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(54) **METHOD OF MEASURING EFFICIENCY FOR OPTICAL DEVICES**

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G01M 11/02 (2006.01)
G01S 7/481 (2006.01)
G01S 17/89 (2020.01)

(52) **U.S. Cl.**
CPC ***G01M 11/0207*** (2013.01); ***G01S 7/481*** (2013.01); ***G01S 17/89*** (2013.01)

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(56) **References Cited**

U.S. PATENT DOCUMENTS

2008/0285026 A1 11/2008 Okawauchi et al.
2009/0059215 A1 3/2009 Mehanian et al.
(Continued)

FOREIGN PATENT DOCUMENTS

CN 202100980 * 1/2021 ..... G01N 21/21
JP H01138623 * 5/1989 ..... G02B 7/28
(Continued)

OTHER PUBLICATIONS

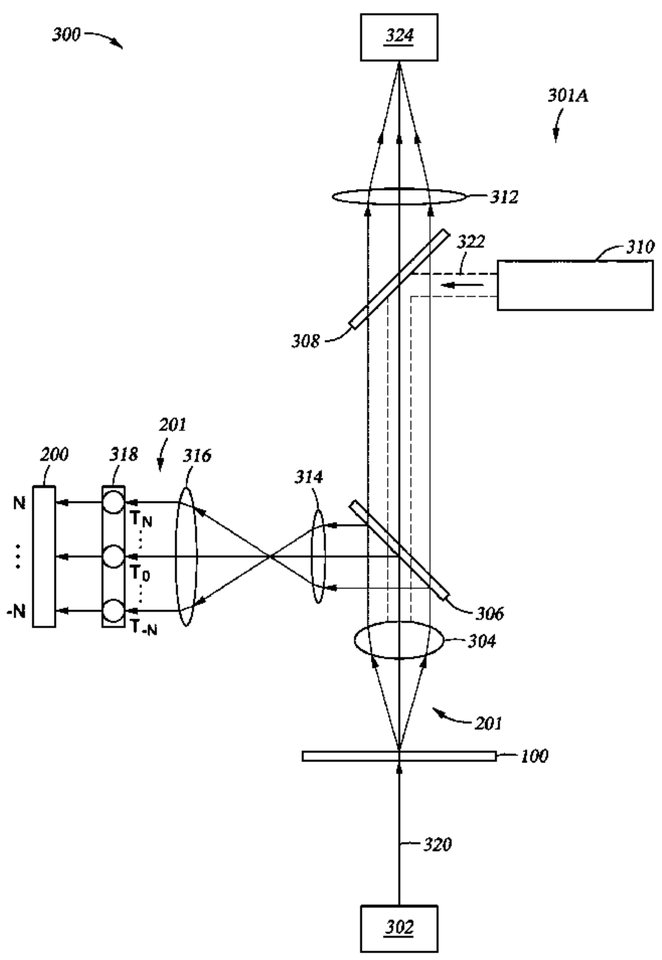
International Search Report and Written Opinion for International Application No. PCT/US2022/019162 dated Jun. 23, 2022.
(Continued)

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(57) **ABSTRACT**

Embodiments of the present disclosure relate to measurement systems and methods of measuring efficiency of optical devices. In one example, the measurement systems include a light source, a mirror, an illumination source, and a sensor. The light source provides a light beam to the optical device to be diffracted into diffraction beams having diffraction orders. The diffractions beams form a diffraction pattern. The method includes positioning the optical device in the measurement system and directing the diffraction beams to the sensor. The sensor is operable to measure the efficiency of the optical device by measuring the diffraction pattern.

7 Claims, 7 Drawing Sheets



(58) **Field of Classification Search**
CPC ... G01N 2021/9511; G01N 2021/9583; G01N 21/958
USPC 356/124
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(56) **References Cited**

U.S. PATENT DOCUMENTS

2013/0208256	A1*	8/2013	Mamidipudi	G01S 7/4815 359/15
2015/0226677	A1*	8/2015	Sullivan	G02B 21/002 356/237.5
2016/0258878	A1*	9/2016	Zhang	G02B 13/143
2017/0184483	A1*	6/2017	Bartels	G01N 15/1468

FOREIGN PATENT DOCUMENTS

JP	09196813	A	7/1997
JP	H9196813	A	7/1997
JP	2008286583	A	11/2008
WO	2006107929	A1	10/2006
WO	2021040936	A1	3/2021

OTHER PUBLICATIONS

Sudheer, Kumar, Diffraction Efficiency of Plasmonic Gratings Fabricated by Electron Beam Lithography Using a Silver Halide Film, Journal of Applied Physics, Jul. 22, 2016, vol. 120, No. 4,pp. 043101(1)-043101(8).

Sudheer K. et al., "Diffraction efficiency of plasmonic gratings fabricated by electron beam lithography using a silver halide film." Journal of Applied Physics, vol. 120, 043101, 2016, pp. 043101-1 to 043101-8, doi: 10.1063/1.4956438.

Japanese Office Action dated Dec. 10, 2024 for Application No. 2023-571440.

Office Action dtd Jun. 10, 2025 for Japanese Patent Application No. 2023-571440.

