US010775158B2

(12) **United States Patent**
Olson et al.

(10) **Patent No.: US 10,775,158 B2**
(45) **Date of Patent: Sep. 15, 2020**

(54) **SYSTEM AND METHOD FOR DETECTING ETCH DEPTH OF ANGLED SURFACE RELIEF GRATINGS**

(71) Applicant: **APPLIED Materials, Inc.**, Santa Clara, CA (US)

(72) Inventors: **Joseph C. Olson**, Beverly, MA (US); **Ludovic Godet**, Sunnyvale, CA (US); **Rutger Meyer Timmerman Thijssen**, Sunnyvale, CA (US); **Morgan Evans**, Manchester, MA (US)

(73) Assignee: **Applied Materials, Inc.**, Santa Clara, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **16/240,301**

(22) Filed: **Jan. 4, 2019**

(65) **Prior Publication Data**

US 2020/0158495 A1 May 21, 2020

Related U.S. Application Data

(60) Provisional application No. 62/767,944, filed on Nov. 15, 2018.

(51) **Int. Cl.**

G01B 11/22	(2006.01)
H01L 21/306	(2006.01)
C03C 15/00	(2006.01)
G02B 5/18	(2006.01)

(52) **U.S. Cl.**

CPC ***G01B 11/22*** (2013.01); ***C03C 15/00*** (2013.01); ***G02B 5/1857*** (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,116,461	A *	5/1992	Lebby	G02B 5/1857 204/192.34
2007/0153298	A1 *	7/2007	Fukui	G01B 11/0625 356/632
2014/0144506	A1	5/2014	Iizuka et al.	
2016/0033697	A1	2/2016	Sainiemi et al.	
2016/0061822	A1	3/2016	Saar et al.	
2019/0258008	A1 *	8/2019	Hautala	G02B 5/1857

FOREIGN PATENT DOCUMENTS

JP	2013149750	A	8/2013

OTHER PUBLICATIONS

International Search Report and Written Opinion for the International Patent Application No. PCT/US2019/059053, dated Feb. 21, 2020, 8 pages.

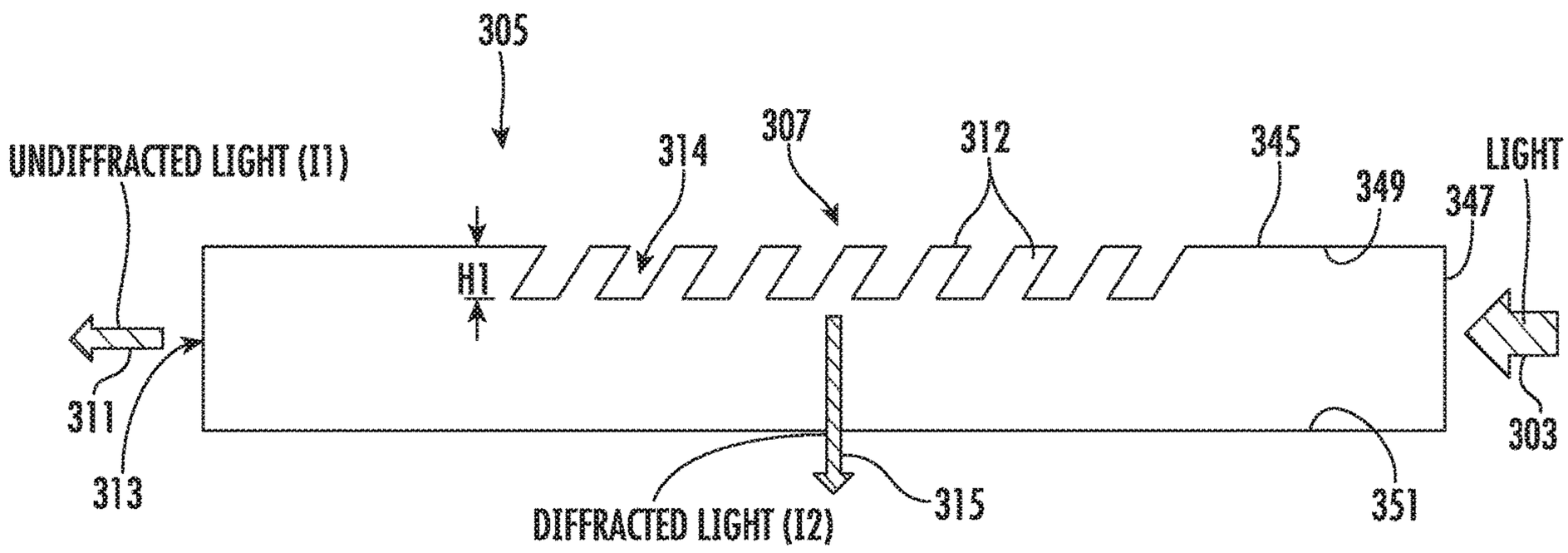
* cited by examiner

Primary Examiner — Shamim Ahmed

(57) **ABSTRACT**

Optical grating components and methods of forming are provided. In some embodiments, a method includes providing an optical grating layer, and forming an optical grating in the optical grating layer, wherein the optical grating comprises a plurality of angled trenches disposed at a non-zero angle of inclination with respect to a perpendicular to a plane of the optical grating layer. The method may further include delivering light from a light source into the optical grating layer, and measuring at least one of: an undiffracted portion of the light exiting the optical grating layer, and a diffracted portion of the light exiting the optical grating layer.

