



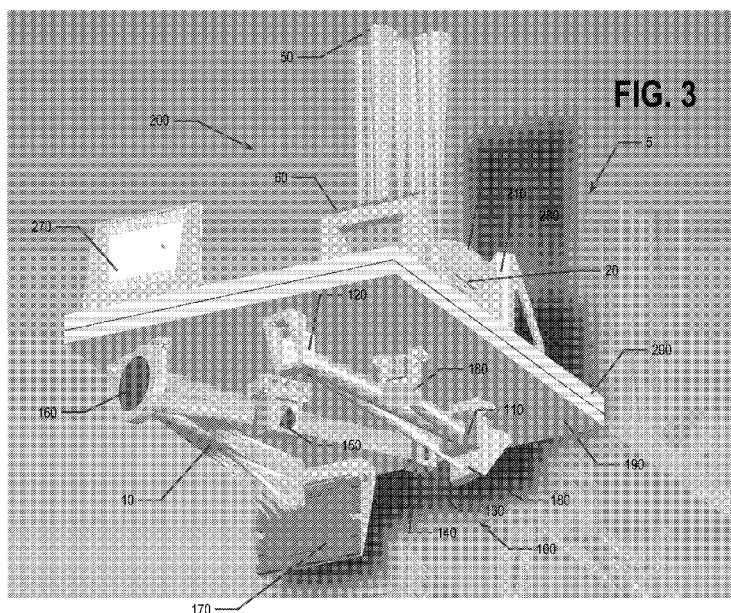
- (51) **International Patent Classification:**
G02B 27/28 (2006.01) *G02B 6/27* (2006.01)
- (21) **International Application Number:**
PCT/US2016/028380
- (22) **International Filing Date:**
20 April 2016 (20.04.2016)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
62/153,720 28 April 2015 (28.04.2015) US
- (71) **Applicant: UNIVERSITY OF FLORIDA RESEARCH FOUNDATION, INC.** [US/US]; 223 Grinter Hall, Gainesville, Florida 32611 (US).
- (72) **Inventors: TELESCO, Charles Michael;** 414 BSSC, P.O. Box 112055, Gainesville, Florida 32611-2055 (US). **SPARKS, William B.;** 3700 San Martin Drive, P624, Baltimore, Maryland 21218 (US). **ZHAO, Bo;** 211 Bryant Space Science Center, P.O. Box 112055, Gainesville, Florida 32611-2055 (US).
- (74) **Agents: DRAPER, Aden R.** et al.; ALSTON & BIRD LLP, Bank of America Plaza, 101 S. Tryon Street, Suite 4000, Charlotte, North Carolina 28280-4000 (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, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, 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, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) **Designated States** (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, 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, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, 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))

(54) **Title:** INTEGRATED MINIATURE POLARIMETER AND SPECTROGRAPH USING STATIC OPTICS



(57) **Abstract:** Embodiments provide an integrated miniature polarimeter and spectrograph (IMPS) and associated methods for using an IMPS to determine Stokes parameters to describe a source beam. In one embodiment an IMPS is provided comprising a spectropolarimeter module. The spectropolarimeter module comprises a miniature optical bench; a slit component; a birefringent wedge; a dichroic prism; a spectral disperser; and a focal plane array. The slit component, birefringent wedge, dichroic prism, spectral disperser, and focal plane array are mounted to the miniature optical bench such that a beam incident on the slit component will be incident on (1) the birefringent wedge, (2) the dichroic prism, (3) the spectral disperser, and (4) the focal plane array, in that order.



INTEGRATED MINIATURE POLARIMETER AND SPECTROGRAPH USING STATIC OPTICS

BACKGROUND

It has long been known that the spectrum of a source encodes a large amount of information about the source. For example, the composition of the sun has been determined based on the observed solar spectrum. The polarized spectrum of a source carries additional information related to the source. For example, the polarized spectrum of an exoplanet may carry information indicative of whether the atmosphere of the exoplanet contains organic molecules associated with life. Thus, spectropolarimeters are important tools for researchers. Additionally, spectropolarimetry has applications in astronomy, remote sensing, medical diagnostics, biophysics, microscopy, and fundamental experimental physics.

Most polarimetric methods include rotating waveplates, polarization analyzers, and/or the like. Rotating waveplates, polarization analyzers, and/or the like require the use of motors, gears, drive shafts, a power source, and/or the like. These components increase the size of the polarimeter, and also the weight, cost, and power consumption of the polarimeter. Additionally, any moving parts greatly increase the possibility for instrument failure. Moreover, such methods can cause approximately half the photons received at the polarimeter to be discarded. In some applications, such as polarimetry measurements of faint astrophysical objects (e.g., exoplanets), the reduction of photon throughput greatly reduces the feasibility of performing polarimetry measurements.

Therefore, a need exists for new and improved apparatuses, systems, and methods for performing spectropolarimetry measurements.

BRIEF SUMMARY

Various embodiments of the present invention provide an integrated miniature polarimeter and spectrograph (IMPS) using static optics. In particular, embodiments of the present invention provide an instrument and associated methods that can be used to deduce, calculate, and/or determine one or more of the four Stokes parameters without the use of moving parts. The Stokes parameters are the quantities measured by IMPS that are then used to compute the actual magnitude and orientation of the polarization.

According to one aspect of the present invention, an integrated miniature polarimeter and spectrograph (IMPS) is provided. In one embodiment the IMPS comprises

a spectropolarimeter module. In example embodiments, the spectropolarimeter module comprises a miniature optical bench; a slit component; a birefringent wedge; a dichroic prism; a spectral disperser; and a focal plane array. The slit component, birefringent wedge, dichroic prism, spectral disperser, and focal plane array are mounted to the miniature optical bench such that a beam incident on the slit component will be incident on (1) the birefringent wedge, (2) the dichroic prism, (3) the spectral disperser, and (4) the focal plane array, in that order.

According to another aspect of the present invention, methods for determining Stokes parameters to describe a source beam are provided. In one embodiment, the method comprises providing an integrated miniature polarimeter and spectrograph (IMPS). In example embodiments, the IMPS comprises a spectropolarimeter module comprising a slit component, a birefringent wedge, a dichroic prism, a spectral disperser, and a focal plane array. In one embodiment, the dichroic prism is a Wollaston prism. The method further comprises causing interference of various polarizations comprising a source beam through use of the birefringent wedge; spatially separating ordinary rays of the source beam and extraordinary rays of the source beam through use of the dichroic prism; dispersing the source beam into spectra through use of the spectral disperser; and converting the source beam into digital image data through use of the focal plane array. In particular in various embodiments, the interference of various polarizations comprising the source beam may be caused by the birefringent wedge; the spatial separation of the ordinary rays and the extraordinary rays of the source beam is caused by the dichroic prism; the dispersion of the source beam into spectra is caused by the spectral disperser; and the conversion of the source beam into digital image data is caused by the source beam being incident upon the focal plane array.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

Fig. 1 provides a block diagram of an integrated miniature polarimeter and spectrograph (IMPS), in accordance with an embodiment of the present invention;

Fig. 2 provides an example output of the spectropolarimeter module, in accordance with an embodiment;

Fig. 3 illustrates an example embodiment of spectropolarimeter module of an IMPS;

Fig. 4 illustrates an example embodiment of a context imager module of an IMPS;
Fig. 5 provides a flowchart illustrating processes and procedures of using an IMPS
to analyze the Stokes parameters of a received beam; and
Fig. 6 provides a block diagram of a data management computing entity according
5 to an embodiment of the present invention.

DETAILED DESCRIPTION OF VARIOUS EMBODIMENTS

The present invention now will be described more fully hereinafter with reference
to the accompanying drawings, in which some, but not all embodiments of the invention
10 are shown. Indeed, this invention may be embodied in many different forms and should
not be construed as limited to the embodiments set forth herein; rather, these embodiments
are provided so that this disclosure will satisfy applicable legal requirements. Like
numbers refer to like elements throughout.

15 I. Overview

Embodiments of the present invention provide an integrated miniature polarimeter
and spectrograph (IMPS). As shown in Figure 1, in various embodiments, an IMPS 5
comprises a spectropolarimeter module 100. In various embodiments, the IMPS 5 may
further comprise a context imager module 200. In various embodiments, the IMPS 5 may
20 further comprise and/or be in communication with a data management computing entity
600 (see Figure 6). In various embodiments, the optics of the IMPS 5 may be optimized
for ultra-violet (UV), optical, or infrared (IR) spectra applications.

According to various embodiments, the IMPS 5 receives an observed beam. For
example, a telescope or telephoto lens 50 may focus an observed beam onto a pick-off
25 mirror 60. For example, the pick-off mirror 60 may be positioned at the image plane for
the telescope or telephoto lens 50. In some embodiments, the telescope or telephoto lens
50 may provide an $f/10$ beam to the IMPS 5. The pick-off mirror 60 may separate the
observed beam into a source beam 10 and a context beam 20 and provide the source beam
10 to the spectropolarimeter module 100. In embodiments having a context imager
30 module 200, the pick-off mirror 60 may provide the context beam 20 to the context imager
module.

In various embodiments, the source beam 10 may be manipulated by various static optical components, as will be described in detail below, to provide polarized spectra such as the spectra shown in Figure 2. Spectrum 310 shows the fringed spectrum of rays having a first polarization and spectrum 320 shows the fringed spectrum of the rays having a second polarization, as will be discussed in more detail below. The observed spectra 310 and 320 may be analyzed to calculate and/or determine a set of Stokes parameters that describes the source beam. Various aspects of the IMPS 5 will now be described in detail.

