schematic, cross-sectional view of the measurement system according to embodiments described herein.

[0011] FIG. **3**A-**3**E are schematic illustrations of a measurement system for determining a modulation transfer function (MTF) of an optical device according to embodiments described herein.

[0012] FIG. **4** is a flow diagram of a method for determining a modulation transfer function (MTF) of an optical device according to embodiments described herein.

[0013] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.

DETAILED DESCRIPTION

[0014] Embodiments of the present disclosure generally relate to optical devices. More specifically, embodiments described herein provide for a method of determining a modulation transfer function (MTF) of an optical device.

[0015] FIG. **1**A is a perspective, frontal view of a substrate **101** according to embodiments described herein. The substrate **101** includes a plurality of optical devices **100** disposed on a surface **103** of the substrate **101**. The optical devices **100** are waveguide combiners utilized for virtual, augmented, or mixed reality. In some embodiments, which can be combined with other embodiments described herein, the optical devices **100** are flat optical devices, such as metasurfaces.

[0016] The substrate **101** can be any substrate used in the art, and can be either opaque or transparent to a chosen laser wavelength depending on the use of the substrate **101**. Additionally, the substrate **101** may be of varying shapes, thicknesses, and diameters. For example, the substrate **101** may have a diameter of about 150 mm to about 300 mm. The substrate **101** may have a circular, rectangular, or square shape. The substrate **101** may have a thickness of between about 300 μm to about 1 mm. Although only nine optical devices **100** are shown on the substrate **101**, any number of optical devices **100** may be disposed on the surface **103**.

[0017] FIG. **1**B is a perspective, frontal view of an optical device **100**. It is to be understood that the optical devices **100** described herein are exemplary optical devices and the other optical devices may be used with or modified to accomplish aspects of the present disclosure. The optical device **100** includes a plurality of optical device structures **102** disposed on a surface **103** of a substrate **101**. The optical device structures **102** may be nanostructures having sub-micron dimensions, e.g., nano-sized dimensions. Regions of the optical device structures **102** correspond to one or more gratings **104**, such as a first grating **104***a*, a second grating **104***b*, and a third grating **104***c*. In some embodiments, which can be combined with other embodiments described herein, the optical device **100** includes at least the first grating **104***a* corresponding to an input coupling grating and the third grating **104***c* corresponding to an output coupling grating. In some embodiments, which can be combined with other embodiments described herein, the optical device **100** also includes the second grating **104***b* corresponding to an intermediate grating. The optical device structures **102** may be angled or binary. The optical device structures **102** may have other shapes including, but not limited to, circular, triangular, elliptical, regular polygonal, irregular polygonal, and/or irregular shaped cross-sections.

[0018] In operation, the first grating **104***a* receives incident beams of light (a virtual image) having an intensity from a light source. The incident beams are split by the optical device structures **102** into T1 beams that have all of the intensity of the incident beams in order to direct the virtual image to the intermediate grating (if utilized) or the third grating **104***c*. In some embodiments, which can be combined with other embodiments described herein, the T1 beams undergo total-internal-reflection (TIR) through the optical device **100** until the T1 beams come in contact with the optical device structures **102** of the intermediate grating. The optical device structures **102** of the intermediate grating diffract the T1 beams to T−1 beams that undergo TIR through the optical device **100** to the optical device structures **102** of the third grating **104***c*. The optical device structures **102** of the third grating **104***c* outcouple the T−1 beams to the user's eye to modulate the field of view of the virtual image produced from the light source from the user's perspective and further increase the viewing angle from which the user can view the virtual image. In some embodiments, which can be combined with other embodiments described herein, the T1 beams undergo TIR through the optical device **100** until the T1 beams come in contact with the optical device structures **102** of the third grating **104***c* and are outcoupled to modulate the field of view of the virtual image produced from the light source.

[0019] To ensure that the optical devices **100** meet image quality standards, the optical device MTF of the optical devices **100** is obtained. In some embodiments, the optical device MTF provides image quality information related to image resolution and image contrast. Embodiments of the measurement system **200** described herein provide for the ability to obtain the optical device MTF with increased throughput and greater quality control. Additionally, embodiments of the measurement system **200** described herein provide for the ability to obtain the optical device MTF such that the measured optical device MTF is not strongly influenced by the imperfections of an image projector and/or a camera, such as distortion and astigmatism. Embodiments described herein allow for image quality separation between the optical device **100** and the measurement system **200**, which may include imperfections attributable solely to a camera or projector. The MTF is a metric utilized to determine the ability of the optical devices **100** to transfer contrast at a particular resolution from an object to an image.