16 Claims, 7 Drawing Sheets



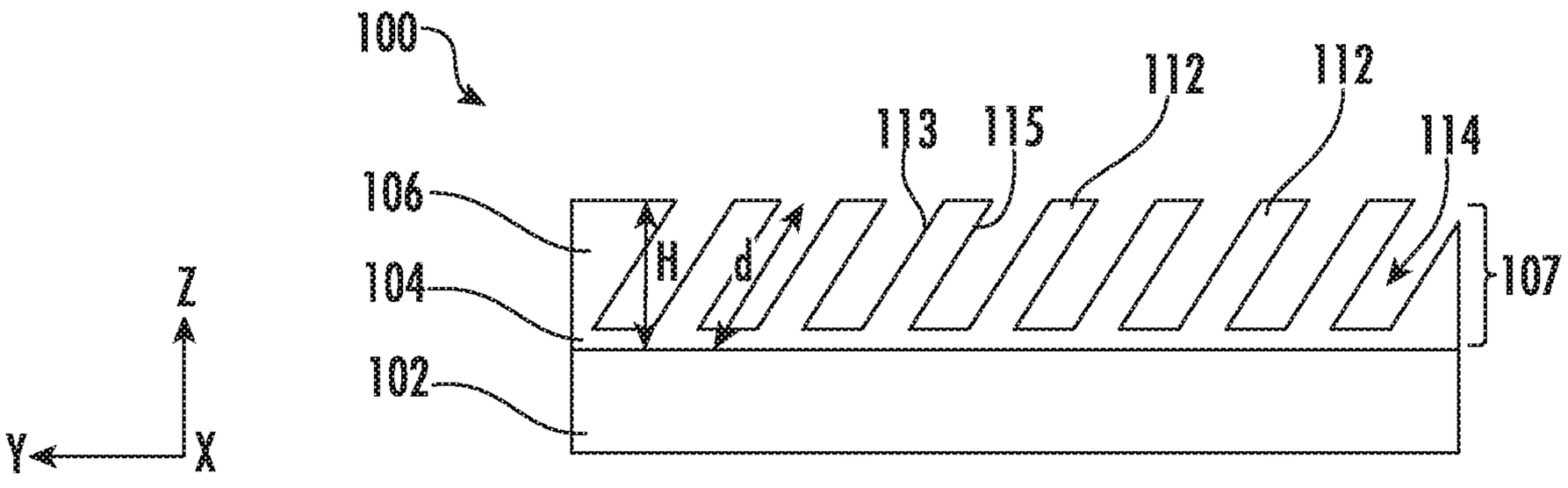

100
112
112
113
115
114
106
104
102
H
d
107
Z
Y
X

FIG. 1A

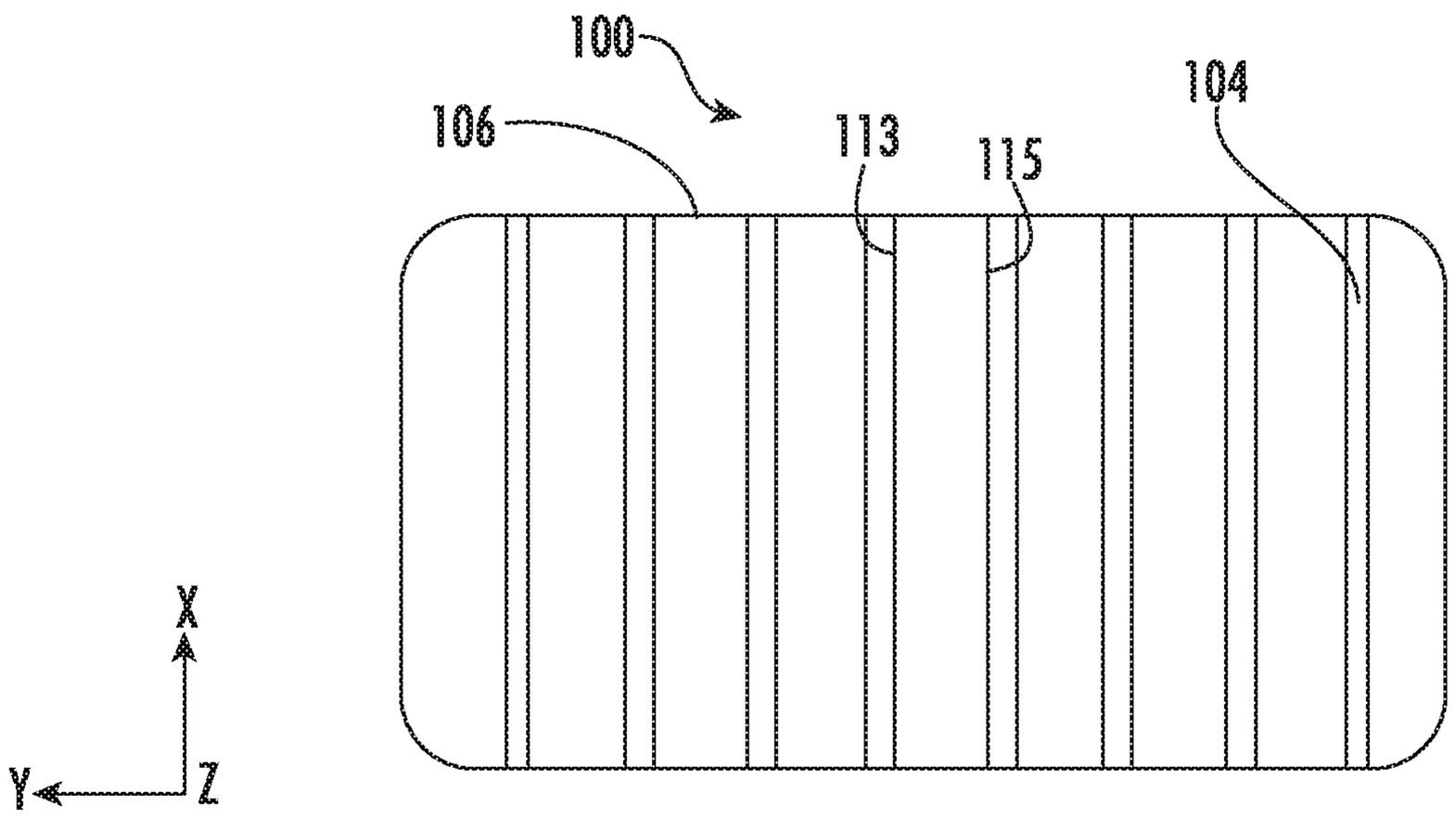

100
106
113
115
104
X
Y
Z

FIG. 1B

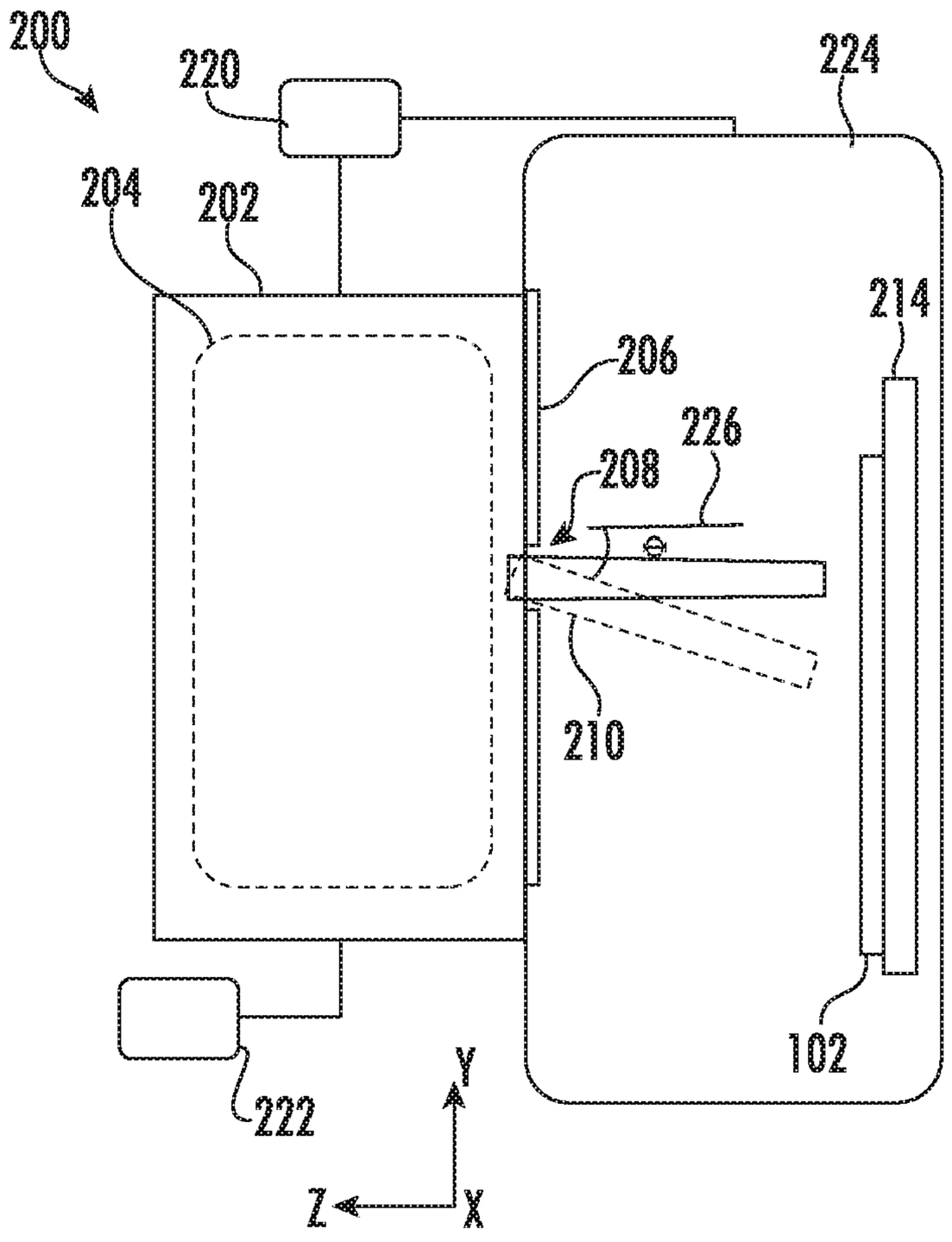

200
220
224
204
202
214
206
226
208
θ
210
102
222
Y
Z
X

FIG. 2A

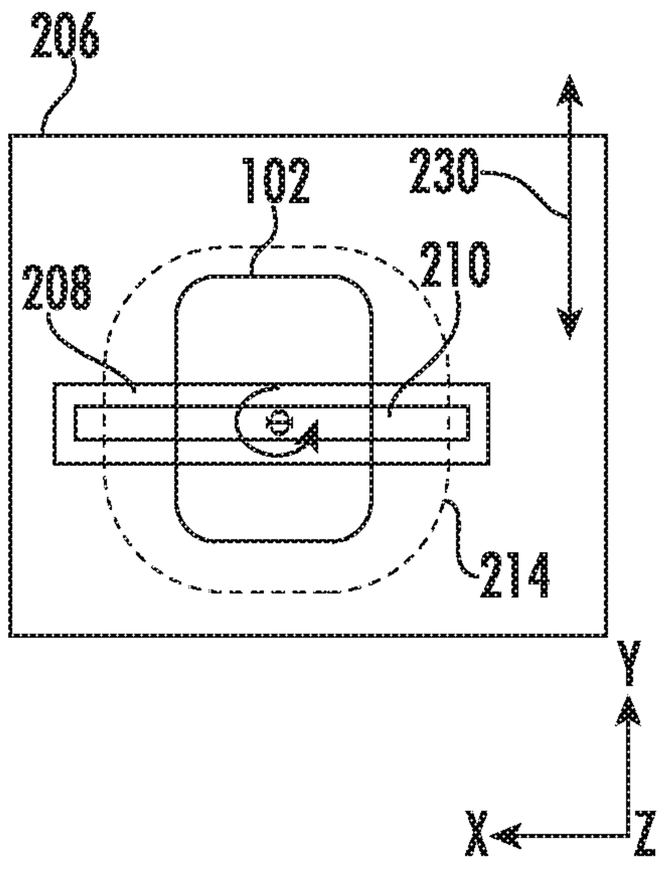

206
102
230
208
210
θ
214
Y
X
Z

FIG. 2B

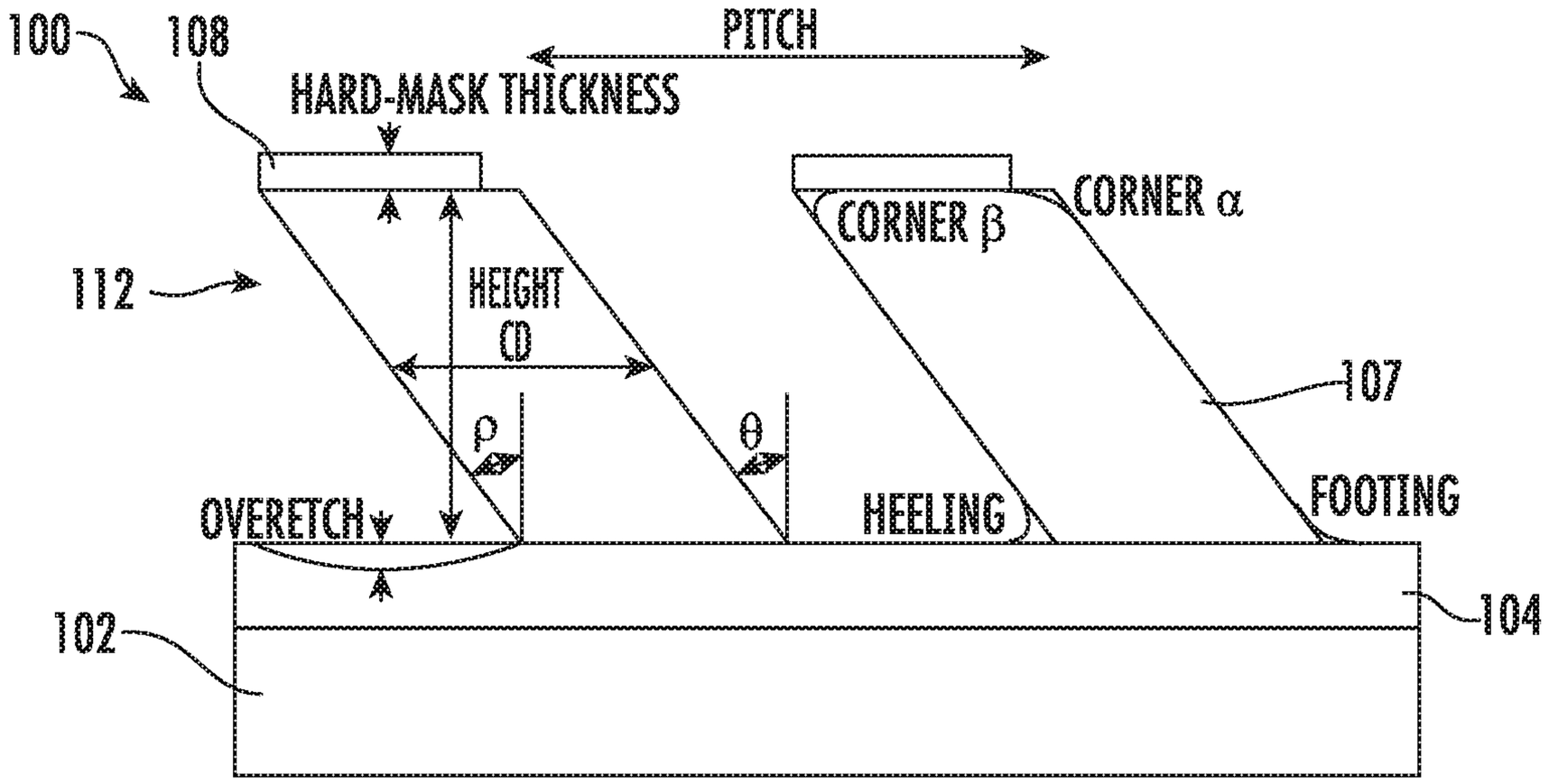

100
