(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
10 April 2025 (10.04.2025)

WIPO | PCT

(10) International Publication Number
WO 2025/076246 A1

(51) International Patent Classification:
A61B 3/16 (2006.01) *A61B 3/15* (2006.01)

(21) International Application Number:
PCT/US2024/049829

(22) International Filing Date:
03 October 2024 (03.10.2024)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
63/588,618 06 October 2023 (06.10.2023) US

(71) Applicant: VERILY LIFE SCIENCES LLC [US/US]; 2999 Olympus Blvd., 10th Floor/Ste 1000, Dallas, Texas 75019 (US).

(72) Inventor: SINHA, Supriyo; 269 E. Grand Avenue, South San Francisco, California 94080 (US).

(74) Agent: WILKINS, Clint et al.; Haynes and Boone, LLP, 2801 N. Harwood St., Suite 2300, Dallas, Texas 75201 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ,

(54) Title: MULTIPLE DISCRETE SOURCES FOR OPTICAL INTERROGATION OF PRESSURE SENSOR USING AN ARRAY OF SPOTS

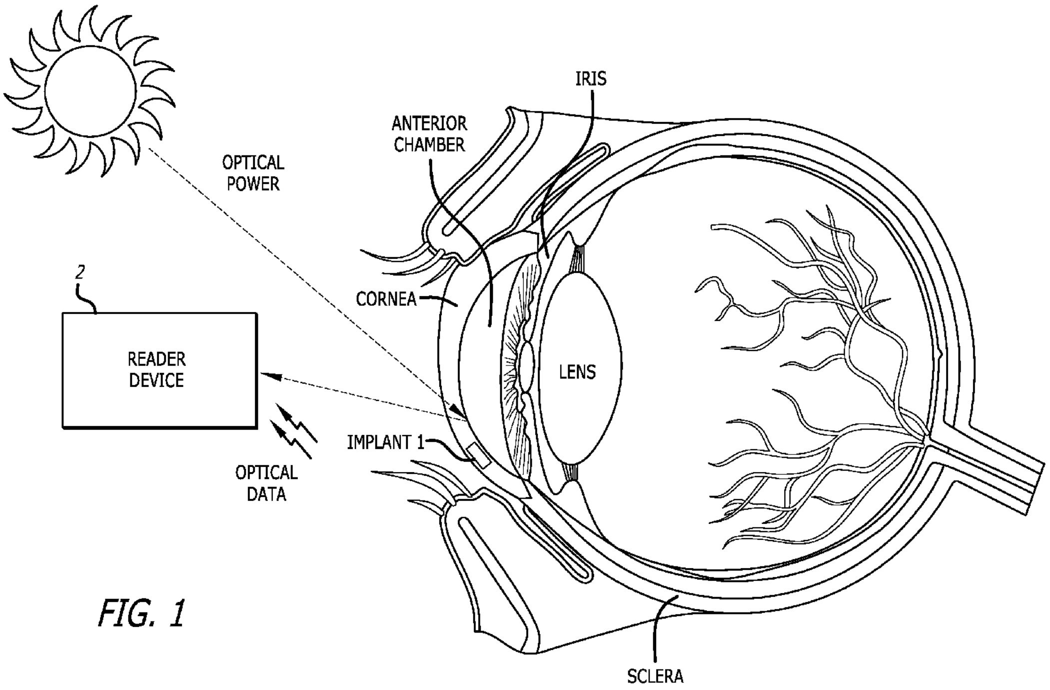


FIG. 1

(57) Abstract: An intraocular pressure measurement system comprising: an intraocular implant having a pressure sensor implantable in an eye, wherein the pressure sensor defines an optical cavity with a depth that varies based on an intraocular pressure of the eye; and an external reader device having a number of laser light sources configured to emit a plurality of beams and project an array of spots formed from the plurality of beams onto the pressure sensor, and a detector configured to receive a reflection of the array of spots off the pressure sensor that is used to measure the intraocular pressure of the eye.

[Continued on next page]

DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

MULTIPLE DISCRETE SOURCES FOR OPTICAL INTERROGATION OF PRESSURE SENSOR USING AN ARRAY OF SPOTS

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims priority to and the benefit of U.S. Provisional Patent Application No. 63/588,618, filed October 6, 2023, the entirety of which is hereby incorporated by reference.

TECHNICAL FIELD

The subject matter described herein relates to systems, devices, and methods for measuring intraocular pressure (IOP) in human eyes using an array of spots to optically interrogate a pressure sensor in the eyes. These systems, devices, and methods have particular, but not exclusive, utility for treating eye diseases, including but not limited to glaucoma.

BACKGROUND

Intraocular pressure (IOP) quantifies the pressure of fluid inside the eye. Many individuals suffer from disorders, such as glaucoma, that cause chronic heightened IOP. Over time, heightened IOP can cause damage to the optical nerve of the eye, leading to loss of vision. Presently, treatment of glaucoma mainly involves periodically administering pharmaceutical agents to the eye to decrease IOP. These drugs can be delivered, for example, by injection or eye drops. However, effective treatment of glaucoma requires adherence to dosage schedules and a knowledge of the patient's IOP. The more current or recent the measurement is, the more relevant it will be and hence the more effective the resulting treatment can be. The IOP for a given patient can vary significantly based on time of day, exercise, recency of medication use, and other factors. This means that any given measurement is subject to uncertainty, so it may take a plurality of measurements over time to provide confidence as to the health status of the patient. IOP measurements performed in a doctor's office typically only take place once or twice per year. These infrequent measurements are less able to account for variation in patient IOP. Annual or biannual measurements in a doctor's office may also grow stale or obsolete due to time lag since the previous measurement. Frequent measurements at home could allow for better treatment at lower cost.

Typically, the IOP is measured using a tonometer, which is a device that is outside the eye and thus does not require a sensor within the eye. Contact tonometry is performed in a clinical setting, and the procedure requires numbing of the patient's eye, resulting in both inconvenience and discomfort. Noncontact tonometry involves directing a puff or jet of air towards the patient's eye and measuring the resulting deflection dynamics of the cornea. However, this requires a bulky and power hungry pump arrangement that may not be practical for home use, and is not as accurate as contact tonometry.

A wireless, implantable, continuous IOP monitoring system has been suggested that has a commercial pressure sensing element with digital readout, and a microelectronic chip that supports wireless power/data telemetry and a wired serial communication interface with the pressure sensing element. An on-chip integrated RF coil receives power from near-field RF coupling at 915 MHz, and transmits pressure measurement bits via RF-backscattering to an external reader. This type of system, however, may require precise optical alignment between the external reader and the sensor in order to ensure the measurement data is accurate. It may be difficult for some users holding the external reader to meet such precise alignment requirements leading to inaccurate measurements.

The information included in this Background section of the specification, including any references cited herein and any description or discussion thereof, is included for technical reference purposes only and is not to be regarded as subject matter by which the scope of the disclosure is to be bound.

SUMMARY

Disclosed here are systems, devices, and methods for measuring intraocular pressure (IOP) in human eyes. More specifically, systems, devices and methods to spectrally interrogate a passive optical pressure sensor in the eye that does not require gratings or two-dimensional imaging sensors is presented and which still retains the ability to interrogate a large area. Representatively, while some systems and methods have been proposed to interrogate an optical pressure sensor using a broadband spatially coherent light that can interrogate a much larger area of the implant, such approaches may have some drawbacks. For example, in some aspects, a spatially coherent broadband light source such as a superluminescent diode (SLD) tends to have very low power, may be expensive, sensitive to feedback and the readout may be sensitive to angular alignment such that it requires a very precise alignment of the optical elements to achieve accurate measurements. In addition, the associated computational cost and complexity to read out and process data from a CMOS area sensor at high rates may increase the cost and power consumption of the handheld device.