[0020] FIG. **2** is a schematic, cross-sectional view of the measurement system **200** according to embodiments described herein. The measurement system **200** includes a body **201** with a first opening **203** and a second opening **205** to allow a stage **207** to move therethrough. The stage **207** is operable to move in an X-direction, a Y-direction, and a Z-direction in the body **201** of the measurement system **200**. The stage **207** includes a tray **209** operable to retain the optical devices **100** (as shown herein) or one or more substrates **101**.

[0021] The measurement system **200** is operable to project images such that the MTF of the optical device **100** can be determined. The stage **207** and the tray **209** may be transparent such that the MTF obtained utilizing the measurement system **200** is not impacted by the translucence of the stage **207** or the tray **209**. The measurement system **200** is

in communication with a controller **220** operable to control operation of measurement system **200** and the method **400** described herein.

[0022] The measurement system **200** includes an upper portion **204** oriented toward a top side of the optical devices **100** and a lower portion **206** oriented toward a bottom side of the optical devices **100**. The upper portion **204** of the measurement system **200** includes an alignment camera **208**, a light engine **210**, and a reflection detector **212**. The reflection detector **212** detects outcoupled beams projected from the third grating **104***c* from the top side of the optical devices **100**. The reflection detector **212** includes a near field detector, a far field detector, a wave sensor, or combinations thereof. The reflection detector **212** of the measurement system **200***a* and measurement system **200***c* include a near field detector **320**. The near field detector **320** is operable to capture an image of the outcoupled beams at the pupil plane of the third grating **104***c* in measurement system **200***a*. By capturing the image of the outcoupled beams at the pupil plane of third grating **104***c*, the measurement system **200***a* can image the outcoupled beams within the third grating **104***c*. The reflection detector **212** of the measurement system **200***c* further includes a lens **322** to focus the outcoupled beams toward the near field detector **320** when the near field detector **320** is not in the pupil plane. The reflection detector **212** of measurement system **200***b* and **200***e* includes a far field detector **310**. The far field detector **310** is operable to capture an image of the outcoupled beams at a position of a display on which the image would be projected. The reflection detector **212** of the measurement system **200***d* includes a wavefront sensor **325**. The wavefront sensor **325** is operable to capture an image of the outcoupled beams at the pupil plane of the third grating **104***c* in measurement system **200***d*. By capturing the image of the outcoupled beams at the pupil plane of third grating **104***c*, the measurement system **200***d* can image the outcoupled beams before the outcoupled beams experience distortion and dispersion as they propagate toward a display.

[0023] The transmission detector **216** detects outcoupled beams projected from the third grating **104***c* through the bottom side of the optical devices **100**. The transmission detector **216** includes a near field detector, a far field detector, a wavefront sensor, or combinations thereof. The transmission detector **216** of the measurement system **200***a* and measurement system **200***c* include a far field detector **310**. The far field detector **310** is operable to capture an image of the outcoupled beams at a position of a display on which the image would be projected. The transmission detector **216** of measurement system **200***b* includes a near field detector **320**. The near field detector **320** is operable to capture an image of the outcoupled beams at the pupil plane of the third grating **104***c* in measurement system **200***b*. By capturing the image of the outcoupled beams at the pupil plane of third grating **104***c*, the measurement system **200***b* can image the outcoupled beams before the outcoupled beams experience distortion and dispersion as they propagate toward a display. The transmission detector **216** of the measurement system **200***e* includes a wavefront sensor **325**. The wavefront sensor **325** is operable to capture an image of the outcoupled beams at the pupil plane of the third grating **104***c* in measurement system **200***e*. By capturing the image of the outcoupled beams at the pupil plane of third grating **104***c*, the measurement system **200***e* can image the outcoupled beams before the outcoupled beams experience distortion and dispersion as they propagate toward a display.

[0024] The alignment camera **208** is operable to determine a position of the stage **207** and the optical devices **100**. The light engine **210** is operable to illuminate the first grating **104***a*. In some embodiments, which can be combined with other embodiments described herein, the light engine **210** projects an image of a pattern to the first grating **104***a*.

[0025] The lower portion **206** of the first subsystem **202** includes a code reader **214** and a transmission detector **216**. The code reader **214** is operable to read a code of the optical devices, such as a quick response (QR) code or barcode of an optical device **100**. The code read by the code reader **214** may include instructions for obtaining the optical device MTF for various optical devices **100**.