108
PITCH
HARD-MASK THICKNESS
112
HEIGHT
CD
CORNER β
CORNER α
107
ρ
θ
OVERETCH
HEELING
FOOTING
102
104

FIG. 3

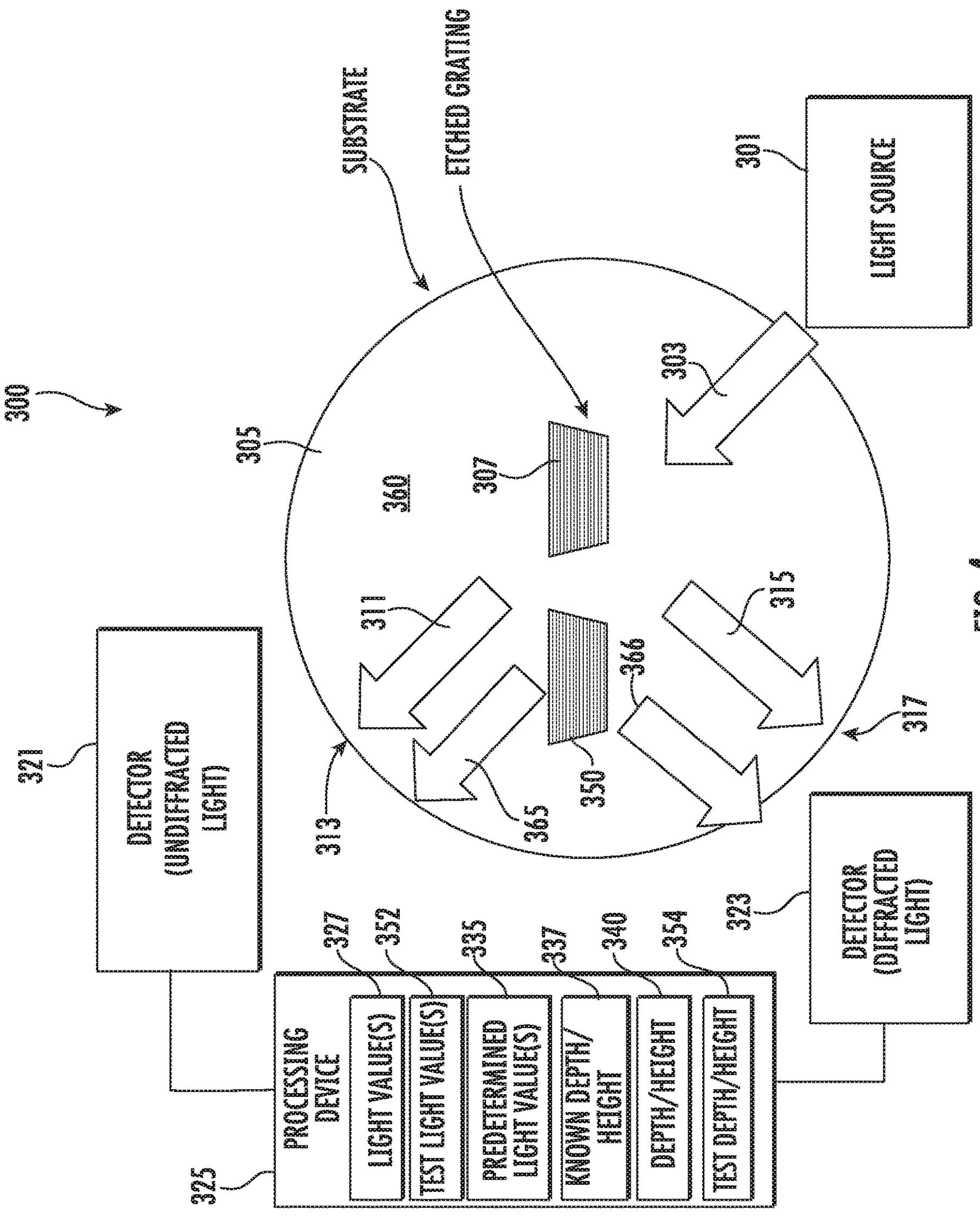

300
301
LIGHT SOURCE
303
305
307
360
311
315
313
365
350
366
317
321
DETECTOR (UNDIFFRACTED LIGHT)
323
DETECTOR (DIFFRACTED LIGHT)
325
PROCESSING DEVICE
327
LIGHT VALUE(S)
352
TEST LIGHT VALUE(S)
335
PREDETERMINED LIGHT VALUE(S)
337
KNOWN DEPTH/HEIGHT
340
DEPTH/HEIGHT
354
TEST DEPTH/HEIGHT