II. Exemplary Spectropolarimeter Module

As noted above, the IMPS 5 comprises a spectropolarimeter module 100. An example spectropolarimeter module 100 is illustrated in Figure 3. In various embodiments, the spectropolarimeter module 100 comprises a slit 130, one or more birefringent wedges 140, a dichroic prism 150, a spectral disperser 160, and a focal plane array 170. The spectropolarimeter module 100 may comprise various other optical components configured to manipulate and/or condition the source beam 10 along the optical path through the spectropolarimeter module 100. For example, the spectropolarimeter module 100 may comprise a collimator 110, a cylindrical mirror 120, one or more flat folding mirrors 180, and/or the like. For example, the collimator 110 and cylindrical mirror 120 may be configured to reshape and/or condition the source beam 10. The flat folding mirrors 180 may be configured to fold the optical path traveled by the source beam 10.

As shown in Figure 3, the source beam 10 is provided to the spectropolarimeter module 100 via the pick off mirror 60. In various embodiments, the pick-off mirror 60 comprises a flat mirror having a pick-off hole in the middle thereof. Thus, when the observed beam is incident on the pick-off mirror 60, the source beam 10 passes through the pick-off hole. The remainder of the observed beam may be reflected off the pick-off mirror and thereby provided to the context imager module 200. In various embodiments, the pick-off hole may be approximately 100 μm in diameter. In other embodiments, the pick-off hole may be larger or smaller than 100 μm as appropriate for the application.

Once the source beam 10 enters the spectropolarimeter module 100, the source beam 10 interacts with collimator 110. In various embodiments, the collimator 110 is configured to collimate the source beam 10. For example, the collimator 110 may convert the source beam 10 into a pencil beam having parallel rays. The source beam 10 may then interact with the cylindrical mirror 120. In various embodiments, the cylindrical mirror 120 may be configured to re-shape the source beam 10 into a narrow beam that is focused

on the slit 130. For example, the cylindrical mirror 120 may elongate the source beam 10 such that the source beam can more efficiently propagate through the slit 130.

In various embodiments, the optical path of the spectropolarimeter module 100 may be folded. For example, the source beam 10 may encounter a folding mirror 180 or other reflective surface configured to fold the optical path of the spectropolarimeter module 100, as appropriate for the application. As should be understood, a variety of methods and optical equipment may be used to fold the optical path of the spectropolarimeter module 100, collimate the source beam 10, re-shape the source beam 10, and/or provide the source beam 10 to the slit 130.

The source beam 10 is focused on to the slit 130. In various embodiments, the slit 130 may be approximately 100 μm wide and 10 mm long. In other embodiments, the slit 130 may be wider or narrower than 100 μm and/or shorter or longer than 10 mm as appropriate for the application. After the source beam 10 passes through the slit 130, the source beam is incident upon a birefringent wedge 140 (e.g., a dichroic wedge, and/or the like). In various embodiments, the source beam 10 is incident upon the birefringent wedge 140 directly after passing through the slit 130. For example, there are no additional optical components between the slit 130 and birefringent wedge 140 and/or the source beam 10 is still close to being focused when the source beam is incident upon the birefringent wedge 140.

In various embodiments, the birefringent wedge 140 may act as a partial wave retarder. In various embodiments, the optical fast axis of the birefringent wedge 140 may be tilted by 45 degrees relative to the length of the slit 130. In various embodiments, the birefringent wedge 140 thickness gradient is parallel to the slit 130. Thus, the thickness of the birefringent wedge 140 changes along the length of the slit 130 (and along the length of the source beam 10). Thus, a ray of the source beam 10 that passes through one location along the slit 130 will pass through a thinner portion of the birefringent wedge 140 than a ray of the source beam 10 that passes through a second location along the slit 130. For example, light of a given wavelength and at each position along the slit has a different optical path length through the birefringent wedge 140. Additionally, the phase of the source beam 10 component having oscillation parallel to the fast optical axis is shifted relative to the source beam 10 component having oscillation perpendicular to the fast optical axis. Thus, the input polarization of the source beam 10 may be rotated and/or transformed at different distances along the birefringent wedge 140 in such a way that, at each position along the slit, the output of birefringent wedge 140 has a different

polarization than the input polarization at that location. This rotation and/or transformation of the input polarization at different points along the birefringent wedge 140 provides a polarized intensity modulation (e.g., a series of fringes) along the length of the source beam 10 after the source beam 10 passes through the dichroic prism 150. For example, the sample spectra shown in Figure 2 illustrate the fringes (light and dark stripes) in the spectra encoding information regarding the polarization of the source beam 10.

In various embodiments, the birefringent wedge 140 may comprise two or more birefringent wedges (e.g., a compound birefringent wedge). In various embodiments, the birefringent wedge 140 may be made of calcite (CaCO_3), quartz (SiO_2), and/or other appropriate material. In various embodiments, the birefringent wedge 140 is a single quartz wedge or a compound wedge made of two quartz wedges. In various embodiments, the birefringent wedge 140 has a wedge angle of approximately 3° or 6° . In various embodiments, the birefringent wedge 140 can have a wedge angle of greater or less than either 3° or 6° . In various embodiments, the use of more than one wedge can be used to shift the fringe pattern such that the orientation of the fringe pattern incident on the focal plane array is better matched to the geometry of the focal plan array geometry and optimized for data analysis.

Returning to Figure 3, in various embodiments, after the source beam 10 passes through the birefringent wedge 140, the source beam 10 is provided to a dichroic prism 150. For example, the source beam 10 may be provided to a Wollaston prism. In various embodiments, the dichroic prism 150 may be configured to spatially separate the ordinary ray (rays with polarization perpendicular to the fast optical axis of the birefringent wedge, dichroic prism, and/or the spectropolarimeter module) and extraordinary rays (rays with polarization parallel to the fast optical axis of the birefringent wedge, dichroic prism, and/or the spectropolarimeter module). This spatial separation of the ordinary and extraordinary rays allows both sets of rays to be analyzed. In most methods of polarimetry, only one of the ordinary and extraordinary rays may be captured at any given moment and the photons associated with the other set of rays are not captured, leading to a significant amount of photon loss. For example, Figure 2 shows two spectra that are captured simultaneously. The spectrum 310 shows the spectrum of the ordinary rays and spectrum 320 shows the spectrum of the extraordinary rays. Thus, the IMPS allows for a greater photon throughput and a more efficient use of captured photons. This is particularly important for the study of the polarized spectra of faint objects.

Returning to Figure 3, after the ordinary and extraordinary rays of the source beam 10 are spatially separated, the source beam 10 is incident upon a spectral disperser 160. For example, the spectral disperser 160 may be a holographic spectroscopic grating. In other embodiments, the spectral disperser 160 may be one or more spectroscopic prisms.

5 In various embodiments, the spectral disperser 160 may be configured to disperse the source beam 10 such that the spectrum of the source beam 10 may be observed. For example, the example output shown in Figure 2 shows the intensity modulation of the ordinary and extraordinary rays as a function of wavelength (e.g., as a spectrum). For the example output shown in Figure 2, the wavelength of light that produces the fringes

10 increases from left to right across the illustrated spectra. Thus, polarization and intensity information for the source beam 10 may be calculated and/or determined at different wavelengths and/or for different wavelength ranges. For example, in some embodiments, the spectra may be binned and analyzed in common photometric filters (e.g., U, B, V, G, R, I, Z, J, K, L, and/or the like).

15 In the embodiment shown in Figure 3, the spectral disperser 160 is a grating imprinted directly onto a mirror. For example, the mirror may be a powered mirror (e.g., a mirror having optical or focusing power). In various embodiments, the mirror may be configured to focus the image of the input slit 130 on to the focal plane array 170. For example, the mirror may act as a camera “lens” for the focal plane array 170. In various

20 embodiments, the spectral disperser 160 and the mirror may be provided as two separate components. In various embodiments, the spectral disperser 160 may be imprinted on a flat mirror (called a plane reflection grating), with the powered mirror being a separate component. For example, the plane reflection grating would be inserted before the powered mirror. In various embodiments, the spectral disperser 160 may be imprinted on a

25 flat transmissive substrate (called a plane transmission grating), with the powered mirror being a separate component. For example, the plane transmission grating would be inserted before the powered mirror. In various embodiments, the spectral disperser 160 may be one or more spectral prisms. In such embodiments, the spectral prisms may be used in association with one or more plane mirrors or powered mirrors. In various

30 embodiments, the spectral disperser 160 may be a combination of a grating imprinted on a transmissive or reflective substrate, one or more spectral prisms, one or more powered or plane mirrors, or some combination thereof.

In various embodiments, the source beam 10 is then incident upon a focal plane array 170. In various embodiments, the focal plane array 170 may be configured to convert the source beam 10 to a digital image, such as that shown in Figure 2. The digital image may then be provided to data management computing entity 600. In various
5 embodiments, the focal plane array 170 may be the focal plane array of a charge-coupled device (CCD), a complementary metal–oxide–semiconductor (CMOS), and/or the like.

In various embodiments, the spectropolarimeter module 100 may be mounted on optical bench 190. In various embodiments, the optical bench 190 may be approximately rectangular with sides of 200 mm by 250 mm in length or smaller. The shape and size of
10 the optical bench 190 may be modified as appropriate for various applications. For example, the size and shape of the optical bench 190 may be determined by the payload cavity onboard a satellite for holding the IMPS 5. The optical path of spectropolarimeter module 100 may be modified to accommodate the size and shape of the optical bench 190.