[0026] The controller **220** is coupled to the measurement system **200**. The controller **220** includes a processor **252**, a memory **254**, and support circuits **256** that are coupled to one another. The controller **220** is electrically coupled to the measurement system **200** via a wire **258**. The wire **258** may also represent, in some embodiments, a wireless connection. The processor **252** may be one of any form of general purpose microprocessor, or a general purpose central processing unit (CPU), each of which can be used in an industrial setting, such as a programmable logic controller (PLC), supervisory control and data acquisition (SCADA) systems, general purpose graphics processing unit (GPU), or other suitable industrial controller. The memory **254** is non-transitory and may be one or more of readily available memory such as random access memory (RAM), read only memory (ROM), or any other form of digital storage, local or remote. The memory **254** contains instructions, that when executed by the processor **252**, facilitates execution of the method **400**. The instructions in the memory **254** are in the form of a program product such as a program that implements the method of the present disclosure. The program code of the program product may conform to any one of a number of different programming languages. Illustrative computer-readable storage media include, but are not limited to: (i) non-writable storage media (e.g., read-only memory devices within a computer such as CD-ROM disks readable by a CD-ROM drive, flash memory, ROM chips, or any type of solid-state non-volatile semiconductor memory) on which information is permanently stored; and (ii) writable storage media (e.g., floppy disks within a diskette drive or hard-disk drive or any type of solid-state random-access semiconductor memory) on which alterable information is stored. Such computer-readable storage media, when carrying computer-readable instructions that direct the functions of the methods described herein, are examples of the present disclosure.

[0027] FIGS. **3**A-**3**E are schematic illustrations of measurement systems **200***a*-**200***e*. The measurement systems **200***a*-**200***e* may be used for a method **400** of for determining an optical device MTF. The measurement system **200** includes the light engine **210**, the transmission detector **216**, and the reflection detector **212**. The light engine **210** includes a light source **302**, a reticle **304**, and a first lens **306**. The light engine **210** may further include at least one of a quarter-wave plate or linear polarizer. In some embodiments, which may be combined with other embodiments described herein, the light source **302** is configured to project red (about 610 nm-660 nm wavelength), green

(about 510 nm-560 nm wavelength), and blue light (about 420 nm-470 nm wavelength). The reticle **304** may be a display.

[0028] In one embodiment, as shown in measurement system **200***a* of FIG. **3**A, the transmission detector **216** includes a far field detector **310**. The far field detector **310** is operable to detect outcoupled beams projected from the third grating **104***c* though the bottom side of the optical devices **100** to form a far field image. A second lens **308** is operable to focus the outcoupled image toward the far field detector **310**. The far field detector **310** captures the far field image that potentially has some lost optical data due to a MTF failure of the optical device **100**. The reflection detector **212** includes the near field detector **320**. The near field detector **320** is operable to detect outcoupled beams projected from the third grating **104***c* through the top side of the optical device **100** to form a near field image. In some embodiments, the near field detector **320** is positioned less than about 3 mm from the third grating **104***c* of the optical device **100**, such as less than about 1 mm from third grating **104***c* of the optical device **100**. The near field detector **320** is positioned as close as possible to the third grating **104***c* of the optical device **100** in order minimize the amount of optical data lost due to MTF failure of the optical device **100**. The near field image captured at the near field detector **320** and the far field image captured at the far field detector **310** are operable to be compared to determine if an MTF failure occurred.

[0029] In another embodiment, as shown in measurement system **200***b* of FIG. **3**B, the reflection detector **212** includes the far field detector **310**. The far field detector **310** is operable to detect outcoupled beams projected from the third grating **104***c* through the top side of the optical device **100** to form a far field image. A second lens **308** is operable to focus the outcoupled image toward the far field detector **310**. The far field detector **310** captures a far field image that potentially has some lost optical data due to a MTF failure of the optical device **100**. The transmission detector **216** includes the near field detector **320**. The near field detector **320** is operable to detect outcoupled beams projected from the third grating **104***c* through the bottom side of the optical device **100** to form a near field image. In some embodiments, the near field detector **320** is positioned less than about 3 mm from the third grating **104***c* of the optical device **100**, such as less than about 1 mm from third grating **104***c* of the optical device **100**. The near field detector **320** is positioned as close as possible to the third grating **104***c* of the optical device **100** in order minimize the amount of optical data lost due to MTF failure of the optical device **100**. The near field image captured at the near field detector **320** and the far field image captured at the far field detector **310** are operable to be compared to determine if an MTF failure occurred.