FIG. 4

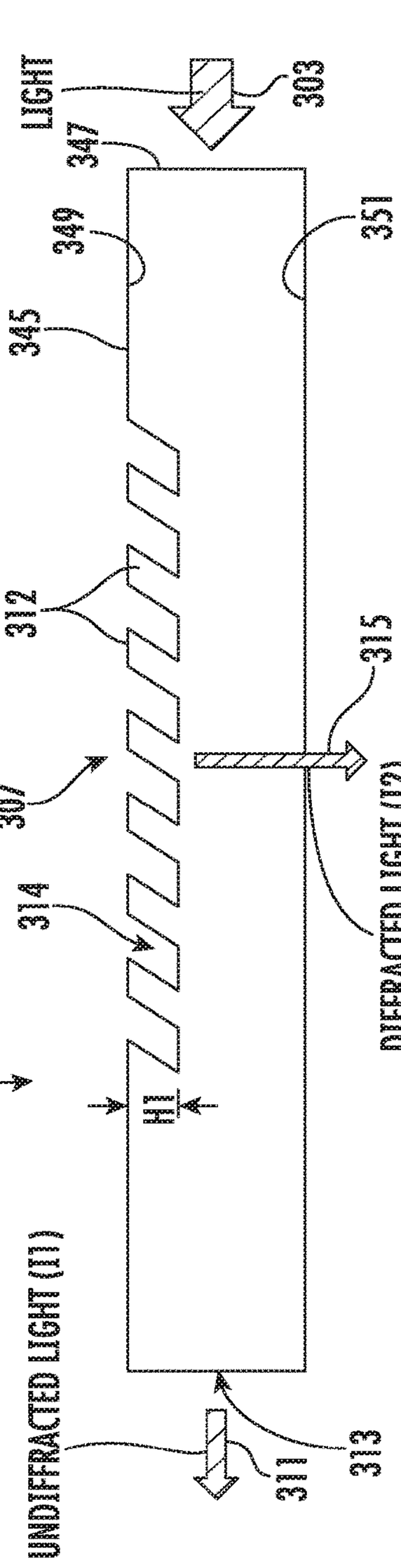

LIGHT
303
347
349
351
345
312
307
314
315
305
H1
DIFFRACTED LIGHT (I2)
UNDIFFRACTED LIGHT (I1)
311
313

FIG. 5A

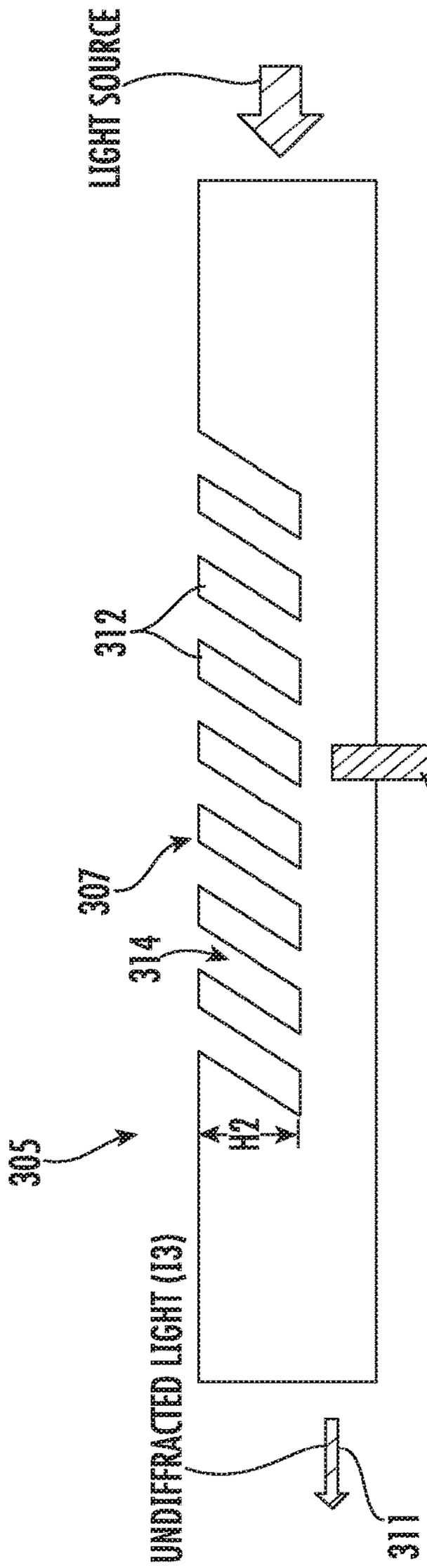

LIGHT SOURCE
312
315
307
314
305
H2
DIFFRACTED LIGHT (I4)
UNDIFFRACTED LIGHT (I3)
311

FIG. 5B

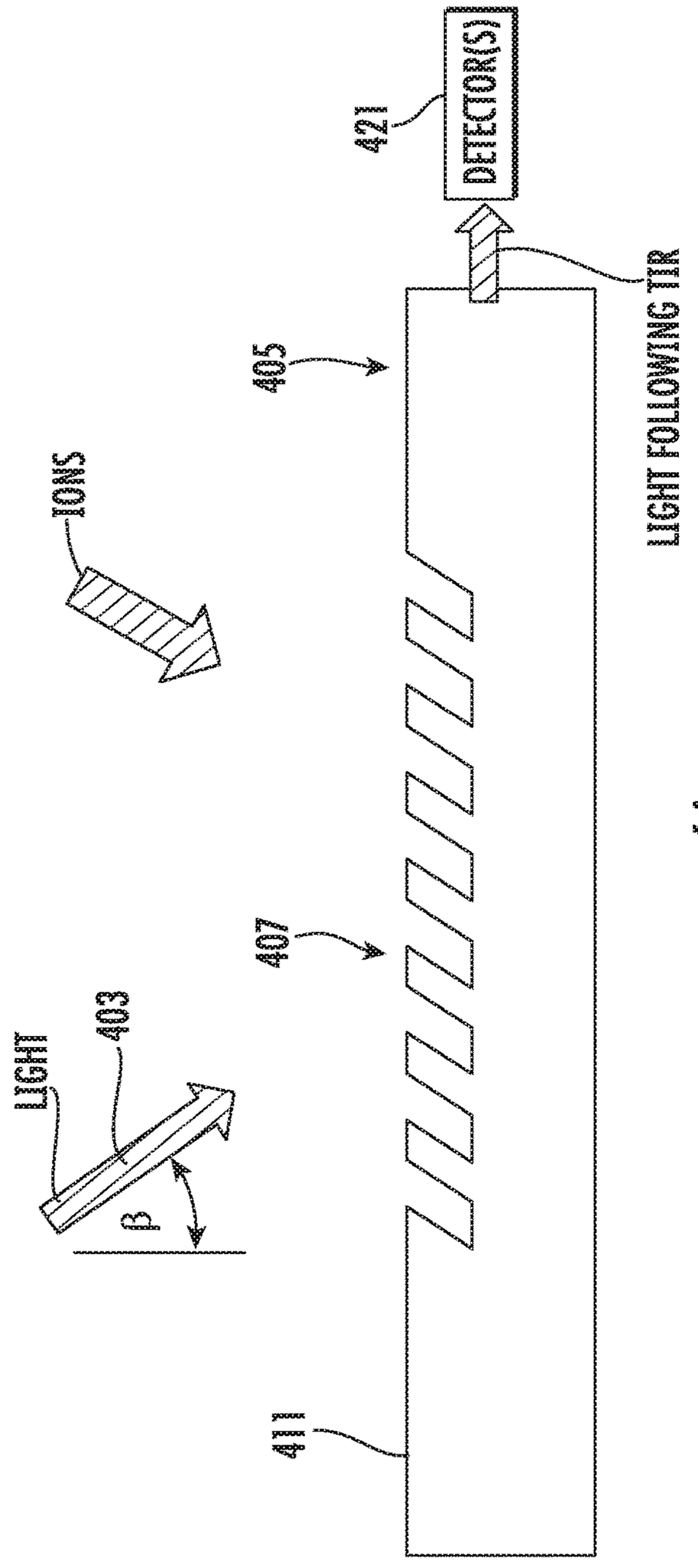

421
DETECTOR(S)
405
LIGHT FOLLOWING TIR
IONS
407
LIGHT
403
B
411

FIG. 6A

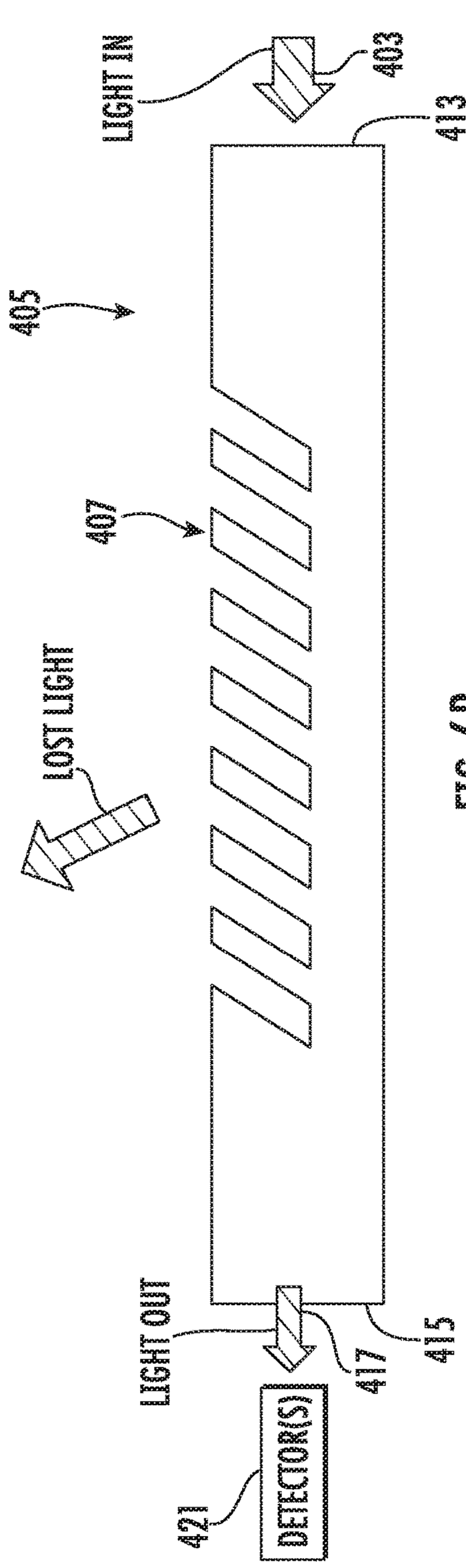

LIGHT IN
403
413
405
407
LOST LIGHT
LIGHT OUT
417
415
421
DETECTOR(S)