In various embodiments, the spectropolarimeter module 100 may be modified from
15 that described herein as appropriate for the application. In various embodiments, rather than both the extraordinary rays and the ordinary rays of the source beam being incident upon the same focal plane array 170, the extraordinary rays may be incident on one focal plane array and the ordinary rays may be incident on a second focal plane array. As noted above, in various embodiments, the spectropolarimeter module 100 may be configured for
20 performing spectropolarimetry in the UV, visible, or IR regions of the electromagnetic spectrum. For example, in an embodiment configured for UV spectropolarimetry, the birefringent wedge 140 may be an alpha barium borate (α -BBO) prism, and/or the like. Mirror coatings, the birefringent wedge 140, dichroic prism 150, spectral disperser 160, and/or focal plane array 170 may be adjusted from those described above as appropriate
25 for the wavelength region to be investigated.

III. Exemplary Context Imager Module

In various embodiments, the IMPS 5 may comprise a context imager module 200. An exemplary context imager module 200 is illustrated in Figure 4. In various
30 embodiments, the pick-off mirror 60 provides a context beam 20 to the context imager module 200. For example, the pick-off mirror 60 may be configured to remove the source beam 10 from the observed beam provided by the telescope and/or telephoto lens 50 and provide the remainder of the observed beam to the context imager module 200 as the context beam 20. The context imager module 200 may be configured to provide a digital

image of the region around the observation region from which the source beam 10 originates.

In various embodiments, the context imager module 200 comprises a field lens 210, beam conditioning and/or focusing components 220, and a context focal plane array 290. For example, the field lens 210 may be a positive-powered lens or group of lenses configured to modify the size of the image carried by the context beam 20. In various embodiments, the context imager module 200 may further comprise one or more flat folding mirrors configured for folding the optical path of the context imager module 200.

In various embodiments, the field lens 210 may be configured to provide image-space telecentricity for the image carried by the context beam 20. In various embodiments, the beam conditioning and/or focusing components 220 may be configured to condition the context beam 20 and/or focus the context beam 20 on to the context focal plane array 290. For example, the beam conditioning and/or focusing components 220 may be a Cooke triplet. In various embodiments, the context imager module 200 further comprises a context focal plane array 270. In various embodiments, the context focal plane array 270 may be configured to convert the context beam 20 to a digital image. The digital image may then be provided to data management computing entity 600 and/or the like. In various embodiments, the context focal plane array 270 may be the focal plane array of a charge-coupled device (CCD), a complementary metal-oxide-semiconductor (CMOS), and/or the like. In various embodiments, the context focal plane array 270 may be configured for converting optical light into a digital image even if the spectropolarimeter module 100 is configured to provide UV or IR spectra.

In various embodiments, the context imager module 200 is mounted on context optical bench 290. In various embodiments, the context optical bench 290 may be approximately rectangular with sides of 200 mm by 250 mm in length or smaller. The shape and size of the context optical bench 290 may be modified as appropriate for various applications. For example, the size and shape of the context optical bench 290 may be determined by the payload cavity onboard a satellite for holding the IMPS 5. The optical path of context imager module 200 may be modified to accommodate the size and shape of the context optical bench 290.

In various embodiments, the optical bench 190 may be mated to the context optical bench 290 to form an integrated IMPS system. For example, the components of the spectropolarimeter module 100 may be mounted on a first side of the optical bench 190 and the components of the context imager module 200 may be mounted on a first side of

the context optical bench 290. The second side of the optical bench 190 and the second side of the context optical bench 290 may be mated, connected, secured together, and/or the like. This may allow the spectropolarimeter module 100 and the context imager module 200 to be assembled and tested separately and mated after each module is optimized individually. In various embodiments, the optical bench 190 and the context optical bench 290 may be mated with mechanical fasteners (e.g., bolts, nuts, screws, and/or the like), adhesive, and/or the like. In one embodiment, the optical bench 190 and the context bench 290 are integrally formed (e.g., opposite sides of one optical bench).

Various methods may be used to mate the spectropolarimeter module 100 to the context imager module 200. For example, in some embodiments, the IMPS 5 may be configured to operate with a binocular telescope. For example, the spectropolarimeter module 100 may receive the observed beam from one aperture of the binocular telescope and the context imager module 200 may receive the observed beam from the other aperture of the binocular telescope.

15

IV. Exemplary Method of Calculating and/or Determining the Stokes Parameters of a Source Beam

In various embodiments, a method for calculating and/or determining the Stokes parameters of a source beam is provided. Figure 5 provides a flowchart illustrating various processes and operations that may be completed in accordance with various embodiments of present invention. Starting at step 502, an observed beam is received (e.g., via telescope or telephoto lens 50) and separated into a source beam 10 and a context beam 20 (e.g., by the pick-off mirror 60). Continuing to step 510, the source beam 10 is collimated, re-shaped, and focused onto the slit. For example, collimator 110 may collimate the source beam 10 and cylindrical mirror 120 may re-shape the source beam 10 and focus the source beam 10 onto the slit 130.

At step 512, separation and recombination ("interference") of various polarizations of the source beam is caused. For example, a birefringent wedge 140 may cause a fringe pattern encoding polarization associated with the source beam 10 into the source beam 10. At step 514, the source beam 10 is separated into two spatially separated beams, one being a beam of ordinary rays and the other being a beam of extraordinary waves. For example, the dichroic prism 150 may spatially separate the ordinary rays and the extraordinary rays. At step 516, the source beam is dispersed into spectra. For example, the spectral disperser 160 may disperse the source beam 10. At step 518, the source beam is focused onto the

focal plane array. For example, a powered mirror may focus the source beam onto the focal plane array 170. At step 520, the source beam is converted into a digital image. For example, the focal plane array 170 may convert the source beam into a digital image and/or digital image data. At step 522, the digital image data is analyzed to calculate and/or determine Stokes parameters describing the source beam 10. For example, the data management computing entity 600 (shown in Figure 6) may receive digital image data from the focal plan array 170 and analyze the digital image data to calculate and/or determine Stokes parameters to describe the source beam 10. For example, in various embodiments, the non-volatile memory 610 of the data management computing entity 600 may store computer program code configured to, when executed by the processing element 605, analyze the digital image data to calculate and/or determine Stokes parameters to describe the source beam 10.

In some embodiments, the context beam 20 is provided to the context imager module 200. At step 504, the context beam is focused on to a context focal plane array 270. At step 506, the context beam 20 is converted into a digital image. For example, the context focal plane array 270 may convert the context beam into a digital image and/or context digital image data. The context focal plane array 270 may provide the context digital image data to the data management computing entity 600, and/or the like.

V. Other Hardware

In various embodiments, an IMPS 5 may be incorporated into a system for calculating and/or determining the Stokes parameters of an observed beam and/or performing other tasks. For example, an IMPS 5 may be configured to provide digital image data (e.g., captured by the spectropolarimeter focal plane array 170) and/or context digital image data (e.g., captured by the context focal plane array 270) to a data management computing entity 600. The data management computing entity 600 may be configured to analyze the digital image data to calculate and/or determine at least one of the Stokes parameters of the observed beam and/or store and/or provide digital image data and/or context digital image data and/or other data/information to various other computing entities. The data management computing entity 600 may be in communication with various other computing entities via one or more wired or wireless networks. For example, the data management computing entity 600 may be in communication with one or more satellite systems onboard the same satellite as the IMPS 5, a display device for displaying results to a user operating the IMPS 5 in the field, a device operated by an

investigator, and/or the like. An example data management computing entity 600 is described in more detail below.

Figure 6 provides a schematic of an example data management computing entity 600 according to one embodiment of the present invention. In general, the terms
5 computing entity, computer, entity, device, system, and/or similar words used herein interchangeably may refer to, for example, one or more computers, computing entities, desktop computers, mobile phones, tablets, phablets, notebooks, laptops, distributed systems, wearable items/devices, kiosks, input terminals, servers or server networks, blades, gateways, switches, processing devices, processing entities, relays, routers,
10 network access points, base stations, the like, and/or any combination of devices or entities adapted to perform the functions, operations, and/or processes described herein. Such functions, operations, and/or processes may include, for example, transmitting, receiving, operating on, processing, displaying, storing, determining, creating/generating, monitoring, evaluating, comparing, calculating, analyzing, and/or similar terms used
15 herein interchangeably. In one embodiment, these functions, operations, and/or processes can be performed on data, content, information, and/or similar terms used herein interchangeably.

As indicated, in one embodiment, the data management computing entity 600 may also include one or more communications interfaces 620 for communicating with various
20 computing entities, such as by communicating data, information, and/or similar terms used herein interchangeably that can be transmitted, received, operated on, processed, displayed, stored, and/or the like. For instance, the data management computing entity 600 may communicate with a satellite control system, investigator computing entity, display device, and/or a variety of other computing entities.

25 As shown in Figure 6, in one embodiment, the data management computing entity 600 may include or be in communication with one or more processing elements 605 (also referred to as processors, processing circuitry, and/or similar terms used herein interchangeably) that communicate with other elements within the data management computing entity 600 via a bus, for example. As will be understood, the processing
30 element 605 may be embodied in a number of different ways. For example, the processing element 605 may be embodied as one or more complex programmable logic devices (CPLDs), microprocessors, multi-core processors, coprocessing entities, application-specific instruction-set processors (ASIPs), microcontrollers, and/or controllers. Further, the processing element 605 may be embodied as one or more other processing devices or

circuitry. The term circuitry may refer to an entirely hardware embodiment or a combination of hardware and computer program products. Thus, the processing element 605 may be embodied as integrated circuits, application specific integrated circuits (ASICs), field programmable gate arrays (FPGAs), programmable logic arrays (PLAs),
5 hardware accelerators, other circuitry, and/or the like. As will therefore be understood, the processing element 605 may be configured for a particular use or configured to execute instructions stored in volatile or non-volatile media or otherwise accessible to the processing element 605. As such, whether configured by hardware or computer program products, or by a combination thereof, the processing element 605 may be capable of
10 performing steps or operations according to embodiments of the present invention when configured accordingly.