[0030] In another embodiment, as shown in measurement system **200***c* of FIG. **3**C, the transmission detector **216** includes the far field detector **310**. The far field detector **310** is operable to detect outcoupled beams projected from the third grating **104***c* through the bottom side of the optical device **100** to form a far field image. A second lens **308** is operable to focus the outcoupled image toward the far field detector **310**. The far field detector **310** captures a far field image that potentially has some lost optical data due to a MTF failure of the optical device **100**. The reflection detector **212** includes the near field detector **320**. The near field detector **320** is operable to detect outcoupled beams projected from the third grating **104***c* through the top side of the optical device **100** to form a near field image. A third lens **322** is disposed between the third grating **104***c*. The third lens is positioned less than about 3 mm from the third grating **104***c* of the optical device **100**, such as less than about 1 mm from third grating **104***c* of the optical device **100**. The third lens **322** is positioned as close as possible to the third grating **104***c* of the optical device **100** in order minimize the amount of optical data lost due to MTF failure of the optical device **100**. The third lens **322** is operable to focus the near field image toward the near field detector **320**. The near field detector **320** is disposed from about 10 mm to about 50 mm from the third grating **104***c*. The near field image captured at the near field detector **320** and the far field image captured at the far field detector **310** are operable to be compared to determine if an MTF failure occurred.

[0031] In another embodiment, as shown in measurement system **200***d* of FIG. **3**D, the transmission detector **216** includes the far field detector **310**. The far field detector **310** is operable to detect outcoupled beams projected from the third grating **104***c* through the bottom side of the optical device **100** to form a far field image. A second lens **408** is operable to focus the outcoupled image toward the far field detector **310**. The far field detector **310** captures an image that potentially has some lost optical data due to a MTF failure of the optical device **100**. The reflection detector **212** is a wavefront sensor **325**. The wavefront sensor **325** is operable to detect outcoupled beams projected from the third grating **104***c* through the top side of the optical device **100** to form a near field image. In some embodiments, the wavefront sensor **325** is positioned less than about 3 mm from the third grating **104***c* of the optical device **100**, such as less than about 1 mm from third grating **104***c* of the optical device **100**. The wavefront sensor **325** is positioned as close as possible to the third grating **104***c* of the optical device **100** in order minimize the amount of optical data lost due to MTF failure of the optical device **100**. The near field image captured at the wavefront sensor **325** and the far field image captured at the far field detector **310** are operable to be compared to determine if an MTF failure occurred. The wavefront sensor **325** is further capable of measuring the phase (e.g., direction) of the light of the image.

[0032] In another embodiment, as shown in measurement system **200***e* of FIG. **3**E, the reflection detector **212** includes the far field detector **310**. The far field detector **310** is operable to detect outcoupled beams projected from the third grating **104***c* through the top side of the optical device **100** to form a far field image. A second lens **308** is operable to focus the outcoupled image toward the far field detector **310**. The far field detector **310** captures a far field image that potentially has some lost optical data due to a MTF failure of the optical device **100**. The transmission detector **216** is a wavefront sensor **325**. The wavefront sensor **325** detects outcoupled beams projected from the third grating **104***c* through the bottom side of the optical device **100** to form a near field image. In some embodiments, the wavefront sensor **325** is positioned less than about 3 mm from the third grating **104***c* of the optical device **100**, such as less than about 1 mm from third grating **104***c* of the optical device **100**. The wavefront sensor **325** is positioned as close as possible to the third grating **104***c* of the optical device **100** in order minimize the amount of optical data lost due to MTF failure of the optical device **100**. The near field image

captured at the wavefront sensor **325** and the far field image captured at the far field detector **310** are operable to be compared to determine if an MTF failure occurred. The wavefront sensor **325** is further capable of measuring the phase (e.g., direction) of the light of the image.

[0033] FIG. **4** is a flow diagram of a method **400** for determining an optical device MTF. The method **400** is operable to be performed in other measurement systems not described herein. The method **400** described herein includes illuminating the first grating **104***a* of an optical device **100** with the light engine **210** where the incoupled light undergoes TIR until it is outcoupled (e.g., reflected or transmitted) from the third grating **104***c* as images captured by the transmission detector **216** and reflection detector **212**. The images may correspond to red, green, and blue channels from the light engine **210**. The images are processed as described in the method **400** to extract the MTF of the optical device **100**.