FIG. 6B

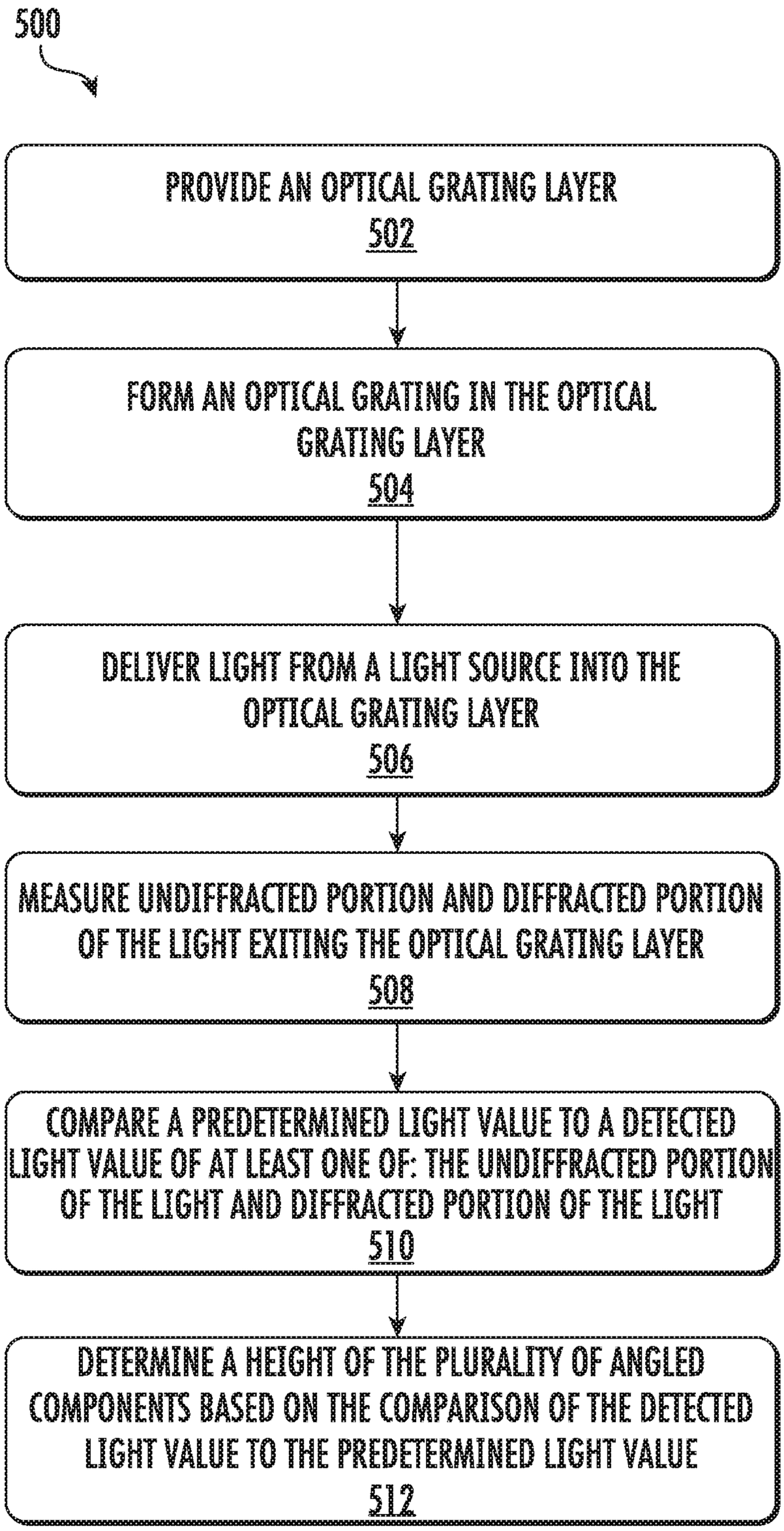

500
PROVIDE AN OPTICAL GRATING LAYER
502
FORM AN OPTICAL GRATING IN THE OPTICAL GRATING LAYER
504
DELIVER LIGHT FROM A LIGHT SOURCE INTO THE OPTICAL GRATING LAYER
506
MEASURE UNDIFFRACTED PORTION AND DIFFRACTED PORTION OF THE LIGHT EXITING THE OPTICAL GRATING LAYER
508
COMPARE A PREDETERMINED LIGHT VALUE TO A DETECTED LIGHT VALUE OF AT LEAST ONE OF: THE UNDIFFRACTED PORTION OF THE LIGHT AND DIFFRACTED PORTION OF THE LIGHT
510
DETERMINE A HEIGHT OF THE PLURALITY OF ANGLED COMPONENTS BASED ON THE COMPARISON OF THE DETECTED LIGHT VALUE TO THE PREDETERMINED LIGHT VALUE
512

FIG. 7

SYSTEM AND METHOD FOR DETECTING ETCH DEPTH OF ANGLED SURFACE RELIEF GRATINGS

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority to U.S. Provisional Patent Application No. 62/767,944 filed Nov. 15, 2018, entitled "System and Method for Detecting Etch Depth of Angled Surface Relief Gratings," and incorporated by reference herein in its entirety.

FIELD

The disclosure relates to optical elements, and more particularly to approaches for optimally detecting etch depth of angled surface relief gratings.

BACKGROUND

Optical elements such as optical lenses have long been used to manipulate light for various advantages. Recently, micro-diffraction gratings have been utilized in holographic and augmented/virtual reality (AR and VR) devices.

One particular AR and VR device is a wearable display system, such as a headset, arranged to display an image within a short distance from a human eye. Such wearable headsets are sometimes referred to as head mounted displays, and are provided with a frame displaying an image within a few centimeters of the user's eyes. The image can be a computer generated image on a display, such as a micro display. The optical components are arranged to transport light of the desired image, where the light is generated on the display to the user's eye to make the image visible to the user. The display where the image is generated can form part of a light engine, so the image generates collimated light beams guided by the optical component to provide an image visible to the user.

Different kinds of optical components have been used to convey the image from the display to the human eye. To properly function in an augmented reality lens or combiner, the geometries of an optical grating may be designed to achieve various effects. In some devices, multiple different regions, such as two or more different regions, are formed on the surface of a lens, wherein the grating geometries in one region are different from the grating geometries in other regions.

Angled surface relief optical gratings can be produced by the direct etching of angled trenches into a substrate or a film stack on a substrate. One of the parameters controlling the efficiency of the optical grating is the trench depth. Etch rate can vary over time though, from sample to sample and from day to day, e.g., due to variations in etch source output, lot to lot variations in the characteristics of the material to be etched, time since maintenance on the etch equipment, and many other reasons. As a result, trench depth may be inconsistent, leading to inadequate results.

Therefore, with respect to at least the above drawbacks the present disclosure is provided.

SUMMARY

A method of forming an optical grating component may include providing an optical grating layer, and forming an optical grating in the optical grating layer, wherein the optical grating comprises a plurality of angled trenches. The method may further include delivering light from a light source into the optical grating layer, and measuring at least one of: an undiffracted portion of the light exiting the optical grating layer, and a diffracted portion of the light exiting the optical grating layer.

A method of forming an optical grating component may include providing an optical grating layer, and delivering a light into the optical grating layer. The method may further include etching the optical grating layer, while the light is traveling through the optical grating layer, to form an optical grating. The optical grating may have a plurality of angled components disposed at a non-zero angle of inclination with respect to a perpendicular to a plane of the optical grating layer. The method may further include detecting, during formation of the optical grating, at least one of: an undiffracted portion of the light exiting the optical grating layer, and a diffracted portion of the light exiting the optical grating layer.

A system for measuring properties of an optical grating may include a light source delivering a light into an optical grating layer, wherein an undiffracted portion of the light continues past an optical grating formed in the optical grating layer and exits the optical grating layer at a first exit point. Furthermore, a diffracted portion of the light may change direction at the optical grating and exit the optical grating layer at a second exit point. The system may further include at least one detector detecting the undiffracted portion of the light and the diffracted portion of the light, and a processing device. The processing device may be operable to receive a determined first light value of the undiffracted portion of the light and a second light value of the diffracted portion of the light. The processing device may be further operable to compare at least one of the first and second light values to a predetermined light value, wherein the predetermined light value correlates to a known optical grating trench depth. The processing device may be further operable to determine a depth of a plurality of angled trenches of the optical grating based on the comparison of the first and/or second light values to the predetermined light value.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings illustrate exemplary approaches of the disclosure, including the practical application of the principles thereof, as follows:

FIG. **1**A depicts a side cross sectional view of an optical grating component according to embodiments of the disclosure;

FIG. **1**B depicts a top plan view of the optical grating component of FIG. **1**A according to embodiments of the disclosure;

FIG. **2**A shows a processing apparatus, depicted in schematic form, in accordance with embodiments of the present disclosure;

FIG. **2**B shows an extraction plate component and substrate in top plan view in accordance with embodiments of the present disclosure;

FIG. **3** shows a side cross-sectional view of angled structures formed in an optical grating layer in accordance with embodiments of the present disclosure;

FIG. **4** shows a system for measuring properties of an optical grating according to embodiments of the present disclosure;

FIGS. **5**A-**5**B show the optical grating layer during processing according to embodiments of the present disclosure;

FIGS. **6**A-**6**B show the optical grating layer during processing according to embodiments of the present disclosure; and

FIG. **7** depicts a process flow in accordance with embodiments of the disclosure.

The drawings are not necessarily to scale. The drawings are merely representations, not intended to portray specific parameters of the disclosure. The drawings are intended to depict exemplary embodiments of the disclosure, and therefore are not be considered as limiting in scope. In the drawings, like numbering represents like elements.

DETAILED DESCRIPTION

The present embodiments will now be described more fully hereinafter with reference to the accompanying drawings, where some embodiments are shown. The subject matter of the present disclosure may be embodied in many different forms and are not to be construed as limited to the embodiments set forth herein. These embodiments are provided so the disclosure will be thorough and complete, and will fully convey the scope of the subject matter to those skilled in the art. In the drawings, like numbers refer to like elements throughout.

As used herein, an element or operation recited in the singular and proceeded with the word "a" or "an" are understood as possibly including plural elements or operations, except as otherwise indicated. Furthermore, references to "one embodiment" or "some embodiments" of the present disclosure may be interpreted as including the existence of additional embodiments also incorporating the recited features.

Furthermore, the terms "approximate" or "approximately," can be used interchangeably in some embodiments, and can be described using any relative measures acceptable by one of skill. For example, these terms can serve as a comparison to a reference parameter, to indicate a deviation capable of providing the intended function. Although nonlimiting, the deviation from the reference parameter can be, for example, in an amount of less than 1%, less than 3%, less than 5%, less than 10%, less than 15%, less than 20%, and so on.

Embodiments herein provide novel optical components and systems and methods for forming an optical component. Various embodiments are related to diffracted optical elements, where the term "optical grating component" refers to a device or part having an optical grating, including AR & VR headsets, eyepieces for AR & VR, or masters for forming optical gratings for eyepieces such as eyeglasses.

As mentioned above, etch rate of optical gratings can vary over time, from sample to sample and from day to day, etc., due to variations in etch source output, lot to lot variations in the characteristics of the material to be etched, time since maintenance on the etch equipment, and many other reasons. To address these deficiencies, embodiments herein provide a system and methods to detect the progress of the etch to enable a tighter distribution of results. More specifically, embodiments herein rely on the optical properties of the grating as the grating is being fabricated to detect when grating formation is done.

In some embodiments, the grating can be used in-situ as part of a system to monitor the evolution of the grating. A light source may introduce photons through the edge of the substrate. The photons propagate toward the grating, relying on internal reflection to remain in the substrate. At the grating, a portion, related to the grating depth, of the photons may be refracted with the remainder continuing on. Detection and comparision of the amount of light detected in a refracted position and a transmitted position can provide a metric of the trench depth increasing over time. Although described primarily herein using a change in relative intensity between the undiffracted and diffracted light as the metric, other characteristics, for instance the spatial distribution, might also be used. In some embodiments, depending on the grating orientation, the detector of refracted photons may be positioned within the platen or within the chamber, instead of being attached to the periphery of the platen.

FIG. **1**A depicts a side cross sectional view of an optical grating component **100**, according to embodiments of the disclosure. FIG. **1**B depicts a top plan view of the optical grating component **100**. The optical grating component **100** may be used as an optical grating to be placed on an eyeglass or formed integrally in the eyeglass in accordance with various embodiments of the disclosure. The optical grating component **100** includes a substrate **102**, and optical grating **106**, disposed on the substrate **102**. In some embodiments, the substrate **102** is an optically transparent material, such as a known glass. In some embodiments, the substrate **102** is silicon. In the latter case, the substrate **102** is silicon, and another process is used to transfer grating patterns to a film on the surface of another optical substrate, such as glass or quartz. The embodiments are not limited in this context. The optical grating **106** may be disposed in an optical grating layer **107**, as described further below. In the embodiment of FIG. **1**A and FIG. **1**B, the optical grating component **100** further includes an etch stop layer **104**, disposed between the substrate **102** and optical grating layer **107**. According to some embodiments of the disclosure, the optical grating layer **107** may be an optically transparent material, such as silicon oxide, silicon nitride, glass, TiO_2, or other material.

