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(54) **Title**: DUAL BEAM DEVICE FOR SIMULTANEOUS MEASUREMENT OF SPECTRUM AND POLARIZATION OF LIGHT

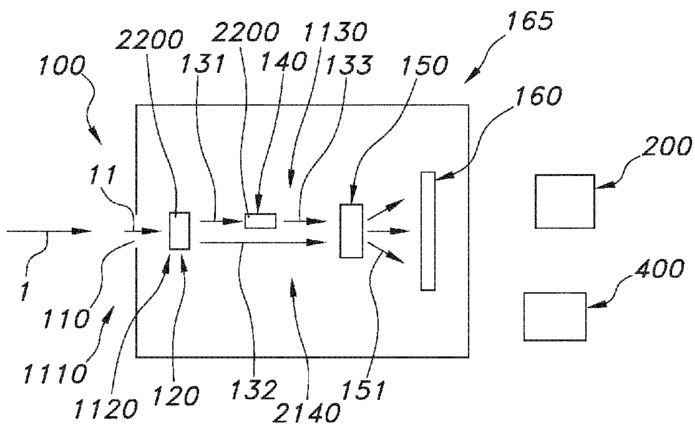

FIG. 8a

(57) **Abstract**: The invention provides a spectrometer setup comprising a light receiving section, a light dispersive element, and a 2D array light detector, wherein the spectrometer setup further comprises a polarization analyzer configured downstream of the light receiving section and upstream of the light dispersive element, wherein the spectrometer setup is configured to allow part of the received light as measuring beam to be intercepted by the polarization analyzer and to allow part of the received light as reference beam to be non-intercepted by the polarization analyzer, wherein the polarization analyzer is configured to modulate a spectral light distribution of only the measuring beam, wherein the spectrometer setup is configured to disperse by the light dispersive element both (i) at least part of the measuring beam downstream of the polarization analyzer and (ii) at least part of the reference beam, and to display at different parts of the 2D array light detector.

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Dual beam device for simultaneous measurement of spectrum and polarization of light

Field of the invention

The invention relates to a spectrometer setup comprising a light receiving section configured to receive incoming light, a light dispersive element, configured downstream of the light receiving section, and configured to spectroscopically disperse at least part of received light to provide dispersed light, and a 2D array light detector, configured downstream of the light dispersive element, and configured to detect at least part of the dispersed light. The invention further relates to an attachment unit for a 2D array light detector comprising device. The invention also relates to the use of such spectrometer setup, as well as to a method to determine the polarization of light having different wavelengths (with such spectrometer setup).

Background of the invention

Spectroscopic apparatus with different light pathways are known in the art. For instance EP0361064, describes a spectroscope device of the dispersion type which receives light to be measured and emits it as dispersed light which corresponds to each of wavelengths to be measured. An optical-path switching device directs the dispersed light emitted from the spectroscope device to pass through first and second paths. A first photoelectric converter receives the light which is directed to pass through the first path by the optical-path switching device. A polarizing/separating device polarizes and separates the light, which is directed to pass through the second path by the optical-path switching device, into two polarized lights. Second and third photoelectric converter respectively receives the two polarized lights polarized and separated by the polarizing/separating device. An arithmetical process section corrects a first optical spectrum strength according to an output from the first photoelectric converter with at least a ratio of second and third optical spectrum strengths according to outputs from the second and third photoelectric converter, to thereby calculate absolute spectrum values of the measured light for every wavelength to be measured about the light.

Summary of the invention

Light can carry much information about the light source and also about the medium that the light traverses to reach the observer. Typical attributes that form such information are intensity, spatial distribution, angular distribution, spectral composition, polarization, phase, and several others.

Spectrometry that explores the spectral composition tells much about the chemical composition of the light source, its temperature, its atomic state, magnetic field, velocity, and much more. It also has information about intervening media, which may be air (hot or cold), chemical vapors, scatterers, and the like. In addition to spectral and other information, there is information about reflecting surfaces or scattering media such as for example, colloidal solutions, dust suspended in the atmosphere, or the blue sky itself. This additional information is carried by the polarization of the light. Polarization tells a tale of scattering and reflection. Polarimetry, however, generally requires totally different equipment than spectrometry.

A disadvantage of prior art systems is that they cannot measure both the spectrum and polarization(s) at the same time, or polarization(s) is measured without the ability to easily filter out between spectral and polarization signals. Further, spectrometer setups cannot easily be coupled with mobile devices, such as cell phones, that include 2D array detectors.

Hence, it is an aspect of the invention to provide an alternative spectrometer setup, an alternative attachment unit, as well as an alternative method, which preferably further at least partly obviate one or more of above-described drawbacks.

The present invention provides a means to simultaneously measure polarization and spectra in a combined unit that transfers polarimetric information into spectral information and measure that in one instrument that has two parallel channels. An important aspect is to apply a spectrograph in a specific dual beam mode configuration.

In a first aspect, the invention provides a spectrometer setup comprising a light receiving section configured to receive incoming light, a light dispersive element, configured downstream of the light receiving section and configured to spectroscopically disperse at least part of received light to provide dispersed light, and a 2D array light detector, configured downstream of the light dispersive element, and configured to detect at least part of the dispersed light, wherein the spectrometer setup further comprises a polarization analyzer configured downstream of the light receiving section and upstream of the light dispersive element, wherein the spectrometer setup is configured to allow part of the received light to propagate as measuring beam to be intercepted by the polarization analyzer and to allow part of the received light to propagate as reference beam to be non-intercepted by the polarization analyzer, and wherein the polarization analyzer is configured to modulate a spectral light distribution of only the measuring beam, wherein the spectrometer setup is further configured to disperse by the light dispersive element both (i) at least part of the measuring beam downstream of the polarization analyzer and (ii) at least part of the reference beam, and (configured) to display (these) at different parts of the 2D array light detector. As indicated below, more than one polarization analyzer may be applied (and thus more than one measuring beam may be modulated (and detected and analyzed)).

Especially, the invention provides a spectrometer setup comprising a light receiving section configured to receive incoming light, a light dispersive element, configured downstream of the light receiving section, and configured to spectroscopically disperse at least part of received light to provide dispersed light, and a 2D array light detector, configured downstream of the light dispersive element, and configured to detect at least part of the dispersed light, wherein the spectrometer setup further comprises (a) a beam splitter, configured downstream of the light receiving section and upstream of the light dispersive element, and configured to split at least part of the received light in a reference beam and a measuring beam ("analysis beam"), and (b) a polarization analyzer configured downstream of the beam splitter and upstream of the light dispersive element, wherein the polarization analyzer is configured to modulate a spectral light distribution of only the measuring beam, wherein the spectrometer setup is further configured to disperse by the light dispersive element both (i) at least part of the measuring beam downstream of the polarization analyzer and (ii) at least part of the reference beam, and to display at different parts of the 2D array light detector.

Note that the beam splitter may also split in more than two beams. For instance, two or more measuring beams. Beam splitters known in the art can be used. In a specific embodiment, the beam splitter comprises one or more of a (non-polarizing) partly transparent or semi-transparent mirror, a (non-polarizing) mirror, and a (non-polarizing) polka dots mirror. Further, the beam splitter may comprise a splitter configured to split the beam in aperture, such as the aperture of an entrance slit, or in amplitude (see also below). The term “beam splitter” may in an embodiment refer to a plurality of beam splitters, e.g. to generate more than one measuring beam.

In an embodiment, the polarization analyzer is configured to modulate the spectral light distribution with a sine wave. Especially, the polarization analyzer comprises a quarter wave plate, a retardation element, and a polarizer, with the retardation element being configured between the quarter wave plate and the polarizer. In a specific embodiment, especially when the polarization of the incoming light is known, the (first) quarter wave plate may not be necessary. In a specific embodiment, the retardation element comprises one or more $n\lambda$ plates, wherein n is in the range of 1-200, especially 5-40; and preferably not more than 10, such as especially not more than 5 $n\lambda$ plates (with n as indicated before to be in the range of 1-200; especially 5-40). Note that n is especially a real number (not necessarily integer). In yet a further advantageous embodiment, the quarter wave plate comprises a fast axis, wherein the retardation element comprises a fast axis, and wherein the polarizer has a polarization axis, wherein the fast axis of the quarter wave plate and the polarizer are arranged parallel, and wherein the fast axis of the retardation element is arranged at 45° relative to the fast axis of the quarter wave plate. Note that 45° may also relate to -45°. The term “polarization analyzer” may in an embodiment refer to a plurality of polarization analyzers, e.g. in the case of more than one measuring beam. Especially, all optics or optical components upstream of the polarization analyzer do not induce a polarization effect. Hence, in further embodiments, wherein optics other than the polarization analyzer have polarization effects on the radiation, such optics are arranged downstream of the polarization analyzer. Further, especially both the reference beam and measuring beam, downstream from the polarization analyzer, should be subjected to the substantially the same further polarization effect with such optics.

In an embodiment, the light dispersive element comprises one or more of a (blazed) grating, a photonic structure, a prism, graded index optics, a transmissive grating, and a Fabry-Perot filter. Especially, the light dispersive element comprises a grating having a blaze wavelength for a wavelength selected from the range of 300-800 nm. Especially, a single light dispersive element may be used. However, also more than one light dispersive element may be applied. In an embodiment, the light of the reference beam is dispersed with another light dispersive element than the light of the measuring beam. When a plurality of measuring beams is applied, also a plurality of light dispersive elements for those measuring beams may be applied. Hence, the term “light dispersive element” may in an embodiment refer to a plurality of light dispersive elements, e.g. to disperse more than one measuring beam. However, as also further indicated herein, also one light dispersive element may be used to disperse multiple beams, like the reference beam and one or more measuring beams (when those beams are (at least partially) spatially separated).

As indicated above, the light dispersive element may comprise a grating having a blaze wavelength for a wavelength selected from the range of 300-800 nm. However, the light dispersive element and/or the 2D array detector may alternatively or additionally also be configured to detect infrared radiation, such as near infrared (NIR) radiation, like radiation in the range of 750-3000 nm, like 800-3000 nm. Another range of interest may be long wave infrared (LWIR) radiation, such as radiation having a wavelength in the range of 3000 - 10000 nm, such as 3000 - 4500nm. For instance, the range of 800-4500 nm may also be of interest. Yet another range of interest may be shorter wavelengths in the ultraviolet (UV) part of the spectrum such as radiation in a wavelength range of 180 - 300 nm, in for instance an air-filled environment, or in even shorter wavelengths, such as in an environment filled with non-absorbing media such as for example, vacuum, nitrogen or argon gas. Clearly the type and materials of optics and detectors will be chosen in accordance with their usefulness at those specific wavelength ranges.

2D array detectors, such as 2D CCD cameras, are known in the art. Especially a single 2D detector is applied, though also a plurality of 2D array detectors may be applied to measure different beams. Hence, the term “2D array detectors” may in an embodiment refer to a plurality of 2D array detectors, e.g. to detect more than one measuring beam and reference beam.

The spectrometer setup may further comprise an analysis unit configured to derive from the 2D array detector information on the polarization of the incoming light based on a comparison of the measuring beam and the reference beam. However, as also further indicated herein, also one 2D array detector may be used to detect multiple beams, like the reference beam and one or more measuring beams (when those beams are (at least partially) spatially separated. Examples thereof are further elucidated below.

In yet a further aspect, the invention provides an attachment unit comprising a light receiving section configured to receive incoming light, a light dispersive element, configured downstream of the light receiving section, and configured to spectroscopically disperse at least part of received light to provide dispersed light, wherein the attachment unit further comprises (a) a beam splitter, configured downstream of the light receiving section and upstream of the light dispersive element, and configured to split at least part of the received light in a reference beam and a measuring beam, (b) a polarization analyzer configured downstream of the beam splitter and upstream of the light dispersive element, wherein the polarization analyzer is configured to modulate a spectral light distribution of only the measuring beam, and (c) a light exit, wherein the attachment unit is further configured to disperse by the light dispersive element both (i) at least part of the measuring beam downstream of the polarization analyzer and (ii) at least part of the reference beam, and to provide at least partially spatially separated beams downstream from the light exit. This attachment unit may e.g. be attached to a 2D array detector comprising device, such as a cell phone or web cam, etc. (see also below). The term “light exit” may in an embodiment refer to a plurality of light exits.

Hence, in yet a further aspect, the invention provides a kit of parts comprising (i) a 2D array detector comprising device and (ii) the attachment unit as defined herein, wherein the 2D array detector comprising device comprises a second light receiving section, wherein the 2D array detector is configured downstream of the second light receiving section, and wherein the 2D array detector comprising device are able to be configured relative to each other to allow to disperse by the light dispersive element of the attachment unit both (i) at least part of the measuring beam downstream of the polarization analyzer and (ii) at least part of the reference beam, and to display at different parts of the 2D array light detector of the 2D array detector comprising device. As indicated above, the 2D array detector comprising device may e.g. comprise a mobile device comprising such 2D array detector, especially a cell phone or web cam, or a personal digital assistant (PDA), a Smartphone, an iPhone, a tablet, an ultrabook, a laptop, etc..