* cited by examiner

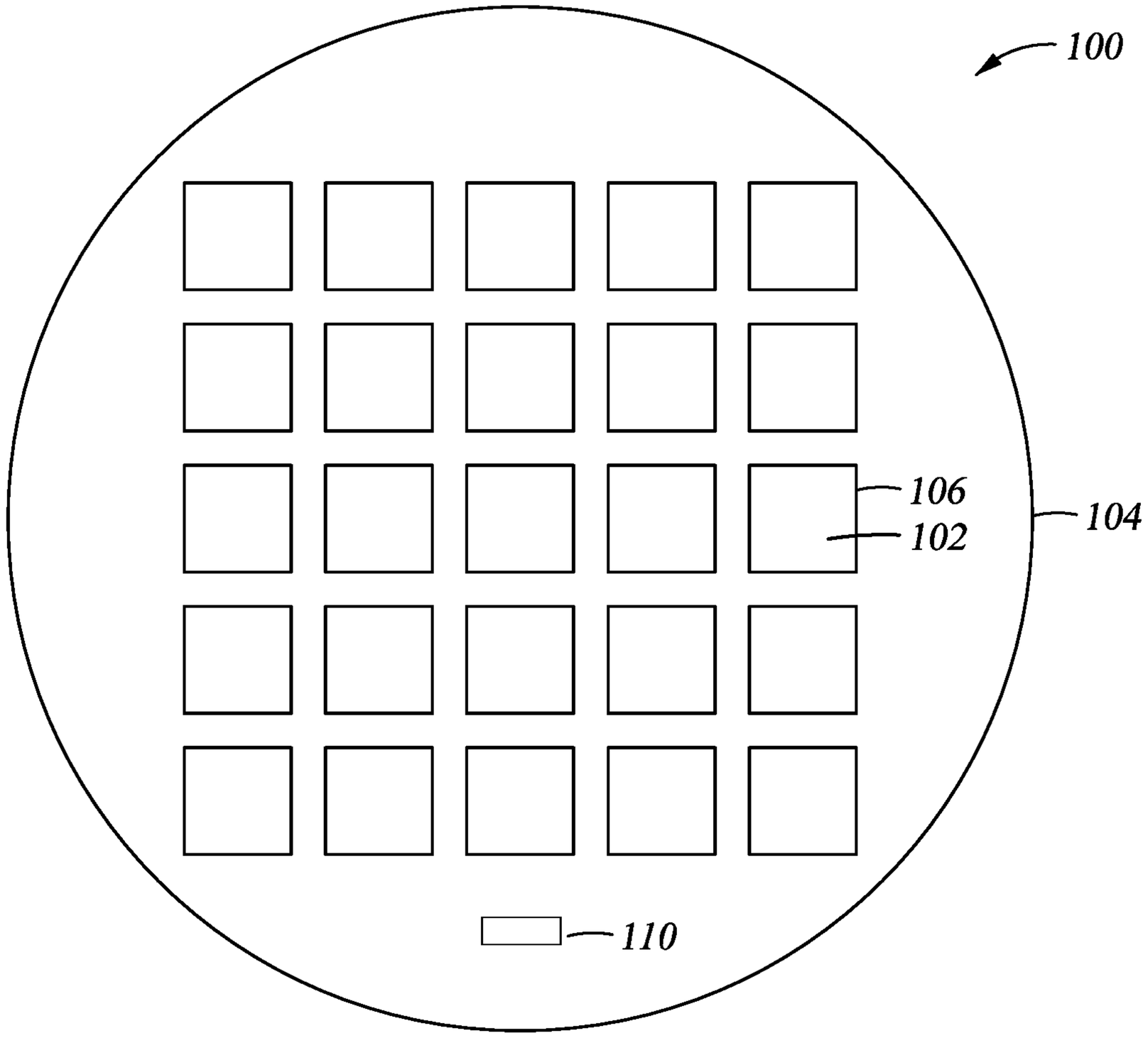


Fig. 1A

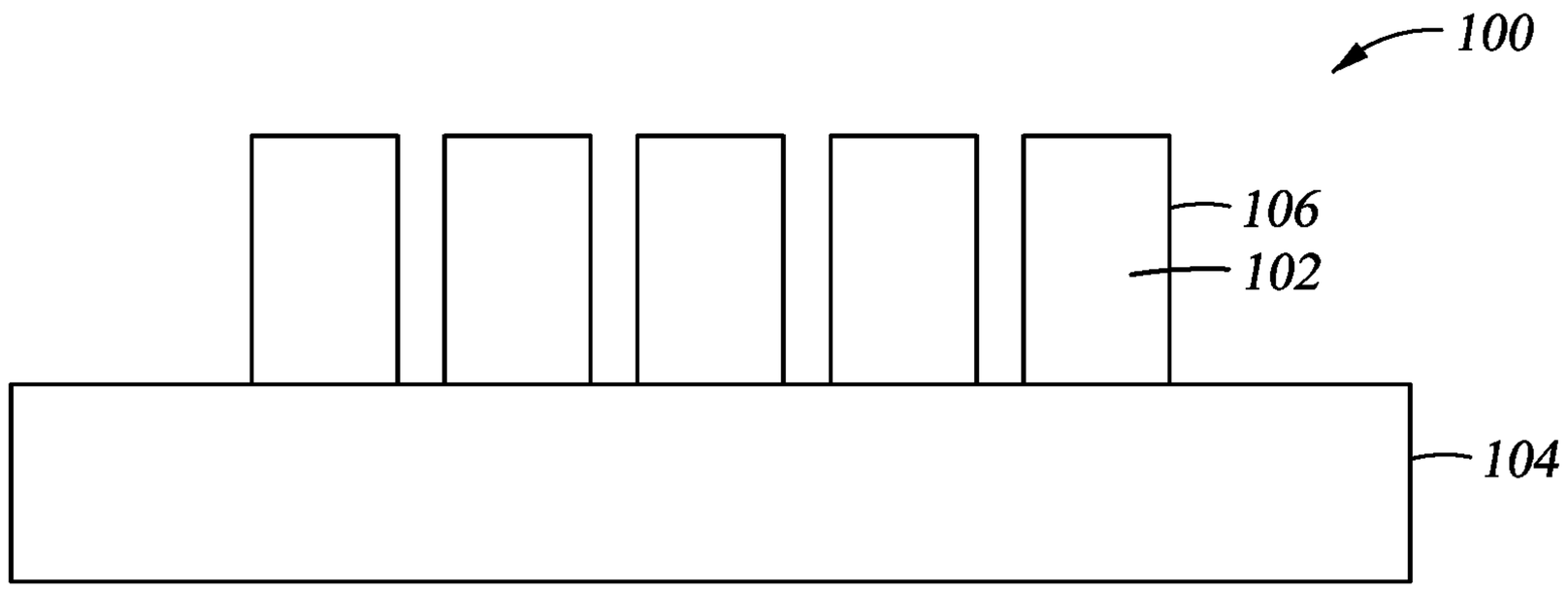


Fig. 1B

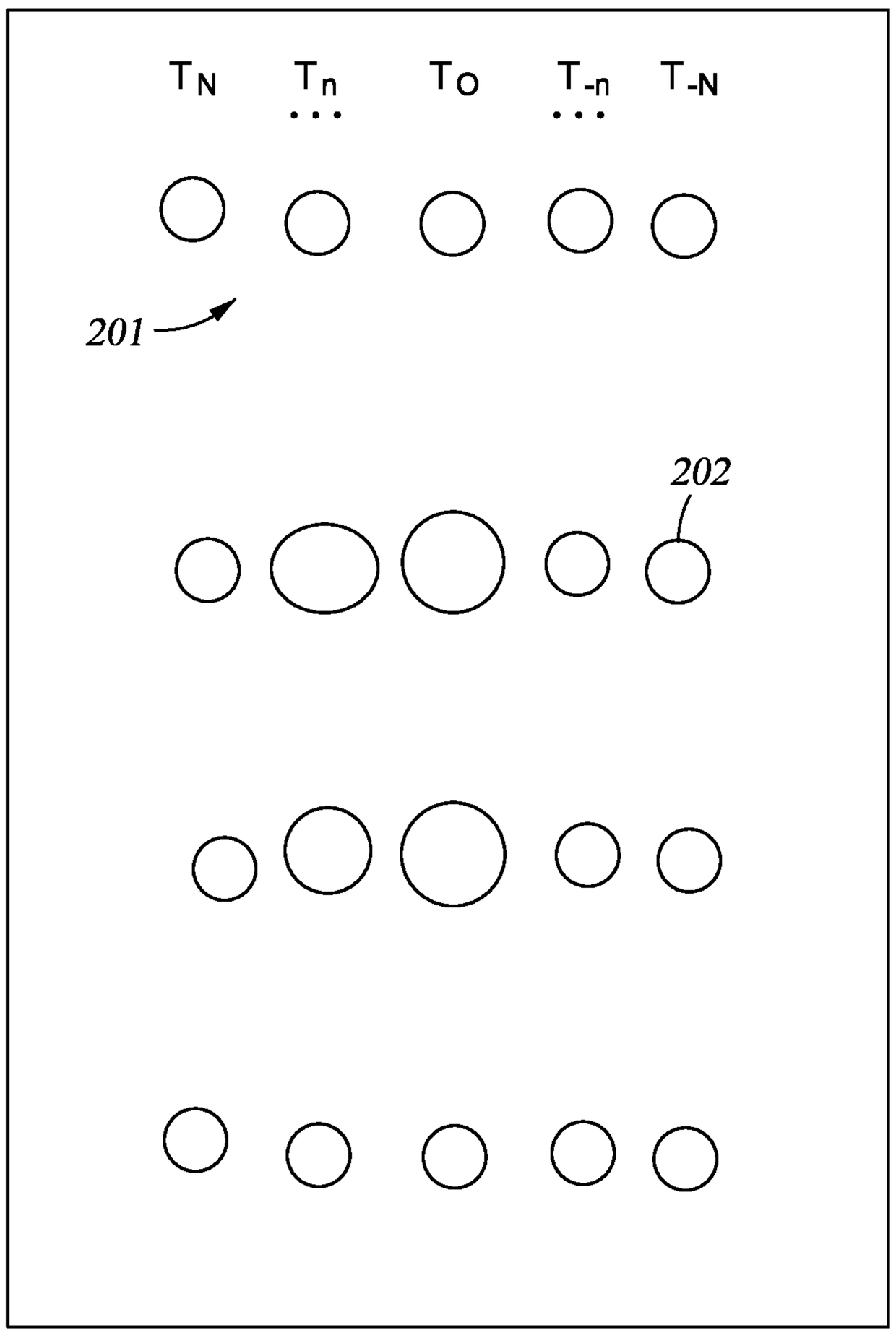


Fig. 2

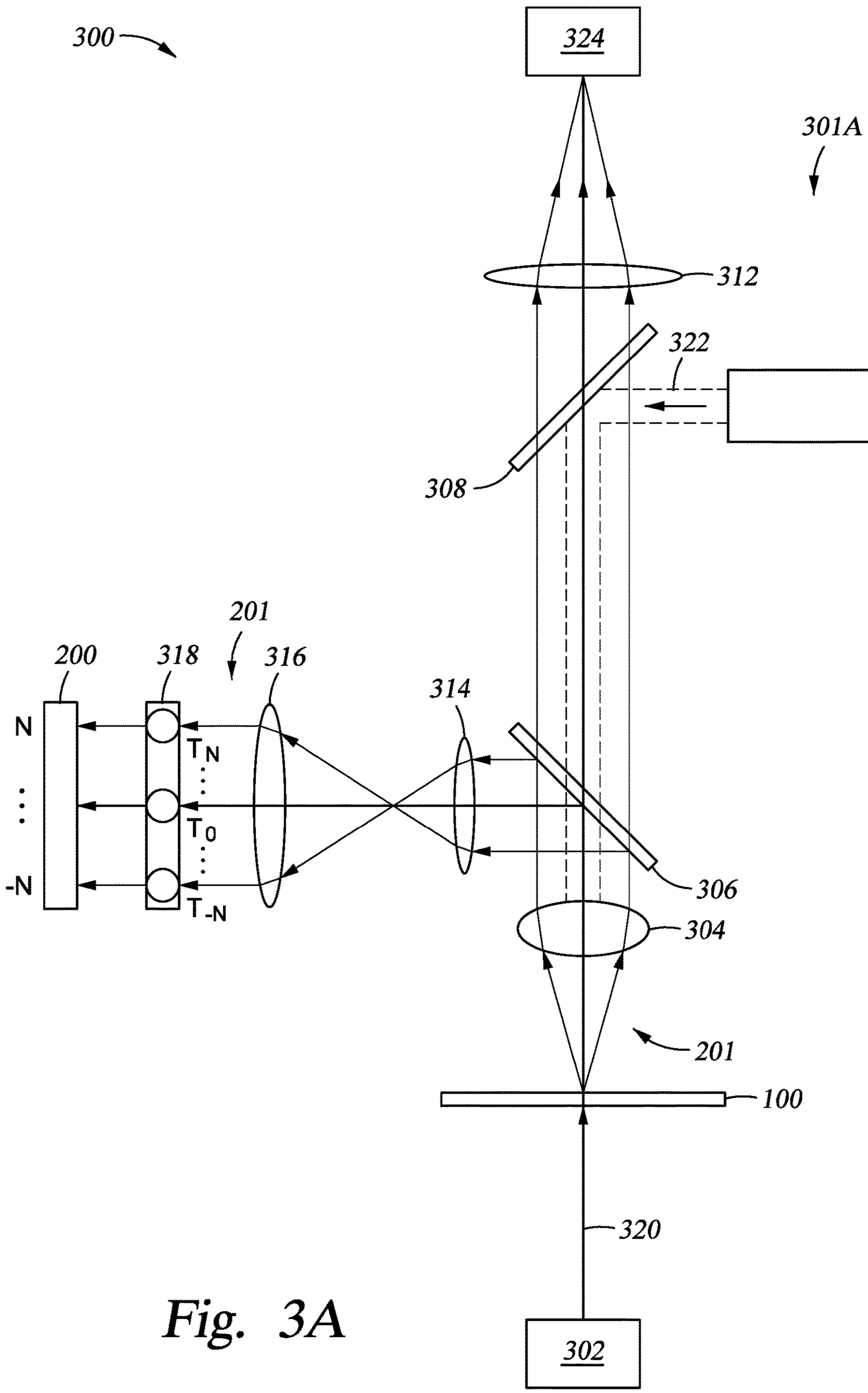

300
324
301A
312
322
310
308
201
200
318
316
314
N
T N
T 0
-N
T -N
306
304
201
100
320
302

Fig. 3A

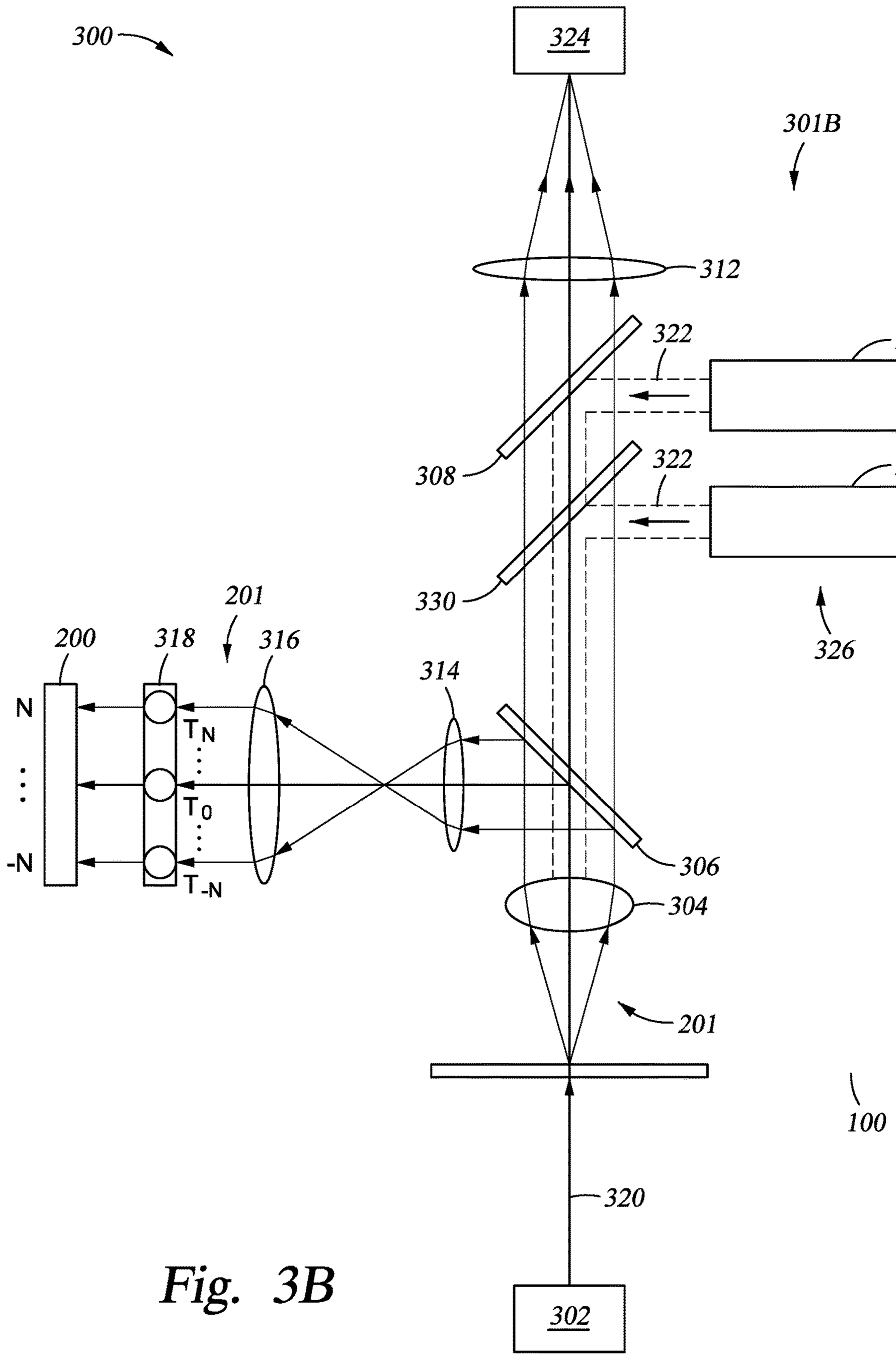

300
324