Aspects disclosed herein solve many of these challenges by using a ratiometric detection scheme in combination with an array of spots to provide robust measurement of the curvature of the IOP sensor membrane upon deflection. For example, one implementation may include, instead of a single broadband source, two or more narrow band laser sources (bandwidth of a few nanometers or less). The sources may be spectrally combined using dichroic filters (a combination of long-pass and/or short pass filters) such that the beams are all along the same optical axis. The sources may also be collimated so that they illuminate an array of pinholes uniformly. The array of pinholes create an array of spots that are reimaged onto the optical pressure sensor, which allows a large portion of the sensor to be interrogated, easing alignment. Alternatively, the sources could also be collimated to illuminate a slit uniformly, which is then reimaged onto the optical pressure sensor. The reflected power may then be collected through polarization multiplexing and then split spectrally using dichroic filters (combination of long-pass and short-pass filters) and incident on linear image sensors. The linear image sensors may be oriented such that the axis joining the array of spots is also the long axis of the sensor. Thus, the received power from each spot for each light source could be detected. A ratio between the powers from different wavelengths could be used to determine the spacing at that point and then a curvature of the membrane could be computed to determine the IOP. Since the ratio may be dependent on the spectrum of the light source and the spectrum of a laser light source is dependent on temperature, a temperature controlled block could be used to stabilize the temperature to within a fraction of 1 degree Celsius. In addition, in some aspects, bandpass filters could be placed either after the source or before the linear image sensor to filter out any out of band light (for example a 5-10 nm band filter could be used for this). In still further aspects, a reference reflection could be employed in the handheld to calibrate the power from each of the sources (for example by using a gold reflection target for some of the spots that do not get sent out from the handheld). A pickoff after each source could also be used for calibration. Additionally, partial reflectors instead of dichroic filters could be used to spectrally combine the sources. Since the power of these sources are several mW and only ~10% of the power is needed, partially reflective broadband mirrors could be used to reduce the cost of the optics even further at the expense of lower transmission throughput. It is further contemplated that temporal multiplexing to simplify the system may be used. In this case, the arrangement of dichroic filters at the receiver end could be omitted and instead the light sources would be pulsed in a known sequence and then the output measured from a single linear image sensor with knowledge of what light source is being measured. A combination could also be used, for example, two linear image sensors could be used with four light sources by having two different time periods. In this aspect, multiple discrete light sources can be used for optical interrogation of the pressure sensor in the eye using an array of spots. The various advantages of the proposed configuration include reduced cost and easier processing since the use of linear detectors is easy, usually just using microcontrollers instead of requiring field-programmable gate arrays (FPGAs) or microprocessors, even at rates of several kHz.

In some aspects, an intraocular pressure measurement system includes an intraocular implant having a pressure sensor implantable in an eye, wherein the pressure sensor defines an optical cavity with a depth that varies based on an intraocular pressure of the eye; and an external reader device having a number of laser light sources configured to emit a plurality of beams and project an array of spots formed from the plurality of beams onto the pressure sensor, and a detector configured to receive a reflection of the array of spots off the pressure sensor that is used to measure the intraocular pressure of the eye. In some aspects, the external reader device further includes a number of dichroic filters configured to spectrally combine the plurality of beams. In still further aspects, the external reader device further includes an array of pinholes between the number of laser light sources and the detector that are configured to form the array of spots from the spectrally combined plurality of beams. In other aspects, the external reader device includes a polarizing beam splitter and a dichroic filter configured to selectively reflect the array of spots onto the detector. The detector may include a number of detectors and the dichroic filter comprises a number of dichroic filters configured to selectively reflect the array of spots onto the number of detectors. In some aspects, a number of bandpass filters may be positioned between the number of laser light sources and the number of detectors to filter out any out of band light. In still further aspects, the external reader device may include a number of partially reflective broadband mirrors to spectrally combine the plurality of beams and an array of pinholes configured to produce the array of spots from the spectrally combined plurality of beams. In some aspects, a temperature controlled block may be coupled to the number of laser light sources. The number of laser light sources may include narrow band laser light sources within a bandwidth of a few nanometers of less.

In other aspects, an external reader device for measuring intraocular pressure from an implant having a pressure sensor implanted in an eye having a dimension that varies according to an intraocular pressure of the eye may include a number of laser light sources configured to emit a plurality of beams and project an array of spots produced from the plurality of beams onto the pressure sensor; and a detector configured to receive a reflection of the array of spots off the pressure sensor that is used to measure the intraocular pressure of the eye. The device may further include a number of dichroic filters configured to spectrally combine the plurality of beams. The device may include an array of pinholes configured to produce the array of spots from the spectrally combined plurality of beams. The device may further include a polarizing beam splitter and a dichroic filter configured to selectively reflect the array of spots onto the detector. In some aspects, the detector includes a number of detectors and the dichroic filter comprises a number of dichroic filters configured to selectively reflect the array of spots onto the number of detectors. In further aspects, a number of bandpass filters may be positioned between the number of laser light sources and the number of detectors to filter out any out of band light. In some aspects, a number of partially reflective broadband mirrors may be included to spectrally combine the plurality of beams and an array of pinholes configured to produce the array of spots from the spectrally combined plurality of beams. A temperature controlled block may also be coupled to the number of laser light sources. The number of laser light sources may include a narrow band laser light source within a bandwidth of a few nanometers of less. In some aspects, the number of laser light sources include at least four laser light sources. The external reader device may be a handheld external reader device that is external to the eye in which the implant is implanted.

The above summary does not include an exhaustive list of all aspects of the present disclosure. It is contemplated that the disclosure includes all systems and methods that can be practiced from all suitable combinations of the various aspects summarized above, as well as those disclosed in the Detailed Description below and particularly pointed out in the Claims section. Such combinations may have particular advantages not specifically recited in the above summary.

BRIEF DESCRIPTION OF THE DRAWINGS

Several aspects of the disclosure here are illustrated by way of example and not by way of limitation in the figures of the accompanying drawings, in which like references indicate similar elements. It should be noted that references to “an” or “one” aspect in this disclosure are not necessarily to the same aspect, and they mean at least one. Also, in the interest of conciseness and reducing the total number of figures, a given figure may be used to illustrate the features of more than one aspect of the disclosure, and not all elements in the figure may be required for a given aspect.

FIG. 1 shows an example system for measuring intraocular pressure, using a reader device and an IOP sensor implanted into an eye.

FIG. 2 is a diagrammatic, cross-sectional representation of an example IOP measurement system in accordance with at least one embodiment of the present disclosure.

FIG. 3 is a diagrammatic, cross-sectional representation of an example IOP measurement system in accordance with at least one embodiment of the present disclosure.

FIG. 4 is a diagrammatic, cross-sectional representation of an example IOP measurement system in accordance with at least one embodiment of the present disclosure.

FIG. 5 is a diagrammatic, cross-sectional representation of an example IOP measurement system in accordance with at least one embodiment of the present disclosure.

FIG. 6 is a diagrammatic, cross-sectional representation of an example IOP measurement system in accordance with at least one embodiment of the present disclosure.

FIG. 7 is a diagrammatic, cross-sectional representation of an example IOP measurement system in accordance with at least one embodiment of the present disclosure.

DETAILED DESCRIPTION

Several aspects of the disclosure with reference to the appended drawings are now explained. Whenever the shapes, relative positions and other aspects of the parts described are not explicitly defined, the scope of the invention is not limited only to the parts shown, which are meant merely for the purpose of illustration. Also, while numerous details are set forth, it is understood that some aspects of the disclosure may be practiced without these details. In other instances, well-known circuits, structures, and techniques have not been shown in detail so as not to obscure the understanding of this description.

The terminology used herein is for the purpose of describing particular aspects only and is not intended to be limiting of the disclosure. Spatially relative terms, such as “beneath”, “below”, “lower”, “above”, “upper”, and the like may be used herein for ease of description to describe one element’s or feature’s relationship to another element(s) or feature(s) as illustrated in the figures. It will be understood that the spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as “below” or “beneath” other elements or features would then be oriented “above” the other elements or features. Thus, the exemplary term “below” can encompass both an orientation of above and below. The device may be otherwise oriented (e.g., rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

As used herein, the singular forms “a”, “an”, and “the” are intended to include the plural forms as well, unless the context indicates otherwise. It will be further understood that the terms “comprises” and/or “comprising” specify the presence of stated features, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, steps, operations, elements, components, and/or groups thereof.

