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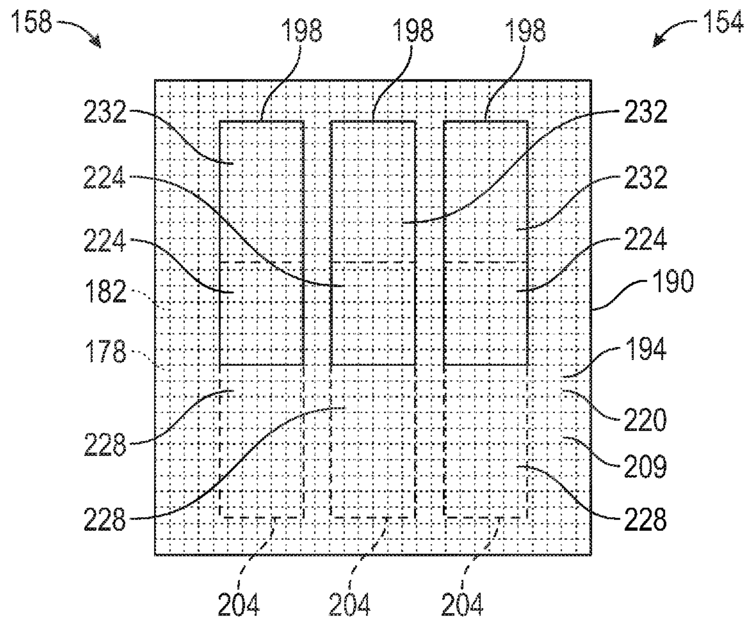

FIG. 8

(57) **Abstract:** An optical system is disclosed and includes an optical sensor, a plurality of photosensitive pixels disposed on the optical sensor, a wavelength-selective optical filter in optical communication with the photosensitive pixels, the wavelength-selective optical filter being disposed remotely from the optical sensor, an area disposed in the wavelength-selective optical filter, the area having a transmission spectrum different from a transmission spectrum of a portion of the wavelength-selective optical filter not in the area and a reflector, the wavelength-selective optical filter and a measurement subject each being disposed between the reflector and the optical sensor along an optical path.

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SENSOR ARRAY SPECTROMETER

Background

Optical filters are employed in a wide variety of applications including optical communication systems, optical sensors, imaging, scientific optical equipment and display systems. Such optical filters may include optical layers that manage the transmission of incident electromagnetic radiation, including light.

Optical filters may reflect or absorb certain portions of incident light and transmit other portions of incident light. Layers within an optical filter may also differ in wavelength selectivity, optical transmittance, optical clarity, optical haze and index of refraction. Systems involving optical sensors and optical filters can gather specific electromagnetic data by nature of the optical filter.

Summary

In some aspects, the present disclosure provides an optical system. The optical system can include an optical sensor, a plurality of photosensitive pixels disposed on the optical sensor and a wavelength-selective optical filter in optical communication with the photosensitive pixels, the wavelength-selective optical filter being disposed remotely from the optical sensor. The optical system can further include an area disposed in the wavelength-selective optical filter, the area having a transmission spectrum different from a transmission spectrum of a portion of the wavelength-selective optical filter not in the area and a reflector, the wavelength-selective optical filter and a measurement subject each being disposed between the reflector and the optical sensor along an optical path.

In some aspects, the present disclosure provides an optical system. The optical system can include an optical sensor, a plurality of photosensitive pixels disposed on the optical sensor and a wavelength-selective optical filter in optical communication with the photosensitive pixels, the wavelength-selective optical filter being disposed remotely from the optical sensor. The optical system can also include a first plurality of spatially-variant areas disposed in the optical filter, and a second plurality of spatially-variant areas disposed in the optical filter, the areas of the first plurality of spatially-variant areas having a transmission spectrum different from that of the areas of the second plurality of spatially-variant areas.

In some aspects, the present disclosure provides an optical system. The optical system can include an optical sensor, a plurality of photosensitive pixels disposed on the optical sensor, a wavelength-selective optical filter in optical communication with the photosensitive pixels, the wavelength-selective optical filter being disposed remotely from the optical sensor, and an area disposed in the wavelength-selective optical filter, the area having a transmission spectrum different from a transmission spectrum of a portion of the wavelength-selective optical filter not in the area.

Brief Description of the Drawings

FIG. 1 is a schematic perspective view of a reflective film according to exemplary implementations of the present disclosure.

FIGS. 2A-2K are schematic illustrations of an optical system according to exemplary implementations of the present disclosure.

FIG. 3 is a front elevation view of an optical sensor and included pixels according to exemplary implementations of the present disclosure.

FIG. 4A is a front elevation view of a first filter sheet, FIG. 4B is a front elevation view of a second filter sheet, and FIG. 4C is a front elevation view of another implementation of the first filter sheet according to exemplary implementations of the present disclosure.

FIG. 5A is a front elevation view of the first filter sheet and second filter sheet adjacent one another and forming an optical filter, FIG. 5B is a top elevation view of the first filter sheet and second filter sheet adjacent one another and forming an optical filter and FIG. 5C is a lateral elevation view of the first filter sheet and second filter sheet adjacent one another and forming an optical filter according to exemplary implementations of the present disclosure.

FIG. 6 is a front elevation view of an exemplary first or second filter sheet including various region shapes according to exemplary implementations of the present disclosure.

FIG. 7 illustrates a schematic view of the optical filter and the optical sensor according to exemplary implementations of the present disclosure.

FIG. 8 illustrates the optical filter proximate the optical sensor, further showing relative positions of regions, areas and pixels, according to exemplary implementations of the present disclosure.

FIG. 9A illustrates an angle-selective filter centered around angle A, according to exemplary implementations of the present disclosure.

FIG. 9B illustrates a second angle-selective filter centered around angle B, according to exemplary implementations of the present disclosure.

FIG. 9C illustrates the first and second angle-selective filters centered around angles A and B, respectively, and where arcs defining a range of possible angle A measurements and possible angle B measurements define perpendicular planes, according to exemplary implementations of the present disclosure.

FIG. 10 and FIG. 11 schematically illustrates portions of the angle-selective filter according to exemplary implementations of the present disclosure.

Detailed Description

In the following description, reference is made to the accompanying drawings that form a part hereof and in which various embodiments are shown by way of illustration. The drawings are not necessarily to scale. It is to be understood that other embodiments and implementations are contemplated and may be made without departing from the scope or spirit of the present description. The following detailed description, therefore, is not to be taken in a limiting sense.

Multilayer optical films, i.e., films that provide desirable transmission and/or reflection properties at least partially by an arrangement of microlayers of differing refractive index, are known. It has been known to make such multilayer optical films by depositing a sequence of inorganic materials in optically thin layers ("microlayers") on a substrate in a vacuum chamber. Inorganic multilayer optical films are described, for example, in textbooks by H. A. Macleod, *Thin-Film Optical Filters,* 2nd Ed., Macmillan Publishing Co. (1986) and by A. Thelan, *Design of Optical Interference Filters*, McGraw-Hill, Inc. (1989).

Multilayer optical films have also been demonstrated by coextrusion of alternating polymer layers. See, e.g., U.S. Patents 3,610,729 (Rogers), 4,446,305 (Rogers et al.), 4,540,623 (Im et al.), 5,448,404 (Schrenk et al.) and 5,882,774 (Jonza et al.). In these polymeric multilayer optical films, polymer materials are used predominantly or exclusively in the makeup of the individual layers. These may be referred to as thermoplastic multilayer optical films. Such films are compatible with high volume manufacturing processes and can be made in large sheets and roll goods. The description and examples below relate, in some implementations of the present disclosure, to thermoplastic multilayer optical films.

A multilayer optical film includes individual microlayers having different refractive index characteristics such that some light is reflected at interfaces between adjacent microlayers. The microlayers are sufficiently thin so that light reflected at a plurality of the interfaces undergoes constructive or destructive interference in order to give the multilayer optical film the desired reflective or transmissive properties. For multilayer optical films designed to reflect light at ultraviolet, visible, or near-infrared wavelengths, each microlayer may have an optical thickness (a physical thickness multiplied by refractive index) of less than about 1 μm. Layers may be arranged generally as thinnest to thickest. In some embodiments, the arrangement of the alternating optical layers may vary substantially linearly as a function of layer count. These layer profiles may be referred to as linear layer profiles. Thicker layers may be included, such as skin layers at the outer surfaces of the multilayer optical film, or protective boundary layers (PBLs) disposed within the multilayer optical films, that separate coherent groupings (referred to herein as "packets") of microlayers. In some cases, the protective boundary layer may be the same material as at least one of the alternating layers of the multilayer optical film. In other cases, the protective boundary layer may be a different material, selected for its physical or rheological properties. The protective boundary layers may be on one side or on both sides of an optical packet. In the case of a single-packet multilayer optical film, the protective boundary layer may be on one or both external surfaces of the multilayer optical film.

Packets, for the purpose of this description, can be monotonically varying thicknesses of optical repeat units. For example, packets may be monotonically increasing, monotonically decreasing, both increasing and constant, or both decreasing and constant. One or several layers that do not follow this pattern should be understood to be nonconsequential to the overall definition or identification of a certain optical repeat layer grouping as a packet. In some embodiments, it may be helpful to define a packet as the largest discrete grouping of consecutive, non-redundant layer pairs that collectively provides reflection over a certain subrange of the spectrum of interest (e.g., the visible spectrum).

In some cases, the microlayers have thicknesses and refractive index values providing a ¼-wave stack, i.e., arranged in optical repeat units or unit cells each having two adjacent microlayers of equal optical thickness (f-ratio = .5), such optical repeat unit being effective to reflect by constructive interference light whose wavelength λ is about twice the overall optical thickness of the optical repeat unit. Other layer arrangements, such as multilayer optical films having 2-microlayer optical repeat units whose f-ratio is different from 50%, or films whose optical repeat units include more than two microlayers, are also known. These optical repeat unit designs can be configured to reduce or to increase certain higher-order reflections. See, e.g., U.S. Patent Nos. 5,360,659 (Arends et al.) and 5,103,337 (Schrenk et al.). Thickness gradients of the optical repeat units along a thickness axis of the film (e.g., the z-axis) can be used to provide a widened reflection band, such as a reflection band that extends over the entire human visible region and into the near infrared so that as the band shifts to shorter wavelengths at oblique incidence angles the microlayer stack continues to reflect over the entire visible spectrum. Thickness gradients tailored to sharpen band edges, i.e., the wavelength transition between high reflection and high transmission, are discussed in U.S. Patent 6,157,490 (Wheatley et al.). Further, the multilayer optical film can use an optical absorber incorporated therein, which can be a pigment or a dye, to modify a transmission spectrum of the multilayer optical film. The optical absorber can be a coating or can be included anywhere along an optical path through the multilayer optical film.

As will be discussed below, the present disclosure provides an optical system for analyzing an optical spectrum of one or more areas. Through various elements and technologies, the optical system can be optimized to gather optical data of a measurand having a particular absorption spectrum. Non-limiting applications could include multispectral "liveness" detection for fingerprints or other biometrics, health care diagnostics including remote medicine modes, authentication of a part using spectra as an identifying feature and many other possible uses.

FIG. 1 is a schematic perspective view of a reflective film. FIG. 1 illustrates a light ray 130 that is incident on a reflective film 110 at an angle of incidence θ, thereby forming a plane of incidence 132. The reflective film 110 includes a first reflection axis 116 that is parallel to the x-axis, and a second reflection axis 114 that is parallel to the y-axis. The plane of incidence 132 of ray 130 is parallel to the first reflection axis 116. Ray 130 has a p-polarized component that is in the plane of incidence 132, and an s-polarized component that is orthogonal to the plane of incidence 132. The p-polarized light of ray 130 will be reflected by the reflective film with a reflectivity of R_{pp-x} (the projection of the electric field of the p-polarized light of ray 130 onto the plane of reflective film 110 is parallel to the x-direction), while the s-polarized light of ray 130 is reflected by the reflective film with a reflectivity of R_{ss-y} (the electric field of the s-polarized light of ray 130 is parallel to the y-direction).

Further, FIG. 1 illustrates ray 120 that is incident on the reflective film in a plane of incidence 122 that is parallel to the second reflection axis 114 of the film 110. Ray 120 has a p-polarized component that is in the plane of incidence 122, and an s-polarized component that is orthogonal to the plane of incidence 122. The p-polarized light of ray 120 will be reflected by the reflective film with a reflectivity of R_{pp-y}, while the s-polarized light of ray 120 is reflected by the reflective film with a reflectivity of R_{ss-x}. The amount of transmission and reflection of p- and s- polarized light, for any plane of incidence, will depend on the characteristics of reflective film.