In yet a further aspect, the invention also provides a kit of parts comprising a beam splitter and a polarization analyzer configured to modulate a spectral light distribution of a measuring beam. As indicated above, the polarization analyzer may especially comprise a quarter wave plate, a retardation element, and a polarizer, with the retardation element configured between the quarter wave plate and the polarizer. In an embodiment, the quarter wave plate comprises a fast axis, the retardation element comprises a fast axis, and the polarizer has a polarization axis, wherein the fast axis of the quarter wave plate and the polarizer are arranged parallel, and wherein the fast axis of the retardation element is arranged at 45° (or -45°) relative to the fast axis of the quarter wave plate. The elements of this kit may be built in existing spectrometers to provide the functionality as described herein, such as the herein indicated (upgraded) use of the spectrometer.

Further, the invention provides in a further aspect the use of the spectrometer setup as defined herein or the kit(s) of parts as defined herein, to analyze e.g. one or more of (i) scattering in a gas, (ii) scattering in water, (iii) reflection in or on a surface that causes polarization, (iv) polarization effects by transmission, and (v) emission of polarized light. Hence, scattering of particles in fluids, such as a gas or water or a beverage, may be analyzed. The particles may in an embodiment include colloidal particles. In general, the particles to be analyzed should have dimensions in the range of typically but not exclusively $0.01\lambda - 5\lambda$, wherein λ the wavelength is with which is being measured.

In yet a further aspect, the invention also provides the polarization analyzer per se.

In yet another aspect, the invention provides a method to determine polarization of light of different wavelengths, the method comprising splitting the light in a measuring beam and a reference beam, modulating a spectral light distribution of only the measuring beam with a polarization analyzer, and spectroscopically dispersing (i) at least part of the measuring beam downstream of the polarization analyzer and (ii) at least part of the reference beam, displaying these dispersed beams at different parts of a 2D array light detector, and deriving with an analysis unit from the 2D array detector information on the polarization of the incoming light based on a comparison of the measuring beam and the reference beam.

The invention especially describes spectral analysis of a light source in a dual beam mode, i.e. it has an analysis beam using a stack of polarizers to transform polarization information into spectral information and a reference beam that does not undergo that transformation. This may in an embodiment basically be a point measurement split in two light paths that are projected on a spectrometer slit at different heights. Two spectra are then formed on a 2-D detector, that are then detected and their signals analysed. Functionally, these two spectra could also have been formed by two identical but entirely separated spectrometers, each serving a light path. In another embodiment there are more than two light paths that can be used in pairs so that there are several analysis beams and several associated reference beams.

The basic thought is that each point along the height of the slit is conjugate to a line spectrum on the detector.

If an image of a scene instead of two points, such as the output of two fibres, is projected onto the slit, a narrow line of light will enter the slit and the spectra of points on that line will be projected on the detector. The detector will thus receive a 2-D distribution of light, an image as it were, with the dimension parallel to the slit having the image line information, and in the other direction having the spectral information of each point. This simple principle is the basis of many so-called hyper spectral or multi-spectral cameras. If the image is now scanned across the slit in many subsequent positions and the corresponding 2-D line-spectral images are recorded and stacked in a 3-D X,Y,Λ data cube (such as a length (X), width (Y), wavelength (Λ) data cube), a full hyper spectral data set is acquired. Hyper spectral microscopy is e.g. described by M.E. Gehm et al. in "High-throughput Hyperspectral Microscopy", Proc. of SPIE, Vol. 6090 (2006), pages 609007-1 - 609007-9.

Hyperspectral sensors can collect information as a set of images. Each image may represent a range of the electromagnetic spectrum and is also known as a spectral band. These images may for instance be combined and form a three-dimensional hyperspectral data cube for processing and analysis.

In an additional embodiment, this principle is exacerbated to also record polarization in the same way as described above. The result now is not only a pair of spectra but a pair of images, one of which has polarization information and the other is the reference. Still these images have been recorded through the same optics and at the same time.

The incoming light is again split in an analysis beam and a reference beam, and sent into the slit. The filtered part follows a different path than the unfiltered part, and these paths are separated using a faceted lens as a splitter prism. Now the data set contains one more dimension, polarization, so after forming the spectra the beam must be split again to bring it to two detectors, one for the polarization data and one for the reference beam. The result is now an X,Y,Λ,P (degree, direction) data set, in fact a 5-D hypercube (such as a length (X), width (Y), wavelength (Λ) data cube, polarisation degree and polarisation direction (both indicated schematically with P)).

Especially, the above describe embodiment may be of interest in push-broom applications, such as push-broom hyper spectral imaging.

Hence, optionally the device setup and/or the attachment unit further comprise a scanning module, such as for instance one or more movable mirrors. Such scanning module may be comprised by the light receiving section. The scanning module may include scanning optics. The scanning module may especially be configured to (optically) scan an area, such as for instance known in push broom-applications.

Hence, the setup and method, etc., as described herein, may e.g. also be used in devices for independent, untethered operation and remote control through a wireless connection, such as e.g., aerial, submersible or naval drones, oceanographic buoys, stratospheric or weather balloons, medical capsule endoscopes etc., etc. For instance, the setup and method, etc., as described herein, may e.g. also be used for surveillance, like mobile security surveillance, like security air surveillance, but also for agricultural surveillance. Further applications that my be possible are cancer detection, wireless capsule endoscopes, or other medical applications, crop yield detection, mineral detection, etc. Specific applications may for instance also be visible and/or infrared applications. Moisture, sugar, protein, fat, etc. may be distinguished, which may also assist in e.g. outdoor agriculture of drugs plants, like marijuana plants. Another application may for instance be detection of different types of waste in a waste stream, such as (bulk) plastic separation.

The light receiving section may also include a plurality of optical fibres. At least one may provide the reference beam, and of at least one provides the measuring beam. Hence, the invention may also include multi-point detection, with e.g. fibres.

Brief description of the drawings

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which corresponding reference symbols indicate corresponding parts, and in which:

Figure 1a shows the continuous spectrum of a polarized light source. Fig 1b shows the sine wave modulation at 12th order retardation superimposed on the spectrum (these drawings are based on photographs 11a-11b);

Fig 2a (non-modulated) and 2b (modulated) illustrate that the modulation has become invisible (these drawings are based on photographs 12a-12b);

Fig. 3 schematically depicts an embodiment of the spectrometer unit;

Figs. 4-6 schematically depict further embodiments of the spectrometer unit;

Fig. 7a-b schematically depict embodiments of a conventional spectrometer including a variant;

Figs. 8a-8b schematically depict some embodiments of the invention;

Fig. 9 schematically depict an embodiment of the polarization analyzer;

Figs. 10a-10h schematically depict some further aspects of the invention (these drawings are based on photographs 13a-13h); and

Figs. 14a-14d schematically depict some embodiments of the invention.

The drawings are not necessarily on scale.

Brief description of the photographs

Photographs 11a-11b are the basis of the schematic drawings 1a-1b;

Photographs 12a-12b are the basis of the schematic drawings 2a-2b; and

Photographs 13a-13h are the basis of the schematic drawings 10a-10h.

Description of preferred embodiments

The present invention amongst others applies birefringent materials to separate the orthogonal components of a polarization vector, delay the one on the slow axis so that at certain wavelengths the plane of polarization is rotated and then blocks that specific wavelength with a polarizer. At which wavelengths that happens depends on the order of retardation (in practice 5-40) and on the degree and direction of polarization present in the light to be analyzed. The spectrum of the light source is thus modulated with a sine wave. The basic stack of polarizing optics that forms the polarization analyzer is a quarter lambda plate, a higher order retarder and a polarizer, positioned at 45° angles.

In modern times this principle is used scientifically to probe polarization in atmospheres of other planets, interstellar gas and dust clouds and also dust in earth's atmosphere, or other pollution.

The typical result of blocking specific wavelengths is a spectrum modulated with a sine wave so that brighter and darker bands are formed. Hence, suppressing specific wavelengths may provide a spectrum modulated with a sine wave (so that brighter and darker bands are formed). This sine wave carries the information about polarization direction and degree.

In a simple test setup this is demonstrated with a halogen bulb spectrum, see Figs. 1a-1b. Fig 1a shows the continuous spectrum of a polarized light source. Fig 1b shows the sine wave modulation at 12th order retardation superimposed on the spectrum.

Unfortunately, these light and dark bands cannot be distinguished from the same features in the spectrum itself. In the extreme of a clean line spectrum the modulation bands become invisible. In other words: spectral and polarization signals intermix and there is no way to know which is what. This is shown in Figs. 2a-2b. Fig 2a (non-modulated) and 2b (modulated) illustrate that the modulation has become invisible. Light source is a fluorescent mercury lamp. Only the general background color due to stray light in the setup and the intensity differences between lines can be seen to be shifted. Some color shifts are also due to the partial saturation of the camera sensor in the bright lines.

The present invention overcomes this problem by separating the probe beam of light in at least two (or more) beams, and pass (at least) one through the polarization analyzer into the spectrograph, and the other directly in the spectrograph as a reference beam. In a functional diagram this has a form as given in the Fig 3.

A specific embodiment is the combination of polarization analyzer and spectrograph in one instrument, both functions using the same light path at the same time.

With reference to figs 3-6 a more detailed description and several preferred embodiments of the invention are given. The sequence of the components is not fixed but does have a logical order, depending on the embodiment.

In figs. 3-8b, reference 1 indicates the incoming light; reference 120 indicates the beam splitter, reference 131 indicates the measuring beam (upstream of the polarization analyzer, which is indicated with reference 140), and reference 133 indicates the measuring beam downstream of the polarization analyzer. Reference 132 indicates the reference beam and reference 165 indicates a spectrometer, which may include a dispersive element 150 and a 2D array detector 160. Reference LE indicates a lens, reference MI indicates a mirror, and reference SL indicates a slit. Note that more than one slit may be present. Reference 2200 indicates a kit of parts of a beam splitter and the polarization analyzer. These may conveniently introduced to or attached to existing spectrometer setups, see e.g. Fig. 4 or 8a.

Further, reference 110 indicates a light receiving section. Reference 137 indicates a fiber that may be used to guide e.g. the reference beam 132 and the measuring beam 133, respectively, to the spectrometer (see e.g. fig. 4). In fig. 5 two lenses LE1 and LE2 are used, with the former downstream of the polarization analyzer 140. Note that also one single lens might be applied. Reference 1120 indicates the beam splitting stage. This may be done with a physical beam splitter, such as schematically depicted in fig. 4, or may be effected by using a part of a beam for processing in the polarization analyzer 140 and by using part of the beam as reference beam (and thus avoiding processing of that part by the polarization analyzer 140). Reference 1130 indicates the output stage. This is the stage of the beams downstream of the polarization analyzer 140; for the measuring beam this is the beam that has been processed by the polarization analyzer; for the reference beam this is in fact (still) the (unprocessed) beam. Reference 1110 (also) indicates the input stage; sometimes also indicated as light receiving section 110. Further, reference 2140 indicates the transfer stage, of the reference beam, and references 1131 and 1132 indicate the output stages of the measuring beam and reference beam, respectively.

The general sequence of components is as follows:

• The sample is the source of the light to be analyzed. This can be a light source looked upon directly or through a reflection, scattered light in a dispersion, light reflected on a product surface, land or water, skin, hair, foliage, molten metals, plastics, glass, foodstuffs, and many other. The sample can be infinitely far away as long as an optical system, here called the collimator, can transfer its light into the input stage.

• The input stage collects light to be analyzed. This can be through imaging optics, reflected or scattered light, through a light conductor or otherwise. The light can be collected through a microscope or an astronomical telescope, from very near to very remote, even from aircraft or a satellite. The collecting system is, however, not allowed to (substantially) alter the polarization or spectral content of the light in any unknown way. The input stage is herein also indicated as light receiving section.

• The splitter ("beam splitter") splits the beam in aperture or in amplitude into two parts that can be but need not be equal, without disturbing the polarization properties. For balancing the beams, an asymmetrical split can be made or an extra attenuation stage can be introduced. Note however the configuration of the spectrometer setup (or attachment unit, see also below) may be chosen in such a way that functionally two (or) more beams are available, without a physical beam splitter upstream of the polarization analyzer. Such embodiments are schematically depicted in figs. 5 and 6. Hence, the stage wherein the light beam is split in two or more beams, of which at least one is used as measuring beam and of which at least one is used as reference beam is herein also indicated as beam splitting stage. This stage is indicated with reference 1120.

It is also possible to split not in just two but in any other number of feasible channels: e.g. 1st-order, 10th order, 50th order for wavelength dependent solutions so that the polarization can be analyzed separately in different wavelength ranges.

- The transfer stage transfers the reference beam directly to its output stage. This can be through a light guide, through air or otherwise.
- The polarization analyzer produces the spectral modulation as described above and transfers it to its output stage. The analyzer is basically a stack of three components 141,142, 143, as schematically indicated in fig. 4-6 and 9 by lines in a box.