[0034] At operation **401**, a baseline image is projected with the light engine **210** of the measurement system **200** toward an optical device **100**. The baseline image is projected after the light source **302** projects red, green, or blue light through a reticle **304** to form a pattern. The baseline image is of the pattern. In some embodiments, which can be combined with other embodiments described, the light engine **210** is a high resolution image projector with a field of view (FOV) of about 10 degrees to about 120 degrees. The FOV of the light engine **210** is fixed or adjustable. The pattern is determined by the reticle **304**. The reticle **304** may have one of a checkerboard pattern, line pair pattern, or a point matrix pattern. In some embodiments, which can be combined with other embodiments described, the reticle **304** is a high-resolution patterned mask. The pattern of the reticle **304** may be formed via e-beam, ion-beam, or photolithography. In other embodiments, which can be combined with other embodiments described, the light engine **210** is one of a LCOS, CLP, micro-light emitting diode (microLED), laser beam scanner, or organic light emitting diode (OLED) microdisplay.

[0035] The pattern is projected through the first lens **306** to a first grating **104***a*. The first lens **306** focuses the pattern toward the first grating **104***a*. The pattern undergoes TIR through the optical device **100** until the pattern is outcoupled from a third grating **104***c*. In some embodiments, which can be combined with other embodiments described herein, the optical device **100** may include a surface relief grating based waveguide combiner, a volume hologram based waveguide combiner, a birdbath waveguide combiner, a partial reflective mirror array combiner, or a free from optics combiner. The pattern is determined by the reticle **304**. The reticle **304** may have one of a checkerboard pattern, a line pair pattern, or a point matrix pattern. In some embodiments, which can be combined with other embodiments described, the reticle **304** is a high-resolution patterned mask.

[0036] At operation **402**, the image is captured at a reflection detector **212** and a transmission detector **216**. The image is of the pattern formed by the reticle **304**. In some embodiments, which can be combined with other embodiments described herein, the transmission detector **216** includes the far field detector **310**, a near field detector **320**, a wavefront sensor **325** or a combination thereof. In some embodiments, the reflection detector **212** includes the far field detector **310**, the near field detector **320**, the wavefront sensor **325**, or a combination thereof. The near field detector **320** or the wavefront sensor **325** detect a near field image of the pattern formed by the reticle. The near field image is captured at or near the pupil pane of the third grating **104***c*, resulting in minimal optical data lost from any potential MTF failure within the optical device **100**. The far field detector **310** detects a far field image at a distance approximately equal to a display distance of the optical device **100** (e.g., the distance at which the optical device would project the image for the user of the optical device to see). Any potential MTF failure would result in a distorted/degraded far field image.

[0037] At operation **403**, the near field image and far field image are analyzed. In some embodiments, which can be combined with other embodiments described herein, the near field image and far field image is analyzed to locate a plurality of points on the near field image and far field image. Each of the plurality of points may correspond to a different FOV across the near field image and far field image. For example, each of the plurality of points may correspond to an edge of adjacent squares in a checkerboard pattern. The plurality of points are converted into a near field function and a far field function depending on the pattern formed. For example, the function may be a point spread function, a line spread function, or an edge spread function.

[0038] At operation **404**, a near field function MTF of the near field function and a far field function MTF of the far field function are obtained. To properly obtain the function MTF corresponding to the baseline image, the light intensity variation across the image needs to be minimized. The light intensity variation across the image can be reduced by adjusting the exposure time of the image. The exposure time can be adjusted for each of the plurality of points of the near field function and the far field function.

[0039] At operation **405**, the optical device MTF is obtained. By correlating the near field image and the far field image using the plurality of points and the function, a MTF performance can be measured and a failure can be detected. Further, the pupil function degradation along the propagation in the third grating **104***c* can be detected. Thus, the cause of the MTF failure can be detected. The optical device MTF obtained with the method **400** is less prone to be affected to imperfections of the light engine **210**.

[0040] In summation, a method and apparatus for determining a MTF of an optical device is described herein. The apparatus includes a measurement system including a stage operable to retain an optical device or an optical device substrate having at least one optical device disposed thereon. A light engine is disposed above the stage. The light engine includes a light source operable to project a light to the optical device at a range of wavelengths. A reticle is operable to form a pattern from the light projected from the light source. A near field detector is operable to detect the light from the optical device or optical device substrate at the pupil plane of the optical device. A far field detector is operable to detect the light from the optical device of optical device substrate at a display distance of the optical device. The images of the light detected at the far field detector and near field detector are compared to determine the MTF of the optical device substrate or optical device. The cause of a MTF failure can further be detected by the measurement system.