FIG. 2A schematically illustrates an exemplary optical system 150. In some implementations, the optical system 150 includes an optical sensor 154, an optical filter 158, a light source 162 and a reflector 163. A measurement subject 170 is also illustrated. In some implementations, light emitted from the light source 162 passes through the optical filter 158 and measurement subject 170, reflects off of the reflector 163 and then passes back through the measurement subject 170 and optical filter 158 before reaching the optical sensor 154. Optical path 173A can be seen from light source 162, reflecting off the reflector 163, and then reaching the optical sensor 154.

FIG. 2B schematically illustrates an exemplary optical system 150. In some implementations, the optical system 150 includes an optical sensor 154, an optical filter 158, a light source 162 and a reflector 163. A measurement subject 170 is also illustrated. In some implementations, light emitted from the light source 162 passes through the measurement subject 170 and optical filter 158, reflects off of the reflector 163 and then passes back through the optical filter 158 and measurement subject 170 before reaching the optical sensor 154. Optical path 173B can be seen from light source 162, reflecting off the reflector 163, and then reaching the optical sensor 154.

FIG. 2C schematically illustrates an exemplary optical system 150 similar to that shown in FIG 2A. However, the optical sensor 154 and light source 162 can be included in an optical device 160. The optical device 160 can be a mobile phone, a tablet, a computer or any other medical, electrical or electromechanical device. Optical path 173C can be seen traveling from the light source 162, to the reflector and then reaching the optical sensor 154.

FIG. 2D schematically illustrates an exemplary optical system 150, similar to that of FIG 2B. However, the optical sensor 154 and light source 162 can be included in the optical device 160. Optical path 173D can be seen travelling from the light source 162, to the reflector 163 and then reaching the optical sensor 154.

FIG. 2E schematically illustrates an exemplary optical system 150. In some implementations, ambient light and/or light emitted from the measurement subject 170 passes through the optical filter 158 before reaching the optical sensor 154. Optical path 173E can be seen between the measurement subject 170 and the optical sensor 154.

FIG. 2F schematically illustrates an exemplary optical system 150. In some implementations, ambient light passes through the optical filter 158 before reaching the optical sensor 154. Optical path 173F can be seen between the optical filter 158 and the optical sensor 154.

FIG. 2G schematically illustrates an exemplary optical system 150. In some implementations, light emitted from the light source 162 and/or ambient light passes through the measurement subject 170 and the optical filter 158 before reaching the optical sensor 154. Optical path 173G can be seen between the light source 162 and the optical sensor 154.

FIG. 2H schematically illustrates an exemplary optical system 150. In some implementations, light emitted from the light source 162 and/or ambient light passes through the optical filter 158 and the measurement subject 170 before reaching the optical sensor 154. Optical path 173H can be seen between the light source 162 and the optical sensor 154.

FIG. 2I schematically illustrates an exemplary optical system 150. In some implementations, the optical system 150 includes an angle-selective filter 166. Light emitted from the light source 162 passes through elements of the optical system 150, reflects off of the reflector 163 and then passes through the measurement subject 170, optical filter 158 and angle-selective filter 166 before reaching the optical sensor 154. Optical path 173I can be seen from the light source 162, reflecting off the reflector 163 and then reaching the optical sensor 154.

FIG. 2J schematically illustrates an exemplary optical system 150 similar to that shown in FIG. 2I. In some implementations, the optical system 150 includes a second angle-selective filter 167 disposed along optical path 173J, as will be described below.

FIG. 2K schematically illustrates an exemplary optical system including a cross polarizer 171. The light source 162, in some implementations, is a polarized light source, whereby at least some light emitted from the polarized light source reflects off of the reflector 163, along optical path 173K, such that only light, or substantially only light, reflected by the reflector 163 is detected by the optical sensor 154 due to the polarized nature of the light and the corresponding pass properties of the cross polarizer 171.

In some implementations, the reflector 163 reflects all, substantially all or a portion of light incident on the reflector 163. In some implementations, the reflector 163 can be a specular reflector, a semi-specular reflector, a lambertian reflector, a diffuse reflector or a retroreflector. In the case of the reflector 163 being a retroreflector, the retroreflector 163 can be one of a cube corner reflector, such as 3M Diamond Grade sheeting, or a bead-based retroreflector, such as 3M Scotchlite, or a phase-conjugate retroreflector

The term “remote” can mean, in certain exemplary implementations of this disclosure, disposed at a distance from, disposed at a minimum distance from, disposed at least 1, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 150, 200, 250, 500, 1000, 2,000 or 10,000 millimeters from, at least 1 kilometer from, apart from, not in contact with, not adjacent to and/or not integrated with. As can be seen in FIGS. 2A-2K, the optical sensor 154 can be disposed remotely from the measurement subject 170, optical filter 158, reflector 163, light source 162, angle-selective filter 166, second angle-selective filter 167 and/or cross polarizer 171. The light source 162 can be disposed remotely from the measurement subject 170, optical filter 158, reflector 163, light source 162, angle-selective filter 166, second angle-selective filter 167, optical sensor 154 and/or cross polarizer 171. The optical device 160 can be disposed remotely from the measurement subject 170, optical filter 158, reflector 163, light source 162, angle-selective filter 166, second angle-selective filter 167 and/or cross polarizer 171. It is to be understood that measurement subject 170 can be disposed anywhere along any disclosed optical path, and further the measurement subject 170 can be a liquid, solid or a gas.

In some implementations, the light source 162 can include one or more of an organic light-emitting diode, an inorganic light-emitting diode, a mini light-emitting diode, a micro light-emitting diode, an incandescent filament, a light-emitting diode, a vertical cavity surface emitting laser or the optical sensor 154 itself can emit light.

It is to be understood that the aforementioned elements of the optical system 150 can be disposed in any permutation, order or arrangement, can be in contact, not in contact, adjacent, proximate or joined while still being in optical communication, and while still falling within the scope of the disclosed optical system 150. FIGS. 2A-2K merely represent exemplary implementations of the optical system 150. For example, the cross polarizer 171 could be included with any exemplary optical system 150 shown in FIGS. 2A-2K. Further, the angle-selective filter 166, or the angle-selective filter 166 and the second angle-selective filter 167 could be included with any exemplary optical system 150 shown in FIGS. 2A-2K.

The optical sensor 154 can sense light over a single area, or can be divided into a plurality of light-gathering photosensitive picture elements, or pixels 178. These pixels 178 can be seen in exemplary FIG. 3. One or more of the pixels 178 can serve a reference pixel 182, as will be described below in further detail. The optical sensor 154 can include a charge-coupled device, a complementary-metal-oxide semiconductor or can employ any other light-sensing sensor technology. Additionally, the optical sensor 154 can include one or more photosensors, organic photosensors, photodiodes and/or organic photodiodes.

In some implementations, the optical sensor 154 is flexible. Such a flexible optical sensor 154 can have properties of being bendable without cracking. Such a flexible optical sensor 154 can also be capable of being formed into a roll. In some implementations, the flexible optical sensor 154 can be bent around a roll core with a radius of curvature of, or up to, 7.6 centimeters (cm) (3 inches), 6.4 cm (2.5 inches), 5 cm (2 inches), 3.8 cm (1.5 inches), 2.5 cm (1 inch), 1.9 cm (3/4 inch), 1.3 cm (1/2 inch) or 0.635 cm (1/4 inch).

FIG. 4A shows an exemplary first filter sheet 190 and FIG. 4B shows an exemplary second filter sheet 194. The optical filter 158 can include the first filter sheet 190 and/or the second filter sheet 194. The first filter sheet 190 and second filter sheet 194 can be formed of one or more packets of optical films, as described above. One or more written regions 198 can be defined, or formed, in the first filter sheet 190. The written regions 198 can be physical apertures formed in the first filter sheet 190 through die cutting, laser ablation, heating, spatially variant coating, printing, inkjet printing, laser printing and/or water jet cutting, among other processes.

Further, as shown in FIG. 4C, an exemplary implementation of the first filter sheet 190 includes the written regions 198 along with one or more auxiliary written regions 199. The written regions 198 and auxiliary written regions 199 can be of different sizes, shapes and/or spatial patterns on the first filter sheet 190. One or more of the auxiliary written regions 199 can be larger than one or each of the pixels 178. Further, one or more of the auxiliary written regions 199 produces or defines an auxiliary transmission spectrum, which can be the same as or different from the transmission spectrum defined, or produced, by the written regions 198. It is to be understood that the written regions 198, 204 can be formed in the same manners as the auxiliary written regions 199.

The written regions 198 can also be formed using spatially tailored optical film processes, such as those described in U.S. Patent No. 9,810,930 (Merrill et al.), incorporated herein by reference. In particular, a laser process can locally destroy the birefringence, and thus change the optical properties and transmission spectra of written regions (such as the written regions 198). These written regions can be made completely clear, or can have a wavelength selective function (or a transmission spectrum) different from a non-written region 200 of the first filter sheet 190. One or more written regions 204 can be defined, or formed, in the second filter sheet 194 through any of the aforementioned ways that the written regions 198 are formed in the first filter sheet 190. Further, a non-written region 206 of the second filter sheet 194 is shown in FIG. 4B. Thus, the optical filter 158 can be a spatially-variant optical filter, a wavelength-selective optical filter or a spatially-variant wavelength-selective optical filter, as will be described in further detail. The written regions 198 can be of differing shapes and/or sizes within the first filter sheet 190, and the written regions 204 can be of different shapes and/or sizes within the second filter sheet 194.

The written regions 198 can be arranged in a pattern, or a repeated pattern, such that the written regions 198 are disposed in a predictable manner. Similarly, the written regions 204 can be arranged in a pattern, or a repeated pattern, such that the written regions 204 are disposed in a predictable manner. The pattern of the written regions 198 and written regions 204 may be identical, similar, dissimilar, overlapping, corresponding, partially-overlapping or unrelated when the first filter sheet 190 and second filter sheet 194 are adjacent, in contact, proximate or joined with one another. In other words, when the first filter sheet

190 and second filter sheet 194 are adjacent, in contact, proximate or joined with one another in a particular manner, the written regions 198 and written regions 204 may be overlapping, corresponding, partially-overlapping, unrelated, identical, similar or dissimilar.

An implementation of the optical filter 158 is shown in FIG. 5A. In some implementations, the optical filter 158 includes the first filter sheet 190 and the second filter sheet 194, and further the first filter sheet 190 and the second filter sheet 194 can be in contact, adjacent or proximate one another. In some implementations, the first filter sheet 190 and second filter sheet 194 are joined, or laminated, together by one of a number of known joining technologies including weldments, adhesives and lamination, among others.

In some implementations, as shown in FIGS. 5A, 5B and 5C, when the first filter sheet 190 and second filter sheet 194 are adjacent, in contact, proximate or joined with one another in a particular manner, to thus form the optical filter 158, the written regions 198 and written regions 204 are partially-overlapping. In such an arrangement, rays of light incident on a front surface 209 of the optical filter 158, or to an entirety of a front surface 209 of the optical filter 158, pass through each of four different areas: a first area 220, where the incident light passes through the non-written region 200 of the first filter sheet 190 and the non-written region 206 of the second filter sheet 194, a second area 224 where the incident light passes through the written region 198 in the first filter sheet 190 and through the written region 204 in the second filter sheet 194, a third area 228 where the incident light passes through the non-written region 200 of the first filter sheet 190 and through the written region 204 in the second filter sheet 194, and a fourth area 232 where the incident light passes through the non-written region 206 of the second filter sheet 194 and through the written region 198 of the first filter sheet 190. Through such an exemplary implementation of the optical filter 158, rays of the incident light can pass through each of the areas 220, 224, 228 and 232 to thereby be filtered in four different manners by varied influences of the first filter sheet 190 and second filter sheet 194.

In some implementations, written regions 198, 204 and/or areas 220, 224, 228 and 232 can be of various shapes that have the same transmission spectrum. In particular, one of written regions 198, 204 and/or areas 220, 224, 228 and 232 can have a first shape and a first transmission spectrum, while another of written regions 198, 204 and/or areas 220, 224, 228 and 232 can have a second shape, different from the first shape, and a second transmission spectrum, different from the first transmission spectrum.