  The heart of the system is a higher order wave plate, indicated with reference 142, of birefringent material such as quartz, mica, stretched plastic or other. It is placed in the middle. This retardation plate works in order numbers, typically from 5 or less to 40 or more, depending on the application. This wave plate rotates the polarization plane of light as a function of wavelength, so that certain wavelengths emerge p-polarized, others emerge s-polarized, and still others are elliptically polarized. The third component 143 is a polarizer that passes and blocks light depending on polarization state, so that in combination with component 142 some wavelengths are blocked and others are not. This produces a sine wave modulation on the spectrum. Component 141 is a quarter wave plate that produces circularly polarized light, preventing that some polarization directions in the sample light beam would pass unaltered through 142 and 143. Its fast axis is especially placed under 45° (or -45°) with respect to component 142's axis.

- Output stages transfer the reference beam and modulated beam to one or a pair of spectrographs. This transfer can happen through fibers or through air; any polarizing effects in the media is not a problem here any more. These stages may include spherical or astigmatic lenses, mirrors, fibers, or just air space.
- The spectrograph(s) analyze the spectrum of both channels. Separation of the beams can be done along the height of the spectrograph slit, so that the spectrum inside the instrument (which is essentially a wavelength dispersed image of the slit) has two layers that can be read with separate detector arrays.

The reference beam can be used as a true reference to calibrate the other beam so that the modulation becomes dimensionless, and is just the ratio of intensities between modulated and unmodulated spectra. It is obvious that in pure line spectra where not all wavelengths are filled, there is no reliable readout in the dark areas. However, this will be immediately recognizable in the corresponding noise numbers.

The whole device can be made very small, and can be placed at different locations in the optical path, even inside the spectrograph. In the latter case the input and output stages can be omitted altogether.

Fig. 4-6, (see also figs. 14a-14c) etc., also show that especially all optics or optical components upstream of the polarization analyzer do not induce a polarization effect. Hence, in further embodiments, wherein optics other than the polarization analyzer have polarization effects on the radiation, such optics are arranged downstream of the polarization analyzer. Especially both the reference beam and measuring beam, downstream from the polarization analyzer, should be subjected to the substantially the same further polarization effect with such optics (if any polarization effects are induced). One could also define that all optics that might be arranged in the incoming light up to the point where there is beam separation should especially not induce a polarization effect.

In a typical spectrograph such as the century-old Czerny-Turner setup in Fig 7a, a spectrum consists of a wavelength-dispersed image of the slit. This image is made by two mirrors. The first collimates the light in a parallel beam and directs it to a flat grating, which forms the spectrum. From here there is a swath of parallel beams travelling towards the second mirror, that images the slit on the detector (or exit slit), in a different place for each wavelength. Imaging means that the light on the upper end of the detector comes from the upper end of the entrance slit. If the slit is illuminated by multiple light sources, at the detector a 'stack' of spectra will be formed, each 'layer' corresponding with its light source. If the detector is equipped with multiple divisions along its height (see fig. 7b), or is even pixelated, all these separate spectra can be read out separately. Fig. 7b schematically depicts a similar embodiment, but now with a second row of detection elements, indicated with reference 160b, in addition to a first row, indicated with reference 160a. Hence, in such way a 2D detector may (also) be provided. However, a 2D array detector may not only consists of two or more separate rows of detection element, but may also include a single 2D array, with detection elements in n (adjacent) rows, with n being at least 2. Light impinging on the second row of detection elements is not shown for the sake of clarity.

This system or a resembling system such as the Ebert layout, using one big mirror instead of two separate mirrors, is contained in the schematic blocks 'Spectrograph' in figs 4 and 5.

As mentioned, the polarization analyzer can also be placed inside this spectrograph, where it uses only part of the height of the (entrance) slit, while leaving free the other part(s). This may not work for spectrographs with extremely large N.A. (such as above 0.5. Especially, N.A $\leq$ 0.3, such as N.A $\leq$ 0.25.) because the analyzer stack may work slightly different for different non-paraxial beam angles. This is illustrated in Fig 6. The term “paraxial” especially indicates something to be aligned parallel to the optical axis or main axis of the optical system.

In all cases it is preferred that the spectrum is captured in the spectrograph by a detector that can discriminate light that falls on different heights. Two (or more) spectra are imaged on it, with probably a small overlap or dark line between them. This means that the detector must have vertical divisions, or even it can be pixelated as in normal digital cameras, and that the readout electronics is capable to read that out at a sufficient speed.

Even more information can be gathered if two of these systems are used in series at different locations along the same light path. Due to the Tyndall effect light reddens as it proceeds through a medium that scatters out the short wavelengths along the way. How that happens depends on the type of dust that is suspended in the probe light beam. The information gathered in such a way comes both from polarization and spectrum.

Fig. 7a (see also above) schematically depicts en embodiment of a conventional spectrometer, for instance, the kit of parts 2200 described above may be arranged upstream of an entrance slit, such as SL, but may also be arranged downstream of an entrance slit, but – referring to fig. 7a (and 7b) – preferably at least upstream of the light dispersive element 150, and also preferably upstream of an optical element such as the first mirror MI (i.e. the first mirror in the optical path). The light dispersive element 150 may especially be a grating.

Fig. 8a very schematically depicts an embodiment of a spectrometer setup 100 as described herein. The spectrometer setup 100 comprises a light receiving section 110, such as a slit, or a plurality of slits, configured to receive incoming light 1. The spectrometer setup 100 further comprises a light dispersive element 150, which is depicted very schematically. Examples of such light dispersive element 150 are a prism or a grating. Of course, when a grating would be applied, which will often be the case, the path of light will be different than depicted in this very schematic drawing, as will be clear to a person skilled in the art. The light dispersive element 150 is configured downstream of the light receiving section 110, and is configured to spectroscopically disperse at least part of received light 1 to provide dispersed light 151. Further, the spectrometer setup 100 comprises a 2D array light detector 160, configured downstream of the light dispersive element 150, and configured to detect at least part of the dispersed light 151. The spectrometer setup 100 further comprises - in this embodiment - (a) a beam splitter 120, configured downstream of the light receiving section 110 and upstream of the light dispersive element 150, and configured to split at least part of the received light (indicated with reference 11) in a reference beam 132 and a measuring beam 131. Further, the spectrometer setup 100 comprises (b) a polarization analyzer 140 configured downstream of the beam splitter 120 and upstream of the light dispersive element 150, wherein the polarization analyzer 140 is configured to modulate a spectral light distribution of only the measuring beam 131. The spectrometer setup 100 is further configured to disperse by the light dispersive element 150 both (i) at least part of the measuring beam 131 downstream of the polarization analyzer (i.e. the modulated measuring beam 131, which is indicated with reference 133) and (ii) at least part of the reference beam 132, and to display at different parts of the 2D array light detector 160 (see for more detail below); for instance, they may be displayed at different heights (i.e. different subset(s) of array(s) of the 2D array light detector).

The spectrometer setup 100 may further optionally comprise an analysis unit 200, which is configured to derive from the 2D array detector 160 information on the polarization of the incoming light (i.e. light 1) based on a comparison of the measuring beam 131 (i.e. as displayed at the 2D array detector 160 after passing the polarization analyzer 140 and the dispersive element 150, respectively) and the reference beam 132 (i.e. as displayed at the 2D array detector 160 after passing the dispersive element 150). Optionally or additionally, the spectrometer setup 100 may comprise a transmitter unit 400, configured to transmit a signal from the 2D array light detector 160 and/or a signal from the analysis to unit to an external receiver, which may for instance be part of or communicate with a higher order analysis unit.

Fig. 8b schematically depicts a kit of parts 1200 comprising (i) a 2D array detector comprising device 360 and (ii) an attachment unit 1100. This figure is also used to describe the attachment unit 1100 per se.

The attachment unit 1100 comprises a light receiving section 110 configured to receive incoming light 1, a light dispersive element 150, configured downstream of the light receiving section 110, and configured to spectroscopically disperse at least part of received light 1 (i.e. light 11) to provide dispersed light 151. The attachment unit 1100 further comprises (a) a beam splitter 120, configured downstream of the light receiving section 110 and upstream of the light dispersive element 150. The beam splitter 120 is configured to split at least part of the received light in a reference beam 132 and a measuring beam 131. The attachment unit further comprises (b) a polarization analyzer 140 configured downstream of the beam splitter 120 and upstream of the light dispersive element 150. The polarization analyzer 140 is configured to modulate a spectral light distribution of only the measuring beam 131. The attachment unit 1100 further comprises (c) a light exit 111. The attachment unit 1100 is further configured to disperse by the light dispersive element 150 both (i) at least part of the measuring beam downstream of the polarization analyzer and (ii) at least part of the reference beam, and to provide at least partially spatially separated beams downstream from the light exit 111.

As indicated above, fig. 8b schematically depicts said kit of parts 1200 comprising (i) the 2D array detector comprising device 360 and (ii) the attachment unit

1100. The 2D array detector comprising device 360 comprises a second light receiving section 112. The 2D array detector 160 is configured downstream of the second light receiving section 112. The 2D array detector comprising device 360 and the attachment unit 1100 are able to be configured relative to each other to allow to disperse by the light dispersive element 160 of the attachment unit 1100 both (i) at least part of the measuring beam downstream of the polarization analyzer and (ii) at least part of the reference beam, and to display at different parts of the 2D array light detector 160 of the 2D array detector comprising device 360. The 2D array detector comprising device 360 may for instance be a cell phone or other mobile device with a camera. In an embodiment, the 2D array detector comprising device comprises a cell phone or web cam. The data obtained by the 2D array detector may be sent wireless (such as Wi-Fi) to an (external) receiver (see also above).

Fig. 9 schematically depicts an embodiment of the polarization analyzer 140. Here, the polarization analyzer 140 comprises a quarter wave plate 141, (downstream thereof) a retardation element 142, and (downstream thereof) a polarizer 143, with the retardation element 142 configured between the quarter wave plate 141 and the polarizer 143. The retardation element comprises one or more nλ plates, wherein n is in the range of 1-200, especially 5-40. Preferably not more than 10, such as especially not more than 5 nλ plates are applied. Especially, the quarter wave plate comprises a fast axis, the retardation element comprises a fast axis, and the polarizer has a polarization axis, wherein the fast axis of the quarter wave plate and the polarizer are arranged parallel, and wherein the fast axis of the retardation element is arranged at 45° (or -45°) relative to the fast axis of the quarter wave plate. Here, the arrangement 45° may also include an -45° arrangement. Reference 144 indicates the optical axis of the system. References FA indicated the fast axes, and reference PA indicates the polarization axis.

The optical system described herein produces multiple light paths through the same optical system that carry different types of information. These light paths transfer light from a source to eventually a detector. The usual detector type consists of a linear array of small photosensitive elements, usually closely placed on an integrated device. The normal type of optical information projected on such a detector is a spectrum, that consists of a number of bright lines and/or a continuum which is basically an infinite number of bright lines, infinitely closely spaced. These bright Lines are images of the entrance slit of a spectrograph of for instance of the Czerny-Turner or Ebert type, see e.g. Fig 10a an exemplary spectrum and thereunder schematically a 1D array detector.

In figs. 10a-10h, each band BA shows the same basic spectrum, with P indicating purple, C indicating cyan, B indicating blue, G indicating green, Y indicating yellow, O indicating orange, and R indicating red. Further, BL indicates bright line and DL indicates dark line.

In order to have enough photoelectric signal from the detector the sensitive elements of the detector are normally shaped as vertical lines as well, preferably of course coinciding with the spectral lines so that the spectral resolution is maximized. This is schematically depicted in fig. 10b.

These images are normally approximately the same size as the entrance slit, but due to optical aberrations they do not have exactly the same shape. Instead of the straight and rectangular slit of for example 2 x 0,05 mm, the images may be sharp or somewhat blurred, straight or curved (commonly known as ‘bananas’). This is schematically depicted in fig. 10c.

This will obviously not fit exactly on the sensor with line-shaped detection elements. This is schematically depicted in fig. 10d.

In any case, it is true that light coming from the middle of the slit on the axis of the spectrometer, lands in the middle of the slit image, that represents a spectral line projected on the detector. In the same way, light coming from the upper and lower ends of the slit lands on a corresponding place next to the middle of the detector, above and below it.

The invention refers to the possibility to offer different optical information on different parts of the slit. This produces spatially separated sets of spectral information on the detector. In the case of a spectropolarimeter application it is of course possible to produce sinusoidally modulated spectra of different orders originating at different heights along the entrance slit.

In the more general case the upper half of the slit gets unprocessed light, while the lower half gets light that has been processed with the polarimetric analyzer described in the invention. In this way, the upper half of the detector will thus receive unprocessed light, whereas the lower half of the detector will receive processed light. The former is the reference beam. In this way, a vertical stack of spectra is projected on the detector, each with its own typical information. This is schematically depicted in fig. 10e.

In the figure above, this is indicated in three schematic spectra, one with bright Lines on a continuum, one with a continuum only (reference spectrum), and one with dark line on a continuum such as the solar spectrum. In fact, 10e can be seen as a combination of two figures, wherein the middle spectrum can be seen as a reference spectrum for either the upper or the lower spectrum.

Essential for this invention is that the detector needs to be divided not only in a horizontal direction so that different wavelengths can be separately measured, but also it must have vertical divisions so that the various stacked spectra can be separately measured. This requires a large 2-D pixelated detector, such as the ones used in digital cameras. This type of detector may contain several millions of photo sites on their surface.