301B
312
322
310
308
322
328
330
326
201
200
318
316
314
N
T_N
T_0
T_{-N}
-N
306
304
201
100
320
302

Fig. 3B

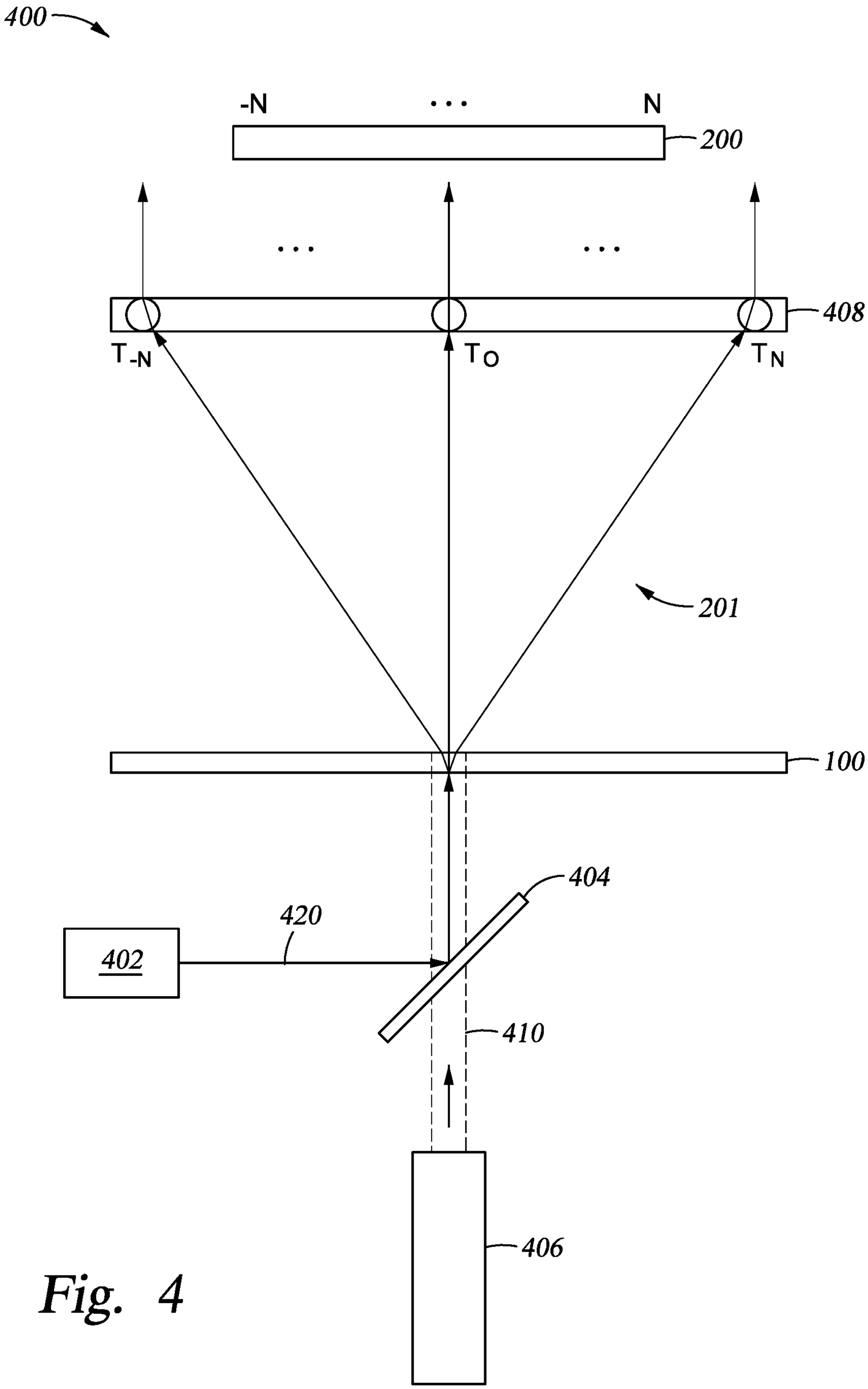


Fig. 4

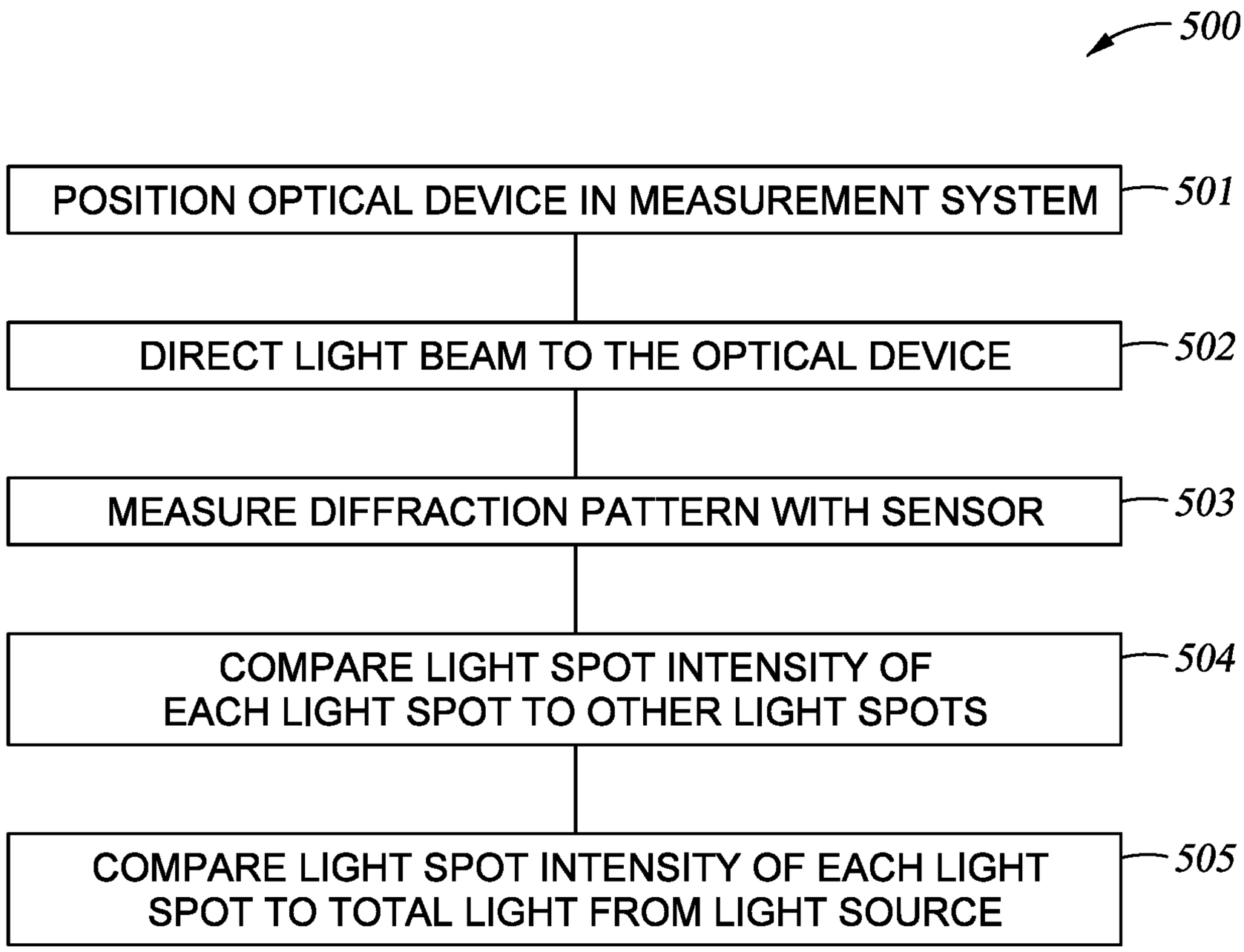

500
POSITION OPTICAL DEVICE IN MEASUREMENT SYSTEM
501
DIRECT LIGHT BEAM TO THE OPTICAL DEVICE
502
MEASURE DIFFRACTION PATTERN WITH SENSOR
503