[0041] While the foregoing is directed to embodiments of the present disclosure, other and further embodiments of the

disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

1. A measurement system, comprising:

a stage operable to retain an optical device or an optical device substrate having at least one optical device disposed thereon;

a light engine disposed above the stage, the light engine including:

a light source, the light source operable to project a light to the optical device at a range of wavelengths;

a reticle operable to form a pattern from the light projected from the light source; and

a first lens operable to collimate the light from the light source toward the optical device or optical device substrate;

a near field detector operable to detect the light from the optical device or optical device substrate; and

a far field detector operable to detect the light from the optical device of optical device substrate.

2. The measurement system of claim **1**, wherein the near field detector is positioned at a top side of the optical device or optical device substrate and the far field detector is positioned at a bottom side of the optical device or optical device substrate.

3. The measurement system of claim **1**, wherein the near field detector is positioned at a bottom side of the optical device or optical device substrate and the far field detector is positioned at a top side of the optical device or optical device substrate.

4. The measurement system of claim **1**, wherein the near field detector is a wavefront sensor.

5. The measurement system of claim **1**, wherein the stage is operable to move in an X-direction, a Y-direction, and a Z-direction.

6. The measurement system of claim **1**, wherein the stage is transparent.

7. The measurement system of claim **1**, further comprising an alignment camera operable to determine a position of the stage and the optical device or the optical device substrate.

8. A method, comprising:

projecting a baseline image of a pattern, the baseline image projected from a light engine of a measurement system, the measurement system having:

a stage disposed under the light engine, the stage operable to have one or more optical devices disposed thereon, wherein the light engine disposed above the stage projects the baseline image to the one or more optical devices; and

a near field detector operable to detect the light from the optical device; and

a far field detector operable to detect the light from the optical device;

capturing a near field image at the near field detector;

capturing a far field image at the far field detector;

analyzing the near field image and far field image to locate a first plurality of points on the near field image and far field image, the first plurality of points converted into a near field function and far field function;

obtaining a near field fast Fourier transform (FFT) of the near field function and far field FFT of the far field function; and

determining an optical device modulation transfer function (MTF) of the one or more optical devices, the optical device MTF determined by comparing the near field FFT to the far field FFT corresponding to the baseline image.

9. The method of claim **8**, wherein the near field detector is positioned at a top side of the optical device or optical device substrate and the far field detector is positioned at a bottom side of the optical device or optical device substrate.

10. The method of claim **8**, wherein the near field detector is positioned at a bottom side of the optical device or optical device substrate and the far field detector is positioned at a top side of the optical device or optical device substrate.

11. The method of claim **8**, wherein the near field detector is a wavefront sensor.

12. The method of claim **8**, wherein the baseline image is projected through a reticle to form the pattern.

13. The method of claim **8**, wherein the light engine has a field of view of about 10 degrees to about 120 degrees.

14. The method of claim **8**, wherein the stage is operable to move in an X-direction, a Y-direction, and a Z-direction.

15. A controller of a measurement system storing instructions that, when executed by a processor, causes the measurements system to measure optical properties of an optical device of optical device substrate disposed in a measurement system, wherein the optical properties of the optical device or optical device substrate comprises:

projecting a baseline image of a pattern, the baseline image projected from a light engine of a measurement system;

capturing a near field image at a near field detector of the measurement system;

capturing a far field image at a far field detector of the measurement system;

analyzing the near field image and far field image to locate a first plurality of points on the near field image and far field image, the first plurality of points converted into a near field function and far field function;

obtaining a near field fast Fourier transform (FFT) of the near field function and far field FFT of the far field function; and

determining an optical device modulation transfer function (MTF) of the one or more optical devices, the optical device MTF determined by comparing the near field FFT to the far field FFT corresponding to the baseline image.

16. The controller of claim **15**, wherein the baseline image is projected through a reticle to form the pattern.

17. The controller of claim **15**, wherein the near field detector is positioned at a top side of the optical device or optical device substrate and the far field detector is positioned at a bottom side of the optical device or optical device substrate.

18. The controller of claim **15**, wherein the near field detector is positioned at a bottom side of the optical device or optical device substrate and the far field detector is positioned at a top side of the optical device or optical device substrate.

19. The controller of claim **15**, wherein the near field detector is a wavefront sensor.

20. The controller of claim **15**, wherein the light engine has a field of view of about 10 degrees to about 120 degrees.

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