According to some embodiments of the disclosure, the optical grating **106** may comprise a grating height H in the range of 100 nm to 1000 nm. As such, the optical grating **106** may be appropriate for use in an eyepiece of an AR &VR apparatus. Embodiments herein are not limited in this context. In accordance with some embodiments, the etch stop layer **104** may be an optically transparent material and may have a thickness of 10 nm to 100 nm. The embodiments are not limited in this context. Examples of a suitable material for the etch stop layer **104** include SiN, SiO_2, TiN, SiC, and other materials. In embodiments where the optical grating **106** is to be applied to or incorporated in an eyepiece of an eyeglass, an especially appropriate material is an optically transparent material. In embodiments where the optical grating component **100** forms a master for fabricating optical gratings for an eyepiece, the etch stop layer **104** need not be optically transparent. Moreover, the etch stop layer **104** may be omitted in some embodiments.

As further shown in FIG. **1**A, the optical grating **106** may comprise a plurality of angled structures, shown as angled components or structures **112**, disposed at a non-zero angle of inclination with respect to a perpendicular to a plane of the substrate **102**. The angled structures **112** may be included within one or more fields of slanted gratings, the slanted grating together forming "micro-lenses." As will be described in greater detail below, the sidewalls **113** and **115** of each angled structure **112** may vary in angle (e.g., with respect to the perpendicular to the plane of the substrate **102**) and shape as beam selectivity, beam angle spread, beam angle mean, etc., are modified. As will be described in greater detail below, the sidewalls **113** and **115** of each angled structure **112** may further vary in angle based on the selectivity between the angled structures **112** and a hard-

mask formed over the angled structures **112**. As used herein, selectivity may be a product of the material(s) of the optical grating layer the angled structures **112** are formed, the chemistry of the etching ions, and tool parameters such as beam intensity, relative pressures of different gasses, and temperature.

Between the angled structures **112** is a plurality of trenches **114**. The angled structures **112** may be arranged to define a uniform or variable height along a first direction. In the example of FIG. **1**A, the angled structures **112** define a uniform height along the direction parallel to the Y-axis of the Cartesian coordinate system shown, where the first direction (Y-Axis) is parallel to the plane of the substrate **102**, i.e., the X-Y plane. In other embodiments, the angled structures **112** may define a variable height along the direction parallel to the Y-axis. The plurality of trenches **114** may be disposed at a non-zero angle of inclination with respect to a perpendicular to a plane, such as a top surface of the substrate **102** or a top surface of optical grating layer **107**.

The width of the optical grating **106** along the Y-direction may be on the order of several millimeters to several centimeters, while the grating height H may be on the order of 1 micrometer or less. Accordingly, the variation in grating height H may range on the order of several hundred nanometers or less. An example of a smooth variation in grating height H or depth d is where a change in grating height H or depth d between adjacent lines of a grating is less than 10%, less than 5%, or less than 1%. The embodiments are not limited in this context. Thus, in an eyepiece, the grating height H may vary continuously and in a non-abrupt fashion in a given direction along the surface of the eyepiece over a distance of, for example, millimeters to centimeters. More particularly, a change in grating height H of 50% over a 5 mm distance may entail changing the grating height H continuously over approximately 5×10^3 lines having a pitch of one micrometer. The change entails an average change in relative height of adjacent lines of $0.5/5\times10^4$ or approximately 0.01%.

Turning now to FIG. **2**A, there is shown a processing apparatus **200**, depicted in schematic form. The processing apparatus **200** represents a processing apparatus for etching portions of a substrate, or depositing on a substrate, to generate, for example, the optical gratings of the present embodiments. The processing apparatus **200** may be a plasma based processing system having a plasma chamber **202** for generating a plasma **204** therein by any convenient method as known in the art. An extraction plate **206** may be provided as shown, having an extraction aperture **208**, where a non-uniform etching or non-uniform deposition may be performed to reactively etch or deposit an optical grating layer **107** (FIGS. **1**A-B). A substrate **102**, including, for example, the aforementioned optical grating structure, is disposed in the process chamber **224**. A substrate plane of the substrate **102** is represented by the X-Y plane of the Cartesian coordinate system shown, while a perpendicular to the plane of the substrate **102** lies along the Z-axis (Z-direction).

As further shown in FIG. **2**A, an ion beam **210** may be extracted when a voltage difference is applied using bias supply **220** between the plasma chamber **202** and substrate **102**, or substrate platen **214**, as in known systems. The bias supply **220** may be coupled to the process chamber **224**, for example, where the process chamber **224** and substrate **102** are held at the same potential.

According to various embodiments, the ion beam **210** may be extracted along the perpendicular **226** or may be extracted at a non-zero angle of incidence, shown as ϕ, with respect to the perpendicular **226**.

The trajectories of ions within the ion beam **210** may be mutually parallel to one another or may lie within a narrow angular spread range, such as within 10 degrees of one another or less. In other embodiments, as will be discussed below, the trajectory of ions within the ion beam **210** may converge or diverge from one another, for example, in a fan shape. Thus, the value of ϕ may represent an average value of incidence angle where the individually trajectories vary up to several degrees from the average value. In various embodiments, the ion beam **210** may be extracted as a continuous beam or as a pulsed ion beam as in known systems. For example, the bias supply **220** may be configured to supply a voltage difference between the plasma chamber **202** and the process chamber **224**, as a pulsed DC voltage, where the voltage, pulse frequency, and duty cycle of the pulsed voltage may be independently adjusted from one another.

In various embodiments, gas, such as reactive gas, may be supplied by the source **222** to plasma chamber **202**. The plasma **204** may generate various etching species or depositing species, depending upon the exact composition of species provided to the plasma chamber **202**.

In various embodiments, the ion beam **210** may be provided as a ribbon reactive ion beam having a long axis extending along the X-direction of the Cartesian coordinate system shown in FIG. **2**B. By scanning a substrate platen **214** including substrate **102** with respect to the extraction aperture **208**, and thus with respect to the ion beam **210** along the scan direction **230**, the ion beam **210** may etch the substrate **102** or deposit upon the substrate **102**. The ion beam **210** may be composed of any convenient gas mixture, including inert gas, reactive gas, and may be provided in conjunction with other gaseous species in some embodiments. In particular embodiments, the ion beam **210** and other reactive species may be provided as an etch recipe to the substrate **102** so as to perform a directed reactive ion etching of a layer, such as the optical grating layer **107**. Such an etch recipe may use known reactive ion etch chemistries for etching materials such as oxide or other material, as known in the art. In other embodiments, the ion beam **210** may be formed of inert species where the ion beam **210** is provided to etch the substrate **102** or more particularly, the optical grating layer **107**, by physical sputtering, as the substrate **102** is scanned with respect to ion beam **210**.

In the example of FIG. **2**B, the ion beam **210** is provided as a ribbon reactive ion beam extending to a beam width along the X-direction, where the beam width is adequate to expose an entire width of the substrate **102**, even at the widest part along the X-direction. Exemplary beam widths may be in the range of 10 cm, 20 cm, 30 cm, or more while exemplary beam lengths along the Y-direction may be in the range of 2 mm, 3 mm, 5 mm, 10 mm, or 20 mm. The embodiments are not limited in this context.

Notably, the scan direction **230** may represent the scanning of substrate **102** in two opposing (180 degrees) directions along the Y-direction, or just a scan toward the left or a scan toward the right. As shown in FIG. **2**B, the long axis of ion beam **210** extends along the X-direction, perpendicularly to the scan direction **230**. Accordingly, an entirety of the substrate **102** may be exposed to the ion beam **210** when scanning of the substrate **102** takes place along a scan direction **230** to an adequate length from a left side to right side of substrate **102**.

The grating features may be accomplished by scanning the substrate **102** with respect to the ion beam **210** using a

processing recipe. In brief, the processing recipe may entail varying at least one process parameter of a set of process parameters, having the effect of changing, e.g., the etch rate or deposition rate caused by the ion beam **210** during scanning of the substrate **102**. Such process parameters may include the scan rate of the substrate **102**, the ion energy of the ion beam **210**, duty cycle of the ion beam **210** when provided as a pulsed ion beam, the spread angle of the ion beam **210**, and rotational position of the substrate **102**. In at least some embodiments herein, the processing recipe may further include the material(s) of the optical grating layer **107**, and the chemistry of the etching ions. In yet other embodiments, the processing recipe may include starting geometry of the optical grating layer **107**, including dimensions and aspect ratios. The embodiments are not limited in this context.

Turning now to FIG. **3**, an example set of fins or angled structures **112** formed in the optical grating layer **107** by the etch processes of the embodiments herein will be described in greater detail. The angled structures **112** may be formed by any of the above described etch processes to manufacture the angled structures **112** with unique locations, shapes, three dimensional orientations, etc. In some examples, the etch processes are capable of controlling or modifying any of the following grating parameters of the set of angled structures **112**: pitch, hardmask **108** thickness, and fin height/trench depth. The etch processes are also capable of controlling or modifying any of the following grating parameters: fin thickness (CD), corner radius β and α, over-etch into the etch stop layer **104**, heeling, first sidewall angle ρ, second sidewall angle θ, and footing.