In one embodiment, the data management computing entity 600 may further include or be in communication with non-volatile media (also referred to as non-volatile storage, memory, memory storage, memory circuitry and/or similar terms used herein
15 interchangeably). In one embodiment, the non-volatile storage or memory may include one or more non-volatile storage or memory media 610, including but not limited to hard disks, ROM, PROM, EPROM, EEPROM, flash memory, MMCs, SD memory cards, Memory Sticks, CBRAM, PRAM, FeRAM, NVRAM, MRAM, RRAM, SONOS, FJG RAM, Millipede memory, racetrack memory, and/or the like. As will be recognized, the
20 non-volatile storage or memory media may store databases, database instances, database management systems, data, applications, programs, program modules, scripts, source code, object code, byte code, compiled code, interpreted code, machine code, executable instructions, and/or the like. The term database, database instance, database management system, and/or similar terms used herein interchangeably may refer to a collection of
25 records or data that is stored in a computer-readable storage medium using one or more database models, such as a hierarchical database model, network model, relational model, entity-relationship model, object model, document model, semantic model, graph model, and/or the like.

In one embodiment, the data management computing entity 600 may further
30 include or be in communication with volatile media (also referred to as volatile storage, memory, memory storage, memory circuitry and/or similar terms used herein interchangeably). In one embodiment, the volatile storage or memory may also include one or more volatile storage or memory media 615, including but not limited to RAM, DRAM, SRAM, FPM DRAM, EDO DRAM, SDRAM, DDR SDRAM, DDR2 SDRAM,

DDR3 SDRAM, RDRAM, TTRAM, T-RAM, Z-RAM, RIMM, DIMM, SIMM, VRAM, cache memory, register memory, and/or the like. As will be recognized, the volatile storage or memory media may be used to store at least portions of the databases, database instances, database management systems, data, applications, programs, program modules, scripts, source code, object code, byte code, compiled code, interpreted code, machine code, executable instructions, and/or the like being executed by, for example, the processing element 605. Thus, the databases, database instances, database management systems, data, applications, programs, program modules, scripts, source code, object code, byte code, compiled code, interpreted code, machine code, executable instructions, and/or the like may be used to control certain aspects of the operation of the management computing entity 100 with the assistance of the processing element 605 and operating system.

As indicated, in one embodiment, the data management computing entity 600 may also include one or more communications interfaces 620 for communicating with various computing entities, such as by communicating data, content, information, and/or similar terms used herein interchangeably that can be transmitted, received, operated on, processed, displayed, stored, and/or the like. Such communication may be executed using a wired data transmission protocol, such as fiber distributed data interface (FDDI), digital subscriber line (DSL), Ethernet, asynchronous transfer mode (ATM), frame relay, data over cable service interface specification (DOCSIS), or any other wired transmission protocol. Similarly, the data management computing entity 600 may be configured to communicate via wireless external communication networks using any of a variety of protocols, such as general packet radio service (GPRS), Universal Mobile Telecommunications System (UMTS), Code Division Multiple Access 2000 (CDMA2000), CDMA2000 1X (1xRTT), Wideband Code Division Multiple Access (WCDMA), Time Division-Synchronous Code Division Multiple Access (TD-SCDMA), Long Term Evolution (LTE), Evolved Universal Terrestrial Radio Access Network (E-UTRAN), Evolution-Data Optimized (EVDO), High Speed Packet Access (HSPA), High-Speed Downlink Packet Access (HSDPA), IEEE 802.11 (Wi-Fi), Wi-Fi Direct, 802.16 (WiMAX), ultra wideband (UWB), infrared (IR) protocols, near field communication (NFC) protocols, Wibree, Bluetooth protocols, wireless universal serial bus (USB) protocols, and/or any other wireless protocol.

Although not shown, the data management computing entity 600 may include or be in communication with one or more input elements, such as a keyboard input, a mouse input, a touch screen/display input, motion input, movement input, audio input, pointing device input, joystick input, keypad input, and/or the like. The management computing entity 100 may also include or be in communication with one or more output elements (not shown), such as audio output, video output, screen/display output, motion output, movement output, and/or the like.

As will be appreciated, one or more of the data management computing entity's 600 components may be located remotely from other data management computing entity 600 components, such as in a distributed system. Furthermore, one or more of the components may be combined and additional components performing functions described herein may be included in the data management computing entity 600. Thus, the data management computing entity 600 can be adapted to accommodate a variety of needs and circumstances. As will be recognized, these architectures and descriptions are provided for exemplary purposes only and are not limiting to the various embodiments.

VI. Conclusion

Additional information and figures are provided in the attached Appendices. Many modifications and other embodiments of the inventions set forth herein will come to mind to one skilled in the art to which these inventions pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the inventions are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

CLAIMS:

1. An integrated miniature polarimeter and spectrograph (IMPS) comprising:
a spectropolarimeter module comprising:
 - 5 a miniature optical bench;
 - a slit component;
 - a birefringent wedge;
 - a dichroic prism;
 - a spectral disperser; and
 - 10 a focal plane array,wherein:
 - the slit component, birefringent wedge, dichroic prism, spectral
 - disperser, and focal plane array are mounted to the miniature optical bench
 - such that a beam incident on the slit component will be incident on (1) the
 - 15 birefringent wedge, (2) the dichroic prism, (3) the spectral disperser, and
 - (4) the focal plane array, in that order.
2. The IMPS of Claim 1, wherein the dichroic prism is a Wollaston prism.
- 20 3. The IMPS of Claim 1, wherein the spectropolarimeter module further comprises a powered mirror configured to focus the beam onto the focal plane array.
4. The IMPS of Claim 3, wherein the spectral disperser is one of (a) a grating imprinted directly onto the powered mirror, (b) a grating imprinted onto a flat transmissive
- 25 or reflective surface positioned just prior to the powered mirror along a light path of the IMPS, (c) one or more spectral prisms positioned just prior to the powered mirror along the light path of the IMPS, or (d) a combination thereof.
5. The IMPS of Claim 1, further comprising a data management computing entity, the
- 30 data management computing entity configured to receive digital image data from the focal plane array.

6. The IMPS of Claim 5, wherein the data management computing entity is configured to calculate up to four Stokes parameters to describe the source beam based on the digital image data received from the focal plane array.
- 5 7. The IMPS of Claim 1, wherein the spectropolarimeter module further comprises one or more folding mirrors, each folding mirror being configured to fold the optical path of the spectropolarimeter module.
8. The IMPS of Claim 1, wherein at least one of the birefringent wedge, dichroic
10 prism, spectral disperser, or the focal plane array is optimized for at least one of optical, ultra-violet, or infrared spectra.
9. The IMPS of Claim 1, wherein the miniature optical bench has dimensions of approximately 200 mm by 250 mm or smaller.
- 15 10. The IMPS of Claim 1, wherein the birefringent wedge is made of at least one of calcite or quartz.
11. The IMPS of Claim 1, wherein the birefringent wedge is a compound birefringent
20 wedge.
12. The IMPS of Claim 11, wherein the compact birefringent wedge is configured to shift a fringe pattern position on the focal plane array such that an orientation of the fringe pattern is optimized to at least one of a geometry of the focal plane array or data analysis
25 of digital image data.
13. The IMPS of Claim 1, wherein the birefringent wedge has a wedge angle of between 1 and 8 degrees.
- 30 14. The IMPS of Claim 1, wherein the birefringent wedge has a wedge angle of at least one of approximately 3 degrees or approximately 6 degrees.

15. The IMPS of Claim 1, wherein at least one of a fast optical axis of the birefringent wedge is tilted by 45 degrees with respect to a long axis of the slit component or a thickness gradient of the of the birefringent wedge is parallel to the long axis of the slit component.
- 5
16. The IMPS of Claim 1, wherein the IMPS is configured for use in at least one of field deployment or onboard a satellite.
17. The IMPS of Claim 1, further comprising at least one of a telescope or a telephoto lens configured to provide an observed beam to the spectropolarimeter module.
- 10
18. The IMPS of Claim 1, further comprising a context imager module, the context imager module comprising:
- a context miniature optical bench; and
- 15 a context focal plane array.
19. The IMPS of Claim 18, further comprising a data management computing entity, the data management computing entity configured to receive digital image data from at least one of the focal plane array or the context focal plane array.
- 20
20. The IMPS of Claim 18, further comprising a pick-off mirror comprising a mirror substrate having a hole therein, the hole configured to provide the source beam to the spectropolarimeter module and a context beam to the context imager module, wherein the source beam passes through the hole and the context beam reflects off of the pick-off mirror.
- 25
21. The IMPS of Claim 20, further comprising at least one of a telescope or telephoto lens, the hole in the pick-off mirror positioned at an image plane of the telescope or telephoto lens.
- 30
22. The IMPS of Claim 18, wherein the context imager module further comprises at least one of a field lens or a Cooke triplet.