The situation then becomes like the figure 10f (not to scale).

In such a detector, different horizontal rows of detector elements get different types of information that can be recognized and separately processed by adequate software. The calibration of the detector / software combination can be so refined as to calibrate it pixel-by-pixel so that from each pixel it is known where it is in the stack of spectra and how much it contributes to what type of information.

It is to be noted that these spectra are present and can be detected at the same time. In this way, continuously varying spectra can be recorded and analyzed.

Using such pixelated detectors also makes other approaches of signal processing possible. Using this topography it becomes possible to automatically align any displacements or rotations in spectra that can exist due to mechanical tolerances in the spectrometer hardware as indicated in the figure 10g.

At the same time, in a further embodiment it is possible to improve spectral resolution by searching and correlating the image for the ‘bananas 'or other deformations, because the type of aberration is precisely known at all locations on the sensor by calibration or ab-initio calculation such as spot diagrams made by ray tracing. This is indicated in the figure 10h.

It is to be noted that these figures are not to scale, it is estimated that the number of horizontal rows can be at least several hundreds, but can also be thousands.

This is a fundamental approach that may require ‘intelligent' software for image processing and fast electronics for sensor readout. Figs. 14a-14d schematically depict some further embodiments, which are partly similar to those schematically depicted in figs 5-6.

Fig.14a schematically depicts an embodiment wherein the light receiving section 110 comprises a plurality of fibers 113, here by way of example two fibers. Fig. 14b schematically depicts an embodiment without lens LE. This lens LE may not always be necessary. Fig. 14c schematically depicts an embodiment with scanning optics. Note that the entire apparatus may be moved to scan an area, but optionally or additionally, scanning optics may be applied. Fig. 14c schematically depicts an embodiment of the apparatus 100 with a scanning module 115. This scanning module 115 may include scanning optics 114, such as one or more mirrors. The scanning module is (thus) upstream of the polarization analyzer.

As indicated above, hyperspectral sensors can collect information as a set of images. Each image may represent a range of the electromagnetic spectrum and is also known as a spectral band. These images may for instance be combined and form a three-dimensional hyperspectral data cube for processing and analysis.

In an additional embodiment, this principle is exacerbated to also record polarization in the same way as described above. The result now is not only a pair of spectra but a pair of images, one of which has polarization information and the other is the reference. Still these images have been recorded through the same optics and at the same time.

The incoming light is again split in an analysis beam and a reference beam, and sent into the slit. This is indicated with the beam splitting stage 1120 and the polarization analyser 140, which provides again the two beams 132,133 (as defined above). Especially an imaging lens, indicated here with LE3 may be applied, to project on a slit SL of a spectrometer 165. Downstream of the slit, again a lens may be arranged, indicated with reference LE5, which may also be indicated as field lens. This lens may especially be configured to project on the light dispersive element 150, here a grating.

The filtered part, i.e. downstream of the light dispersive element 150, follows a different path than the unfiltered part, and these paths are separated using a splitter 170, such as a faceted lens as a splitter prism. This splitter 170 may take the form of a patterned two- or more-faceted transparent plate, e.g. made of glass or a transparent polymer, with the facets oriented in such way that light rays take paths in different directions by the different refraction in the facets. Facet patterns will be conjugate to the patterns of the polarization analyzer 140, so may simply consist of two halves, four quarters or interlaced stripes as is convenient for its specific application. It may be noted that the splitter may also consist of a faceted mirror or diffraction device that fulfils the same function. Now the data set contains one more dimension, polarization, so after forming the spectra the beam must be split again to bring it to two detectors (or detector rows), one for the polarization data and one for the reference beam. The result is now an X,Y,Λ,P (degree, direction) data set, in fact a 5-D hypercube. With reference to Fig. 14d, the function can be described as follows. Light reflected or emitted from a scene enters an imaging lens LE3. A part, such as one half, of the lens is covered by a polarizer stack 140 that processes polarization information and codes it into the spectrum of the light (indicated with reference 133 in the figure). The other part, such as another half, is unobstructed and is the reference part (indicated with reference 132 in the figure). The image is projected on the spectrometer slit SL that transmits only a narrow line of the image into the spectrometer. The beams 132,133 have different directions and hit a (field) lens LE4 that makes a beam parallel to the axis (optical axis, indicated with the dashed line). The parallel beam is subjected to a light dispersive element 150, such as passed through a transmission grating. The 0^{th} order follows its original path, whereas the 1^{st} order disperses under an angle (the measuring beam 133 has a 1^{st} order 133b; the reference beam 132 has a 1^{st} order 132b). The grating is placed close to a beam splitter 170, such as a faceted plate that is configured to acts as a beam splitter and to send the beams in different direction: the first order of the measuring beam 133 is indicated with ref. 133b; the 0^{th} order thereof is indicated with reference 133a; the first order of the reference beam 132 is indicated with reference 132b; the 0^{th} order of the reference beam 132 is indicated with reference 132a. Ideally the edge of the polarizer stack in front of the imaging lens may be imaged on the apex of this splitter prism. A last lens, indicated with reference LE5 focuses the hitherto parallel beams and forms two sets of 2-D images. These images have 0^{th} orders that should be weak by the design of the diffraction device 150, it has 1^{st}, -1^{st} and higher orders. The 1^{st} orders should be brightest and have the X, Λ information. The full image is formed by scanning the whole system. Hence, especially the way in which the beam is split and the configuration of the splitter 170 is chosen to allow the beams being projected on the splitter 170.

Applications of the invention

Situations where reflection or scattering play a role cause formation or alterations of polarization conditions. These situations include at least the following:

Scattering in gases:

• air pollution / smog / traffic concentrations at traffic lights,
• fine dust detection in smoke stacks, ventilators,
• soot detection in factory conditions (foundry),
• car exhausts,
• wildfires,
• volcanic dust,
• wind-blown dust, salt

Scattering in water – turbidity:

• waste water,
• beer,
• dispersions of particles (wavelength dependent),
• oil spill emulsions in sea water (deep water horizon),
• sediment loads,
• algae / plankton, etc..

Reflection on / in surfaces that cause polarization

• Water /wet ground / mud,
• foliage / crops,
• building materials,
• glass /stress in glass,
• skin of man and animals (octopus),
• tissue of man and animals,
• hair,
• collagen
• fibers (asbestos)
• photonic structures,
• optical components

• metals, painted surfaces, plastics, wood, etc.

• breaking of camouflage

Polarization effects by transmission:

• birefringence by strain in transparent materials,

• crystalline orientation,

• minerals,

• LC,

• Chiral materials in solutions: sugars

Emissions of polarized light:

• special light sources,

• molten metals

The terms “upstream” and “downstream” relate to an arrangement of items or features relative to the propagation of the light from a light generating means (here the especially the first light source), wherein relative to a first position within a beam of light from the light generating means, a second position in the beam of light closer to the light generating means is “upstream”, and a third position within the beam of light further away from the light generating means is “downstream”.

The term “substantially” herein, such as in “substantially all emission” or in “substantially consists”, will be understood by the person skilled in the art. The term “substantially” may also include embodiments with “entirely”, “completely”, “all”, etc. Hence, in embodiments the adjective substantially may also be removed. Where applicable, the term “substantially” may also relate to 90% or higher, such as 95% or higher, especially 99% or higher, even more especially 99.5% or higher, including 100%. The term “comprise” includes also embodiments wherein the term “comprises” means “consists of”. The term “and/or” especially relates to one or more of the items mentioned before and after “and/or”. For instance, a phrase “item 1 and/or item 2” and similar phrases may relate to one or more of item 1 and item 2.

Furthermore, the terms first, second, third and the like in the description and in the claims, are used for distinguishing between similar elements and not necessarily for describing a sequential or chronological order. It is to be understood that the terms so used are interchangeable under appropriate circumstances and that the embodiments of the invention described herein are capable of operation in other sequences than described or illustrated herein.

The devices or apparatus herein are amongst others described during operation. As will be clear to the person skilled in the art, the invention is not limited to methods of operation or devices in operation.

It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. Use of the verb "to comprise" and its conjugations does not exclude the presence of elements or steps other than those stated in a claim. The article "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. The invention may be implemented by means of hardware comprising several distinct elements, and by means of a suitably programmed computer. In the device or apparatus claims enumerating several means, several of these means may be embodied by one and the same item of hardware. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

The invention further applies to an apparatus or device comprising one or more of the characterizing features described in the description and/or shown in the attached drawings. The invention further pertains to a method or process comprising one or more of the characterizing features described in the description and/or shown in the attached drawings.

The various aspects discussed in this patent can be combined in order to provide additional advantages. Furthermore, some of the features can form the basis for one or more divisional applications.

Claims

1. A spectrometer setup comprising a light receiving section configured to receive incoming light, a light dispersive element, configured downstream of the light receiving section and configured to spectroscopically disperse at least part of received light to provide dispersed light, and a 2D array light detector, configured downstream of the light dispersive element, and configured to detect at least part of the dispersed light, wherein the spectrometer setup further comprises a polarization analyzer configured downstream of the light receiving section and upstream of the light dispersive element, wherein the spectrometer setup is configured to allow part of the received light to propagate as measuring beam to be intercepted by the polarization analyzer and to allow part of the received light to propagate as reference beam to be non-intercepted by the polarization analyzer, and wherein the polarization analyzer is configured to modulate a spectral light distribution of only the measuring beam, wherein the spectrometer setup is further configured to disperse by the light dispersive element both (i) at least part of the measuring beam downstream of the polarization analyzer and (ii) at least part of the reference beam, and to display at different parts of the 2D array light detector.

2. The spectrometer setup according to claim 1, comprising a light receiving section configured to receive incoming light, a light dispersive element, configured downstream of the light receiving section, and configured to spectroscopically disperse at least part of received light to provide dispersed light, and a 2D array light detector, configured downstream of the light dispersive element, and configured to detect at least part of the dispersed light, wherein the spectrometer setup further comprises (a) a beam splitter, configured downstream of the light receiving section and upstream of the light dispersive element, and configured to split at least part of the received light in a reference beam and a measuring beam, and (b) a polarization analyzer configured downstream of the beam splitter and upstream of the light dispersive element, wherein the polarization analyzer is configured to modulate a spectral light distribution of only the measuring beam, wherein the spectrometer setup is further configured to disperse by the light dispersive element both (i) at least part of the measuring beam downstream

of the polarization analyzer and (ii) at least part of the reference beam, and to display at different parts of the 2D array light detector.

3. The spectrometer setup according to any one of the preceding claims, wherein the polarization analyzer is configured to modulate the spectral light distribution with a sine wave.

4. The spectrometer setup according to any one of the preceding claims, wherein the polarization analyzer comprises a quarter wave plate, a retardation element, and a polarizer, with the retardation element configured between the quarter wave plate and the polarizer.

5. The spectrometer setup according to claim 4, wherein the retardation element comprises one or more nλ plates, wherein n is in the range of 1-120, especially 5-40.

6. The spectrometer setup according to any one of the preceding claims, wherein the quarter wave plate comprises a fast axis, wherein the retardation element comprises a fast axis, and wherein the polarizer has a polarization axis, wherein the fast axis of the quarter wave plate and the polarizer are arranged parallel, and wherein the fast axis of the retardation element is arranged at 45° relative to the fast axis of the quarter wave plate.

7. The spectrometer setup according to any one of the preceding claims, wherein the light dispersive element comprises one or more of a (blazed) grating, a photonic structure, a prism, graded index optics, a transmissive grating, and a Fabry-Perot filter.

8. The spectrometer setup according to any one of the preceding claims, wherein the light dispersive element comprises a grating having a blaze wavelength for a wavelength selected from the range of 300-800 nm.

9. The spectrometer setup according to any one of claims 1-7, wherein the light dispersive element comprises a grating having a blaze wavelength for a wavelength selected from the range of 800-4500 nm.

10. The spectrometer setup according to any one of the preceding claims, wherein the beam splitter comprises a splitter configured to split the beam in aperture or in amplitude.

11. The spectrometer setup according to claim 10, wherein the beam splitter comprises one or more of a semi-transparent mirror, a mirror, and a polka dots mirror.

12. The spectrometer setup according to any one of the preceding claims, further comprising an analysis unit configured to derive from the 2D array detector information on the polarization of the incoming light based on a comparison of the measuring beam and the reference beam.

13. An attachment unit comprising a light receiving section configured to receive incoming light, a light dispersive element, configured downstream of the light receiving section, and configured to spectroscopically disperse at least part of received light to provide dispersed light, wherein the attachment unit further comprises a polarization analyzer configured downstream of the beam splitter and upstream of the light dispersive element, wherein the attachment unit is configured to allow part of the received light to propagate as measuring beam to be intercepted by the polarization analyzer and to allow part of the received light to propagate as reference beam to be non-intercepted by the polarization analyzer, wherein the polarization analyzer is configured to modulate a spectral light distribution of only the measuring beam, wherein the attachment unit further comprises a light exit, wherein the attachment unit is further configured to disperse by the light dispersive element both (i) at least part of the measuring beam downstream of the polarization analyzer and (ii) at least part of the reference beam, and to provide at least partially spatially separated beams downstream from the light exit.