Turning now to FIG. **4** a system **300** for measuring properties of an optical grating layer **305** according to embodiments of the present disclosure will be described in greater detail. The optical grating layer **305** may be the same or similar to the optical grating layer **107** shown in FIG. **3**. Although non-limiting, the system **300** may include a light source **301** delivering a light **303** into a substrate or optical grating layer **305**. In some embodiments, the light **303** may be a plurality of rays and photons directed towards an optical grating **307**, wherein the optical grating **307** may be etched into the optical grating layer **305**. As shown, an undiffracted portion **311** of the light **303** may continue past the optical grating **307** and exit the optical grating layer **305** at a first exit point **313**. A diffracted portion **315** of the light **303** may impact the optical grating **307** and change direction, exiting the optical grating **307** at a second exit point **317**.

The system **300** may further include a first detector **321** receiving/detecting the undiffracted portion **311** of the light **303**, and a second detector **323** receiving/detecting the diffracted portion **315** of the light **303**. As shown, the first detector **321** may be positioned proximate the first exit point **313**, while the second detector **323** may be positioned proximate the second exit point **317**. In some embodiments, the first and second detectors **321**, **323** may be capable of sensing an intensity of the undiffracted portion **311** and the diffracted portion **315**, respectively. The undiffracted portion **311** and the diffracted portion **315** of the light **303** may be converted to corresponding electrical signals sampled at regular intervals and digitized to produce corresponding light intensity values (for instance in W or W/m^2).

The light intensity values may be delivered to a processing device **325** programmed to perform analysis of the signals, as will be described in greater detail below. In various embodiments, different classes of light intensities may also be associated with other parameters affecting the scanning and the sensing of reflected light, such as spectral differences. In the non-limiting embodiment shown, the processing device **325** may be operable to receive one or more light values **327** determined from the undiffracted portion **311** and/or the diffracted portion **315** of the light **303**. In some embodiments, the light values **327** may be light intensities of the undiffracted portion **311** and/or the diffracted portion **315** of the light **303**. Alternatively, the light value **327** may be the difference, over a period of time, between the light intensity of the undiffracted portion **311** of the light **303** and the intensity of the diffracted portion **315** of the light **303**. In other embodiments, the light value **327** may correspond to a spatial distribution of the undiffracted portion **311** and/or the diffracted portion **315** of the light **303**

The processing device **325** may be further operable to compare the light value(s) **327** of the undiffracted portion **311** and/or the diffracted portion **315** of the light **303** to a predetermined light value **335**. The predetermined light value **335**, stored in memory (not shown), may be part of a plurality of known light intensity values previously obtained or determined for a given optical grating characteristic, such as trench depth/angled component height. Said differently, for each of a series of known grating trench depths/angled component heights **337**, corresponding light intensities are provided. In various embodiments, the predetermined light value **335** may be known intensities of the undiffracted portion **311** and/or the diffracted portion **315** of the light **303**. Alternatively, the predetermined light value **335** may be a known relative difference between the undiffracted portion **311** and the diffracted portion **315** of the light **303**.

The processing device **325** may be further operable to determine a depth/height **340** of the plurality of angled components of the optical grating **307** based on the comparison of the determined light value(s) **327** to the predetermined light value **335**. For example, when the determined light value(s) **327** is equal, or approximately equal, to the predetermined light value **335**, the depth/height **340** of the plurality of angled components will be equal to the known grating trench depth/angled component height **337** linked with the predetermined light value **335**. The processing device **325** may be able to determine the depth of the trenches in situ, e.g., as the optical grating **307** is being etched. Once the grating trench depth/angled component height of the plurality of angled components of the optical grating **307** is equal to the known grating trench depth/angled component height, as determined by a match between the determined light value(s) **327** to the predetermined light value **335**, the etching to the optical grating **307** may cease. In some embodiments, the processing device **325** may send a signal to the processing apparatus **200** (FIG. **2**A) to prevent further processing to the optical grating layer **305**.

As further shown, the light source **301**, or an additional light source (not shown), may deliver the light **303** into a test optical grating **350**. An undiffracted portion **365** of the light **303** may continue past the test optical grating **350** and exit the optical grating layer **305**. A diffracted portion **366** of the light **303** may impact the test optical grating **350** and change direction, exiting the optical grating **307** at a second exit point.

The first detector **321**, or an additional detector (not shown), may receive and detect the undiffracted portion **365** of the light **303**, and the second detector **323**, or an additional detector (not shown), may receive and detect the diffracted portion **366** of the light **303** from the test optical grating **350**. In some embodiments, the first and second detectors **321**, **323** may be capable of sensing an intensity of the undiffracted portion **365** and the diffracted portion **366** of the light **303** after reaching the test optical grating **350**.

Similar to above, the undiffracted portion **365** and the diffracted portion **366** of the light **303** may be converted to corresponding electrical signals sampled at regular intervals and digitized to produce corresponding light intensity values (for instance in W or W/m^2).

The light intensity values corresponding to the test optical grating **350** may be delivered to the processing device **325** programmed to perform analysis of the signals, as will be described in greater detail below. In various embodiments, different classes of light intensities may also be associated with other parameters affecting the scanning and the sensing of reflected light, such as spectral differences. In the non-limiting embodiment shown, the processing device **325** may be operable to receive one or more test light values **352** determined from the undiffracted portion **365** and/or the diffracted portion **366** of the light **303** interacting with the test optical grating **350**. In some embodiments, the test light values **352** may be light intensities of the undiffracted portion and/or the diffracted portion of the light **303**. Alternatively, the test light value **352** may be the difference, over a period of time, between the light intensity of the undiffracted portion **365** of the light **303** and the intensity of the diffracted portion **366** of the light **303**. In other embodiments, the test light value **352** may correspond to a spatial distribution of the undiffracted portion **365** and/or the diffracted portion **366** of the light **303** interacting with the test optical grating **350**.

The processing device **325** may be further operable to compare the test light value(s) **352** of the undiffracted portion **365** and/or the diffracted portion **366** of the light **303** to the predetermined light value **335**. Furthermore, the light value(s) **327** of the undiffracted portion **311** and/or the diffracted portion **315** of the light **303** impacting the optical grating **307** may also be compared to the test light value **352**. The processing device **325** may be further operable to determine a depth/height **354** of the trenches of the test optical grating **350** based on the comparison of the test light value **352** to the predetermined light value **335**. The processing device **325** may be further operable to determine a depth/height **340** of the plurality of angled components of the optical grating **307**. The determination may be based on a comparison of the determined light value(s) **327** to at least one of: the predetermined light value **335**, the test light value **352**, and/or the depth/height **354** of the trenches of the test optical grating **350**. When the determined light value(s) **327** is equal, or approximately equal, to the predetermined light value **335** or the test light value **352**, depth/height **340** of the plurality of angled components will be equal to the known grating trench depth/angled component height **337** linked with the predetermined light value **335** and/or the test light value **352**. As such, the processing device **325** can determine the depth of the trenches in situ, e.g., as the optical grating **307** and/or the test optical grating **350** are being etched. Once the grating trench depth/angled component height of the trenches of the optical grating **307** and/or the test optical grating **350** is equal to the known grating trench depth/angled component height, as determined by a match between the determined light value(s) **327** to the predetermined light value **335** and/or the test light value **352**, the etching to the optical grating **307** and/or the test optical grating **350** may cease. In some embodiments, the processing device **325** may send a signal to the processing apparatus **200** (FIG. **2**A) to prevent further processing to the optical grating **307** and/or test optical grating **350**.

Although shown along a first surface **360** (e.g., an upper surface) of the optical grating layer **305**, the test optical grating **350** may be along front and/or back side of the optical grating layer **305**. The test optical grating **350** may be formed/positioned in a known location, both on the optical grating layer **305** and relative to the optical grating **307**, to enable easier testing when device layout changes.

Turning now to FIGS. **5**A-**5**B, propagation of the light **303** through the optical grating layer **305** during formation of the optical grating **307** according to embodiments of the present disclosure will be described in greater detail. As shown, the optical grating layer **305** is provided with an optical grating **307** formed therein. The optical grating **307** includes a plurality of angled structures **312**, disposed at a non-zero angle of inclination with respect to a perpendicular to a plane **345** (e.g., top surface) of the optical grating layer **305**. The angled structures **312** are formed by etching a plurality of trenches **314** into the optical grating layer **305**. Therefore, the plurality of trenches **314** may also be disposed at the non-zero angle of inclination. In non-limiting embodiments, the grating height H**1** may be on the order of 0.5 micrometer or less.

As shown, the light **303** may be introduced into the optical grating layer **305** through a side surface **347** thereof. In some embodiments, the light **303** is introduced along a plane approximately parallel to the plane **345**. The light **303** may include a plurality of rays and photons propagating through the optical grating layer **305**, reflecting internally between an upper inner surface **349** and a lower inner surface **351**. As shown, the undiffracted portion **311** of the light **303** continues past (e.g., beneath) the optical grating **307** and exits the optical grating layer **305** at the first exit point **313**. The undiffracted portion **311** may be recognized by the first detector **321** (FIG. **4**) as having a first intensity, I**1**. Meanwhile, the diffracted portion **315** of the light **303** changes direction at the optical grating **307** and exits the optical grating layer **305** at a second exit point. The diffracted portion **315** may be recognized by the second detector **323** (FIG. **4**) as having a second intensity, I**2**.

As processing of the optical grating **307** continues, demonstrated in FIG. **5**B, the plurality of trenches **314** deepen, causing the height H**2** of the plurality of angled structures **312** to effectively increase. In some embodiments, the grating height H**2** may be between approximately 0.5 micrometers and 1.0 micrometers. As shown, the undiffracted portion **311** of the light **303** continues past (e.g., beneath) the optical grating **307** and exits the optical grating layer **305** at the first exit point **313**. The undiffracted portion **311** may be recognized by the first detector **321** (FIG. **4**) as having a third intensity, I**3**. Meanwhile, the diffracted portion **315** of the light **303** changes direction at the optical grating **307** and exits the optical grating layer **305** at the second exit point **317**. The diffracted portion **315** may be recognized by the second detector **323** (FIG. **4**) as having a fourth intensity, I**4**. Comparing processing of the optical grating layer **305** as shown between FIGS. **5**A-**5**B, H**1**>H**2**, thus causing I**3**>I**1** for the undiffracted portion **311** and I**4**>I**2** for diffracted portion. Stated another way, as the trenches **314** of the optical grating **307** deepen, more of the light **303** is diffracted by the optical grating **307**. The difference can be captured, and used to accurately determine trench depth optically, as described above.