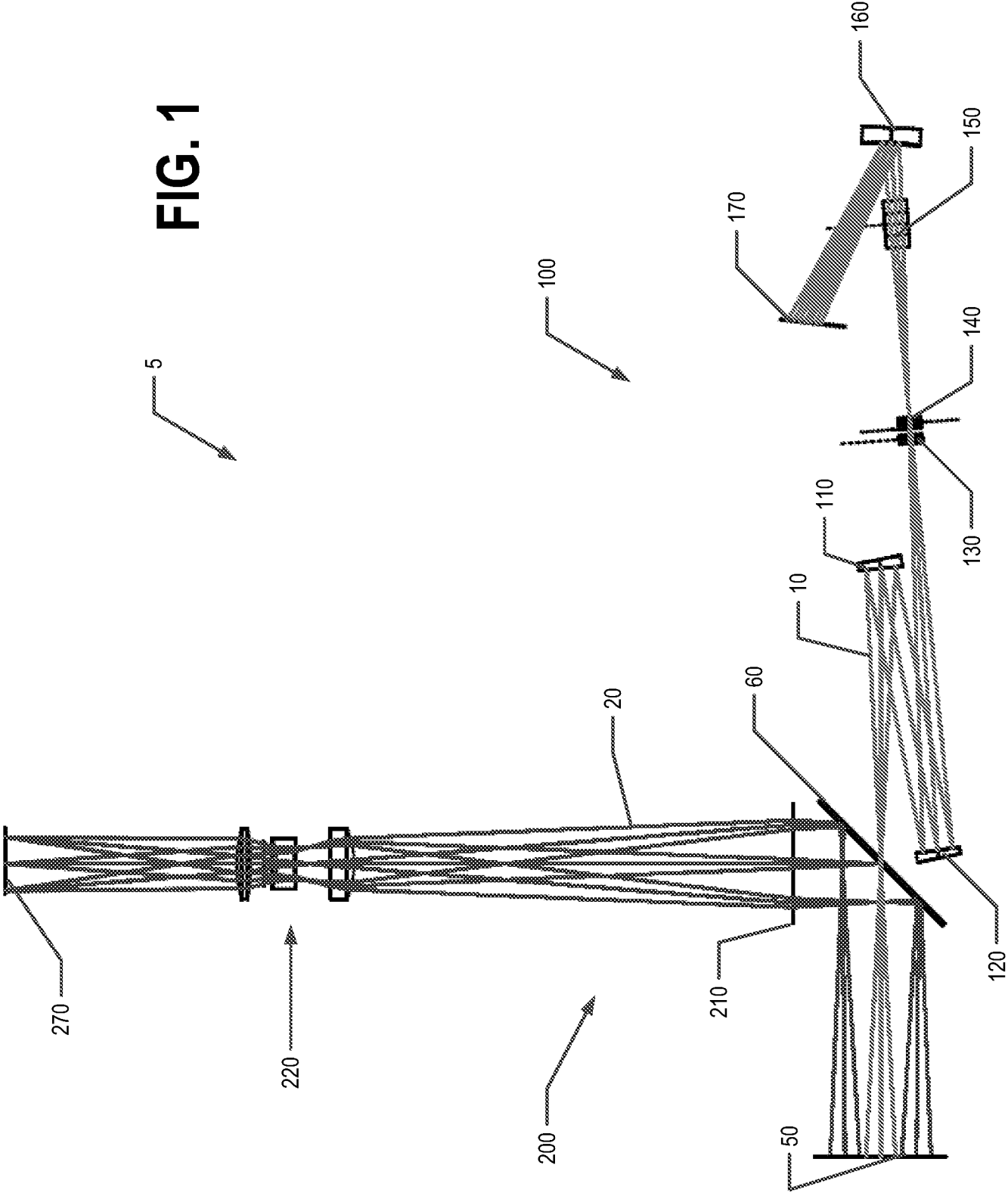
23. The IMPS of Claim 18, wherein:
the miniature optical bench has a first side having the slit component, birefringent wedge, prism, grating, and focal plane array mounted thereto and a second side,
the context miniature optical bench has a first context bench side having the
5 context focal plane array mounted thereto and a second context bench side,
the second side be mated to the second context bench side.
24. The IMPS of Claim 18, wherein the miniature optical bench and the context
miniature optical bench have the same dimensions.
- 10 25. A method for determining Stokes parameters to describe a source beam, the
method comprising:
providing an integrated miniature polarimeter and spectrograph (IMPS)
comprising:
15 a spectropolarimeter module comprising:
a slit component,
a birefringent wedge,
a dichroic prism,
a spectral disperser, and
20 a focal plane array;
causing interference of various polarizations comprising a source beam, the
interference caused by the birefringent wedge;
spatially separating ordinary rays of the source beam and extraordinary rays of the
source beam, the spatial separation caused by the dichroic prism;
25 dispersing the source beam into spectra, the dispersion caused by the spectral
disperser; and converting the source beam into digital image data, the conversion caused
by the source beam being incident upon the focal plane array.
26. The method of Claim 25, wherein:
30 the spectropolarimeter module further comprises a data management computing
entity, and
the method further comprises the steps of:
providing the digital image data to the data management computing entity;
and

calculating at least one Stokes parameter, the calculating performed by the data management computing entity.

27. The method of Claim 26, wherein the data management computing entity
5 comprises comprising at least one processor and at least one memory including program code, the at least one memory and the program code configured to, with the processor, cause the apparatus to at least:
- analyze the digital image data; and
 - calculate the at least one Stokes parameter based at least in part on the results of
10 the analysis of the digital image data.
28. The method of Claim 25, wherein:
- the spectropolarimeter module further comprises a collimator and a cylindrical mirror, the collimator and the cylindrical mirror located upstream of the slit component,
15 and
 - the method further comprises the steps of:
 - collimating the source beam, the collimating caused by the collimator;
 - re-shaping the source beam, the re-shaping caused by the cylindrical mirror; and
20 focusing the source beam on the slit component, the focusing caused by the cylindrical mirror.
29. The method of Claim 25, wherein:
- the IMPS further comprises a context imager module, the context imager module
25 comprising a context focal plane array, and
 - the method further comprises the step of:
 - converting a context beam in to digital image data, the converting caused by the context beam being incident upon the context focal plane array.
30. The method of Claim 29, wherein:
- the context imager module further comprises a field lens, and
 - the method further comprises the step of:
 - resizing the context beam before the context beam is incident on the context focal plane array via the field lens.

31. The method of Claim 29, wherein:
the context imager module further comprises a Cooke triplet, and
the method further comprises the step of:
- 5 focusing the context beam onto the context focal plane array via the Cooke triplet.