14. The attachment unit according to claim 13, comprising a light receiving section configured to receive incoming light, a light dispersive element, configured downstream of the light receiving section, and configured to spectroscopically disperse at least part of received light to provide dispersed light, wherein the attachment unit further comprises (a) a beam splitter, configured downstream of the light receiving

section and upstream of the light dispersive element, and configured to split at least part of the received light in a reference beam and a measuring beam, (b) a polarization analyzer configured downstream of the beam splitter and upstream of the light dispersive element, wherein the polarization analyzer is configured to modulate a spectral light distribution of only the measuring beam, and (c) a light exit, wherein the attachment unit is further configured to disperse by the light dispersive element both (i) at least part of the measuring beam downstream of the polarization analyzer and (ii) at least part of the reference beam, and to provide at least partially spatially separated beams downstream from the light exit.

15. A kit of parts comprising (i) a 2D array detector comprising device and (ii) the attachment unit according to any one of claim 13-14, wherein the 2D array detector comprising device comprises a second light receiving section, wherein the 2D array detector is configured downstream of the second light receiving section, and wherein the 2D array detector comprising device are able to be configured relative to each other to allow to disperse by the light dispersive element of the attachment unit both (i) at least part of the measuring beam downstream of the polarization analyzer and (ii) at least part of the reference beam, and to display at different parts of the 2D array light detector of the 2D array detector comprising device.

16. The kit of parts according to claim 15, wherein the 2D array detector comprising device comprises a mobile device comprising such 2D array detector, especially a cell phone or web cam.

17. A kit of parts comprising a beam splitter and a polarization analyzer configured to modulate a spectral light distribution of a measuring beam.

18. The kit of parts according to claim 17, wherein the polarization analyzer comprises a quarter wave plate, a retardation element, and a polarizer, with the retardation element configured between the quarter wave plate and the polarizer.

19. The kit of parts according to any one of claims 17-18, wherein the quarter wave plate comprises a fast axis, wherein the retardation element comprises a fast axis, and

wherein the polarizer has a polarization axis, wherein the fast axis of the quarter wave plate and the polarizer are arranged parallel, and wherein the fast axis of the retardation element is arranged at 45° relative to the fast axis of the quarter wave plate.

20. Use of the spectrometer setup according to any one of claims 1-12 or the kit of parts according to any one of claims 15-19, to analyze one or more of (i) scattering in a gas, (ii) scattering in water, (iii) reflection in or on a surface that causes polarization, (iv) polarization effects by transmission, and (v) emission of polarized light.

21. A method to determine polarization of light of different wavelengths, the method comprising splitting the light in a measuring beam and a reference beam, modulating a spectral light distribution of only the measuring beam with a polarization analyzer, and spectroscopically dispersing (i) at least part of the measuring beam downstream of the polarization analyzer and (ii) at least part of the reference beam, displaying these dispersed beams at different parts of a 2D array light detector, and deriving with an analysis unit from the 2D array detector information on the polarization of the incoming light based on a comparison of the measuring beam and the reference beam.