In some implementations, written regions 198, 204 and/or areas 220, 224, 228 and 232 can include various absorptive materials, such as dyes and/or pigments. The absorptive materials could be adhered to, inserted into or formed within the first filter sheet 190, optical filter 158 and/or the second filter sheet 194, and the absorptive materials can be printed, printed using flexographic or offset techniques, coated or extruded onto the first filter sheet 190, second filter sheet 194 and/or optical filter 158.

In some implementations, the first filter sheet 190 and second filter sheet 194 can be adhered together using an adhesive to form the optical filter 158, and the adhesive can include the absorptive material.

In some implementations, a first absorptive material can be adhered to, inserted into or formed within the first filter sheet 190, and may form the written regions 198, while a second absorptive material can be adhered to, inserted into or formed within the second filter sheet 194, and may form the written regions 204. The first absorptive material could have a different transmission spectrum from that of the second absorptive material. In some implementations, the first absorptive material absorbs light with wavelengths approximately from 400-700nm while the second absorptive material absorbs light with wavelengths approximately from 400-1000nm. Given the differing block and pass properties of the first and second absorptive materials, and the exemplary construction of the first and second filter sheets 190, 194 to form the optical filter 158 as shown in FIG. 5A, light along an optical path can be thusly filtered to provide valuable data about the measurement subject 170 when absorbed by the optical sensor 154.

In some implementations of the optical filter 158, one or more absorptive filters, formed from the absorptive material, could be patterned on a reflective interference filter.

In some implementations, the written regions 198 disposed in the first filter sheet 190 and/or the written regions 204 disposed in the second filter sheet 194 can include particular shapes. For example, at least some written regions 198 disposed in the first filter sheet 190 and/or at least some written regions 204 disposed in the second filter sheet 194 can include one or more of circles, squares, triangles, ovals, rectangles, pentagons, hexagons, heptagons, octagons, organic shapes, partially-organic shapes, parallelograms, polygons and non-polygonal organic shapes. Examples of these shapes are shown, in non-limiting fashion, in FIG. 6. It is to be understood that one or more of the written regions 198 in the first filter sheet 190 and the written regions 204 in the second filter sheet 194 can form one or more of these shapes, in any order, arrangement or permutation. Further, one or more of the written regions 198 in the first filter sheet 190 and the written regions 204 in the second filter sheet 194 can be the same shape or can be different shapes.

In some implementations, the written regions 198 in the first filter sheet 190 and/or the written regions 204 in the second filter sheet 194 can include particular sizes. Further, one or more of the written regions 198 in the first filter sheet 190 and the written regions 204 in the second filter sheet 194 can be the same size or can be different sizes. Individual sizes of the written region can vary depending on the sensing application, but can be chosen to be larger than the pixel 178 size used in the optical sensor 154 so that multiple pixels 178 are used to collect the light to increase detection power for the spectral region defined by the written region. The optical sensor pixels 178 can then be grouped by hardware or software methods to align those pixels 178 to the written region resulting in spectral-spatial mapping of the measurement layer, or measurement subject. Any one or more of the written regions 198, 204, auxiliary written regions 199 and/or areas 220, 224, 228, 232 can be larger than one pixel 178, than two pixels, 178, than five pixels 178, than ten pixels 178, than one hundred pixels 178, than one thousand pixels 178 or than any number of pixels 178 in certain implementations.

As shown in FIG. 7, the optical filter 158 may be in optical communication with the optical sensor 154. In other words, light incident on the optical filter 158 may pass through one or more areas (220, 224, 228, 232) of the optical filter 158 and then reach the optical sensor 154. The optical filter 158 may be adjacent, in contact with, joined with, proximate or distal to the optical sensor 154 while still residing in optical communication with the optical sensor 154. FIG. 7 illustrates the optical filter 158 and the optical sensor 154, whereby the optical sensor is brought proximate, or adjacent, the optical sensor 154. FIG. 8 illustrates a possible relationship between the optical filter 158 and the optical sensor 154, where the optical sensor 154 is proximate, adjacent or in contact with the optical filter 158.

It can be seen in FIGS. 7 and 8 that, in some implementations, at least some of the pixels 178 are smaller than the written regions 198 in the first filter sheet 190, the written regions 204 in the second filter sheet 194, the first area 220, the second area 224, the third area 228 and/or the fourth area 232. Further, in some implementations, each of the pixels 178 is smaller than the written regions 198 in the first filter sheet 190, the written regions 204 in the second filter sheet 194, the first area 220, the second area 224, the third area 228 and/or the fourth area 232. At least one pixel 178 can be in optical communication with one of the written regions 198, written regions 204, first area 220, second area 224, third area 228 and fourth area 232, depending on the makeup of the optical filter 158, such that light incident on the optical system 150 and influenced by an aforementioned portion of the optical filter 158 is registered to, and recorded by, at least one pixel 178. Additionally, as described earlier, the presence of other elements (such as the light source 162 or angle-selective filter 166) does not preclude the optical filter 158 from being in optical communication with the optical sensor 154, even if the optical filter 158 is not adjacent, in contact with or proximate the optical sensor 154.

Each portion of the first filter sheet 190, second filter sheet 194 and optical filter 158 defines, or produces, a transmission spectrum or transmission spectra. It is to be understood that such a transmission spectrum or spectra defines a wavelength range of light which is transmitted, substantially transmitted, 90% transmitted, substantially 90% transmitted or partially transmitted. Similarly, light having a wavelength outside of the transmission spectrum or spectra is blocked, substantially blocked or partially blocked. In some implementations, a visible spectrum is defined as 400nm-700nm, or approximately 400nm-700nm, a near-infrared spectrum is defined as 700nm-2000nm, or approximately 700nm-2000nm, and a near-ultraviolet spectrum is defined as 350nm-400nm, or approximately 350nm-400nm.

In some implementations, the transmission spectrum of the non-written region 200 of the first filter sheet 190 is, or includes, the visible spectrum, the near-ultraviolet spectrum and/or the near-infrared spectrum. In some implementations, the transmission spectrum of the non-written region 200 of the first filter sheet 190 is, or includes, approximately the visible spectrum, approximately the near-ultraviolet spectrum and/or approximately the near-infrared spectrum. In some implementations, the transmission spectrum of the non-written region 206 of the second filter sheet 194 is, or includes, the visible spectrum, the near-ultraviolet spectrum and/or the near-infrared spectrum. In some implementations, the transmission spectrum of the non-written region 206 of the second filter sheet 194 is, or includes, approximately the visible spectrum, approximately the near-ultraviolet spectrum and/or approximately the near-infrared spectrum.

In some implementations, the transmission spectrum of the written region 198 of the first filter sheet 190 is, or includes, the visible spectrum, the near-ultraviolet spectrum and/or the near-infrared spectrum. In some implementations, the transmission spectrum of the written region 198 of the first filter sheet 190 is, or includes, approximately the visible spectrum, approximately the near-ultraviolet spectrum and/or approximately the near-infrared spectrum. In some implementations, the transmission spectrum of the auxiliary written region 199 of the first filter sheet 190 is, or includes, the visible spectrum, the near-ultraviolet spectrum and/or the near-infrared spectrum. In some implementations, the transmission spectrum of the auxiliary written region 199 of the first filter sheet 190 is, or includes, approximately the visible spectrum, approximately the near-ultraviolet spectrum and/or approximately the near-infrared spectrum. In some implementations, the transmission spectrum of the written region 204 of the second filter sheet 194 is, or includes, the visible spectrum, the near-ultraviolet spectrum and/or the near-infrared spectrum. In some implementations, the transmission spectrum of the written region 204 of the second filter sheet 194 is, or includes, approximately the visible spectrum, approximately the near-ultraviolet spectrum and/or approximately the near-infrared spectrum.

In some implementations, the transmission spectrum of the first area 220 is, or includes, the visible spectrum, the near-ultraviolet spectrum and/or the near-infrared spectrum. In some implementations, the transmission spectrum of the first area 220 is, or includes, approximately the visible spectrum, approximately the near-ultraviolet spectrum and/or approximately the near-infrared spectrum. In some implementations, the transmission spectrum of the second area 224 is, or includes, the visible spectrum, the near-ultraviolet spectrum and/or the near-infrared spectrum. In some implementations, the transmission spectrum of the second area 224 is, or includes, approximately the visible spectrum, approximately the near-ultraviolet spectrum and/or approximately the near-infrared spectrum. In some implementations, the transmission spectrum of the third area 228 is, or includes, the visible spectrum, the near-ultraviolet spectrum and/or the near-infrared spectrum. In some implementations, the transmission spectrum of the third area 228 is, or includes, approximately the visible spectrum, approximately the near-ultraviolet spectrum and/or approximately the near-infrared spectrum. In some implementations, the transmission spectrum of the fourth area 232 is, or includes, the visible spectrum, the near-ultraviolet spectrum and/or the near-infrared spectrum. In some implementations, the transmission spectrum of the fourth area 232 is, or includes, approximately the visible spectrum, approximately the near-ultraviolet spectrum and/or approximately the near-infrared spectrum.

In some implementations, the transmission spectrum of one or more of the first, second, third or fourth areas (220, 224, 228, 232) is, substantially is, substantially includes or includes, the same transmission spectrum as one or more of the others of the first, second, third or fourth areas (220, 224, 228, 232). In some implementations, the transmission spectrum of one or more of the first, second, third or fourth areas (220, 224, 228, 232) is distinct, substantially distinct, substantially partially distinct or partially distinct, from the transmission spectrum as one or more of the others of the first, second, third or fourth areas (220, 224, 228, 232).

In some implementations, the optical filter 158 (which can be a wavelength-selective optical filter) includes a first plurality of areas, or of spatially-variant areas, which can be one or more of the first, second, third or fourth areas (220, 224, 228, 232) and a second plurality of areas, or of spatially-variant areas, which can be one or more of the first, second, third or fourth areas (220, 224, 228, 232). The areas of the first plurality of areas, or of spatially-variant areas, can have a transmission spectrum different from that of the areas of the second plurality of areas, or of spatially-variant areas.

In some implementations, the optical filter 158 is flexible. Such a flexible optical filter 158 can have properties of being bendable without cracking. Such a flexible optical filter 158 can also be capable of being formed into a roll. In some implementations, the flexible optical filter 158 can be bent around a roll core with a radius of curvature of up to 7.6 centimeters (cm) (3 inches), 6.4 cm (2.5 inches), 5 cm (2 inches), 3.8 cm (1.5 inches), 2.5 cm (1 inch), 1.9 cm (3/4 inch), 1.3 cm (1/2 inch) or 0.635 cm (1/4 inch).

Further, the optical sensor 154 may be active in a particular wavelength range. In other words, the optical sensor 154 may absorb and electronically register incident light, optimally absorb and electronically register incident light or partially absorb and electronically register incident light in the visible spectrum, the near-ultraviolet spectrum and/or the near-infrared spectrum.

As described, one or more of the pixels 178 may be, or serve as, the reference pixel 182. The reference pixel 182 can be used to reference one or more wavelengths to a lookup table of known thresholds or values. Such a reference pixel 182 can be used to calibrate the optical system 150 and to ensure measurement conditions remain acceptable before, during and/or after a measurement is performed.

In some implementations, the optical system 150 includes the angle-selective filter 166. The angle-selective filter 166 limits an angle of light transmission through the angle-selective filter 166 such that light rays greater than a certain incident angle, greater than an approximate incident angle, less than a certain incident angle, less than an approximate incident angle, greater than a first incident angle and less than a second incident angle and greater than an approximate first incident angle and less than a second approximate incident angle are blocked, substantially blocked or partially blocked from transmitting through the angle-selective filter 166.

In some implementations, as shown in FIG. 9A, the angle-selective filter 166 is centered around a particular angle A, meaning a range of light rays 223 incident to the angle-selective filter 166 is centered around A degrees as measured from the angle-selective filter 166. In some implementations, angle A equals 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80 or 85 degrees. In some implementations, angle A equals approximately 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80 or 85 degrees.

In some implementations, as shown in FIG. 9B, the second angle-selective filter 167 is used in the optical system 150 in addition to the angle-selective filter 166. The second angle-selective filter 167 can be centered around a particular angle B, meaning a range of light rays 225 incident to the second angle-selective filter 167 is centered around B degrees as measured from the second angle-selective filter 167. In some implementations, angle B equals 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80 or 85 degrees. In some implementations, angle B equals approximately 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80 or 85 degrees.