FIG. 1



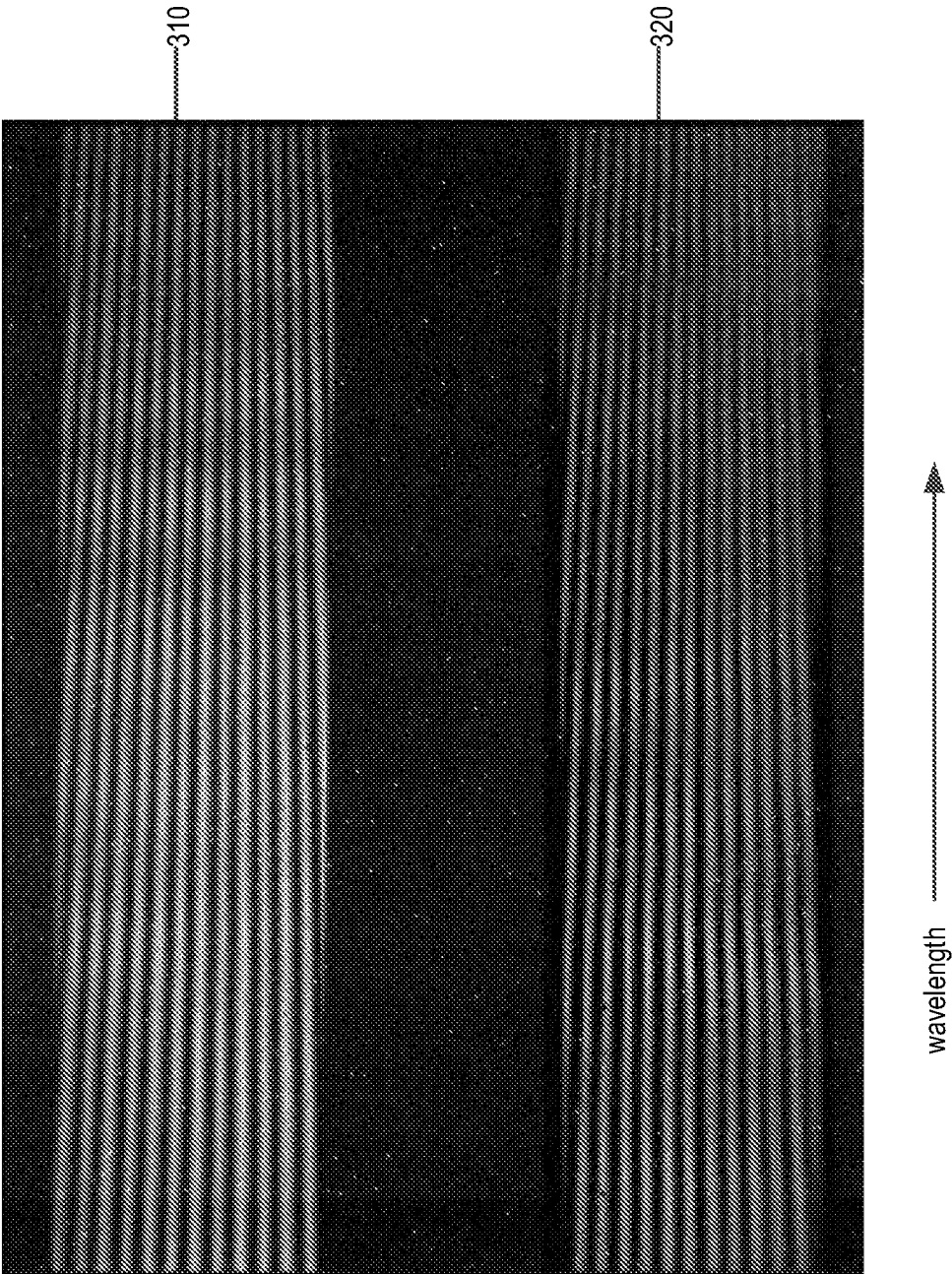
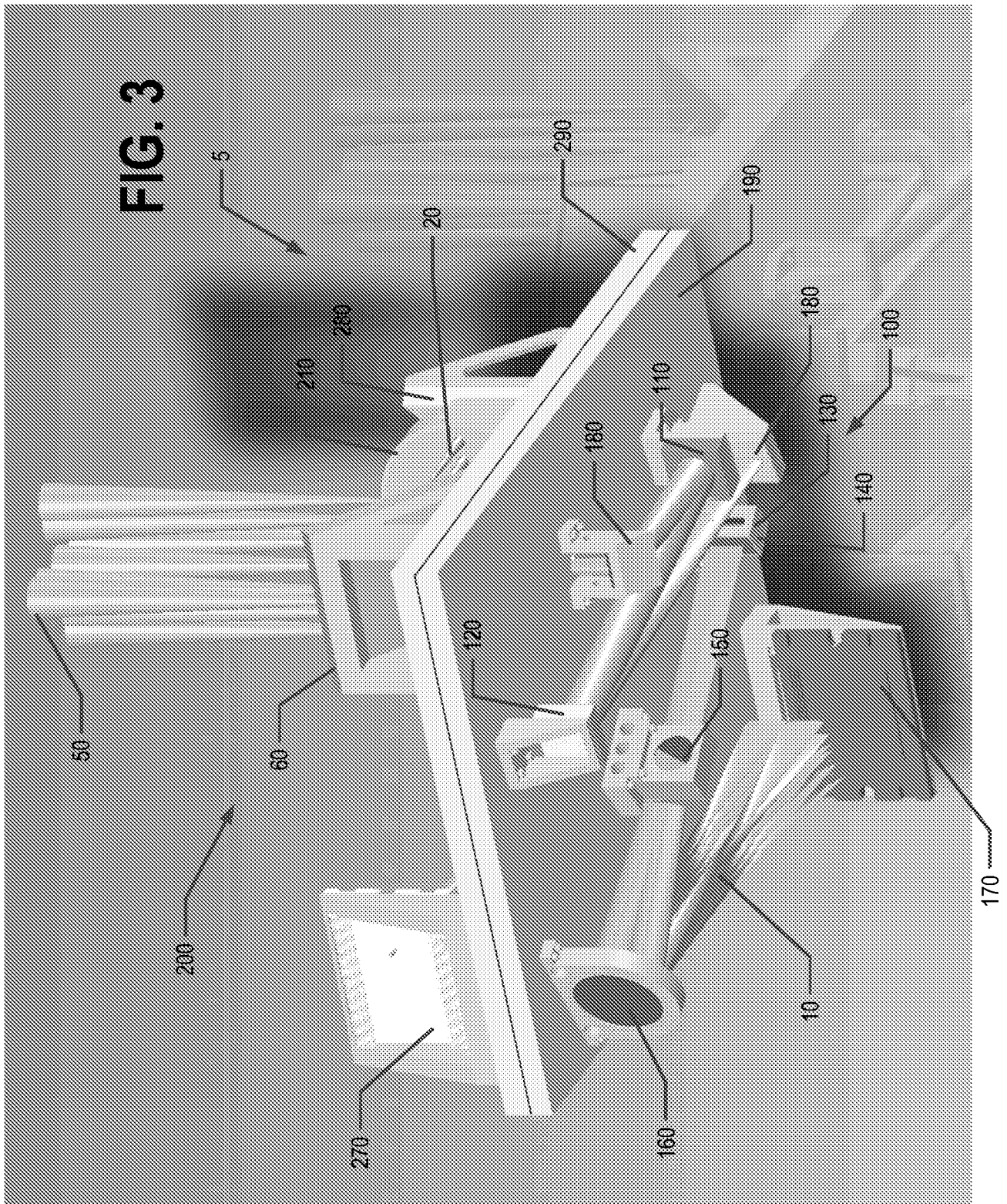
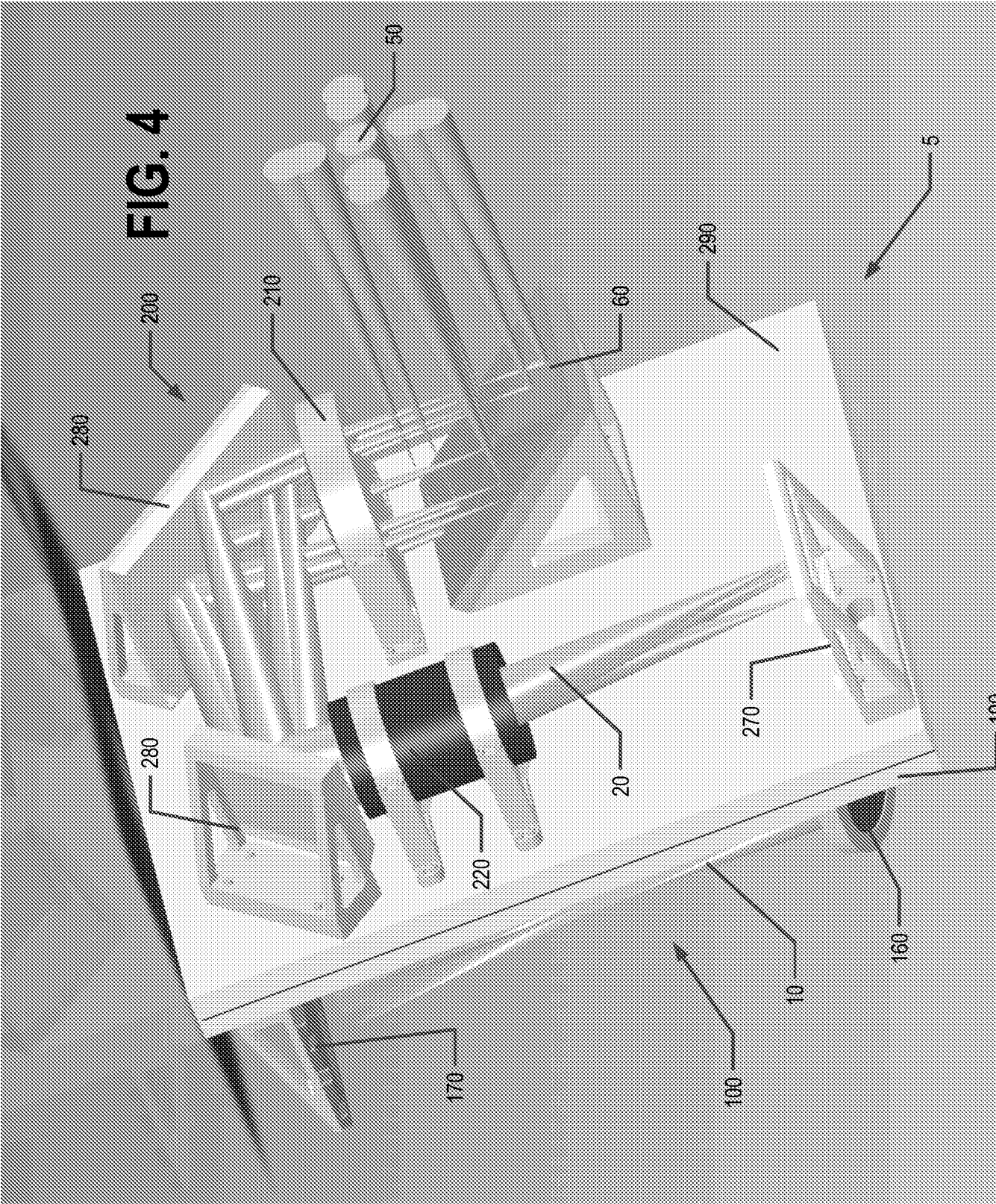
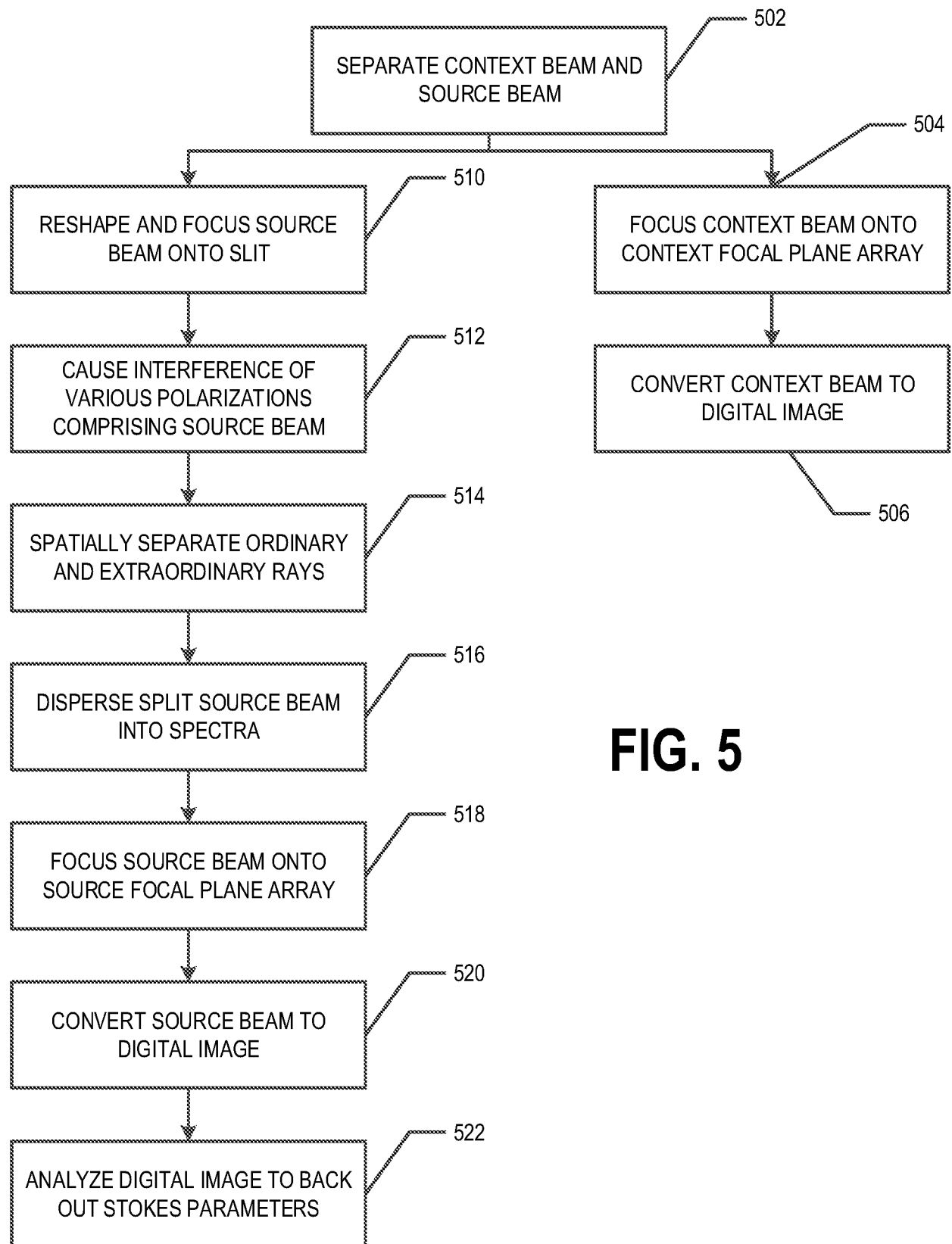
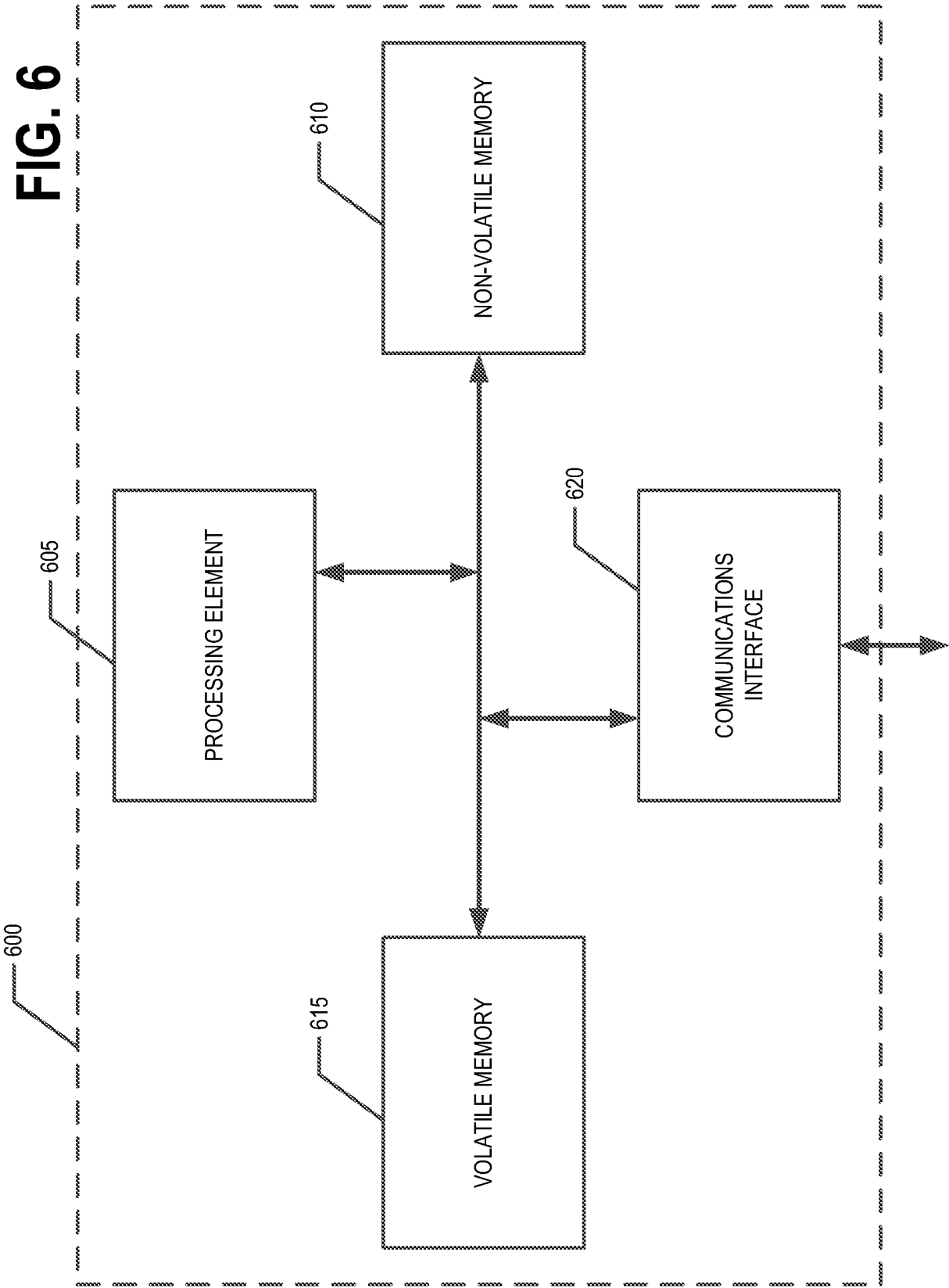