COMPARE LIGHT SPOT INTENSITY OF EACH LIGHT SPOT TO OTHER LIGHT SPOTS
504
COMPARE LIGHT SPOT INTENSITY OF EACH LIGHT SPOT TO TOTAL LIGHT FROM LIGHT SOURCE
505

Fig. 5

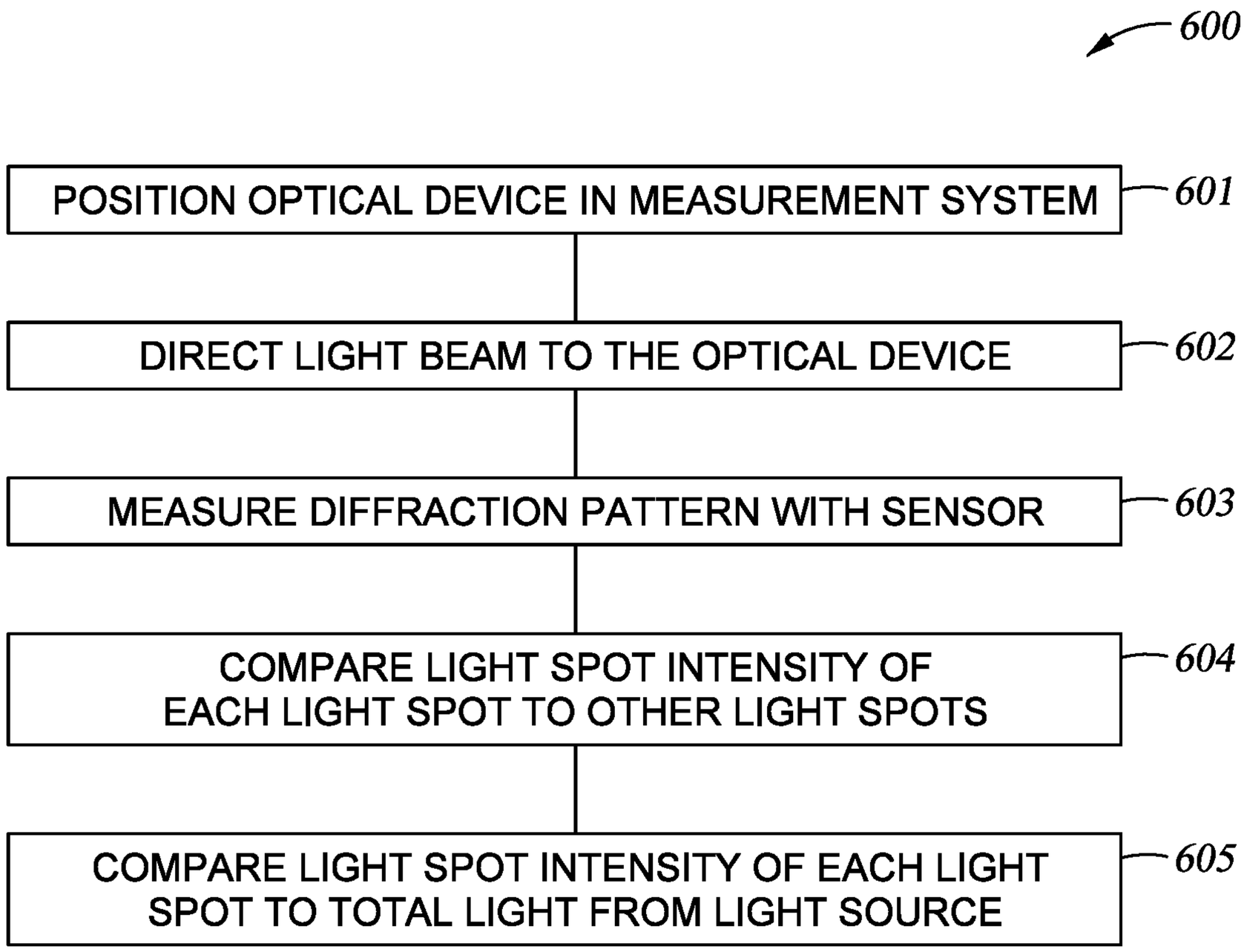

600
POSITION OPTICAL DEVICE IN MEASUREMENT SYSTEM
601
DIRECT LIGHT BEAM TO THE OPTICAL DEVICE
602
MEASURE DIFFRACTION PATTERN WITH SENSOR
603
COMPARE LIGHT SPOT INTENSITY OF EACH LIGHT SPOT TO OTHER LIGHT SPOTS
604
COMPARE LIGHT SPOT INTENSITY OF EACH LIGHT SPOT TO TOTAL LIGHT FROM LIGHT SOURCE
605

Fig. 6

METHOD OF MEASURING EFFICIENCY FOR OPTICAL DEVICES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims benefit of U.S. Provisional Patent Application No. 63/161,346, filed Mar. 15, 2021, which is herein incorporated by reference in its entirety.