FIGS. **6**A-**6**B demonstrate a variety of light source and detector arrangements according to various embodiments of the disclosure. In the embodiment of FIG. **6**A, a light **403** from free space is injected into the optical grating **407** of the optical grating layer/substrate **405** and one or more detectors **421** measure light propagation after total internal reflection (TIR) and propagation through the optical grating/substrate **405**. In some non-limiting implementations, the light **403** is

directed into the optical grating **407** at a non-zero angle of inclination (β) with respect to a perpendicular to a plane (e.g., top surface **411**) of the optical grating layer **405**. In the embodiment of FIG. **6**B, a light **403** is injected through a first side/edge **413** of the optical grating/substrate **405**, and the output light **417** is detected through a second side/edge **415** of the optical grating/substrate **405**. As shown, the optical grating **407** separates the first and second sides **413** and **415**. The detector **421** may be configured to measure the light 'lost' to diffractive outcoupling.

For example, in other embodiments, measurement may be obtained in various other physical locations or points in the process. In a first example, measurement can be taken on the mainframe. In some cases, measurement is not on the actual chamber. Instead, the measurement is outside, either in the transfer chamber or a separate measurement chamber. In a second example, measurement may be made on the factory interface (FI). The measurement may be similar to an optical metrology tool capable of being placed on a loadport or on the side of a FI.

Turning now to FIG. **7**, a method **500** according to embodiments of the present disclosure will be described in greater detail. Specifically, at block **502**, an optical grating layer is provided. In some embodiments, the optical grating layer is formed over a substrate. In some embodiments, the optical grating layer may comprise an optically transparent material, including, yet not limited to, silicon oxide, silicon nitride, glass, or other material. In some embodiments, the optical grating layer is formed atop an etch stop layer. The etch stop layer may be an optically transparent material and may have a thickness of 10 nm to 100 nm.

At block **504**, the method **500** may include forming an optical grating in the optical grating layer, wherein the optical grating includes a plurality of angled trenches disposed at a non-zero angle of inclination with respect to a perpendicular to a plane of the optical grating layer. In some embodiments the plurality of angled trenches have a uniform depth. In some embodiments, the plurality of angled trenches are formed by a reactive ion etch into the optical grating layer. In some embodiments, the optical grating may be a test grating not part of the active device.

At block **506**, the method **500** may include delivering light from a light source into the optical grating layer. In some embodiments, the light is delivered into the optical grating layer as the optical grating is being formed.

At block **508**, the method may further include measuring an undiffracted and a diffracted portion of the light exiting the optical grating layer. In some embodiments, the undiffracted and the diffracted portion of the light is measured by one or more detectors positioned proximate an edge of the optical grating layer. In some embodiments, the undiffracted and the diffracted portion of the light are continuously or periodically measured while the optical grating is being formed.

At block **510**, the method **500** may further include comparing a predetermine light value to a detected light value of at least one of: the undiffracted portion of the light and the diffracted portion of the light, wherein the predetermined light value corresponds to a known angled component height. In some embodiments, the detected light value is a light intensity.

At block **512**, the method **500** may further include determining a height of the plurality of angled components based on the comparison of the detected light value to the predetermined light value.

Embodiments herein may be computer implemented. For example, the processing apparatus **200** and/or the system **300** may include a computer processor, such as the processing device **325**, to perform logic operations, computational tasks, control functions, etc. In some embodiments, the computer processor may be a component of a processor. The computer processor may include one or more subsystems, components, modules, and/or other processors, and may include various logic components operable using a clock signal to latch data, advance logic states, synchronize computations and logic operations, and/or provide other timing functions. During operation, the computer processor may receive signals transmitted over a LAN and/or a WAN (e.g., T1, T3, 56 kb, X.25), broadband connections (ISDN, Frame Relay, ATM), wireless links (802.11, Bluetooth, etc.), and so on. In some embodiments, the signals may be encrypted using, for example, trusted key-pair encryption. Different systems may transmit information using different communication pathways, such as Ethernet or wireless networks, direct serial or parallel connections, USB, Firewire®, Bluetooth®, or other proprietary interfaces. (Firewire is a registered trademark of Apple Computer, Inc. Bluetooth is a registered trademark of Bluetooth Special Interest Group (SIG)).

In general, the computer processor executes computer program instructions or code stored in a memory unit and/or storage system. For example, when executing computer program instructions, the computer processor causes the processing apparatus **200** to receive inputs, such as any of the processing parameters discussed herein, and provide, from the computer processor, the outputs. In some embodiments, the computer processor executes and carries out the processing recipe to form optical grating component **100** and optical grating layer **305**.

While executing computer program code, the computer processor can read and/or write data to/from the memory unit and/or the storage system. The storage system may comprise VCRs, DVRs, RAID arrays, USB hard drives, optical disk recorders, flash storage devices, and/or any other data processing and storage elements for storing and/or processing data. Although not shown, the processing apparatus **200** could also include I/O interfaces communicating with one or more hardware components of computer infrastructure to enable a user to interact with the processing apparatus **200** (e.g., a keyboard, a display, camera, etc.).

In sum, various embodiments described herein provide approaches for forming optical grating components. Manufacturing may be accomplished by direct application of the angled ions on the substrate, and/or on a mask used to transfer the pattern to the substrate of interest. A first technical advantage of the present embodiments includes efficiently controlling the trench depth of the grating, as the grating can be used in situ as part of a system to monitor the evolution of the grating. A second technical advantage of the present embodiments is the use of optical depth detection techniques, as these techniques are less intrusive and results in less downtime.

The present disclosure is not to be limited in scope by the specific embodiments described herein. Indeed, other various embodiments of and modifications to the present disclosure, in addition to those described herein, will be apparent to those of ordinary skill in the art from the foregoing description and accompanying drawings. Thus, such other embodiments and modifications are intended to fall within the scope of the present disclosure. Furthermore, the present disclosure has been described herein in the context of a particular implementation in a particular environment for a particular purpose. Those of ordinary skill in the art will recognize the usefulness is not limited thereto and the

present disclosure may be beneficially implemented in any number of environments for any number of purposes. Thus, the claims set forth below are to be construed in view of the full breadth and spirit of the present disclosure as described herein.

What is claimed is:

1. A method of forming an optical grating component, comprising:

providing an optical grating layer;

forming an optical grating in the optical grating layer, wherein the optical grating comprises a plurality of angled trenches;

delivering light from a light source into the optical grating layer; and

simultaneously measuring, while the plurality of angled trenches are being formed, at least one of: an undiffracted portion of the light exiting the optical grating layer, and a diffracted portion of the light exiting the optical grating layer.

2. The method of claim **1**, further comprising:

comparing a baseline light value to a detected light value of at least one of: the undiffracted portion of the light and the diffracted portion of the light, wherein the baseline light value corresponds to a known angled trench depth; and

determining a depth of the plurality of angled trenches based on the comparison of the detected light value to the baseline light value, wherein the detected light value is a light intensity.

3. The method of claim **2**, further comprising:

forming a test optical grating in the optical grating layer, wherein the optical grating comprises a second plurality of angled trenches; and

measuring at least one of: an undiffracted portion of the light passing by the test optical grating, and a diffracted portion of the light exiting the optical grating layer after engagement with the test optical grating.

4. The method of claim **2**, further comprising measuring a difference, over a period of time, between the light intensity of the undiffracted portion of the light and the light intensity of the diffracted portion of the light.

5. The method of claim **2**, wherein forming the optical grating comprises etching the optical grating layer to form the plurality of angled trenches, and wherein the etching comprises an angled reactive ion etch.

6. The method of claim **5**, further comprising stopping the etching of the optical grating layer when the depth of the plurality of trenches equals a baseline depth.

7. The method of claim **1**, wherein the plurality of angled trenches is disposed at a non-zero angle of inclination with respect to a perpendicular to a plane of the optical grating layer.

8. The method of claim **1**, further comprising measuring the undiffracted portion of the light and the diffracted portion of the light while the plurality of angled trenches are being etched.

9. A method of forming an optical grating component, comprising:

providing an optical grating layer;

delivering a light into the optical grating layer;

etching the optical grating layer, while the light is traveling through the optical grating layer, to form an optical grating, the optical grating having a plurality of angled components disposed at a non-zero angle of inclination with respect to a perpendicular to a plane of the optical grating layer; and

detecting, during formation of the plurality of angled components, at least one of: an undiffracted portion of the light exiting the optical grating layer, and a diffracted portion of the light exiting the optical grating layer.

10. The method of claim **9**, further comprising:

comparing a baseline light value to a detected light value of at least one of: the undiffracted portion of the light and the diffracted portion of the light, wherein the predetermined light value corresponds to a known angled component height;

determining a height of the plurality of angled components based on the comparison of the predetermined light value and the detected light value; and

stopping etching of the optical grating layer when the height of the plurality of angled components is approximately equal to the known angled component height.

11. The method of claim **10**, wherein the detected light value is a light intensity.

12. The method of claim **11**, further comprising measuring a difference, over a period of time, between the light intensity of the undiffracted portion of the light and the light intensity of the diffracted portion of the light.

13. The method of claim **9**, wherein the light is delivered directly into the optical grating layer at a non-zero angle of inclination with respect to a perpendicular to a plane of the optical grating layer.

14. The method of claim **13**, wherein the undiffracted portion of the light is measured to determine an amount of the light lost as a result of the optical grating.

15. The method of claim **9**, wherein the light is delivered into an edge of the optical grating layer.

16. The method of claim **9**, wherein the undiffracted portion of the light continues past the optical grating and exits the optical grating layer at a first exit point, and wherein the diffracted portion of the light changes direction at the optical grating and exits the optical grating layer at a second exit point.

* * * * *