FIG. 2





**FIG. 5**



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/028380**A. CLASSIFICATION OF SUBJECT MATTER****G02B 27/28(2006.01)i, G02B 6/27(2006.01)i**

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G02B 27/28; G02B 26/00; G02B 5/30; G01J 3/447; G02F 1/01; G01J 3/51; G01J 3/30; G01J 3/45; G01B 9/02; G02B 6/27

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & keywords: polarimeter, spectrograph, slit, wedge, prism, disperser

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013-0063722 A1 (SPARKS) 14 March 2013 See paragraphs [0024]-[0033], claims 1, 12-15 and figure 1.	25, 28-31
Y		1-24, 26-27
Y	US 2007-0030551 A1 (OKA et al.) 08 February 2007 See paragraphs [0362]-[0376] and figures 12-15.	1-24, 26-27
A	US 2014-0168772 A1 (THE AEROSPACE CORPORATION) 19 June 2014 See abstract and figures 1A-3.	1-31
A	US 2001-0021018 A (BASIIJI et al.) 13 September 2001 See figures 1-10.	1-31
A	US 7616319 B1 (WOOLLAM et al.) 10 November 2009 See figures 1a-5b.	1-31



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

27 July 2016 (27.07.2016)

Date of mailing of the international search report

28 July 2016 (28.07.2016)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea



Facsimile No. +82-42-481-8578

Authorized officer

KANG, Sung Chul

Telephone No. +82-42-481-8405



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/028380

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2013-0063722 A1	14/03/2013	US 9097585 B2	04/08/2015
US 2007-0030551 A1	08/02/2007	JP 2007-040805 A	15/02/2007
		JP 4205704 B2	07/01/2009
		US 7336360 B2	26/02/2008
US 2014-0168772 A1	19/06/2014	None	
US 2001-0021018 A1	13/09/2001	AU 2001-11969 A1	31/07/2001
		AU 2001-11969 B2	22/04/2004
		AU 2001-11994 A1	31/07/2001
		AU 2001-211994 B2	18/11/2004
		AU 2001-297843 A8	23/12/2002
		AU 2002-11898 A1	22/04/2002
		AU 2002-11899 A1	22/04/2002
		AU 2002-11913 A1	22/04/2002
		AU 2002-13157 A1	22/04/2002
		AU 2002-211898 A8	22/04/2002
		AU 2002-319621 A8	03/03/2003
		CA 2395627 A1	26/07/2001
		CA 2395627 C	26/04/2005
		CA 2401614 A1	26/07/2001
		CA 2401614 C	02/06/2009
		CA 2660897 A1	31/07/2008
		CA 2660897 C	16/06/2015
		CA 2858582 A1	31/07/2008
		CA 2858582 C	16/06/2015
		EP 1257794 A1	20/11/2002
		EP 1272822 A1	08/01/2003
		EP 1330650 A2	30/07/2003
		EP 1330650 B1	28/12/2011
		EP 1334338 A2	13/08/2003
		EP 1844426 A2	17/10/2007
		EP 1886139 A2	13/02/2008
		EP 1886139 B1	17/08/2011
		JP 2003-520954 A	08/07/2003
		JP 2004-522163 A	22/07/2004
		JP 2004-532969 A	28/10/2004
		JP 2007-263983 A	11/10/2007
		JP 2008-533440 A	21/08/2008
		JP 2008-539724 A	20/11/2008
		JP 3996056 B2	24/10/2007
		JP 4018063 B2	05/12/2007
		JP 4067826 B2	26/03/2008
		JP 4982385 B2	25/07/2012
		JP 5160158 B2	13/03/2013
		US 2002-0030812 A1	14/03/2002
		US 2002-0051070 A1	02/05/2002
		US 2002-0057432 A1	16/05/2002