BACKGROUND

Field

Embodiments of the present disclosure generally relate to optical devices. More specifically, embodiments of the present disclosure relate to measurement systems and methods of measuring diffraction efficiency of optical devices.

Description of the Related Art

Optical devices including waveguide combiners and flat optical devices, such as metasurfaces and flat lenses, are used in various sensing applications (e.g., facial identification sensors). Generated light is propagated through the optical device until the light exits the optical device with a diffraction pattern. It is beneficial to improve the diffraction efficiency of the optical devices as well as to obtain a uniform distribution across a field of view of the optical devices. Additionally, it is beneficial to measure the diffraction orders of the diffraction pattern with a large numerical aperture. However, it is difficult to measure the efficiency of all of the diffraction orders simultaneously.

Therefore, what is needed in the art are measurement systems and methods of measuring diffraction efficiency of optical devices.

SUMMARY

In one embodiment, a measurement system is provided. The measurement system includes a light source configured to project a light beam, an objective lens disposed in the light beam. The light beam includes diffraction beams. The measurement system further includes a mirror operable to direct the diffraction beams from the objective lens through two or more relay lenses and a sensor disposed adjacent to the two or more relay lenses. The two or more relay lenses direct the diffraction beams having a diffraction pattern to the sensor. The measurement system further includes an illumination source disposed opposite of the light source.

In another embodiment, a measurement system is provided. The measurement system includes a light source configured to project a light beam, the light beam includes diffraction beams. The measurement system further includes an illumination source configured to provide white light and a sensor disposed opposite of the light source and the illumination source. The measurement system further includes a mirror operable to direct the diffraction beams having a diffraction pattern to the sensor.

In yet another embodiment, a method is provided. The method includes positioning an optical device in a measurement system. The method further includes aligning the optical device with a light source by capturing fiducial marks on the optical device. The method further includes directing a light beam from a light source to the optical device. The optical device diffracts the light beam into diffraction beams. The method further includes directing the diffraction beams through an objective lens, directing the diffraction beams to a sensor with a mirror and one or more relay lenses and measuring a diffraction efficiency of a diffraction pattern formed by the diffraction beams with the sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

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 scope, as the disclosure may admit to other equally effective embodiments.

FIG. **1**A is a schematic, top view of an optical device according to embodiments.

FIG. **1**B is a schematic, side view of an optical device according to embodiments.

FIG. **2** is a schematic, top view of a diffraction pattern according to embodiments.

FIG. **3**A is a schematic, cross-sectional view of a configuration of a measurement system according to embodiments.

FIG. **3**B is a schematic, cross-sectional view of a configuration of a measurement system according to embodiments.

FIG. **4** is a schematic, cross-sectional view of a of a measurement system according to embodiments.

FIG. **5** is a flow diagram of a method of measuring diffraction efficiency of one or more optical devices with a measurement system according to embodiments.

FIG. **6** is a flow diagram of a method of measuring diffraction efficiency of one or more optical devices with a measurement system according to embodiments.

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

Embodiments of the present disclosure relate to measurement systems and methods of measuring diffraction efficiency of optical devices.

FIG. **1**A is a schematic, top view of an optical device **100** according to embodiments. FIG. **1**B is a schematic, side view of an optical device **100**, according to embodiments. The optical device **100** may be any optical device operable to be utilized in sensing applications (e.g., facial identification sensors). For example, the optical device **100** may be a waveguide combiner or a flat optical device, such as a metasurface or a flat lens.

The optical device **100** includes a plurality of optical device structures **102** disposed on a substrate **104**. The optical device structures **102** may be nanostructures having sub-micron dimensions, e.g., nano-sized dimensions. While FIGS. **1**A and **1**B depict the optical device structures **102** as having square or rectangular shaped cross-sections, the cross-sections of 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. Although only twenty five

optical device structures **102** are shown on the substrate **104**, any number of optical device structures **102** may be disposed on the substrate **104**. In some embodiments, the optical device structures **102** may be angled, with at least one sidewall **106** of the plurality of optical device structures **102** angled relative to the substrate **104**. The optical device **100** includes fiducial marks **110** disposed on the substrate **104**.

The substrate **104** can be any used in the art, and can be either opaque or transparent depending on the use of the substrate **104**. The substrate **104** includes any suitable material, provided that the substrate **104** can adequately transmit light in a predetermined wavelength or wavelength range and can serve as an adequate support for the plurality of optical device structures **102**. The substrate **104** includes, but is not limited to, amorphous dielectrics crystalline dielectrics, silica (e.g., fused silica), magnesium oxide, polymers, silicon (Si), silicon dioxide (SiO_2), quartz, silicon carbide (SiC), germanium (Ge), silicon germanium (SiGe), indium phosphide (InP), gallium arsenide (GaAs), gallium nitride (GaN), sapphire, or combinations thereof. In some embodiments, which can be combined with other embodiments described herein, the substrate **104** includes a transparent material. Suitable examples may include an oxide, sulfide, phosphide, telluride, or combinations thereof. The substrate **104** can be any size or shape, such as, but not limited to, 150 mm, 200 mm, or 300 mm diameter wafers.

FIG. **2** is a schematic, top view of a diffraction pattern **200** according to embodiments. The diffraction pattern **200** is produced when a light beam is diffracted by an optical device **100**. The diffraction pattern **200** includes diffraction beams **201** which form the diffraction pattern **200**. The diffraction beams **201** include one or more diffraction orders n with a highest order N and a negative highest order −N. As shown in FIG. **2**, a highest order N (T_N) beam is diffracted and a negative highest order −N (T_{-N}) beam is diffracted. When the light beam is incident on the optical device **100**, the light is diffracted from the optical device structures **102** in directions corresponding to diffraction orders n, where n=−2, −1, 0, 1, 2, 3, etc. The zero-order mode (T_0) beam is also diffracted. The diffraction beams **201** do not have an upper limit on the highest order N and the negative highest order −N.

The diffraction beams **201** produce a plurality of light spots **202** in the diffraction pattern **200**. The plurality of light spots **202** each have a light spot intensity. The light spot intensity of each light spot **202** may be compared to the other light spots **202**, to determine the uniformity of the light spot intensity of the diffraction pattern **200**. Additionally, the light spot intensity of each light spot **202** may be compared with the total light emitted from a light source to determine a diffraction efficiency of the diffraction orders n of the diffraction beams **201**. The light spot intensity is the total power of the light spot **202**. The diffraction efficiency is a measure of how much optical power is diffracted into a designated direction compared to the power incident onto the optical device **100**. In some embodiments, each of the light spots **202** have the same size but different light spot intensities.

FIG. **3**A is a schematic, cross-sectional view of a configuration **301**A of a measurement system **300** according to embodiments. The measurement system **300** may be used for methods of measuring diffraction efficiency of optical devices described herein. The measurement system **300** enables both real space imaging (microscopy) and k-space (angular space/back focal plane) imaging. Therefore, the diffraction efficiency (k space) can be measured and the device can be inspected simultaneously. The measurement system **300** includes a light source **302**, an objective lens **304**, a first mirror **306**, a second mirror **308**, an illumination source **310**, a tube lens **312**, a first relay lens **314**, a second relay lens **316**, and a sensor **318**. The measurement system **300** images the diffraction pattern **200** at the back focal plane of an objective lens. The back focal plane is between the objective lens **304** and the first mirror **306**. The back focal plane is relayed to the sensor **318** through the first relay lens **314** and the second relay lens **316**. One or more optical devices **100** are disposed between the objective lens **304** and the light source **302**. In one embodiment, which can be combined with other embodiments described herein, multiple optical devices **100** may be disposed between the objective lens **304** and the light source **302**. For example, multiple optical devices **100** may be disposed on a translation stage to be measured by the measurement system **300**. In another embodiment, which can be combined with other embodiments described herein, only the optical device **100** is disposed between the objective lens **304** and the light source **302**.