22. The method according to claim 21, wherein the spectrometer setup according to any one of claims 1-12 is applied.

23. The method according to claim 21, wherein the attachment unit according to any one of claims 13-14 is applied.

24. The method according to claim 21, wherein the kit of parts according to any one of claims 15-19 is applied.

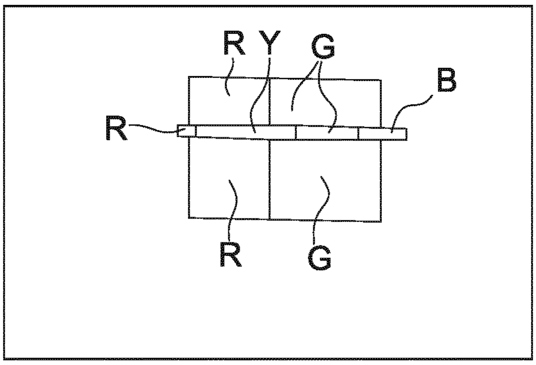

FIG. 1a

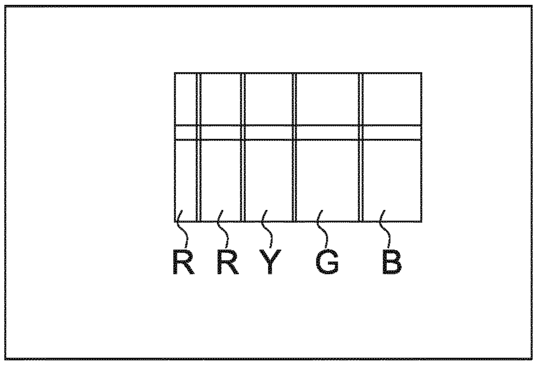

FIG. 1b

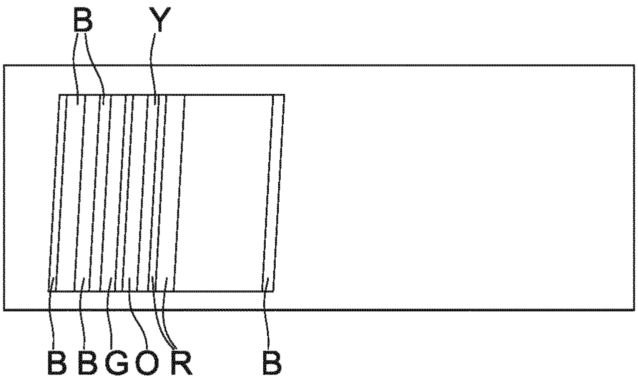

FIG. 2a

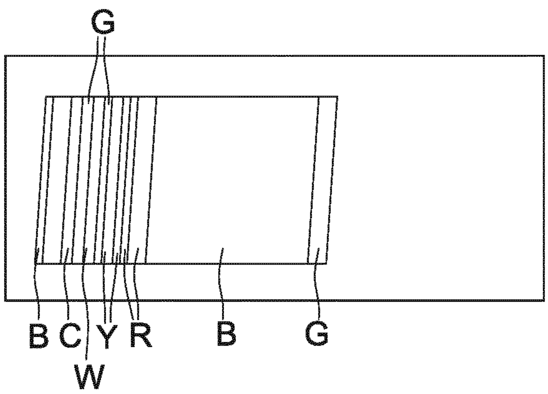

FIG. 2b

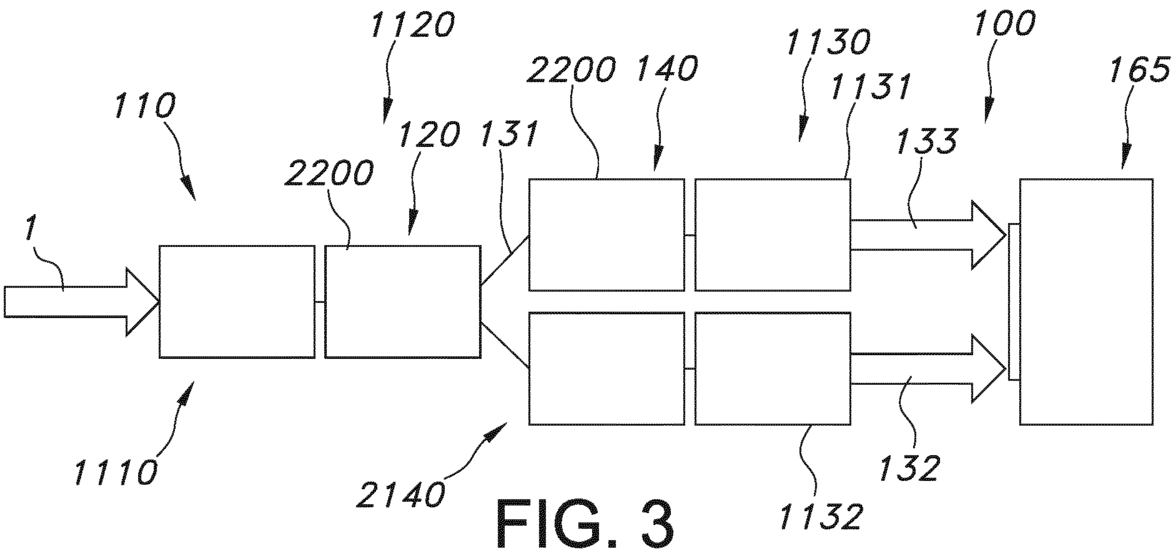

FIG. 3

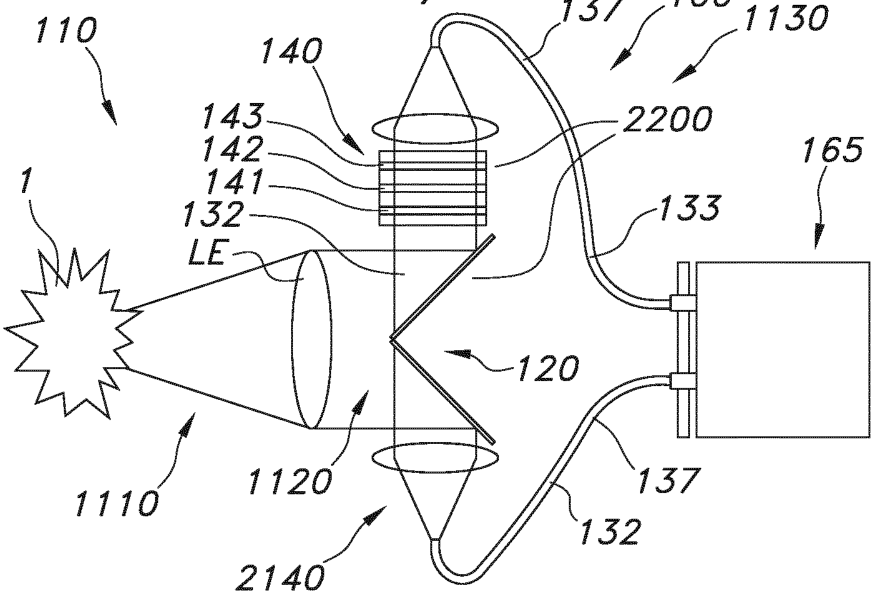

FIG. 4

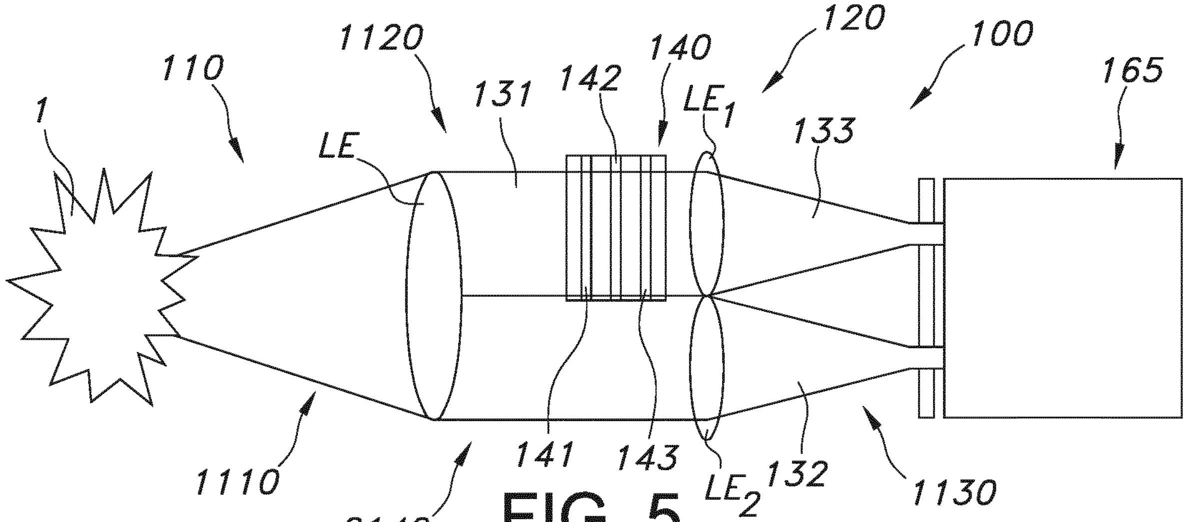

FIG. 5

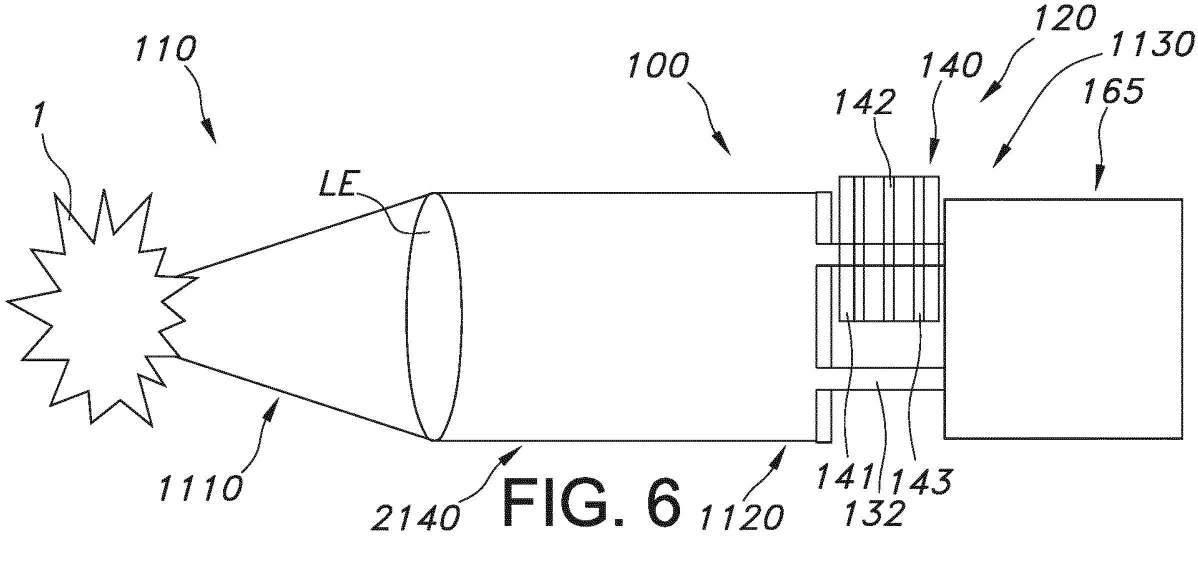

FIG. 6

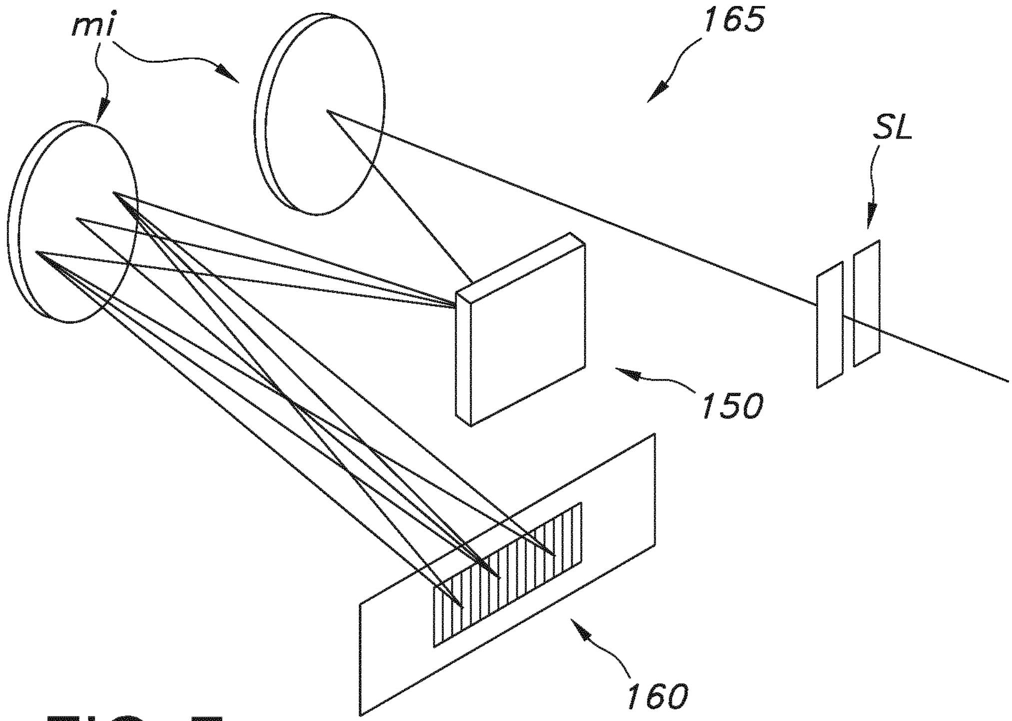

FIG. 7a

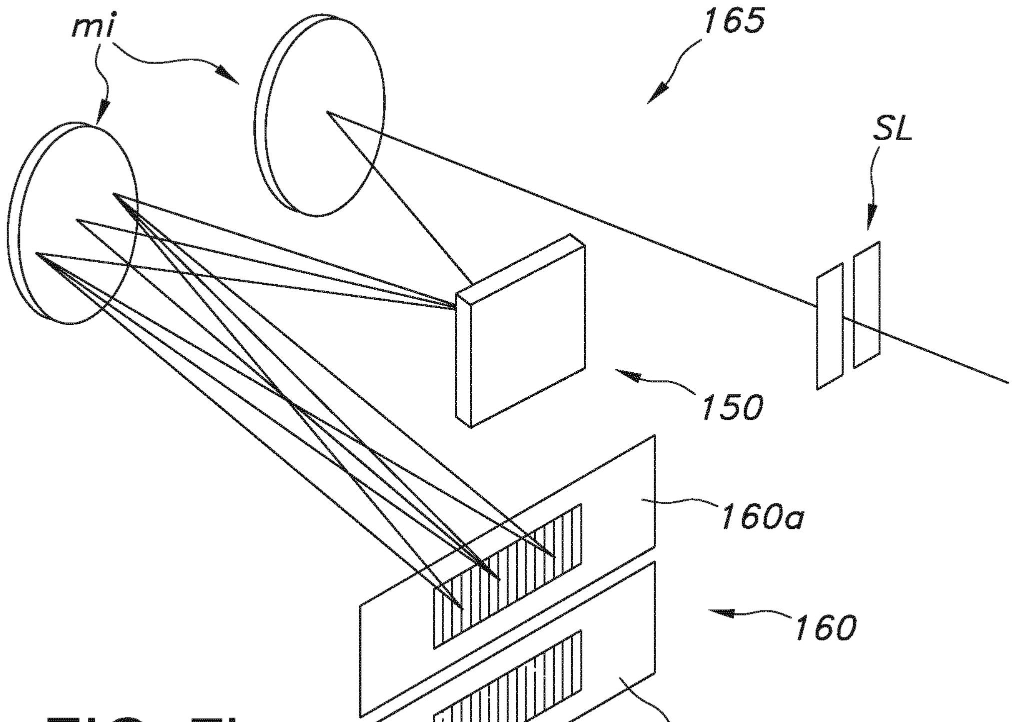

FIG. 7b

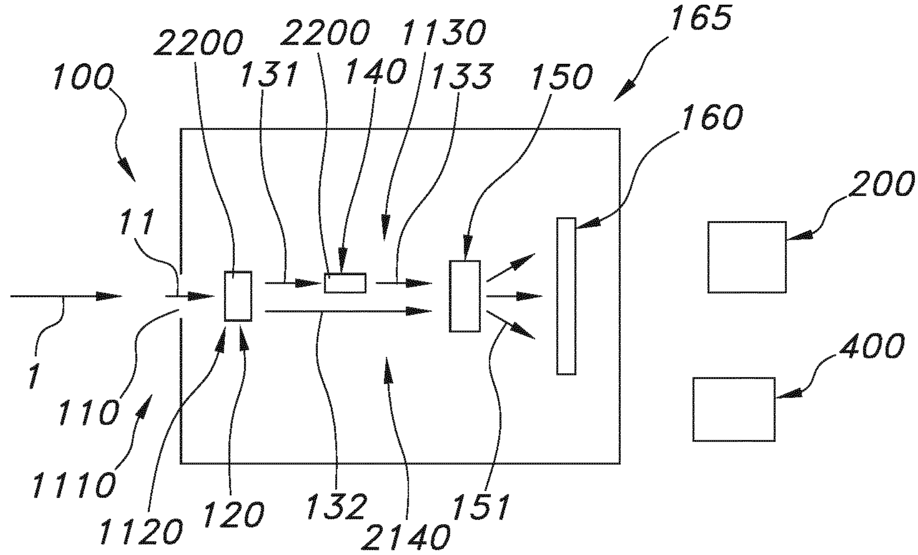
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FIG. 8a

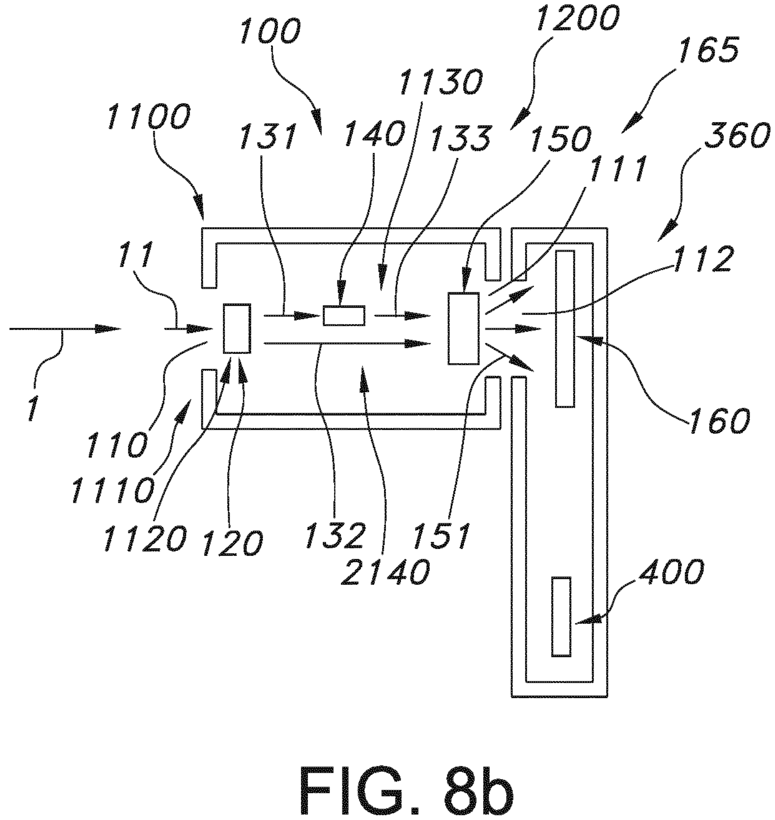
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FIG. 8b