The terms “or” and “and/or” as used herein are to be interpreted as inclusive or meaning any one or any combination. Therefore, “A, B or C” or “A, B and/or C” mean “any of the following: A; B; C; A and B; A and C; B and C; A, B and C.” An exception to this definition will occur only when a combination of elements, functions, steps or acts are in some way inherently mutually exclusive.

FIG. 1 shows an example system for measuring intraocular pressure, using a reader device 2 and an implant 1. Implant 1 may be composed of several parts or components which cooperate to enable the intraocular pressure sensor integrated therein to detect an intraocular pressure (IOP). In FIG. 1, IOP sensor implant 1 is shown implanted within the cornea of the eye. In other aspects, it is contemplated that implant 1 may be implanted within a sclera, anterior chamber or other portion of the eye suitable for detecting an IOP of the eye. Implant 1 may be composed of several parts or components which cooperate to enable the implant 1 to measure an IOP of the eye, as will be discussed in more detail in reference to FIG. 2. In some aspects, implant 1 may be a passive device. Reader device 2 may be a portable or handheld device having electronic components and/or circuitry operable to read implant 1. For example, reader device 2 may include components configured to communicate with, and receive data from, implant 1. It then processes the received measured pressure data using a processor to inform the user about their IOP. The reader device 2 may be deemed close to the eye when it can receive optically transmitted, measured pressure data, for example at no more than three inches away from the eye.

Referring now to FIG. 2, FIG. 2 illustrates a schematic cross-sectional side view of a general operation of the implant 1 of FIG. 1 for measuring IOP. In some aspects, interferometry may be employed on one or more reflections from the implantable sensor, of two or more narrow band laser light sources (e.g., a bandwidth of a few nanometers or less) emitted from reader device 2. The intraocular pressure sensor 4 integrated into implant 1 may generally include a cavity 10 (e.g., a low-finesse cavity) formed between a rigid substrate 6 and a flexible membrane 8, whose deflection affects the depth of the cavity 10 (i.e., the distance between the substrate 6 and the membrane 8) and is indicative of IOP. For example, substrate 6 may be a clear glass substrate that is spaced apart from membrane 8 which may be a clear glass membrane (e.g., by about 5-30 microns) that moves relative to the substrate depending on the IOP. The reader device 2 may include two or more narrow band laser sources that produce an array of spots that may pass through the cornea, vitreous humor, and/or aqueous humor of the eye to interrogate sensor 4. Spots that are incident on the implantable pressure sensor 4 will reflect from the sensor and may be captured by reader device 2, which in turn includes a processor that determines the IOP from the reflections. In general, a reflection off a cavity will yield different measured distances between the substrate and membrane based on the viewing angle. For example, a head-on measurement (incident angle of zero degrees, measured from the normal) will yield a first distance, whereas an incident angle of 45 degrees will yield a different distance due to the geometry of the beam and cavity. Generally, a measurement taken off-normal will mimic a shorter cavity. An incident angle close to 90 degrees will generally not return a reflection to the optical interrogation system. This presents a challenge to IOP measurement systems, as small movements of the eye or measuring device may change the incident angle and thus result in inaccurate readings. However, the systems of the present disclosure may be relatively insensitive to lateral alignment since an array of spots or beams are used to interrogate the sensor which provides immunity against misalignment.

Representatively, pressure sensor 4 implanted in the eye includes a diaphragm or membrane 8 and substrate 6 that together form an optical cavity 10 as previously discussed. In some aspects, a cross-section of the cavity 10 in a plane perpendicular to FIG. 2 may be circular. IOP measurement is achieved by reimaging an array of spots produced by narrow band laser light sources of the reader 2 onto membrane 8 and/or substrate 6 of sensor 4. Membrane 8 bends predictably and reversibly in proportion to increasing pressure (e.g., intraocular pressure), which in turn reduces the distance between the centers (or other corresponding points) of the two surfaces of substrate 6 and membrane 8. For example, the distance between a point on the surface of membrane 8 and a point on a surface of the substrate 6 decreases as pressure increases. The membrane 8 and the substrate 6 differ in stiffness, such that for a range of expected IOP, the substrate exhibits little-to-no deflection, whereas the membrane exhibits measurable deflection. In various aspects, the stiffness of the substrate 6 exceeds the stiffness of the membrane 8 by a factor of 100 or 1000 or more. In operation, membrane 8 exhibits flexibility with respect to IOP, whereas substrate 6 exhibits rigidity. FIG. 2 illustrates light incident on substrate 6 first, with light that is not reflected transmitted next to membrane 8. In other aspects, the light is incident on the membrane 8 first, with light that is not reflected transmitted next to the substrate 6. Since implant 1 is implanted within the eye, changes in the IOP within the eye will apply a pressure to membrane 8, which in turn, changes the depth of optical cavity 10. Membrane 8 bends predictably and reversibly in proportion to increasing IOP, which in turn reduces the distance (or depth) between the centers (or other corresponding points) of the surfaces of substrate 6 and membrane 8. For example, the distance or depth between a point on the surface of membrane 8 and a point on a surface of the substrate 6 decreases as pressure increases. In operation, membrane 8 exhibits flexibility with respect to IOP, whereas the substrate exhibits rigidity. These changes in depth of cavity 10 due to the bending or deflection of membrane 8 in response to IOP pressure changes may be interrogated by reader device 2 as previously discussed and used to determine the IOP of the eye.

As previously discussed, one of the challenges for optical readout is ensuring that the measurement is not impacted by relative motion (translational or rotational) between the sensor and the light source or the handheld reader. This means that the system may need to detect when it is properly interrogating the sensor as well as minimize the chances that motion would affect the result. For example, when interrogating the membrane with a single focused light beam any deviation of focus position from the center (due to handheld misalignment) causes measurement error because the membrane deflection is not uniform across its area. In the context of a handheld measurement, this limitation becomes prohibitive.

To overcome the above limitation, the IOP measurement system of the present disclosure reimages or projects an array of spots onto the sensor (membrane) implanted in the eye. The reflected power from each spot is then split spectrally and collected by image sensors of the handheld reader. A ratio between the powers from different wavelengths can then be used to determine the spacing at that point and then a curvature of the membrane could be computed to determine the eye IOP. For example, a ratiometric detection scheme in combination with the array of spots may be used to provide robust measurement of the curvature of the sensor membrane upon deflection, and in turn, determine the eye IOP. Overall, interrogation of an implanted sensor with an array of spots (as opposed to a single spot) allows for a much greater volume (e.g., based on an increase in lateral area) where the handheld may be positioned to take the intraocular pressure measurement.

Referring now to FIG. 3, FIG. 3 illustrates a schematic representation of an example IOP measurement system. Representatively, it can generally be understood from this view that handheld device 2 interrogates implant 1 using an array of spots 22 that are reimaged onto the IOP sensor of implant 1 and then processes the reflected power from each of the array of spots 22 to compute a curvature of the sensor membrane, and in turn, the eye IOP. To achieve this, device 2 includes a number of light sources 12 that emit beams of light for interrogating implant 1. In some aspects, light sources 12 may include two or more narrow band laser sources within a bandwidth of a few nanometers or less. For example, light sources 12 may include at least four or more narrow band laser light sources. Light sources