Further, the angle-selective filter 166 and second angle-selective filter 167 can be disposed such that arcs defining a range of possible angle A measurements and possible angle B measurements define perpendicular planes, as shown in FIG. 9C, when the angle-selective filter 166 and second angle-selective filter 167 are in contact, proximate, adjacent or joined in a parallel and/or planar-parallel fashion. In some implementations, any other angle can be formed between planes defined by the arc defining a range of possible angle A measurements and the arc defining a range of possible angle B measurements.

With reference to FIG. 10, a cross-sectional view of an exemplary angle-selective filter 166, or light control film (LCF), 166 is shown. The angle-selective filter 166 includes a light output surface 300 and an opposing light input surface 304. The light output surface 300 can be parallel to the light input surface 304. Angle-selective filter 166 includes alternating transmissive regions 308 and absorptive regions 312 disposed between the light output surface 300 and a light input surface 304.

In some embodiments, as depicted in FIG. 10, the transmissive regions 308 are typically integral with a land region "L", meaning that there is no interface between the land region and the base portion 316 of the transmissive regions 308. Alternatively, the angle-selective filter may lack such land region L or an interface may be present between the land region, L, and transmissive regions 308. In some embodiments, the land region is disposed between the alternating transmissive regions 308 and absorptive regions 312, and the light input surface 304.

In some embodiments, surface 300 is the light input surface and surface 304 may be the light output surface. In such an embodiment, the land region is disposed between the alternating transmissive regions 308 and absorptive regions 312, and the light output surface.

The transmissive regions 308 can be defined by a width "W_T". Excluding the land region “L”, the transmissive regions 308 typically have nominally the same height as the absorptive regions 312. In typical embodiments, the height of the absorptive regions, H_A, is at least 30, 40, 50, 60, 70, 80, 90 or 100 microns. In some embodiments, the height is no greater than 200, 190, 180, 170, 160 or 150 microns. In some embodiments, the height is no greater than 140, 130, 120, 110 or 100 microns. The angle-selective filter typically comprises a plurality of transmissive regions having nominally the same height and width. In some embodiments, the transmissive regions have a height, "H_T", a maximum width at its widest portion, "W_T", and an aspect ratio, H_T/W_T, of at least 1.75. In some embodiments, H_T/W_T is at least 2.0, 2.5, 3.0, 3.5, 4.0, 4.5 or 5.0. In other embodiments, the aspect ratio of the transmissive regions is at least 6, 7, 8, 9 or 10. In other embodiments, the aspect ratio of the transmissive regions is at least 15, 20, 25, 30, 35, 40, 45 or 50.

Absorptive regions 312 have a height "H_A" defined by the distance between a bottom surface 320 and top surface 324, such top and bottom surfaces typically being parallel to the light output surface 300 and light input surface 304. The absorptive regions 312 have a maximum width W_A and are spaced apart along the light output surface 300 by a pitch "P_A".

The width of the absorptive regions, W_A, at the base (i.e. adjacent bottom surface 320) is typically nominally the same as the width of the absorptive regions adjacent the top surface 324. However, when the width of the absorptive regions at the base differs from the width adjacent the top surface, the width is defined by the maximum width. The maximum width of a plurality of absorptive regions can be averaged for an area of interest, such as an area in which the transmission (e.g. brightness) is measured. The angle-selective filter typically comprises a plurality of absorptive regions having nominally the same height and width. In typical embodiments, the absorptive regions generally have a width no greater than 10, 9, 8, 7, 6, 5, 4, 3, 2 or 1 micron. In some embodiments, the absorptive regions generally have a width no greater than 900, 800, 700, 600 or 500 nanometers. In some embodiments, the absorptive regions have a width of at least 50, 60, 70, 80, 90 or 100 nanometers.

An absorptive region can be defined by an aspect ratio, the height of the absorptive region divided by the maximum width of the absorptive region (H_A/W_A). In some embodiments, the aspect ratio of the absorption regions is at least 1, 2, 3, 4, 5, 6, 7, 8, 9 or 10. In some embodiments, the height and width of the absorptive region(s) are selected such that the absorptive region(s) have an even higher aspect ratio. In some embodiments, the aspect ratio of the absorption regions is at least 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95 or 100. In other embodiments, the aspect ratio of the absorption regions is at least 200, 300, 400 or 500. The aspect ratio can range up to 10,000 or greater. In some embodiments, the aspect ratio is no greater than 9,000, 8,000, 7,000, 6,000, 5,000, 4,000, 3000, 2,000 or 1,000.

As shown in FIG. 11, angle-selective filter 166 includes alternating transmissive regions 308 and absorptive regions 312, and an interface 330 between transmissive regions 308 and absorptive regions 312. Interface 330 forms a wall angle θ with line 334 that is perpendicular to light output surface 300.

Larger wall angles θ decrease transmission at normal incidence, or at a viewing angle of 0 degrees. Smaller wall angles are preferred such that the transmission of light at normal incidence can be made as large as possible. In some embodiments, the wall angle θ is less than 10, 9, 8, 7, 6 or 5 degrees. In some embodiments, the wall angle is no greater than 2.5, 2.0. 1.5, 1.0, 0.5 or 0.1 degrees. In some embodiments, the wall angle is zero or approaching zero. When the wall angle is zero, the angle between the absorptive regions and light output surface 300 is 90 degrees. Depending on the wall angle, the transmissive regions can have a rectangular or trapezoidal cross-section.

The transmission (e.g. brightness) can be increased when incident light undergoes total internal reflection (TIR) from the interface between the absorptive and transmissive regions. Whether a light ray will undergo TIR or not can be determined from the incidence angle with the interface, and the difference in refractive index of the materials of the transmissive and absorptive regions.

As shown in FIG. 11, transmissive regions 308 between absorptive regions 312 have an interface angle θ_I defined by the geometry of alternating transmissive regions 308 and absorptive regions. The polar cut-off viewing angle θP can be equal to the sum of a polar cut-off viewing half angle θ1 and a polar cut-off viewing half angle θ2, each of which are measured from the normal to light input surface 304. In typical embodiments, the polar cut-off viewing angle θP is symmetric, and polar cut-off viewing half angle θ1 is equal to polar viewing half angle θ2. Alternatively, the polar cut-off viewing angle θP can be asymmetric and polar cut-off viewing half angle θ1 is not equal to polar cut-off viewing half angle θ2.

The alternating transmissive and absorptive regions or total angle-selective filter can exhibit increased relative transmission (e.g. brightness) at a viewing angle of 0 degrees. In some embodiments, the relative transmission (e.g. brightness) is at least 75, 80, 85 or 90%. The relative transmission (e.g. brightness) is typically less than 100%. In typical embodiments, the angle-selective filter has significantly lower transmission at other viewing angles. For example, in some embodiments, the relative transmission (e.g. brightness) at a viewing angle of -30 degrees, +30 degrees, or an average of -30 degrees and +30 degrees is less than 50, 45, 40, 35, 30 or 25%. In other embodiments, the relative transmission (e.g. brightness) at a viewing angle of 30 degrees, +30 degrees, or the average of -30 degrees and +30 degrees is less than 25, 20, 15, 10 or 5%. In some embodiments, the relative transmission (e.g. brightness) at a viewing angle of +/-35, +/-40, +/-45, +/-50, +/-55, +/-60, +/-65, +/-70, +/-75 or +/-80 degrees is less than 25, 20, 15, 10 or 5%, or less than 5%. In some embodiments, the average relative transmission (e.g. brightness) for viewing angles ranging from +35 to +80 degrees, -35 to -80 degrees, or the average of these ranges is less than 10, 9, 8, 7, 6, 5, 4, 3 or 2%.

In some implementations, the absorptive regions 312 can be formed by coating a surface of a microstructured film. Further, in some implementations, the angle-selective filter 166 and/or second angle-selective filter 167 can include refractive structures. The angle-selective filter 166 can improve wavelength resolution over gradual transitions that are typical of absorptive solutions.

In some implementations, the optical system 150, optical filter 158 and/or angle-selective filter 166 defines, produces or includes a spectrally sharp transition. In contrast to a common reflective film having moderately sloped band edges, which can cause reflections or passing outside of a desired wavelength range, a spectrally sharp transition provides a more sudden change in a percentage of light blocked or reflected to reduce or eliminate light reflections or passing outside of a desired wavelength range. In some implementations, such a spectrally sharp transition occurs in less than, or less than about, 75nm, 50nm, 40nm, 30nm, 20nm or 10nm. In some implementations, a spectrally sharp transition includes, or includes about, a 70%, 75%, 80%, 85%, 90%, 95% or 99% change in transmission. In some implementations, a spectrally sharp transition occurs in less than, or less than about, 75nm, 50nm, 40nm, 30nm, 20nm or 10nm and includes, or includes about, a 70%, 75%, 80%, 85%, 90%, 95% or 99% change in transmission.

To obtain bandedge sharpening in accordance with the present disclosure at a first edge of the reflection band, a multilayer stack M1 having an optical repeating unit R1 is combined with a multilayer stack M2 having an optical repeating unit R2. Both multilayer stacks are designed to have a first order reflection band in a desired wavelength region. It is possible to produce a film or other optical body having a first order reflection band in a particular region of the spectrum by selecting polymeric materials with appropriate indices of refraction and by manipulating the physical thickness of each of the individual polymeric layers of an optical repeating unit such that the optical thickness of the optical repeating unit appears at the desired wavelength. By varying the optical thickness of the optical repeating unit in the multilayer film, the desired reflection over a particular range in the spectrum can be obtained. The optical repeating unit R1 of multilayer stack M1 can be monotonically varied in optical thickness such that the desired reflection band is obtained. However, it is also possible to use several multilayer stacks comprising different optical repeating units to cover a desired reflection band.

The optical thickness of optical repeating unit R1 may increase monotonically along the thickness of multilayer stack M1. Multilayer stack M2 may include an optical repeating unit R2 that is substantially constant in optical thickness or the optical thickness of optical repeating unit R2 may decrease monotonically along the thickness of multilayer stack M2. If the optical thickness of optical repeating unit R2 is substantially constant, the optical thickness thereof should be approximately equal to the minimum optical thickness of optical repeating unit R1 along the thickness of multilayer stack M1. The optical thickness of optical repeating unit R2 can be substantially equal to the minimum optical thickness of optical repeating unit R1.

In some implementations, the optical filter 158 is birefringent, meaning that refractive indices for light traveling along at least two of three principal and perpendicular directions (x, y and z axes) of the optical filter 158, are not equal. Further, the refractive indices for light traveling along three principal and perpendicular directions (x, y and z axes) may not be equal in certain implementations.

In some implementations, the optical system 150 includes a polarizer. Such a polarizer can be a circular polarizer, a linear polarizer, a reflective polarizer or any other type of polarizer commonly known to one skilled in the art. The polarizer allows light of certain polarizations to pass while blocking others. In some implementations, the optical system 150 includes a retarder. The retarder functions to alter a polarization state of light passing therethrough. Through the polarization properties of the polarizer and polarization alteration properties of the retarder, along with the small size of pixels 178 relative to the written regions 198, 204 and areas 220, 224, 228, 232, optical data sensed by the optical sensor 154 can be refined to thereby increase a signal-to-noise ratio of the optical system and/or to achieve a particular polarization to best suit the absorptive properties of the optical sensor 154.

Further, the optical system can include a plurality of polarizers. In some implementations, the light source can include a polarizer. In some implementations, the optical system can include a second polarizer. In some implementations, the light source includes a polarizer while the optical system 150 includes another polarizer. In some implementations, the polarizer included with the light source and/or the polarizer included with the optical system 150 are wavelength selective.

In some implementations, the polarizer included with the light source and/or the polarizer included with the optical system 150 is a linear polarizer. In some implementations, the polarizer included with the light source and/or the polarizer included with the optical system 150 is a circular polarizer. In some implementations, the polarizer included with the light source and the polarizer included with the optical system 150 are linear polarizers and each of the polarizers are arranged in parallel, or that the polarization axes of the polarizers are arranged in parallel or substantially in parallel. In some implementations, the polarizer included with the light source and the polarizer included with the optical system 150 are linear polarizers and each of the polarizers are arranged orthogonal to one another, or that the polarization axes of the polarizers are arranged orthogonal to one another or substantially orthogonal to one another.

In some implementations, the polarizer included with the light source and the polarizer included with the optical system 150 are circular polarizers and each of the polarizers are arranged in parallel, or that the polarization axes of the polarizers are arranged in parallel or substantially in parallel. In some implementations, the polarizer included with the light source and the polarizer included with the optical system 150 are circular polarizers and each of the polarizers are arranged orthogonal to one another, or that the polarization axes of the polarizers are arranged orthogonal to one another or substantially orthogonal to one another.