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/028380

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		US 2002-0071121 A1	13/06/2002
		US 2002-0093641 A1	18/07/2002
		US 2002-0094116 A1	18/07/2002
		US 2002-0122167 A1	05/09/2002
		US 2003-0016882 A1	23/01/2003
		US 2003-0086608 A1	08/05/2003
		US 2003-0137661 A1	24/07/2003
		US 2003-0142289 A1	31/07/2003
		US 2004-0021868 A1	05/02/2004
		US 2004-0080748 A1	29/04/2004
		US 2004-0161165 A1	19/08/2004
		US 2004-0217256 A1	04/11/2004
		US 2004-0218184 A1	04/11/2004
		US 2004-0223135 A1	11/11/2004
		US 2005-0127271 A1	16/06/2005
		US 2006-0002634 A1	05/01/2006
		US 2006-0029267 A1	09/02/2006
		US 2006-0066837 A1	30/03/2006
		US 2006-0068371 A1	30/03/2006
		US 2006-0119731 A1	08/06/2006
		US 2006-0192955 A1	31/08/2006
		US 2006-0198558 A1	07/09/2006
		US 2006-0204071 A1	14/09/2006
		US 2006-0257884 A1	16/11/2006
		US 2007-0146873 A1	28/06/2007
		US 2008-0138816 A1	12/06/2008
		US 2008-0202198 A1	28/08/2008
		US 2008-0234984 A1	25/09/2008
		US 2009-0003681 A1	01/01/2009
		US 2009-0190822 A1	30/07/2009
		US 2010-0021039 A1	28/01/2010
		US 2010-0188559 A1	29/07/2010
		US 2010-0232675 A1	16/09/2010
		US 2010-0240062 A1	23/09/2010
		US 2011-0030264 A1	10/02/2011
		US 6211955 B1	03/04/2001
		US 6249341 B1	19/06/2001
		US 6473176 B2	29/10/2002
		US 6507391 B2	14/01/2003
		US 6532061 B2	11/03/2003
		US 6563583 B2	13/05/2003
		US 6580504 B1	17/06/2003
		US 6608682 B2	19/08/2003
		US 6671044 B2	30/12/2003
		US 6707551 B2	16/03/2004
		US 6763149 B2	13/07/2004
		US 6778263 B2	17/08/2004
		US 6875973 B2	05/04/2005
		US 6906792 B2	14/06/2005
		US 6934408 B2	23/08/2005

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/028380

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		US 6947136 B2	20/09/2005
		US 6975400 B2	13/12/2005
		US 7006710 B2	28/02/2006
		US 7009651 B2	07/03/2006
		US 7057732 B2	06/06/2006
		US 7079708 B2	18/07/2006
		US 7087877 B2	08/08/2006
		US 7190832 B2	13/03/2007
		US 7221457 B2	22/05/2007
		US 7286719 B2	23/10/2007
		US 7315357 B2	01/01/2008
		US 7450229 B2	11/11/2008
		US 7522758 B2	21/04/2009
		US 7567695 B2	28/07/2009
		US 7634125 B2	15/12/2009
		US 7634126 B2	15/12/2009
		US 7719598 B2	18/05/2010
		US 7889263 B2	15/02/2011
		US 7925069 B2	12/04/2011
		US 8001714 B2	23/08/2011
		US 8005314 B2	23/08/2011
		US 8009189 B2	30/08/2011
		US 8365455 B2	05/02/2013
		US 8406498 B2	26/03/2013
		WO 2001-053783 A1	26/07/2001
		WO 2001-053784 A1	26/07/2001
		WO 2002-031182 A2	18/04/2002
		WO 2002-031182 A3	06/09/2002
		WO 2002-031467 A1	18/04/2002
		WO 2002-031501 A1	18/04/2002
		WO 2002-031583 A1	18/04/2002
		WO 2002-101339 A2	19/12/2002
		WO 2002-101339 A3	01/05/2003
		WO 2003-009579 A2	30/01/2003
		WO 2003-009579 A3	12/09/2003
		WO 2003-042644 A1	22/05/2003
		WO 2004-066189 A2	05/08/2004
		WO 2004-066189 A3	04/11/2004
		WO 2006-083969 A2	10/08/2006
		WO 2006-083969 A3	26/06/2008
		WO 2006-118857 A2	09/11/2006
		WO 2006-118857 A3	22/02/2007
		WO 2007-067999 A2	14/06/2007
		WO 2007-067999 A3	29/11/2007
		WO 2008-091388 A2	31/07/2008
		WO 2008-091388 A3	20/11/2008
US 7616319 B1	10/11/2009	CA 2368605 A1	30/10/2002
		CA 2368605 C	20/12/2005
		EP 1026495 A2	09/08/2000

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/028380

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		EP 1026495 A3	17/12/2003
		EP 1026495 B1	15/06/2005
		EP 1038165 A1	27/09/2000
		EP 1038165 A4	25/10/2000
		EP 1038165 B1	07/08/2002
		EP 1124120 A2	16/08/2001
		EP 1124120 A3	19/01/2005
		EP 1902281 A1	26/03/2008
		EP 1902281 B1	18/06/2014
		EP 1952107 A2	06/08/2008
		EP 2283401 A1	16/02/2011
		EP 2283401 B1	04/03/2015
		JP 2000-509830 A	02/08/2000
		JP 2011-524000 A	25/08/2011
		JP 3285365 B2	27/05/2002
		US 2001-0033377 A1	25/10/2001
		US 2001-0042832 A1	22/11/2001
		US 2001-0046089 A1	29/11/2001
		US 2002-0158073 A1	31/10/2002
		US 2004-0257567 A1	23/12/2004
		US 2005-0179897 A1	18/08/2005
		US 2006-0268271 A1	30/11/2006
		US 2006-0268272 A1	30/11/2006
		US 2007-0097373 A1	03/05/2007
		US 2008-0117413 A1	22/05/2008
		US 2008-0285035 A1	20/11/2008
		US 2009-0103093 A1	23/04/2009
		US 2011-0109906 A1	12/05/2011
		US 5373359 A	13/12/1994
		US 5504582 A	02/04/1996
		US 5521706 A	28/05/1996
		US 5666201 A	09/09/1997
		US 5706212 A	06/01/1998
		US 5805285 A	08/09/1998
		US 5872630 A	16/02/1999
		US 5929995 A	27/07/1999
		US 5946098 A	31/08/1999
		US 5963325 A	05/10/1999
		US 5963327 A	05/10/1999
		US 5969818 A	19/10/1999
		US 6034777 A	07/03/2000
		US 6084674 A	04/07/2000
		US 6084675 A	04/07/2000
		US 6100981 A	08/08/2000
		US 6118537 A	12/09/2000
		US 6141102 A	31/10/2000
		US 6268917 B1	31/07/2001
		US 6353477 B1	05/03/2002
		US 6455853 B2	24/09/2002
		US 6456376 B1	24/09/2002

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/028380

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		US 6483586 B1	19/11/2002
		US 6535286 B1	18/03/2003
		US 6549282 B1	15/04/2003
		US 6585128 B2	01/07/2003
		US 6590655 B2	08/07/2003
		US 6636309 B1	21/10/2003
		US 6804004 B1	12/10/2004
		US 6822738 B1	23/11/2004
		US 6859278 B1	22/02/2005
		US 6930813 B1	16/08/2005
		US 6937341 B1	30/08/2005
		US 6940595 B1	06/09/2005
		US 6950182 B1	27/09/2005
		US 6982789 B1	03/01/2006
		US 6982792 B1	03/01/2006
		US 7057717 B1	06/06/2006
		US 7075649 B1	11/07/2006
		US 7075650 B1	11/07/2006
		US 7084978 B1	01/08/2006
		US 7099006 B1	29/08/2006
		US 7136172 B1	14/11/2006
		US 7158231 B1	02/01/2007
		US 7193708 B1	20/03/2007
		US 7193710 B1	20/03/2007
		US 7215423 B1	08/05/2007
		US 7215424 B1	08/05/2007
		US 7230699 B1	12/06/2007
		US 7239391 B2	03/07/2007
		US 7245376 B2	17/07/2007
		US 7253900 B1	07/08/2007
		US 7265838 B1	04/09/2007
		US 7268876 B1	11/09/2007
		US 7274450 B1	25/09/2007
		US 7277171 B1	02/10/2007
		US 7283234 B1	16/10/2007
		US 7295313 B1	13/11/2007
		US 7301631 B1	27/11/2007
		US 7304737 B1	04/12/2007
		US 7307724 B1	11/12/2007
		US 7317529 B1	08/01/2008
		US 7317530 B2	08/01/2008
		US 7327456 B1	05/02/2008
		US 7333198 B1	19/02/2008
		US 7336361 B1	26/02/2008
		US 7345762 B1	18/03/2008
		US 7349092 B1	25/03/2008
		US 7385697 B2	10/06/2008
		US 7385698 B1	10/06/2008
		US 7426030 B1	16/09/2008
		US 7468794 B1	23/12/2008

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/028380

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		US 7489400 B1	10/02/2009
		US 7505134 B1	17/03/2009
		US 7508510 B2	24/03/2009
		US 7518725 B1	14/04/2009
		US 7522279 B1	21/04/2009
		US 7535566 B1	19/05/2009
		US 7554662 B1	30/06/2009
		US 7567345 B1	28/07/2009
		US 7619752 B2	17/11/2009
		US 7633625 B1	15/12/2009
		US 7671989 B2	02/03/2010
		US 7738105 B1	15/06/2010
		US 7746471 B1	29/06/2010
		US 7746472 B1	29/06/2010
		US 7768660 B1	03/08/2010
		US 7872751 B2	18/01/2011
		US 8436994 B2	07/05/2013
		WO 1998-039633 A1	11/09/1998
		WO 2007-008335 A1	18/01/2007
		WO 2007-061460 A2	31/05/2007
		WO 2007-061460 A3	15/11/2007
		WO 2008-048312 A2	24/04/2008
		WO 2008-048312 A3	30/10/2008
		WO 2009-136901 A1	12/11/2009