12 may emit light beams that are then spectrally combined using dichroic filters 16. The dichroic filters 16 may include a combination of long-pass and/or short pass filters. Alternatively, in some aspects, partially reflecting mirrors may instead be used in place of the dichroic filters 16. For example, the different partially reflecting mirrors may be configured to reflect yellow/green, yellow/green/blue and/or yellow/green/blue/red wavelength light. In this configuration, beam dumps (not shown) may also be included in the rejected paths. The light sources 12 may be combined such that the beams are all along the same optical axis as shown. In addition, light sources 12 may be collimated using collimation lenses 14 so that they uniformly illuminate an array of pinholes 20. Array of pinholes 20 may be, for example, an elongated structure that includes a number of linearly arranged pinholes of the same size and shape. Array of pinholes 20 then produce an array of spots 22 from the collimated light which are used to interrogate implant 1. Representatively, array of spots 22 may pass through a beam splitter 26 and are imaged onto implant 1 using the lens 24 and focusing lens 30 as shown. In some aspects, beam splitter 26 may be a polarizing cube beam splitter. As previously discussed, interrogating implant 1 with array of spots 22 allows a larger portion of the IOP sensor (e.g., membrane) to be interrogated which, in turn, eases the typically precise alignment requirements necessary for accurate measurement by the handheld reader 2. The reflected power from the array of spots 22, which is illustrated by the dashed arrows, then passes through an achromatic quarter-wave plate (QWP) 28 to beam splitter 26. The reflected power is then collected through polarizing multiplexing using beam splitter 26 and split spectrally using dichroic filters 36. In this aspect, dichroic filters 36 may include a combination of long-pass and short-pass filters. Representatively, the reflected power passes through beam splitter 26 and filters 36 to detectors 38 as shown. In some aspects, detectors 38 may be linear image sensors 38 that are oriented such that the axis joining the array of spots 22 is also the long axis of image sensors 38. Thus, the received power from each spot from each of light sources 12 may be detected. A ratio between the powers from different wavelengths can then be used to determine the spacing at that point and then a curvature of the sensor membrane can be computed to determine the IOP. Since the ratio will be dependent on the spectrum of the light source and the spectrum of a laser light source is dependent on temperature, a temperature controlled block 40 could also be used to stabilize the temperature to within a fraction of one degree Celsius. For example, temperature controlled block 40 may be any suitable type of temperature controlled block and coupled to light sources 12.

Referring now to FIG. 4, FIG. 4 illustrates a schematic representation of an alternative exemplary IOP measurement system. The IOP measurement system of FIG. 4 may include all the same components as previously discussed in reference to FIG. 3. The duplicate components and their operation will therefore not be discussed in detail in reference to FIG. 4. In addition to the previously discussed components, however, the IOP measurement system of FIG. 4 may further include bandpass filters 15 to filter out any out of band light. For example, bandpass filters 15 could be 5-10 nanometer bandpass filters. Bandpass filters 15 may, in some aspects, be positioned between light sources 12 and dichroic filters 16 as shown to filter out any out of band light. In other aspects, bandpass filters 15 could alternatively be positioned before detectors 38 as illustrated by the filter structures shown in dashed lines.

Referring now to FIG. 5, FIG. 5 illustrates a schematic representation of an alternative exemplary IOP measurement system. The IOP measurement system of FIG. 5 may include all the same components as previously discussed in reference to FIG. 3. The duplicate components and their operation will therefore not be discussed in detail in reference to FIG. 5. In addition to the previously discussed components, however, the IOP measurement system of FIG. 5 may further include a reference reflection in the handheld reader 2 to calibrate the power from each of the sources (for example by using a gold reflection target for some of the spots that do not get sent out from the handheld). Representatively, in some aspects, a beam pickoff 42 after the collimating lens 14 of each light source 12 could be used to pick-off some of the incident beam and calibrate the power from each light source 12. In this aspect, detectors 44 may also be arranged after pickoffs 42 to receive the picked-off beams from each light source 12. In some aspects, one or more of detectors 44 may be photodiodes. Alternatively, a pickoff 42 may be positioned between the lens 24 after the pinhole array 20 and the beam splitter 26, as illustrated by the pickoff 42 drawn in dashed lines. Pickoff 42 at this location picks off some of the unused spots and puts them onto a photodiode 44 also drawn in dashed lines. In this configuration, light sources 12 may also be temporally multiplexed to know which light source is being measured by the photodiode at any given time.

Referring now to FIG. 6, FIG. 6 illustrates a schematic representation of an alternative exemplary IOP measurement system. The IOP measurement system of FIG. 6 may include some of the same components as previously discussed in reference to FIG. 3. The duplicate components and their operation will therefore not be discussed in detail in reference to FIG. 6. In this configuration, however, temporal multiplexing is used to simplify the system. In this aspect, the arrangement of dichroic filters 36 at the receiver end as discussed in the previous configurations may be omitted. Instead, the light sources 12 may be pulsed in a known sequence and then the output from a single linear image sensor or detector 38 is measured. Alternatively, as illustrated by FIG. 7, a combination of a single dichroic filter 36 and two linear image sensors or photodetectors 38 (e.g., blue + green photodetector and yellow + red photodetector) in the detection path could be used. The dichroic filter 36 may have a cutoff that is between the second and third wavelengths (e.g., a cutoff at 550 nm) when numbered from increasing to decreasing wavelengths. In this aspect, dichroic filter 36 could be a short pass and/or long pass dichroic filter.

While certain aspects have been described and shown in the accompanying drawings, it is to be understood that such are merely illustrative of and not restrictive on the broad invention, and that the invention is not limited to the specific constructions and arrangements shown and described, since various other modifications may occur to those of ordinary skill in the art. For example, while implant 1 is shown positioned in the anterior chamber, it is contemplated that in some configurations, implant could be implanted in the cornea or sclera. Moreover, while implant is described as a passive device, it is contemplated that in some aspects the implant may be an active device. In addition, regarding the reader device 2, although not specifically discussed, device may also include a receiver and transmitter to communicate with implant 1, and a processor to process the output from the implant and measure IOP. Also, while FIG. 1 shows the sun as providing its sunlight to power implant 1, other sources of optical power are possible such as artificial room lighting or a lamp that is within an accessory worn by the user (e.g., eyeglasses). The description is thus to be regarded as illustrative instead of limiting.

CLAIMS

What is claimed is:

1. An intraocular pressure measurement system comprising:

an intraocular implant having a pressure sensor implantable in an eye, wherein the pressure sensor defines an optical cavity with a depth that varies based on an intraocular pressure of the eye; and

an external reader device having a number of laser light sources configured to emit a plurality of beams and project an array of spots formed from the plurality of beams onto the pressure sensor, and a detector configured to receive a reflection of the array of spots off the pressure sensor that is used to measure the intraocular pressure of the eye.

2. The intraocular pressure measurement system of claim 1 wherein the external reader device further comprises a number of dichroic filters configured to spectrally combine the plurality of beams.

3. The intraocular pressure measurement system of claim 2 wherein the external reader device further comprises an array of pinholes between the number of dichroic filters and the detector that are configured to form the array of spots from the spectrally combined plurality of beams.

4. The intraocular pressure measurement system of claim 1 wherein the external reader device further comprises a polarizing beam splitter and a dichroic filter configured to selectively reflect the array of spots onto the detector.

5. The intraocular pressure measurement system of claim 4 wherein the detector comprises a number of detectors and the dichroic filter comprises a number of dichroic filters configured to selectively reflect the array of spots onto the number of detectors.

6. The intraocular pressure measurement system of claim 5 further comprising a number of bandpass filters between the number of laser light sources and the number of detectors to filter out any out of band light.

7. The intraocular pressure measurement system of claim 1 wherein the external reader device further comprises a number of partially reflective broadband mirrors to spectrally

combine the plurality of beams and an array of pinholes configured to produce the array of spots from the spectrally combined plurality of beams.

8. The intraocular pressure measurement system of claim 1 further comprising a temperature controlled block coupled to the number of laser light sources.

9. The intraocular pressure measurement system of claim 1 wherein the number of laser light sources comprise narrow band laser light sources within a bandwidth of a few nanometers of less.

10. An external reader device for measuring intraocular pressure from an implant having a pressure sensor implanted in an eye having a dimension that varies according to an intraocular pressure of the eye, the device comprising:

a number of laser light sources configured to emit a plurality of beams and project an array of spots produced from the plurality of beams onto the pressure sensor; and

a detector configured to receive a reflection of the array of spots off the pressure sensor that is used to measure the intraocular pressure of the eye.

11. The device of claim 10 further comprising a number of dichroic filters configured to spectrally combine the plurality of beams.

12. The device of claim 11 further comprising an array of pinholes configured to produce the array of spots from the spectrally combined plurality of beams.

13. The device of claim 10 further comprising a polarizing beam splitter and a dichroic filter configured to selectively reflect the array of spots onto the detector.

14. The device of claim 13 wherein the detector comprises a number of detectors and the dichroic filter comprises a number of dichroic filters configured to selectively reflect the array of spots onto the number of detectors.