In some implementations, the light source 162 has, defines and/or produces an emission spectrum of light. In some implementations, the emission spectrum of the light source 162 is wider than a transmission spectrum of one or more of the areas 220, 224, 228, 232, written regions 198, 204, non-written regions 200, 206 and/or auxiliary written regions 199. In some implementations, the light source 162 includes one or more narrow emission peaks, which can be defined as 80nm full width at half maximum.

In some implementations, the optical system 150 includes a measurement taken via ambient light and/or light from the light source 162 as described above and passing through the optical filter 158 before reaching the optical sensor 154. In some implementations, multiple measurements could be taken at different times. In some implementations, multiple measurements could be taken where the optical sensor 154 is disposed at different incident angles, distances and/or orientations relative to one or more of the optical filter 158, measurement subject 170 and reflector 163. In some implementations, the optical filter 158 and/or the measurement subject 170 can be measured at different incident angles, which could prove valuable as different angular measurements could yield varied data collected by the optical sensor 154 due to the angular relationship between a disclosed optical path, the optical filer 158 and the first and/or second angle-selective filters 166, 167. In some implementations, the multiple measurements could be taken by the optical sensor 154 at different times, while in some implementations the multiple measurements could be taken by the optical sensor 154 and a second optical sensor.

The measurement subject could be animate or inanimate. In some implementations, the measurement subject 170 can be a person, animal, plant, living tissue or other animate object. In some implementations, the measurement subject could be a film, an electronic display, non-living plant or animal tissue or any other inanimate object.

In some implementations, the optical filter 158 can be curved, spherically-curved, cylindrically-curved, planar, flat or have any other curved shape. Similarly, in some implementation, the optical sensor 154 can be curved, spherically-curved, cylindrically-curved, planar, flat or have any other curved shape. In some implementations, the optical filter 158 and optical sensor 154 can have the same or different types of curvature.

Item 1. An optical system, comprising an optical sensor; a plurality of photosensitive pixels disposed on the optical sensor; a wavelength-selective optical filter in optical communication with the photosensitive pixels, the wavelength-selective optical filter being disposed remotely from the optical sensor; an area disposed in the wavelength-selective optical filter, the area having a transmission spectrum different from a transmission spectrum of a portion of the wavelength-selective optical filter not in the area; and a reflector, the wavelength-selective optical filter and a measurement subject each being disposed between the reflector and the optical sensor along an optical path.

Item 2. The optical system of item 1, further including a light source, wherein the wavelength-selective optical filter and a measurement subject are each disposed between the light source and the reflector along an optical path.

Item 3. The optical system of item 1, wherein the wavelength-selective optical filter is disposed between the optical sensor and a measurement subject along an optical path.

Item 4. The optical system of item 1, wherein a measurement subject is disposed between the wavelength-selective optical filter and the optical sensor along an optical path.

Item 5. The optical system of item 1, wherein the reflector is a retroreflector.

Item 6. An optical system, comprising an optical sensor; a plurality of photosensitive pixels disposed on the optical sensor; a wavelength-selective optical filter in optical communication with the photosensitive pixels, the wavelength-selective optical filter being disposed remotely from the optical sensor; a first plurality of spatially-variant areas disposed in the optical filter; and a second plurality of spatially-variant areas disposed in the optical filter, the areas of the first plurality of spatially-variant areas having a transmission spectrum different from that of the areas of the second plurality of spatially-variant areas.

Item 7. The optical system of item 6, further including a light source, wherein the wavelength-selective optical filter and a measurement subject are each disposed between the light source and the optical sensor along an optical path.

Item 8. The optical system of item 6, wherein the wavelength-selective optical filter is disposed between the optical sensor and a measurement subject along an optical path.

Item 9. The optical system of item 6, wherein a measurement subject is disposed between the wavelength-selective optical filter and the optical sensor along an optical path.

Item 10. The optical system of item 6, wherein the optical sensor includes at least one reference pixel.

Item 11. An optical system, comprising an optical sensor; a plurality of photosensitive pixels disposed on the optical sensor; a wavelength-selective optical filter in optical communication with the photosensitive pixels, the wavelength-selective optical filter being disposed remotely from the optical sensor; and an area disposed in the wavelength-selective optical filter, the area having a transmission spectrum different from a transmission spectrum of a portion of the wavelength-selective optical filter not in the area.

Item 12. The optical system of item 11, further including a light source, wherein the wavelength-selective optical filter and a measurement subject are each disposed between the light source and the optical sensor along an optical path.

Item 13. The optical system of item 11, wherein the wavelength-selective optical filter is disposed between the optical sensor and a measurement subject along an optical path.

Item 14. The optical system of item 11, wherein a measurement subject is disposed between the wavelength-selective optical filter and the optical sensor along an optical path.

Item 15. The optical system of item 11, wherein the wavelength-selective optical filter is flexible.

The present disclosure should not be considered limited to the particular examples and embodiments described above, as such embodiments are described in detail in order to facilitate explanation of various aspects of the disclosure. Rather, the present disclosure should be understood to cover all aspects of the disclosure, including various modifications, equivalent processes, and alternative devices falling within the scope of the disclosure as defined by the appended claims and their equivalents.

Terms such as "about" will be understood in the context in which they are used and described in the present description by one of ordinary skill in the art. If the use of "about" as applied to quantities expressing feature sizes, amounts, and physical properties is not otherwise clear to one of ordinary skill in the art in the context in which it is used and described in the present description, "about" will be understood to mean within 10 percent of the specified value. A quantity given as about a specified value can be precisely the specified value. For example, if it is not otherwise clear to one of ordinary skill in the art in the context in which it is used and described in the present description, a quantity having a value of about 1, means that the quantity has a value between 0.9 and 1.1, and that the value could be 1.

All references, patents, and patent applications referenced in the foregoing are hereby incorporated herein by reference in their entirety in a consistent manner. In the event of inconsistencies or contradictions between portions of the incorporated references and this application, the information in the preceding description shall control.

Descriptions for elements in figures should be understood to apply equally to corresponding elements in other figures, unless indicated otherwise. Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that a variety of alternate and/or equivalent implementations can be substituted for the specific embodiments shown and described without departing from the scope of the present disclosure. This application is intended to cover any adaptations or variations of the specific embodiments discussed herein. Therefore, it is intended that this disclosure be limited only by the claims and the equivalents thereof.

What is claimed is:

1. An optical system, comprising:

an optical sensor;

a plurality of photosensitive pixels disposed on the optical sensor;

a wavelength-selective optical filter in optical communication with the photosensitive pixels, the wavelength-selective optical filter being disposed remotely from the optical sensor;

an area disposed in the wavelength-selective optical filter, the area having a transmission spectrum different from a transmission spectrum of a portion of the wavelength-selective optical filter not in the area; and

a reflector, the wavelength-selective optical filter and a measurement subject each being disposed between the reflector and the optical sensor along an optical path.

2. The optical system of claim 1, further including a light source, wherein the wavelength-selective optical filter and a measurement subject are each disposed between the light source and the reflector along an optical path.

3. The optical system of claim 1, wherein the wavelength-selective optical filter is disposed between the optical sensor and a measurement subject along an optical path.

4. The optical system of claim 1, wherein a measurement subject is disposed between the wavelength-selective optical filter and the optical sensor along an optical path.

5. The optical system of claim 1, wherein the reflector is a retroreflector.

6. An optical system, comprising:

an optical sensor;

a plurality of photosensitive pixels disposed on the optical sensor;

a wavelength-selective optical filter in optical communication with the photosensitive pixels, the wavelength-selective optical filter being disposed remotely from the optical sensor;

a first plurality of spatially-variant areas disposed in the optical filter; and

a second plurality of spatially-variant areas disposed in the optical filter, the areas of the first plurality of spatially-variant areas having a transmission spectrum different from that of the areas of the second plurality of spatially-variant areas.

7. The optical system of claim 6, further including a light source, wherein the wavelength-selective optical filter and a measurement subject are each disposed between the light source and the optical sensor along an optical path.

8. The optical system of claim 6, wherein the wavelength-selective optical filter is disposed between the optical sensor and a measurement subject along an optical path.

9. The optical system of claim 6, wherein a measurement subject is disposed between the wavelength-selective optical filter and the optical sensor along an optical path.

10. The optical system of claim 6, wherein the optical sensor includes at least one reference pixel.

11. An optical system, comprising:

an optical sensor;

a plurality of photosensitive pixels disposed on the optical sensor;

a wavelength-selective optical filter in optical communication with the photosensitive pixels, the wavelength-selective optical filter being disposed remotely from the optical sensor; and

an area disposed in the wavelength-selective optical filter, the area having a transmission spectrum different from a transmission spectrum of a portion of the wavelength-selective optical filter not in the area.

12. The optical system of claim 11, further including a light source, wherein the wavelength-selective optical filter and a measurement subject are each disposed between the light source and the optical sensor along an optical path.

13. The optical system of claim 11, wherein the wavelength-selective optical filter is disposed between the optical sensor and a measurement subject along an optical path.

14. The optical system of claim 11, wherein a measurement subject is disposed between the wavelength-selective optical filter and the optical sensor along an optical path.