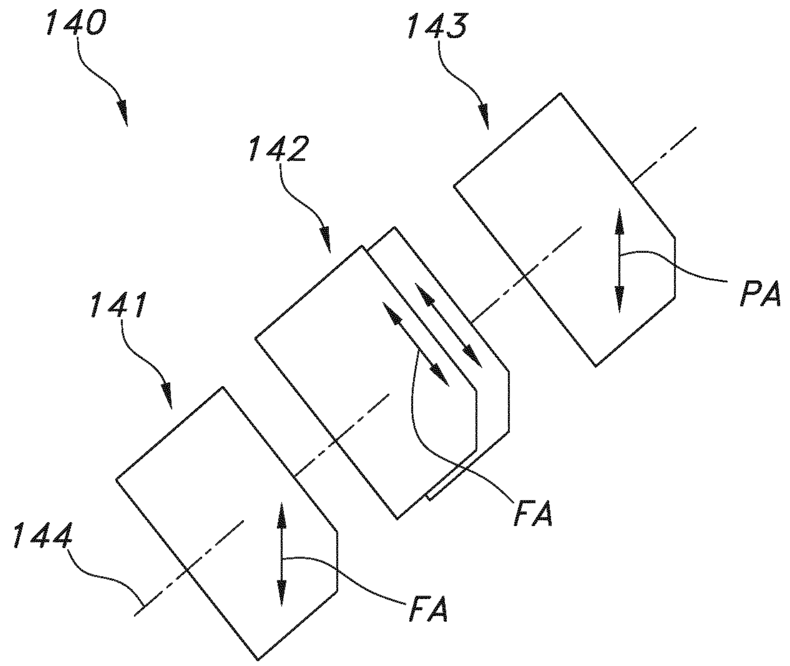

FIG. 9

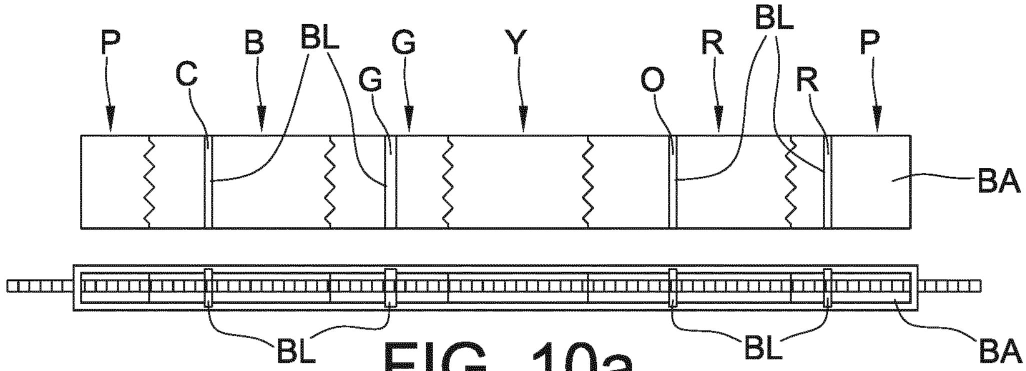

FIG. 10a

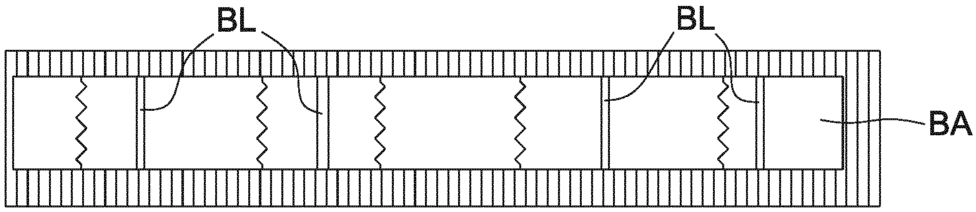

FIG. 10b

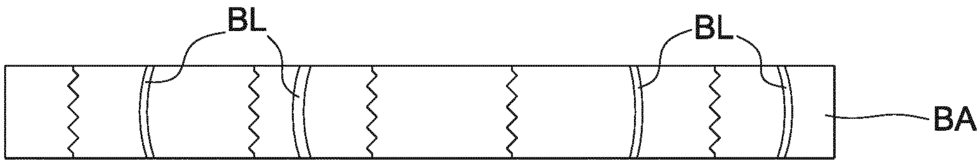

FIG. 10c

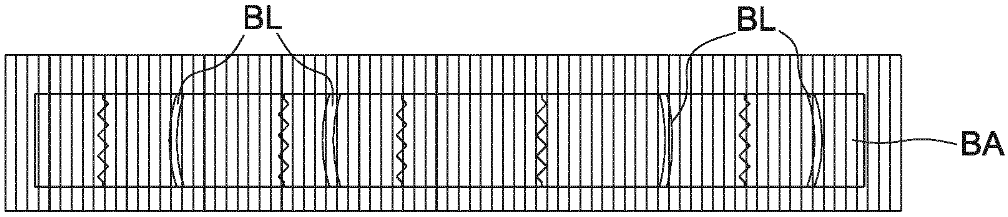

FIG. 10d

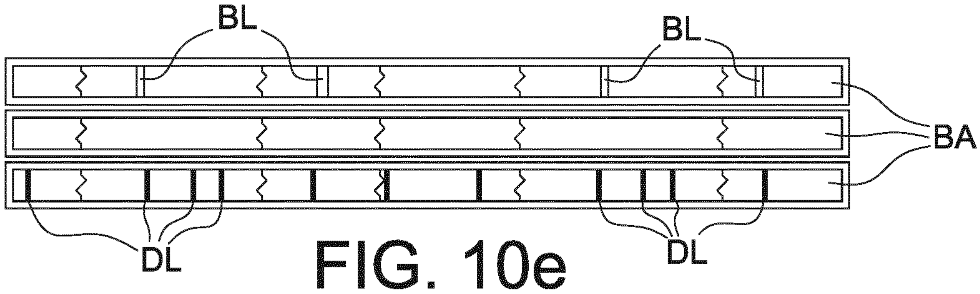

FIG. 10e

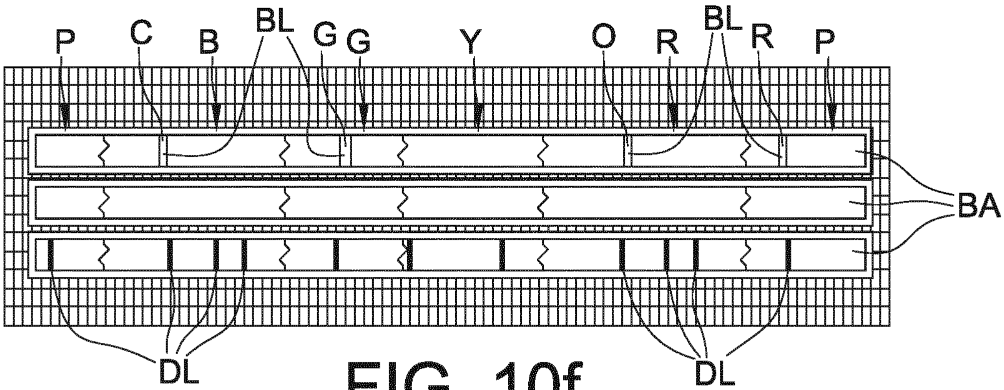

FIG. 10f

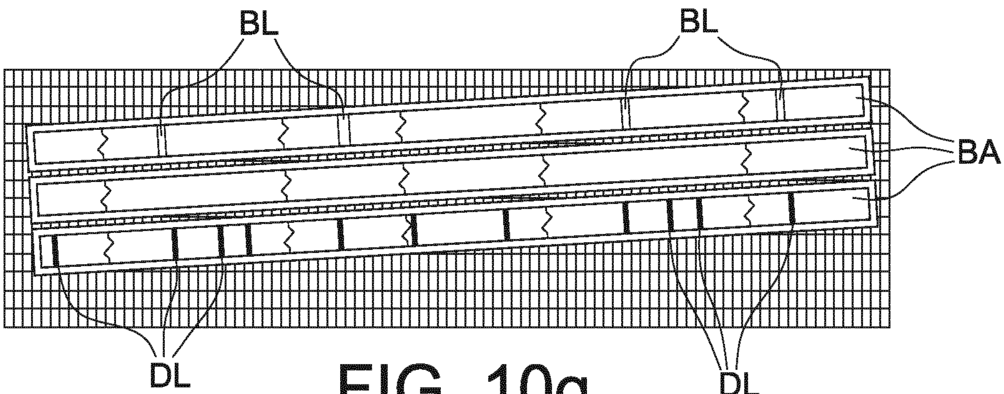

FIG. 10g

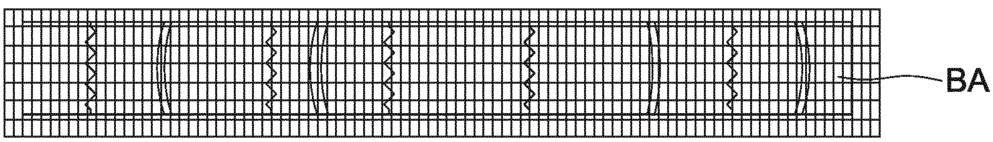

FIG. 10h

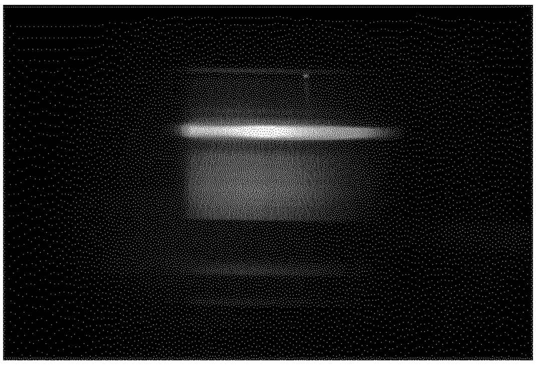

FIG. 11a

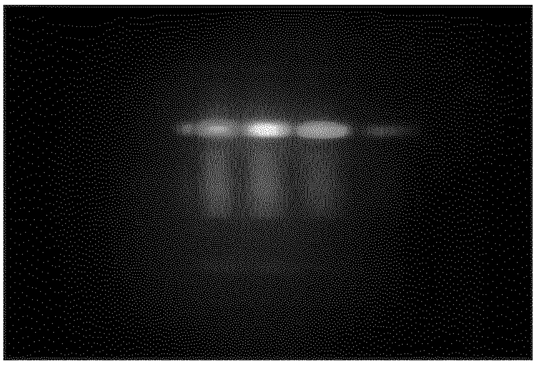

FIG. 11b

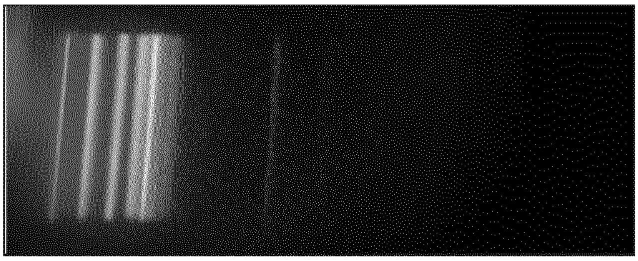

FIG. 12a

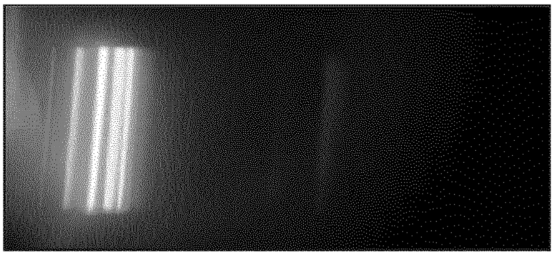

FIG. 12b

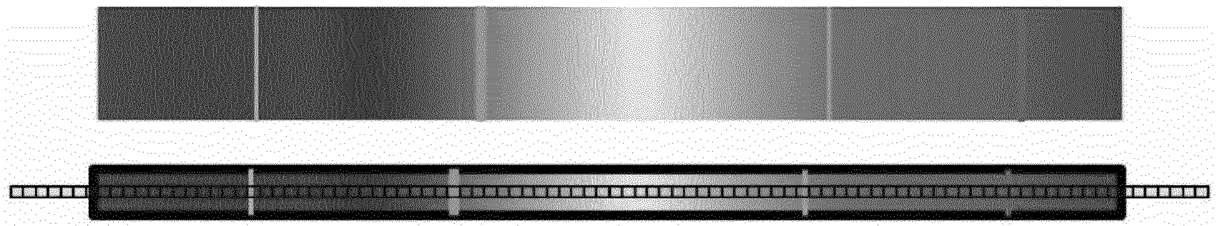

FIG. 13a

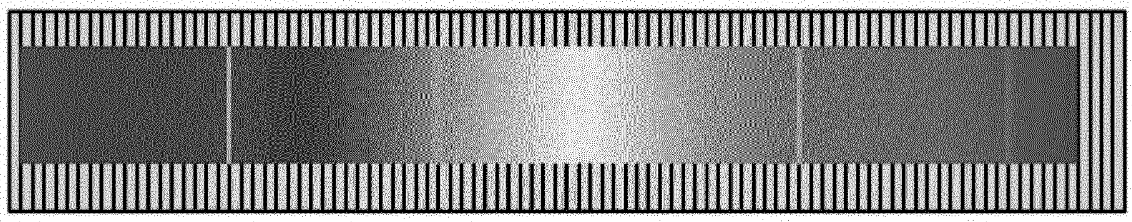

FIG. 13b

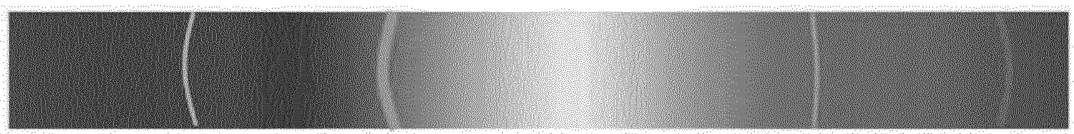

FIG. 13c

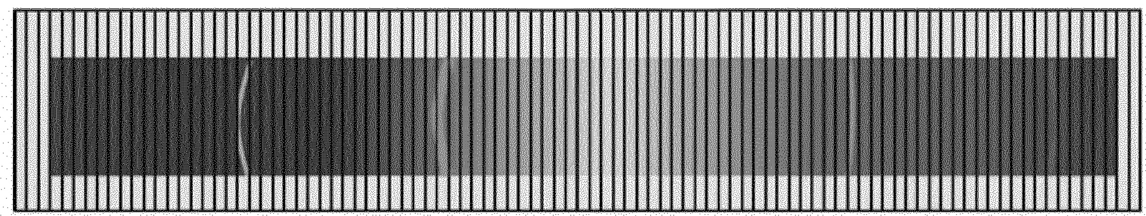

FIG. 13d

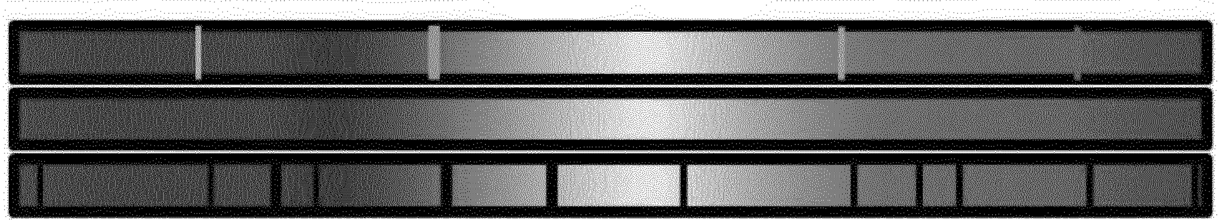

FIG. 13e

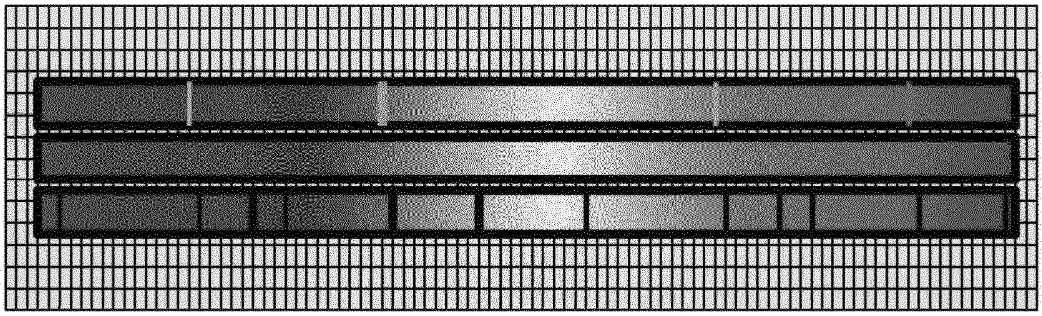

FIG. 13f

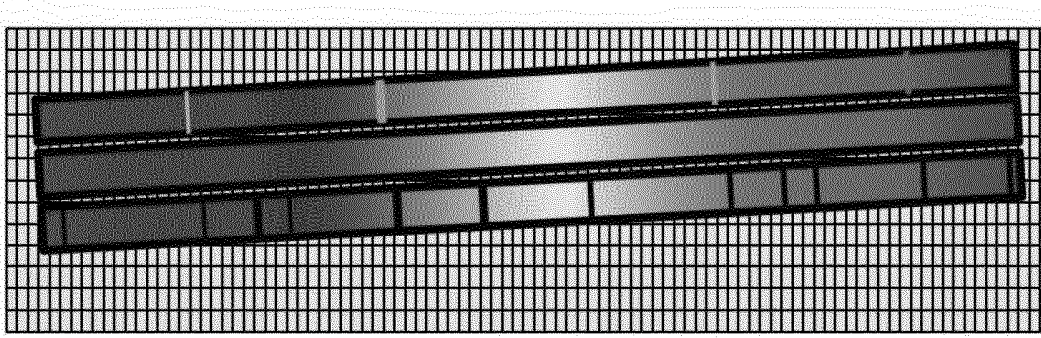

FIG. 13g

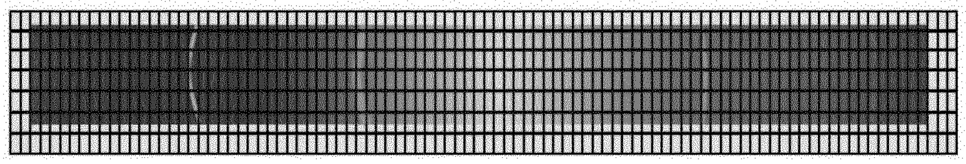

FIG. 13h

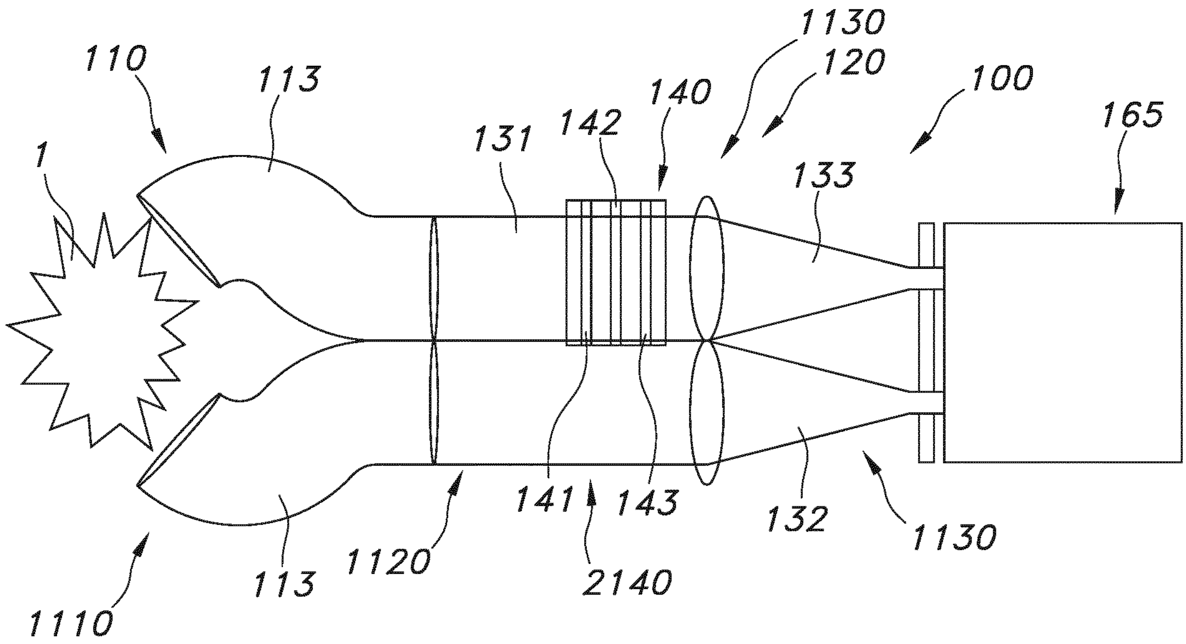

FIG. 14a

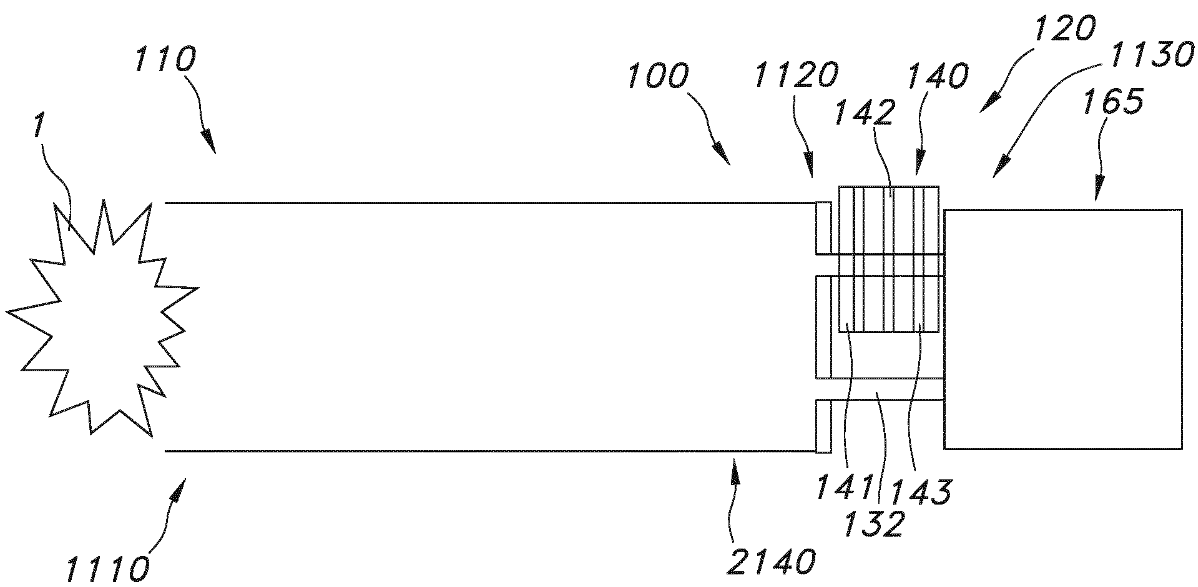

FIG. 14b

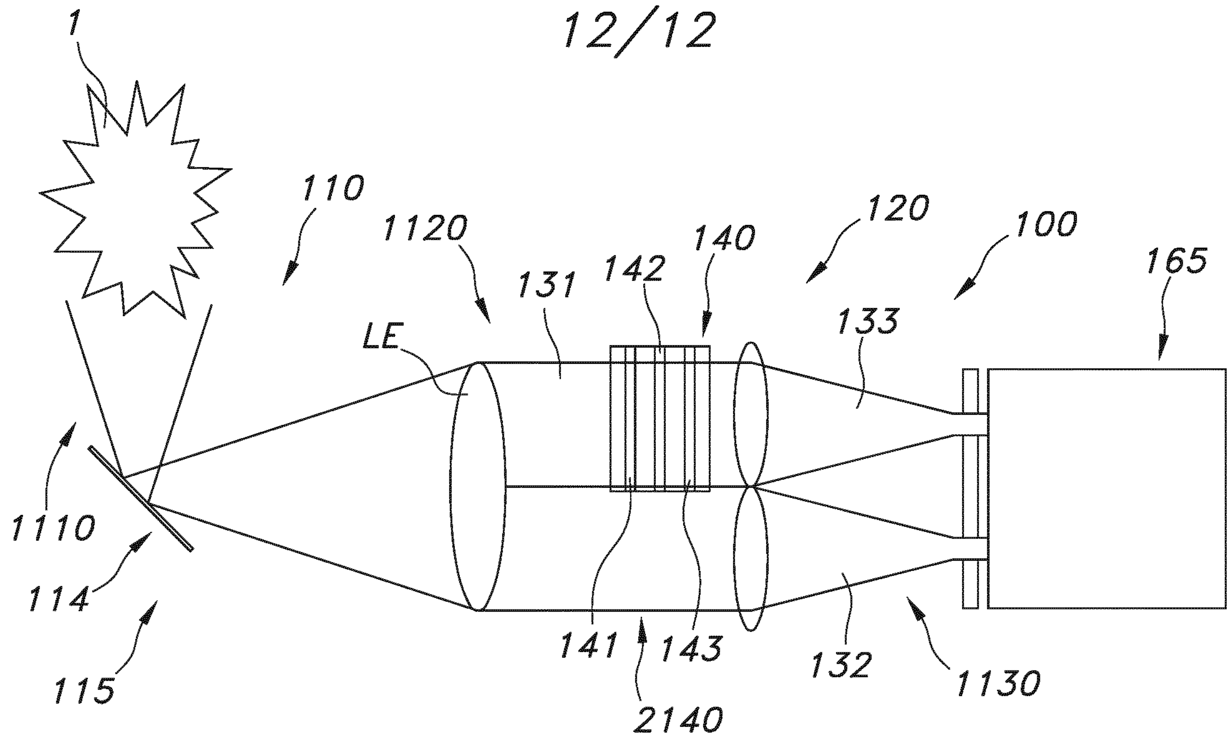