15. The device of claim 14 further comprising a number of bandpass filters between the number of laser light sources and the number of detectors to filter out any out of band light.

16. The device of claim 10 further comprising a number of partially reflective broadband mirrors to spectrally combine the plurality of beams and an array of pinholes configured to produce the array of spots from the spectrally combined plurality of beams.

17. The device of claim 10 further comprising a temperature controlled block coupled to the number of laser light sources.

18. The device of claim 10 wherein the number of laser light sources comprise narrow band laser light sources within a bandwidth of a few nanometers of less.

19. The device of claim 10 wherein the number of laser light sources comprise at least four laser light sources.

20. The device of claim 10 wherein the external reader device is a handheld external reader device that is external to the eye in which the implant is implanted.

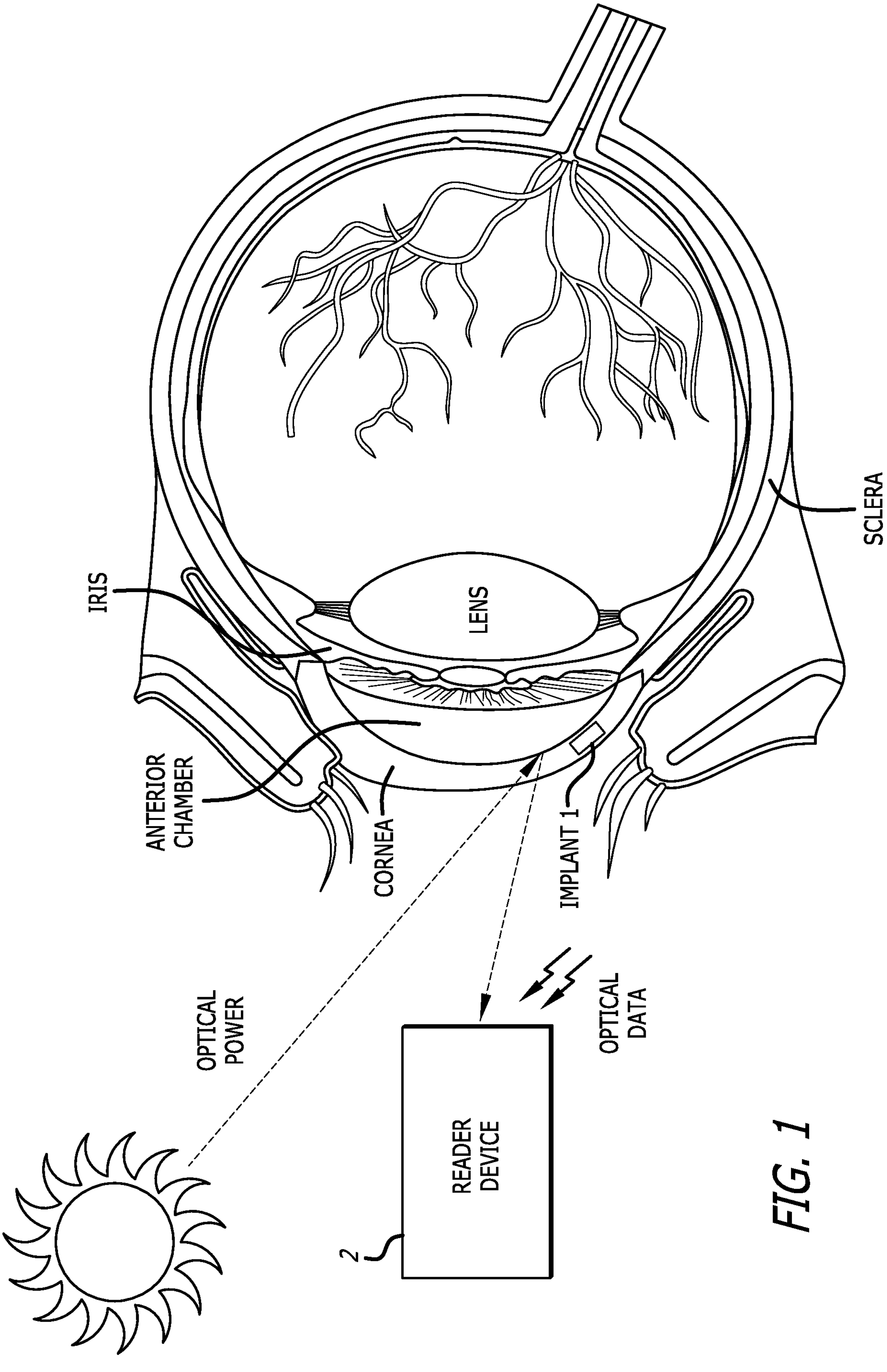

IRIS
LENS
SCLERA
ANTERIOR CHAMBER
CORNEA
IMPLANT 1
OPTICAL POWER
OPTICAL DATA
READER DEVICE
2

FIG. 1

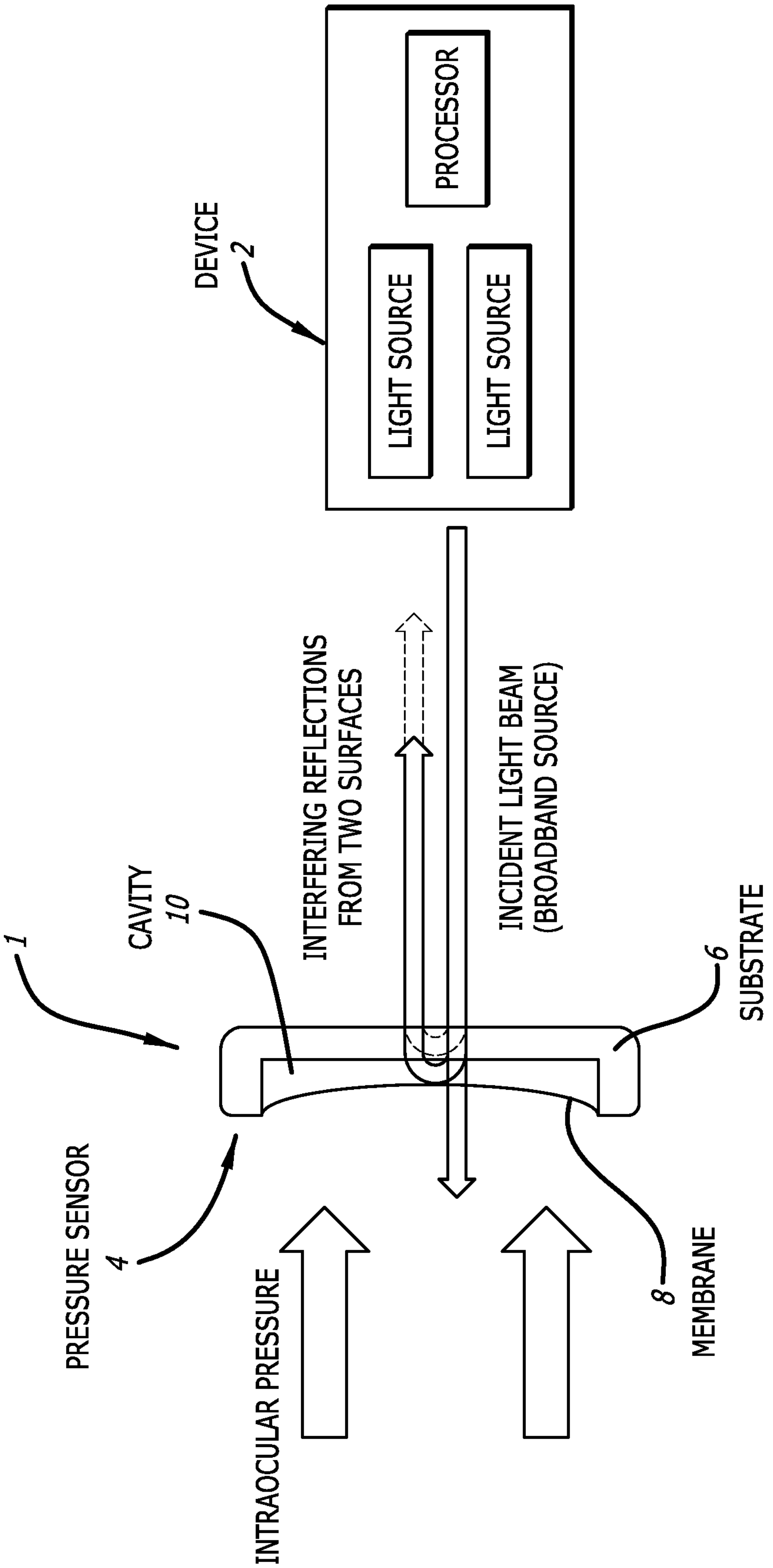

DEVICE
2
PROCESSOR
LIGHT SOURCE
LIGHT SOURCE
INTERFERING REFLECTIONS FROM TWO SURFACES
INCIDENT LIGHT BEAM (BROADBAND SOURCE)
1
CAVITY
10
6
SUBSTRATE
PRESSURE SENSOR
4
INTRAOCULAR PRESSURE
8
MEMBRANE