15. The optical system of claim 11, wherein the wavelength-selective optical filter is flexible.

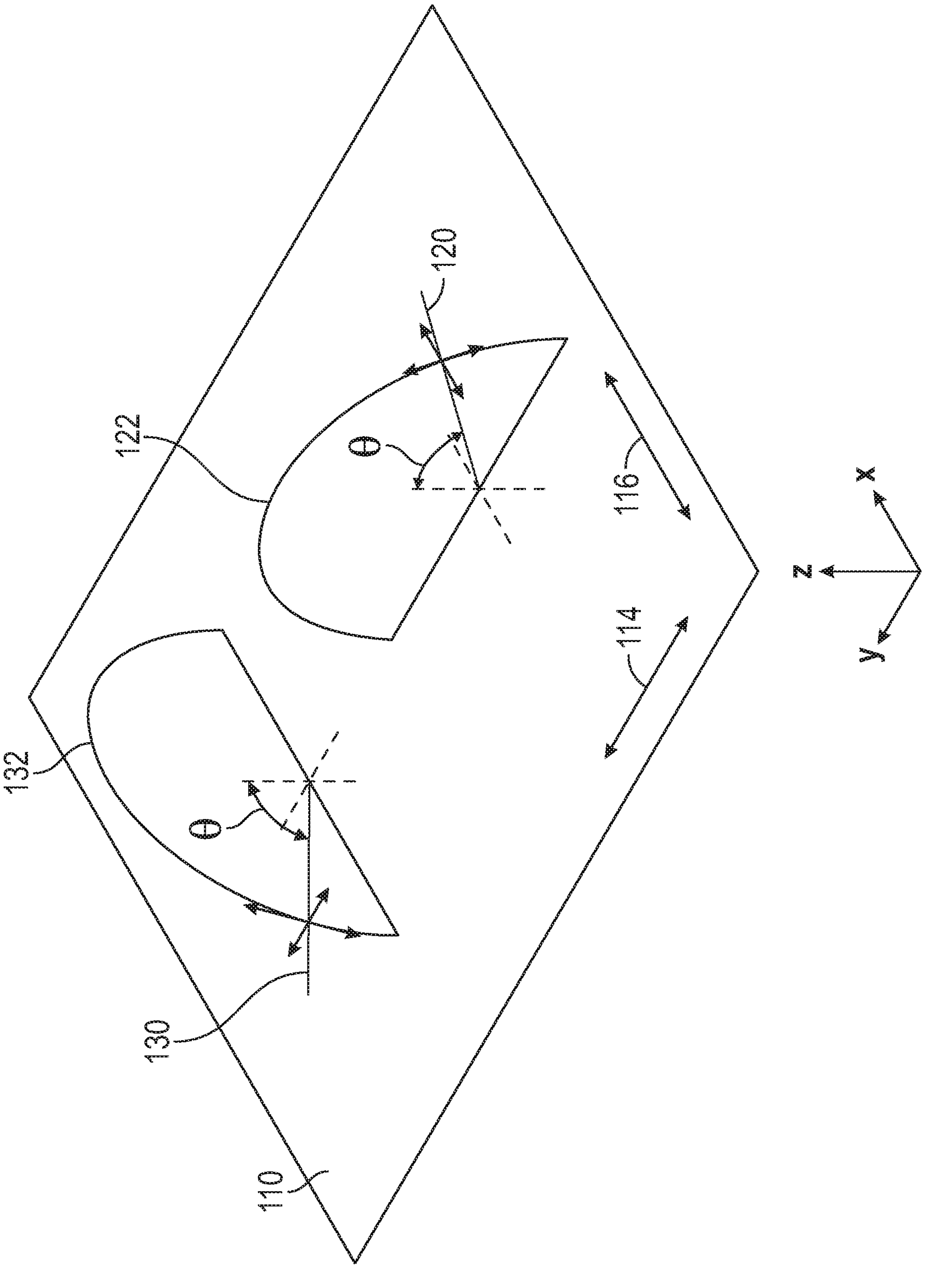

FIG. 1

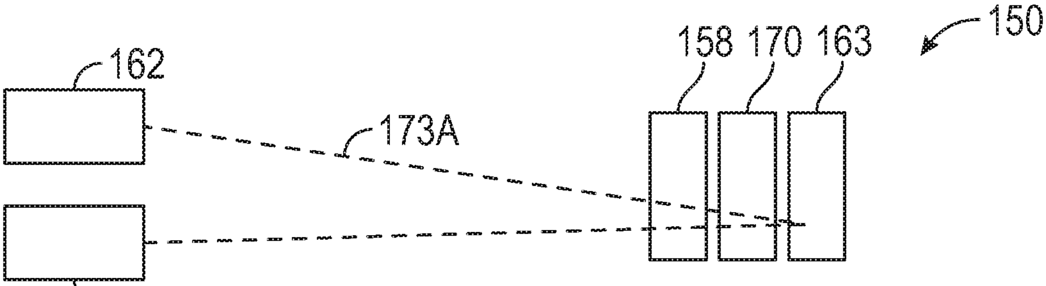

FIG. 2A

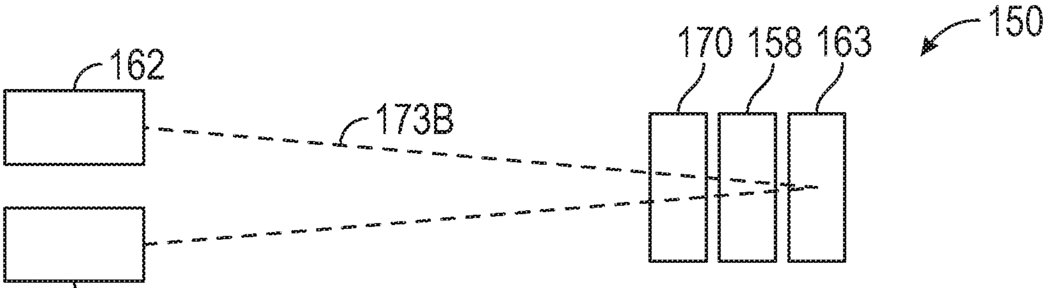

FIG. 2B

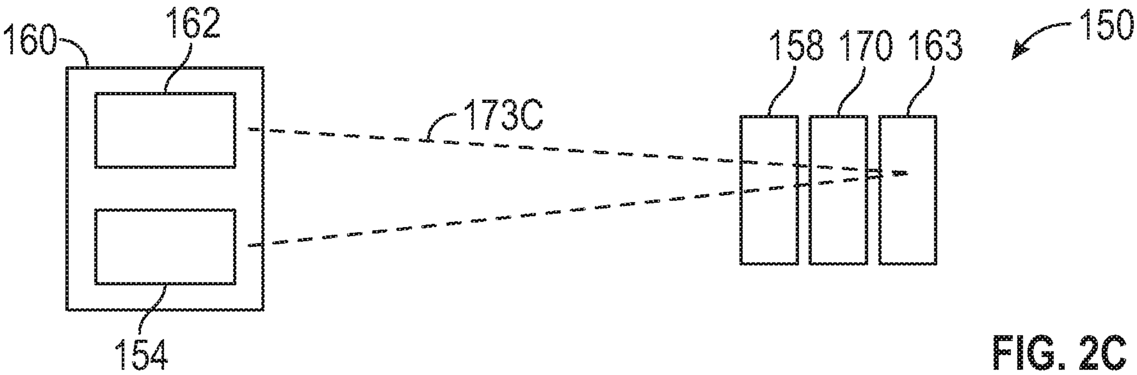

FIG. 2C

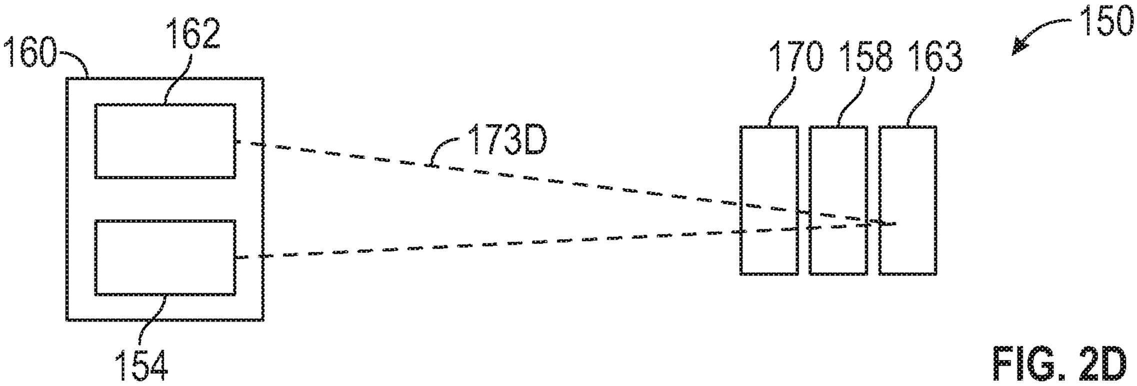

FIG. 2D

FIG. 2E

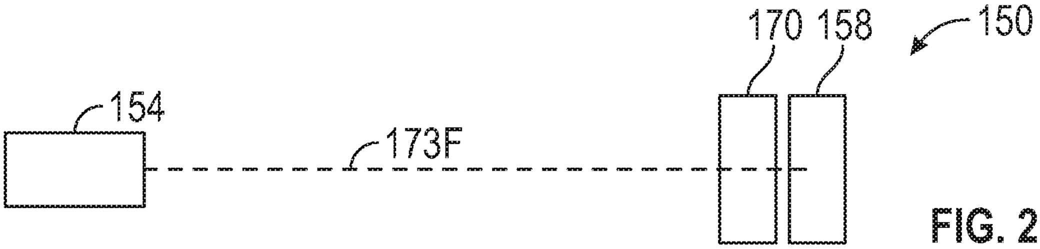

FIG. 2F

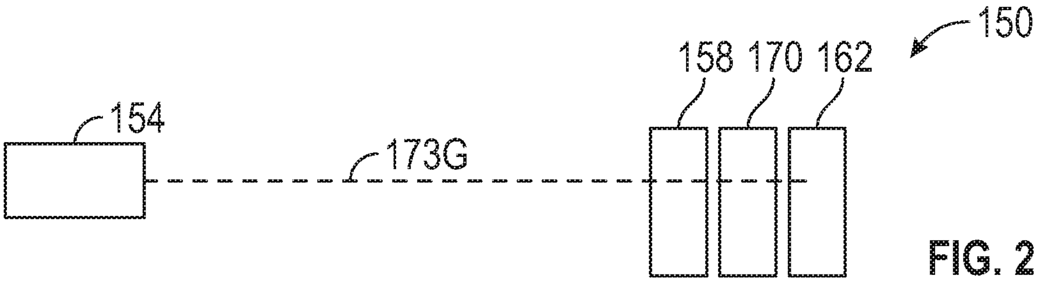

FIG. 2G

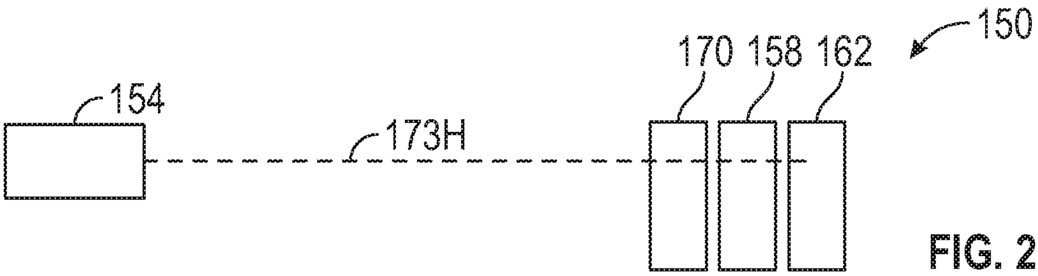

FIG. 2H