FIG. 14c

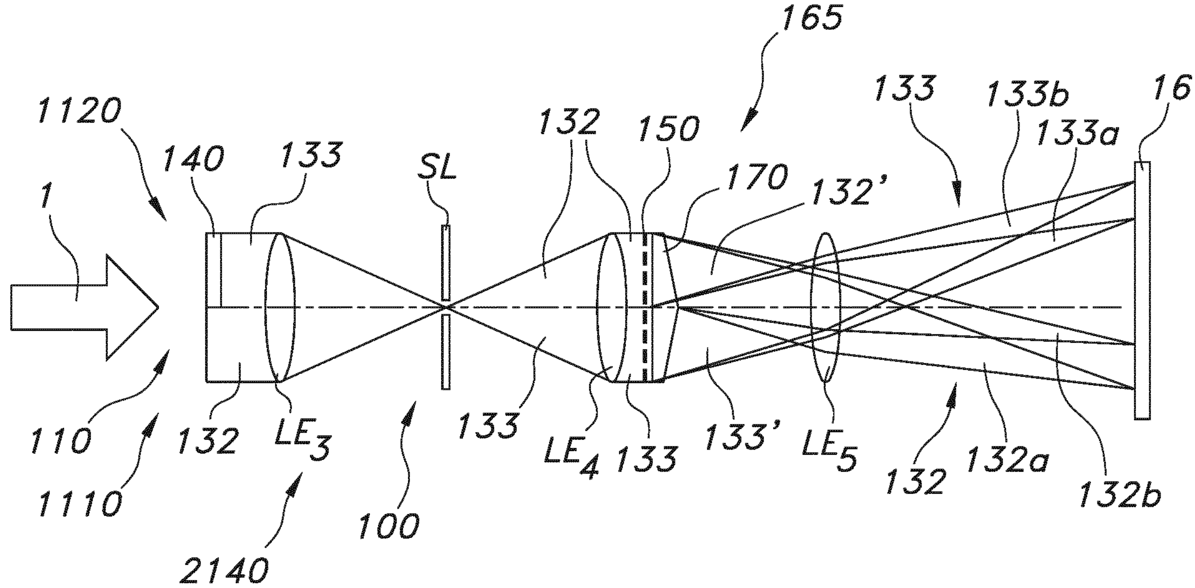

FIG. 14d

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/058808

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01J3/02 G01J3/28 G01J4/04
ADD.

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)
G01J

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2004/195511 A1 (ELMORE DOUGLAS L [US] ET AL) 7 October 2004 (2004-10-07) paragraphs [0107] - [0110], [0145], [0158], [0159], [0170]; figure 3D	1-14, 17-24 15,16
Y	GB 2 483 482 A (UNIV DUBLIN CITY [IE]) 14 March 2012 (2012-03-14) abstract; figure 1	15,16

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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

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"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	Date of mailing of the international search report
17 June 2013	24/06/2013

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Jacquin, Jérôme

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2013/058808

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 2004195511	A1	07-10-2004	NONE		
GB 2483482	A	14-03-2012	GB 2483482	A	14-03-2012
			WO 2012032171	A1	15-03-2012

Form PCT/ISA/210 (patent family annex) (April 2005)