FIG. 2

FIG. 3

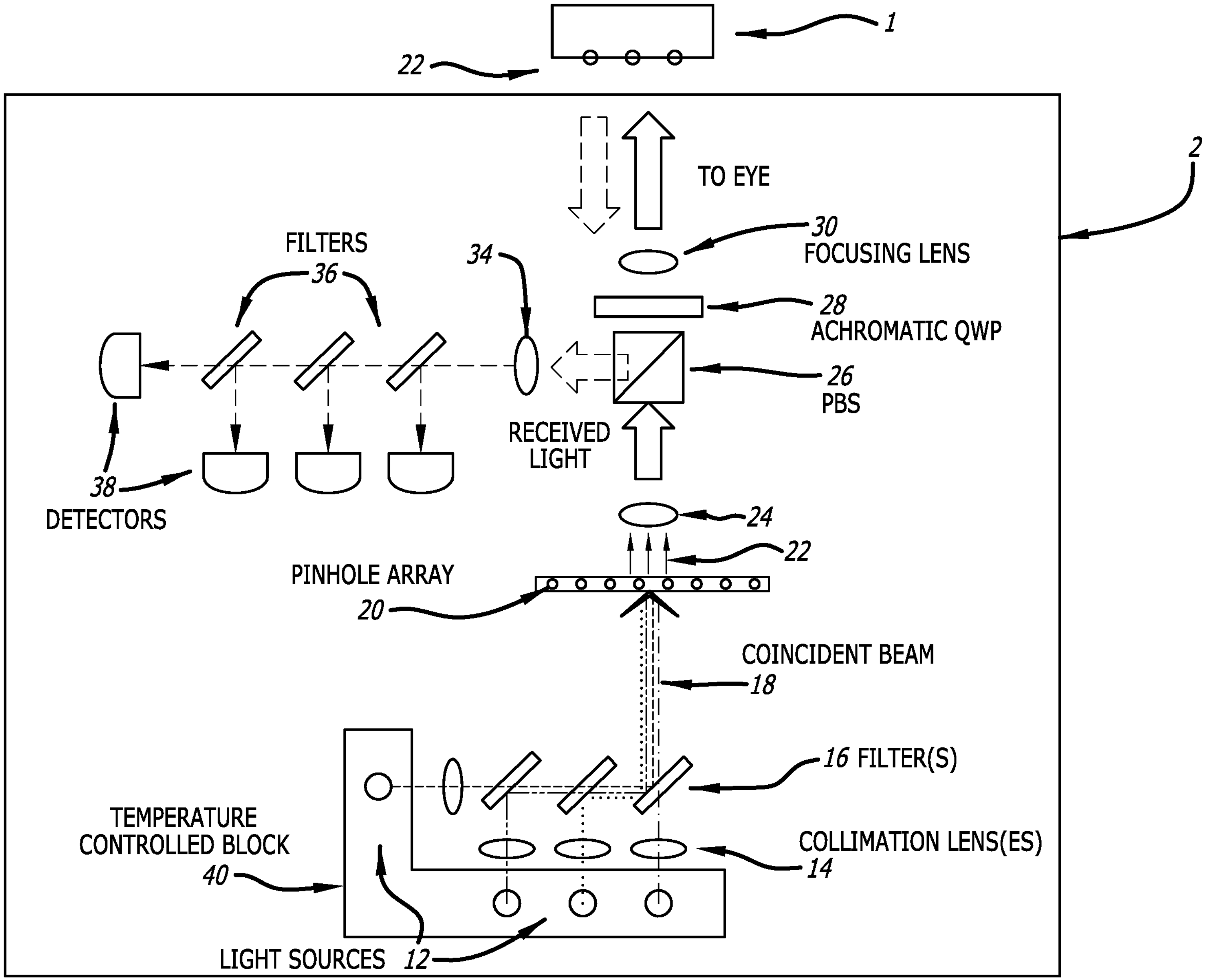
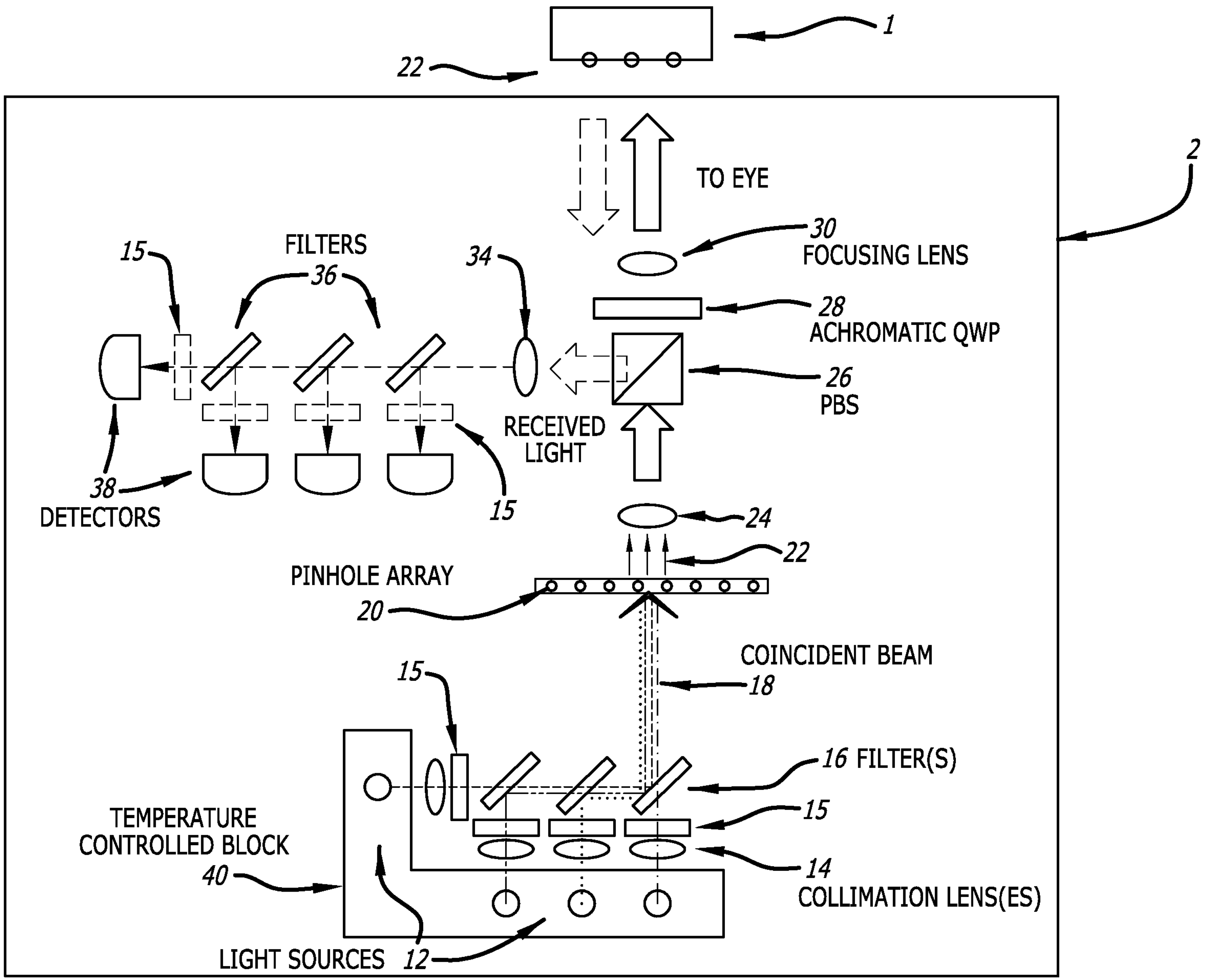