The light source **302** is configured to direct a light beam **320** to one of the optical devices **100**. As shown in FIG. **3**A, the light beam **320** passes through the optical device **100** and is diffracted to the objective lens **304**. The objective lens **304** is disposed between the optical devices **100** and the first mirror **306**. In some embodiments, which can be combined with other embodiments described herein, the light beam **320** is directed to the optical device **100** and the light beam **320** propagates through the optical device **100** prior to being diffracted to the objective lens **304**. For example, in embodiments where the optical device **100** is a waveguide, the light beam **320** may propagate through the optical device **100**. The light beam **320** is diffracted into diffraction beams **201** and directed to the objective lens **304**. The objective lens **304** may have a numerical aperture (NA) between about 0.5 and about 1.0. The objective lens **304** may have a magnification power of between about 20× and about 60×.

The illumination source **310** is configured to direct white light **322** to the second mirror **308**. The illumination source **310** is disposed opposite the light source **302**. The second mirror **308** may be a dichroic mirror. The white light **322** is reflected by the second mirror **308** to the objective lens **304**. A dichroic mirror is a mirror with different reflection or transmission properties depending on the wavelength of the incident light. As such, the diffraction beams **201** may be directed to the tube lens **312** by transmitting through the second mirror **308**. The tube lens **312** directs the diffraction beams **201** to create a real image **324**. The real image **324** and the white light **322** directed to the objective lens **304** are utilized to position the optical device **100** in the measurement system **300**. For example, the optical device **100** may be aligned such that desired portions of the optical device **100** to be measured are positioned in the measurement system **300**. In some embodiments, alignment cameras (not shown) capture fiducial marks **110** on the optical device **100**. The relative position of the fiducial marks **110** on the optical device **100** are known and the design of the optical device **100** is known. Therefore, a scan map for each optical device **100** to be measure can be built. As such, the optical device **100** can be positioned in alignment with the light source **302**.

The diffraction beams **201** are further directed to the first mirror **306**. The first mirror **306** may be a dichroic mirror. The first mirror **306** is disposed between the second mirror **308** and the objective lens **304**. The first mirror **306** reflects the diffraction beams **201** from the objective lens **304** to the first relay lens **314** and the second relay lens **316**. The

diffraction beams **201** may also be transmitted through the first mirror **306** to second mirror **308**. The first relay lens **314** is disposed between the first mirror **306** and the second relay lens **316**. The second relay lens **316** is disposed between the first relay lens **314** and the sensor **318**. The sensor **318** has a surface area between about 70 mm^2 and about 864 mm^2. The second relay lens **316** directs the diffraction beams **201** to the sensor **318**. The diffraction beams **201** form a diffraction pattern **200** on the sensor **318**. The sensor **318** may be a 2D LIDAR sensor. The diffraction pattern **200** includes the diffraction beams **201** with one or more diffraction orders n with a highest order N and a negative highest order −N. As shown in FIG. **3**, a highest order N (T_N) beam is diffracted and a negative highest order −N (T_{-N}) beam is diffracted. A zero-order mode (T_0) beam is also diffracted.

FIG. **3**B is a schematic, cross-sectional view of a configuration **301**B of a measurement system **300**. The measurement system **300** may be used for methods of measuring diffraction efficiency of optical devices described herein. The measurement system **300** includes a light source **302**, an objective lens **304**, a first mirror **306**, a second mirror **308**, an illumination source **310**, a tube lens **312**, a first relay lens **314**, a second relay lens **316**, and a sensor **318**. One or more optical devices **100** are disposed between the objective lens **304** and the light source **302**. The diffraction efficiency is obtained by directly mounting the sensor **318** after the optical devices **100**. In one embodiment, which can be combined with other embodiments described herein, multiple optical devices **100** may be disposed between the objective lens **304** and the light source **302**. For example, multiple optical devices **100** may be disposed on a translation stage to be measured by the measurement system **300**. In another embodiment, which can be combined with other embodiments described herein, only the optical device **100** is disposed between the objective lens **304** and the light source **302**.

The configuration **301**B is utilized to control the gap between one or more optical devices **100** and the objective lens **304**. The configuration **301**B includes the measurement system **300** described with reference to FIG. **3**A and an autofocus system **326**. The autofocus system **326** includes an autofocus module **328** and a third mirror **330**. The autofocus system **326** compensates for sagging and bowing of the substrate **104**. Due to the distance between the objective lens **304** and the optical device **100** varying from sag and bowing, the autofocus system **326** will compensate for the varying distance.

FIG. **4** is a schematic, cross-sectional view of a of a measurement system **400** according to embodiments. The measurement system **400** may be used for methods of measuring diffraction efficiency of optical devices described herein. The measurement system **400** includes a light source **402**, a mirror **404**, an illumination source **406**, and a sensor **408**. One or more optical devices **100** are disposed between the light source **402** and the sensor **408**. In one embodiment, which can be combined with other embodiments described herein, multiple optical devices **100** may be disposed between the light source **402** and the sensor **408**. For example, multiple optical devices **100** may be disposed on a translation stage to be measured by the measurement system **400**. In another embodiment, which can be combined with other embodiments described herein, only the optical device **100** is disposed between the light source **402** and the sensor **408**. The sensor **408** includes a surface area of between about 70 mm^2 and about 864 mm^2. The sensor **408** is disposed opposite of the light source **402** and the illumination source **406**.

The light source **402** is configured to direct a light beam **420** to one of the optical devices **100**. As shown in FIG. **4**, the light beam **420** is directed to the mirror **404**. The mirror **404** reflects the light beam **420** to pass through the optical device **100**. The light beam **420** is diffracted to the sensor **408**. In some embodiments, which can be combined with other embodiments described herein, the light beam **420** is directed to the optical device **100** and the light beam **420** propagates through the optical device **100** prior to being diffracted to the sensor **408**. For example, in embodiments where the optical device **100** is a waveguide, the light beam **420** may propagate through the optical device **100**. The light beam **420** is diffracted into diffraction beams **201** and directed to the sensor **408**. The sensor **408** may have a numerical aperture (NA) between about 0.85 and about 1.0. The sensor **408** may be a 20 mm sensor.

The illumination source **406** is configured to direct white light **410** to the light beam **420** as the light beam **420** contacts the optical device **100**. The white light **410** is utilized to position the optical device **100** in the measurement system **400**. For example, the optical device **100** may be aligned such that desired portions of the optical device **100** to be measured are positioned in the measurement system **400**. Fiducial marks **110** on the optical device **100** are utilized to align the optical device **100** within the measurement system **300**.

The diffraction beams **201** are directed to the sensor **408**. The diffraction beams **201** form a diffraction pattern **200** on the sensor **408**. The sensor **408** may be a 2D LIDAR sensor. The diffraction pattern **200** includes the diffraction beams **201** with one or more diffraction orders n with a highest order N and a negative highest order −N. As shown in FIG. **3**, a highest order N (T_N) beam is diffracted and a negative highest order −N (T_{-N}) beam is diffracted. A zero-order mode (T_0) beam is also diffracted.