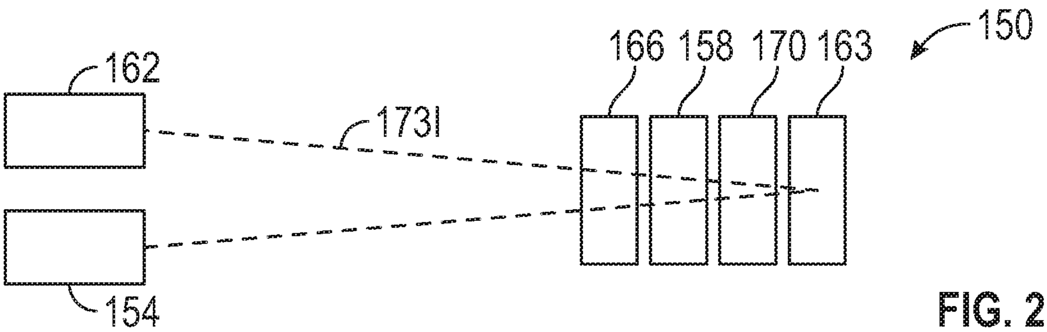

FIG. 2I

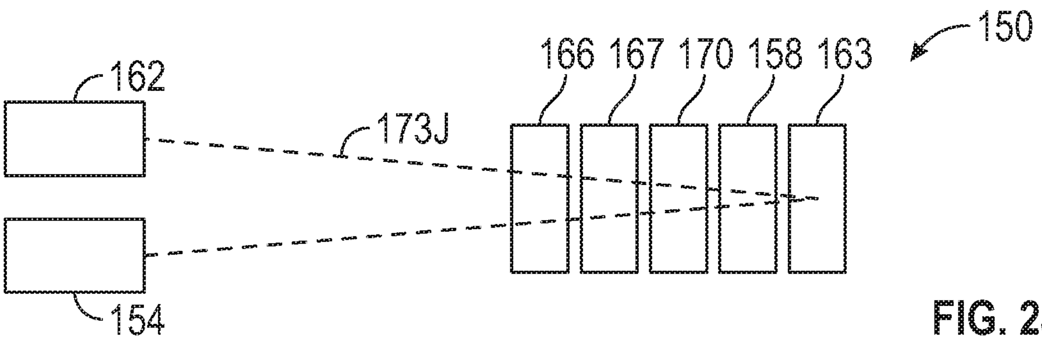

FIG. 2J

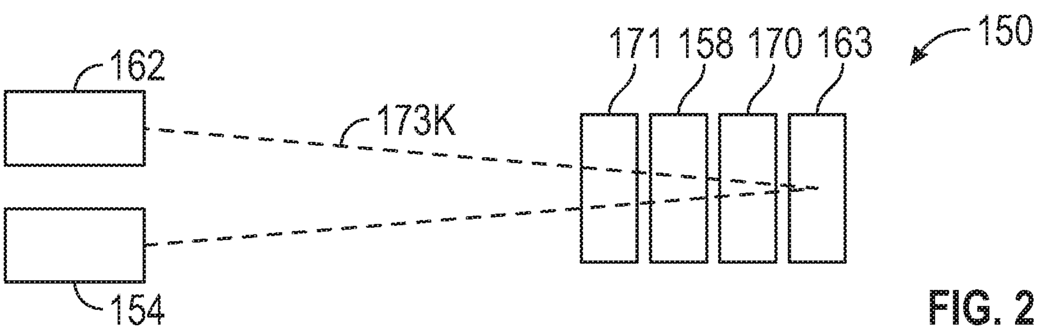

FIG. 2K

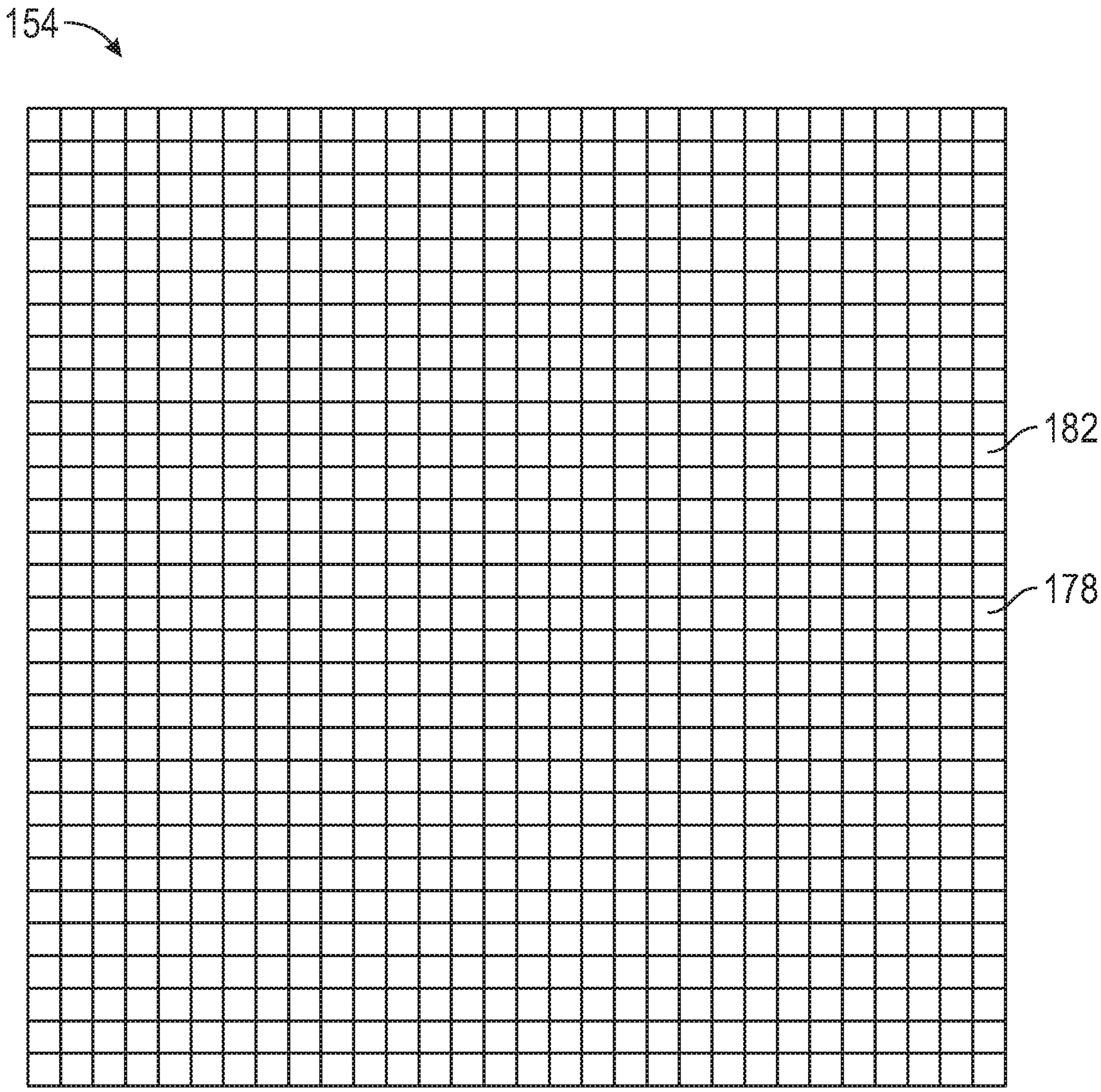

FIG. 3

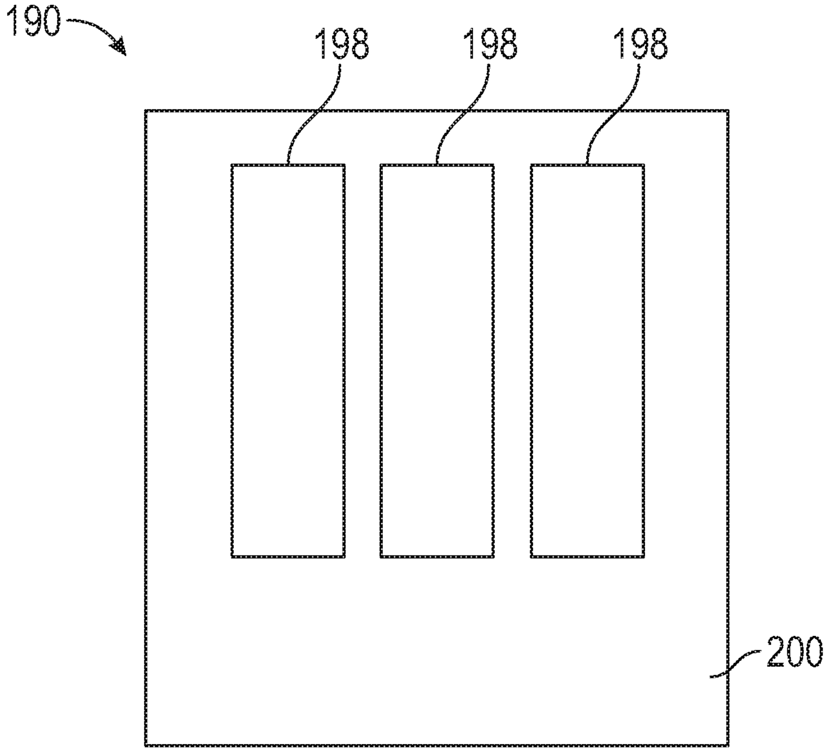

FIG. 4A

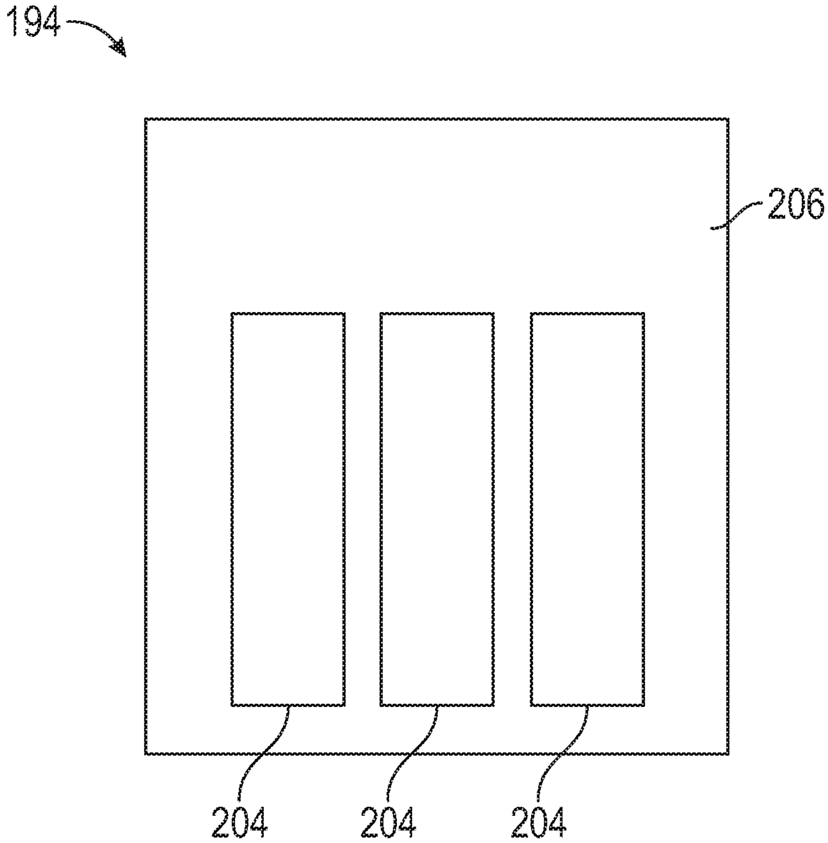

FIG. 4B

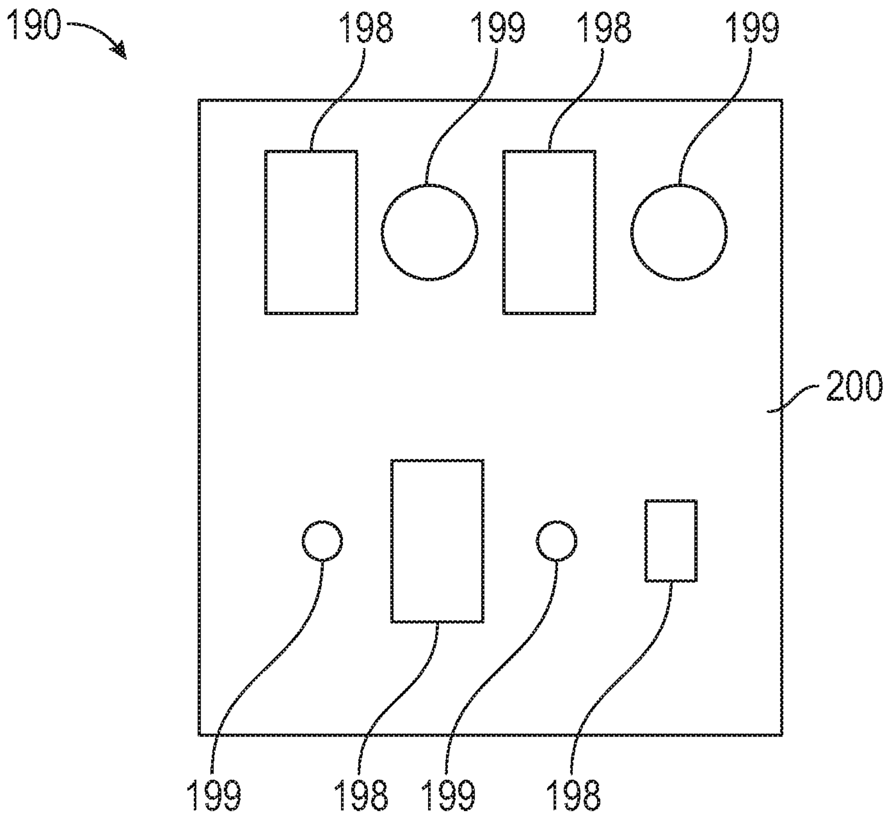
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FIG. 4C

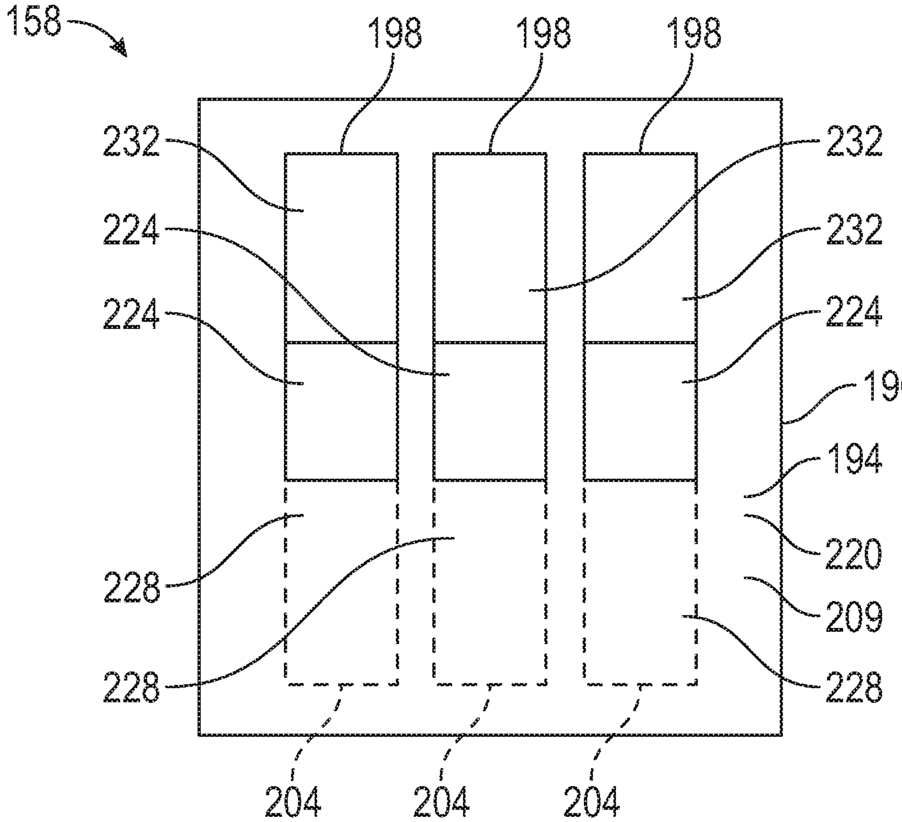
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FIG. 5A