1
22
2
TO EYE
30
FOCUSING LENS
28
ACHROMATIC QWP
26
PBS
FILTERS
36
34
RECEIVED
LIGHT
38
DETECTORS
24
22
PINHOLE ARRAY
20
COINCIDENT BEAM
18
16 FILTER(S)
TEMPERATURE
CONTROLLED BLOCK
40
COLLIMATION LENS(ES)
14
LIGHT SOURCES 12

FIG. 4


1
22
2
TO EYE
30
FOCUSING LENS
28
ACHROMATIC QWP
26
PBS
15
FILTERS
36
34
RECEIVED
LIGHT
38
DETECTORS
15
24
22
PINHOLE ARRAY
20
COINCIDENT BEAM
18
15
16 FILTER(S)
15
TEMPERATURE
CONTROLLED BLOCK
40
14
COLLIMATION LENS(ES)
LIGHT SOURCES 12

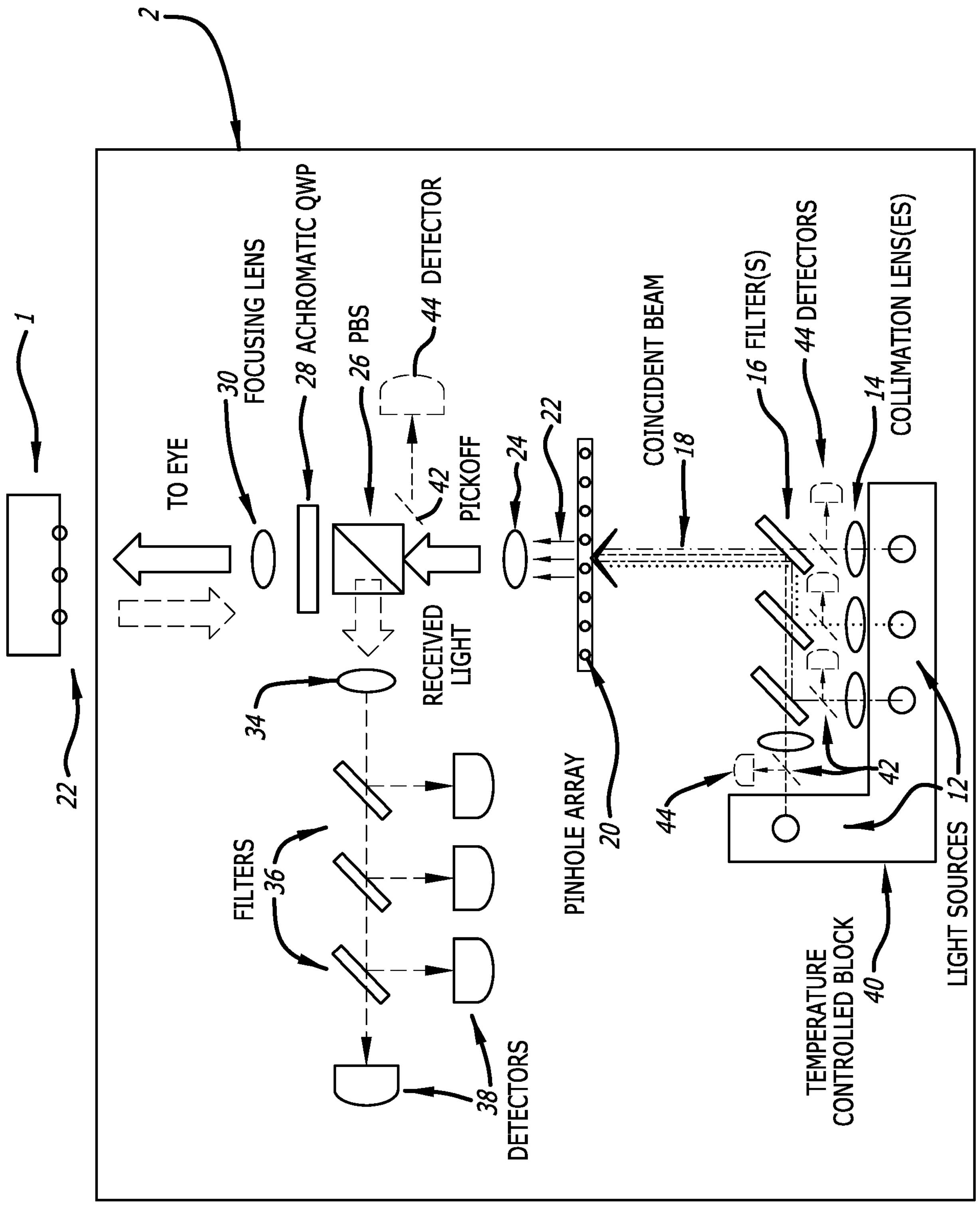

1
2
22
TO EYE
30 FOCUSING LENS
28 ACHROMATIC QWP
26 PBS
44 DETECTOR
42
PICKOFF
RECEIVED LIGHT
34
24
22
COINCIDENT BEAM
18
PINHOLE ARRAY
20
16 FILTER(S)
44 DETECTORS
14 COLLIMATION LENS(ES)
42
44
12
LIGHT SOURCES
TEMPERATURE CONTROLLED BLOCK
40
FILTERS
36
38
DETECTORS