The diffraction beams **201** produce a plurality of light spots **202** in the diffraction pattern **200**. The sensor **408** is operable to measure a light spot intensity of each light spot **202**. The light spot intensity may be compared to the other light spots **202**, to determine the uniformity of the light spot intensity of the diffraction pattern **200**. Additionally, the light spot intensity of each light spot **202** may be compared with the total light from the light source **402** to determine an efficiency of the diffraction orders n of the diffraction beams **201**. In some embodiments, the uniformity and intensity of the light spots **202** may be compared to light spots **202** of other optical devices **100**.

FIG. **5** is a flow diagram of a method **500** of measuring diffraction efficiency of one or more optical devices **100** with a measurement system **300**. The measurement system **300** described herein allows for a numerical aperture near 1 to be achieved. By controlling the distance between the optical device **100** and the sensor **318**, and having a large surface area of the sensor **318**, the numerical aperture may be near 1. The numerical aperture is achieved by utilizing microscope objectives. Additionally, the diffraction orders may be measured in parallel for all diffraction orders to increase throughput. To facilitate explanation, the method will be described with reference to a configuration **301**A of the measurement system **300**, but it is to be understood that a configuration **301**B may be utilized in conjunction with the method provided herein.

At operation **501**, an optical device **100** is positioned within the measurement system **300**. For example, the portions of the optical device **100** to be measured are positioned within the measurement system **300**. The real image **324** and the white light **322** are utilized to position the

optical device **100** in the measurement system **300**. The optical device **100** is aligned with a light source **302**. The optical device **100** is aligned by capturing fiducial marks **110** on the optical device **100**. The white light **322** illuminates the fiducial marks **110**. Once the fiducial marks are located, the optical device **100** can be positioned in alignment with the light source **302** based on the relative positons of the fiducial marks **110**. Further, the distance variation between the optical device **100** and an objective lens **304** of the measurement system **300** is measured. In embodiments where the measurement system **300** includes an autofocus system **326**, the autofocus system **326** is utilized to compensate for bowing and sagging of the optical device **100**. The autofocus system **326** allows for the optical device **100** to be in focus in the measurement system **300**.

At operation **502**, a light beam **320** is directed to the optical device **100**. The optical device **100** diffracts the light into diffraction beams **201**. The diffraction beams **201** are directed to an objective lens **304**. The diffraction beams **201** are then directed to a sensor **318** by a first mirror **306**, a first relay lens **314**, and a second relay lens **316**.

At operation **503**, the diffraction beams **201** forming a diffraction pattern **200** are measured by the sensor **318**. The diffraction beams **201** produce a plurality of light spots **202** (shown in FIG. **2**) in the diffraction pattern **200**. The sensor **318** measures a light spot intensity of each light spot **202** (shown in FIG. **2**).

At operation **504**, the light spot intensity of each light spot **202** is compared to the other light spots **202**. The comparing allows for the determination of the uniformity of the light spot intensity of the diffraction pattern **200**. Additionally, at operation **505**, the light spot intensity of each light spot **202** (shown in FIG. **2**) may be compared with the total light from the light source **302** to determine a diffraction efficiency of the diffraction orders n of the diffraction beams **201**. In some embodiments, the uniformity and intensity of the light spots **202** (shown in FIG. **2**) may be compared to light spots **202** of other optical devices **100**.

FIG. **6** is a flow diagram of a method **600** of measuring diffraction efficiency of one or more optical devices **100** with a measurement system **400**. The measurement system **400** described herein allows for a numerical aperture near 1 to be achieved. By controlling the distance between the optical device **100** and the sensor **408**, and having a large surface area of the sensor **408**, the numerical aperture may be near 1. Additionally, the diffraction orders may be measured in parallel for all diffraction orders to increase throughput.

At operation **601**, an optical device **100** is positioned within the measurement system **400**. For example, the portions of the optical device **100** to be measured are positioned within the measurement system **400**. The white light **410** is utilized to position the optical device **100** in the measurement system **400**. The optical device **100** is aligned with a light source **402**. The optical device **100** is aligned by capturing fiducial marks **110** on the optical device **100**. The illumination source **406** illuminates the fiducial marks **110** to be captured. Once the fiducial marks **110** are located, the optical device **100** can be positioned in alignment with the light source **402** based on the relative positons of the fiducial marks **110**.

At operation **602**, a light beam **420** is directed to the optical device **100**. The light beam **420** may be directed to the optical device **100** by a mirror **404**. The optical device **100** diffracts the light into diffraction beams **201**. The diffraction beams **201** are directed to a sensor **408**.

At operation **603**, the diffraction beams **201** forming a diffraction pattern **200** are measured by the sensor **408**. The diffraction beams **201** produce a plurality of light spots **202** in the diffraction pattern **200**. The sensor **408** measures a light spot intensity of each light spot **202**.

At operation **604**, the light spot intensity is compared to the other light spots **202**. The comparing allows the determination of the uniformity of the light spot intensity of the diffraction pattern **200**. Additionally, at operation **605**, the light spot intensity of each light spot **202** may be compared with the total light from the light source **402** to determine a diffraction efficiency of the diffraction orders n of the diffraction beams **201**. In some embodiments, the uniformity and intensity of the light spots **202** may be compared to light spots **202** of other optical devices **100**.

In summation, measurement systems and methods of measuring efficiency of optical devices are described herein. The measurement systems, in one example, include at least a light source, a mirror, an illumination source, and a sensor. The light source provides a light beam to the optical device to be diffracted into diffraction beams having diffraction orders. The diffractions beams form a diffraction pattern. The method includes positioning the optical device in the measurement system and directing the diffraction beams to the sensor. The sensor is operable to measure the efficiency of the optical device by measuring the diffraction pattern. Additionally, the uniformity of the diffraction pattern may be measured by the sensor. The embodiments described herein allow for a numerical aperture near 1 to be achieved. The sensor is operable to measure the efficiency of the diffraction orders simultaneously, thus improving throughput. The measurement systems may be easily integrated into production lines to minor the diffraction efficiency and uniformity.

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 light source configured to project a light beam;

an objective lens disposed in the light beam, the light beam including diffraction beams;

a first mirror operable to reflect the diffraction beams from the objective lens through two or more relay lenses;

a sensor disposed adjacent to the two or more relay lenses, wherein the two or more relay lenses are positioned to direct the diffraction beams having a diffraction pattern to the sensor; and

an illumination source disposed opposite of the light source, the illumination source configured to project white light toward a second mirror, the second mirror positioned to reflect the white light toward the objective lens.

2. The measurement system of claim **1**, further comprising a tube lens configured to direct the diffraction beams to form a real image.

3. The measurement system of claim **1**, wherein an optical device is configured to be disposed between the light source and the objective lens, wherein the light beam is operable to propagate through the optical device and the light beam is operable to be diffracted by the optical device.

4. The measurement system of claim **1**, wherein the first mirror is a dichroic mirror.

5. The measurement system of claim **1**, wherein the sensor is a 2D LIDAR sensor.

6. The measurement system of claim **1**, wherein the objective lens has a numerical aperture (NA) between about 0.5 and about 1.0.

7. The measurement system of claim 1, wherein the diffraction beams produce a plurality of light spots in the diffraction pattern, wherein the sensor is operable to measure a light spot intensity of each light spot.

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