FIG. 5

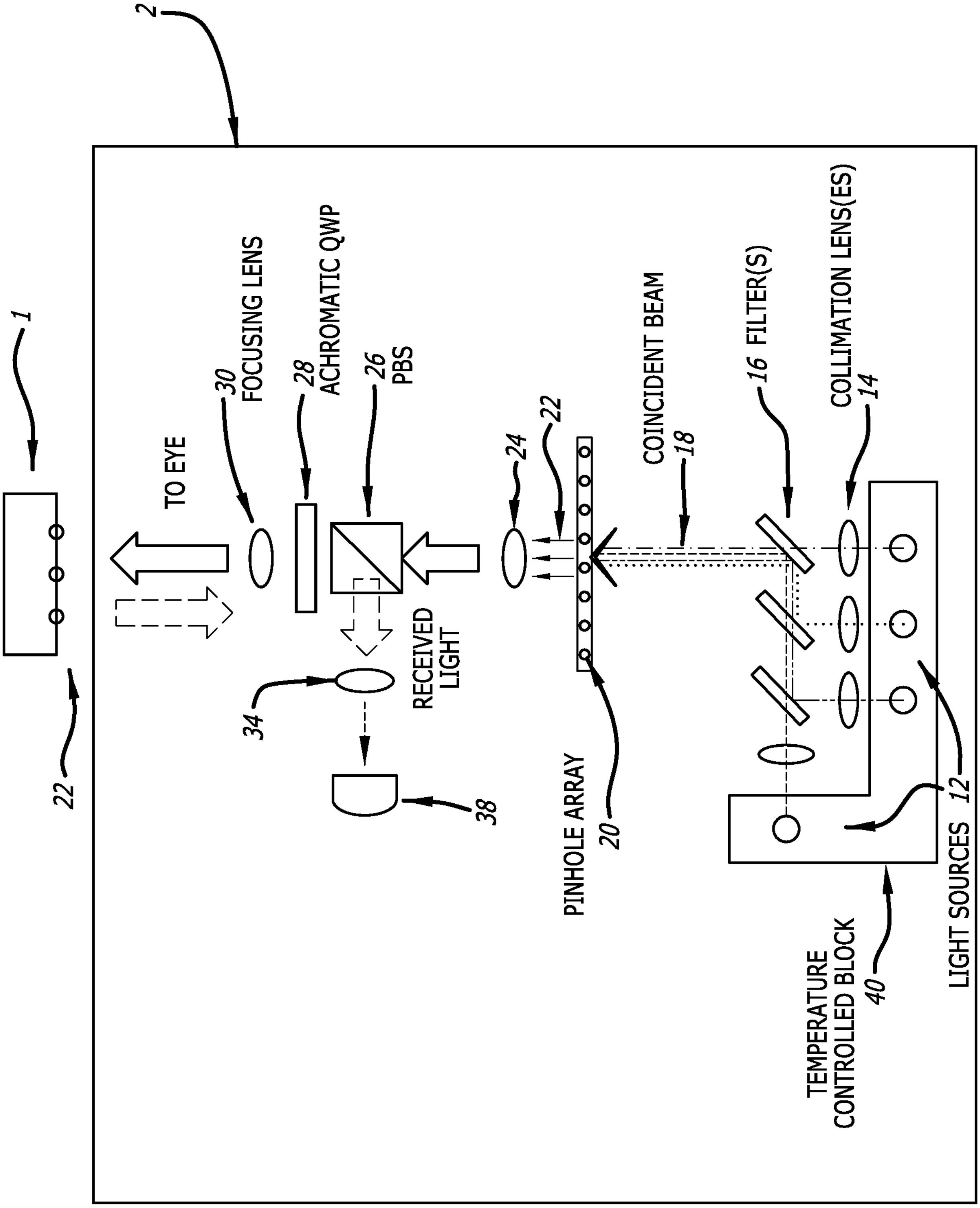

1
2
22
TO EYE
30
FOCUSING LENS
28
ACHROMATIC QWP
26
PBS
24
22
COINCIDENT BEAM
18
16 FILTER(S)
COLLIMATION LENS(ES)
14
RECEIVED LIGHT
34
38
PINHOLE ARRAY
20
12
LIGHT SOURCES
TEMPERATURE CONTROLLED BLOCK
40

FIG. 6

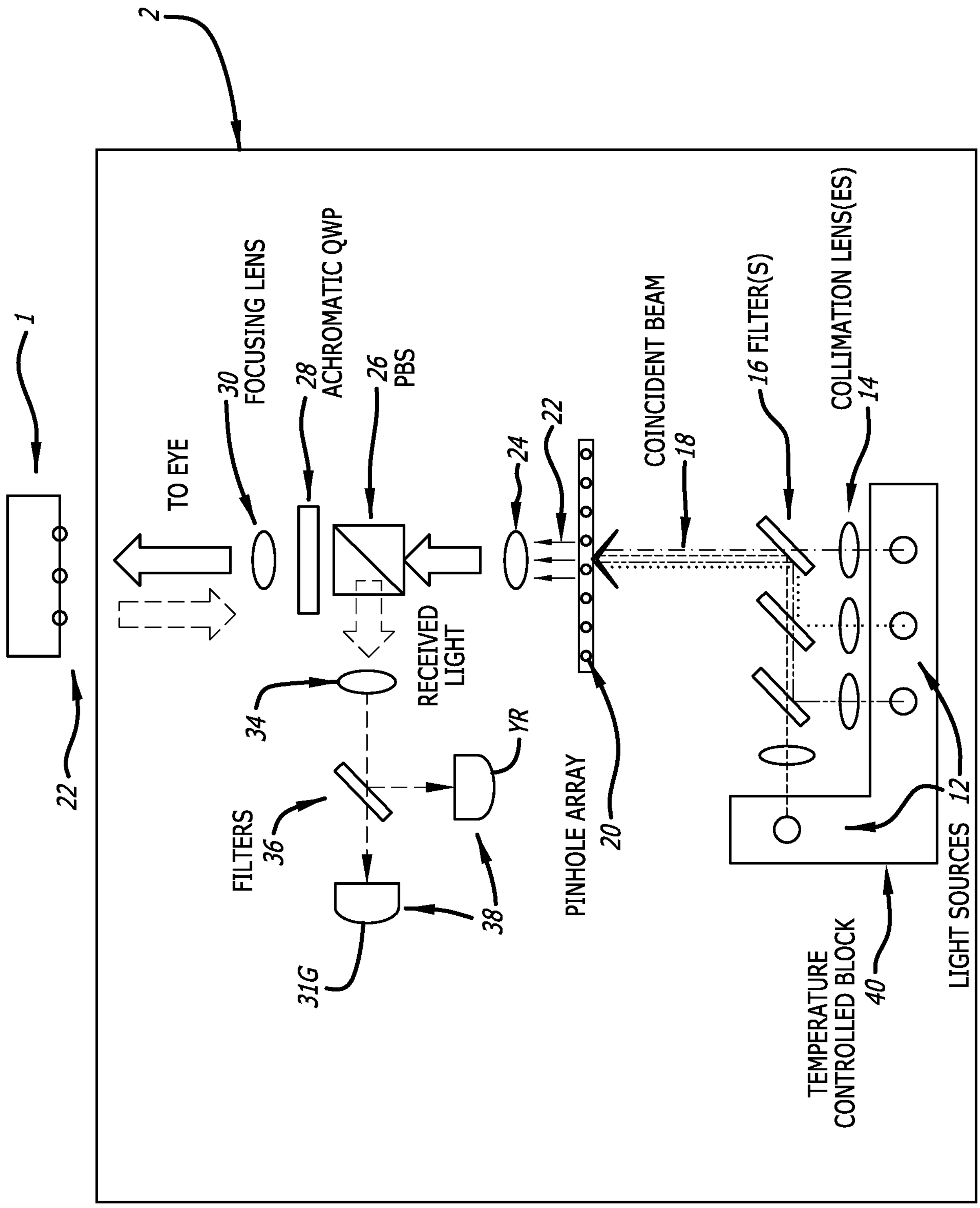

1
22
2
TO EYE
30
FOCUSING LENS
28
ACHROMATIC QWP
26
PBS
24
22
RECEIVED LIGHT
34
YR
FILTERS
36
38
31G
PINHOLE ARRAY
20
COINCIDENT BEAM
18
16 FILTER(S)
COLLIMATION LENS(ES)
14
12
LIGHT SOURCES
TEMPERATURE CONTROLLED BLOCK
40

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2024/049829

A. CLASSIFICATION OF SUBJECT MATTER

IPC: ***A61B 3/16*** (2024.01); ***A61B 3/15*** (2024.01)

CPC: ***A61B 3/16; A61B 3/0008; A61B 3/15;*** *A61B 2562/0247*

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History Document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

See Search History Document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	US 2022/0395178 A1 (TWENTY TWENTY THERAPEUTICS LLC) 15 December 2022 (15.12.2022)	
X	entire document	1, 9, 10, 18-20
Y	entire document	2, 4, 11, 13
	US 2023/0309816 A1 (TWENTY TWENTY THERAPEUTICS LLC) 05 October 2023 (05.10.2023)	
Y	entire document	2, 4, 11, 13
	US 2022/0218201 A1 (TWENTY TWENTY THERAPEUTICS LLC) 14 July 2022 (14.07.2022)	
Y	entire document	4, 13
	US 10,702,142 B1 (VERILY LIFE SCIENCES LLC) 07 July 2020 (07.07.2020)	
A	entire document	1-20
	US 2003/0078487 A1 (JEFFRIES et al.) 24 April 2003 (24.04.2003)	
A	entire document	1-20

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

* Special categories of cited documents:

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

Date of the actual completion of the international search **04 December 2024 (04.12.2024)**	Date of mailing of the international search report **11 December 2024 (11.12.2024)**
Name and mailing address of the ISA/US **COMMISSIONER FOR PATENTS** **MAIL STOP PCT, ATTN: ISA/US** **P.O. Box 1450** **Alexandria, VA 22313-1450** **UNITED STATES OF AMERICA** Facsimile No. **571-273-8300**	Authorized officer **TAINA MATOS** Telephone No. **571-272-4300**

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 9,289,123 B2 (VERILY LIFE SCIENCES LLC) 22 March 2016 (22.03.2016) entire document	1-20