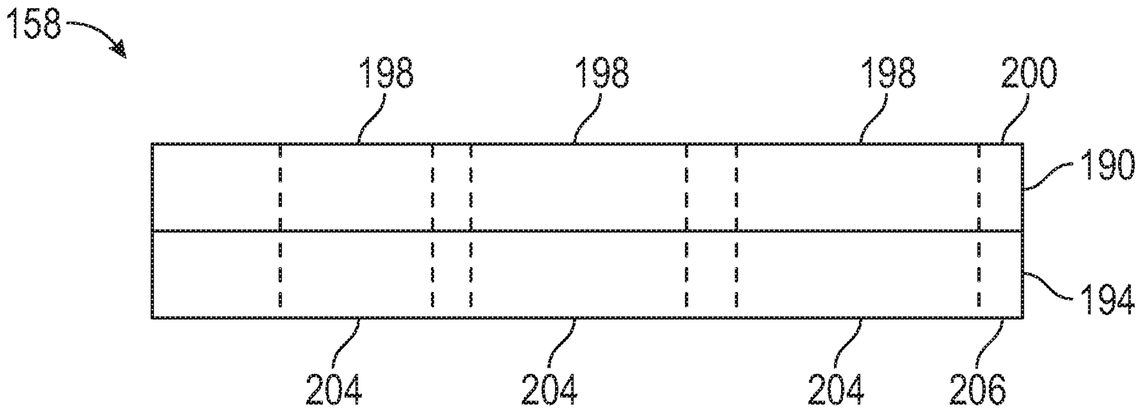

FIG. 5B

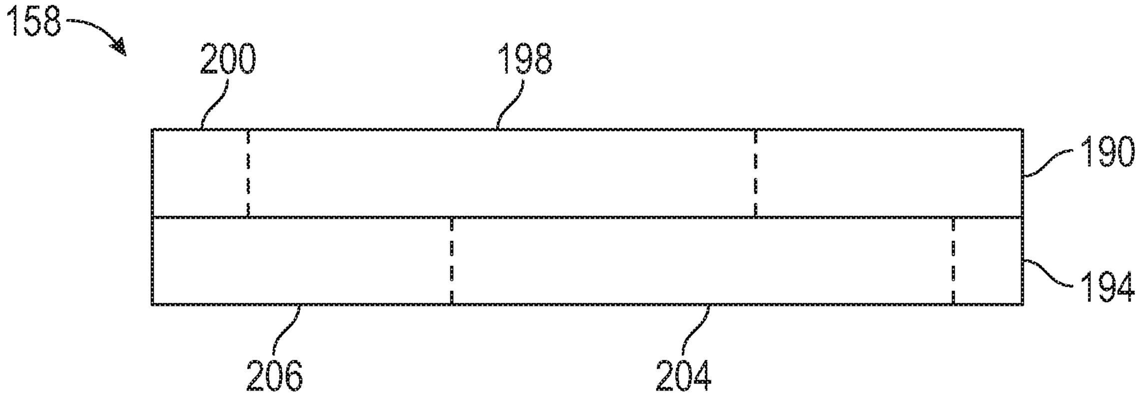

FIG. 5C

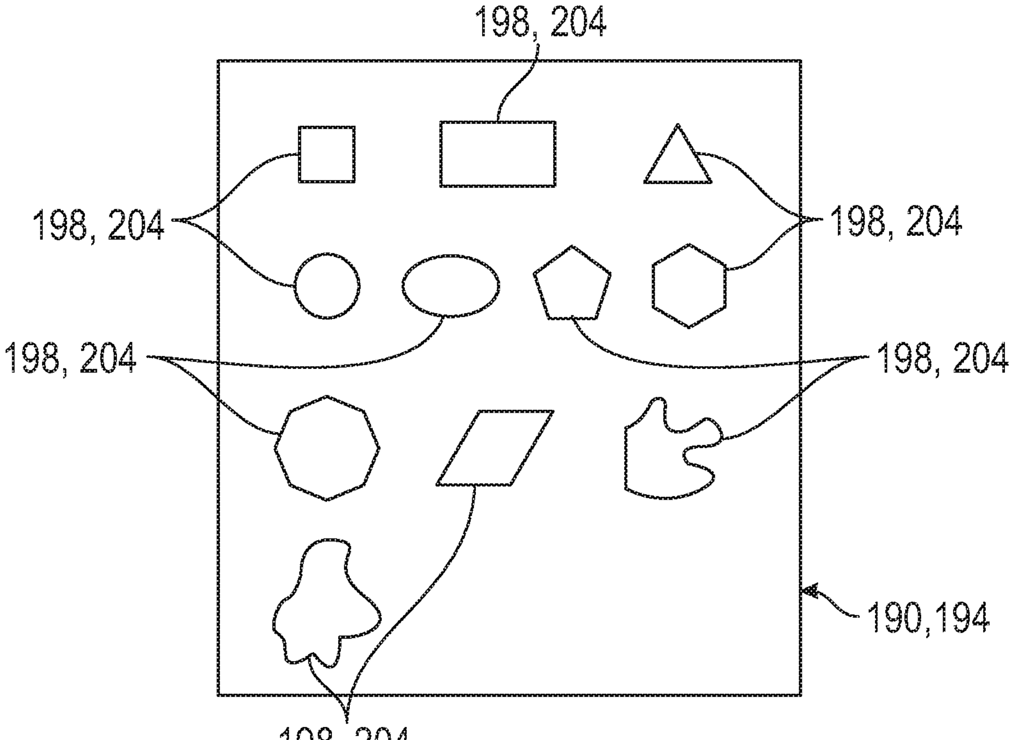

FIG. 6

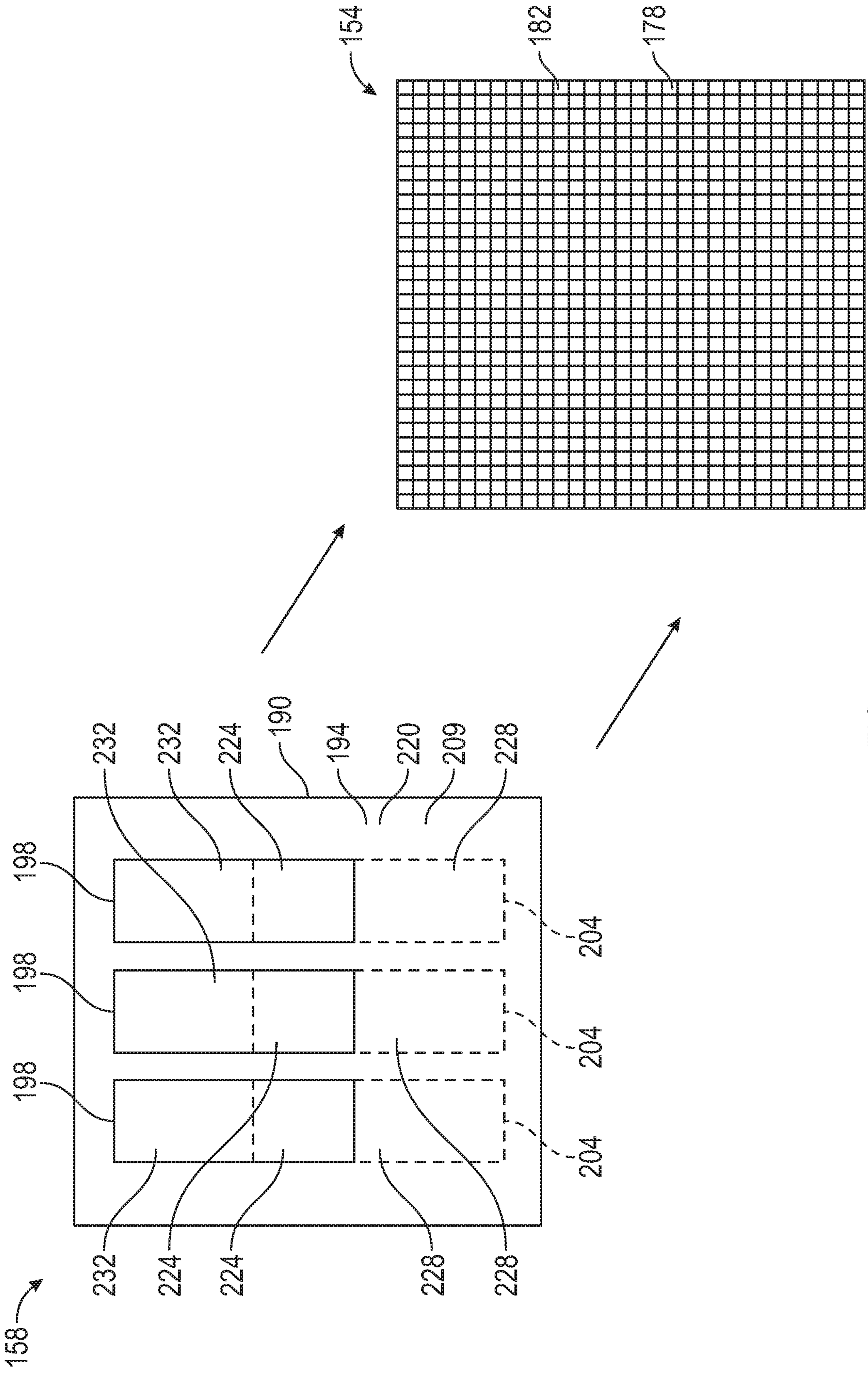

FIG. 7

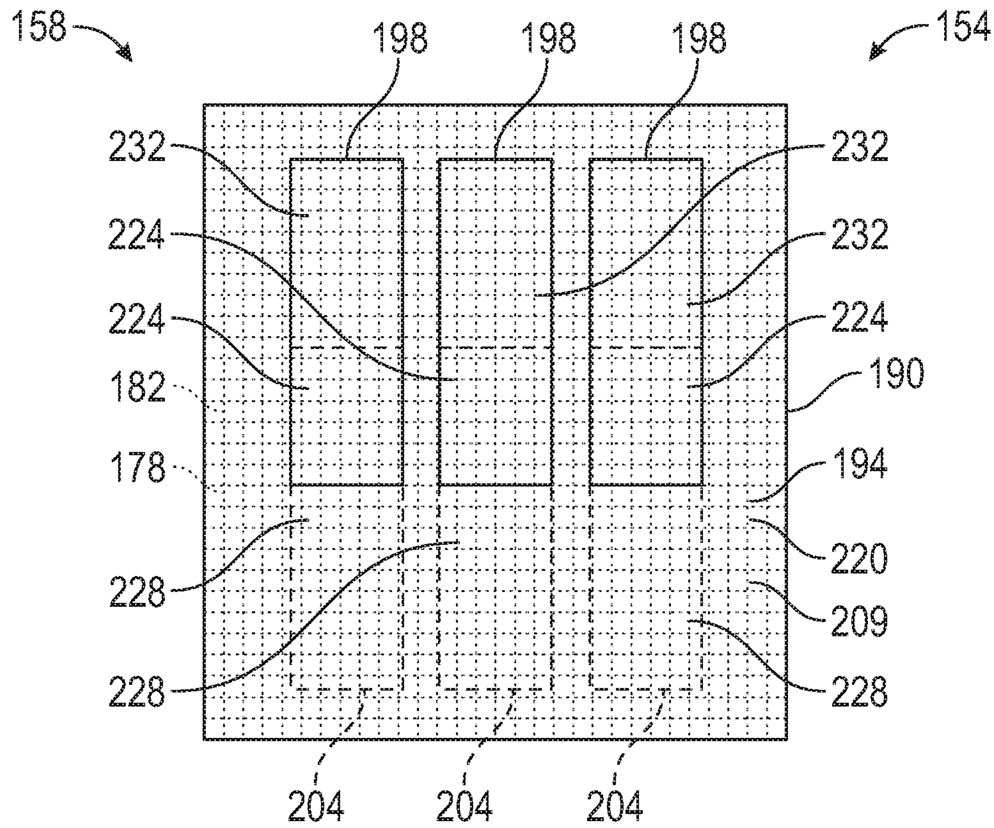
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FIG. 8

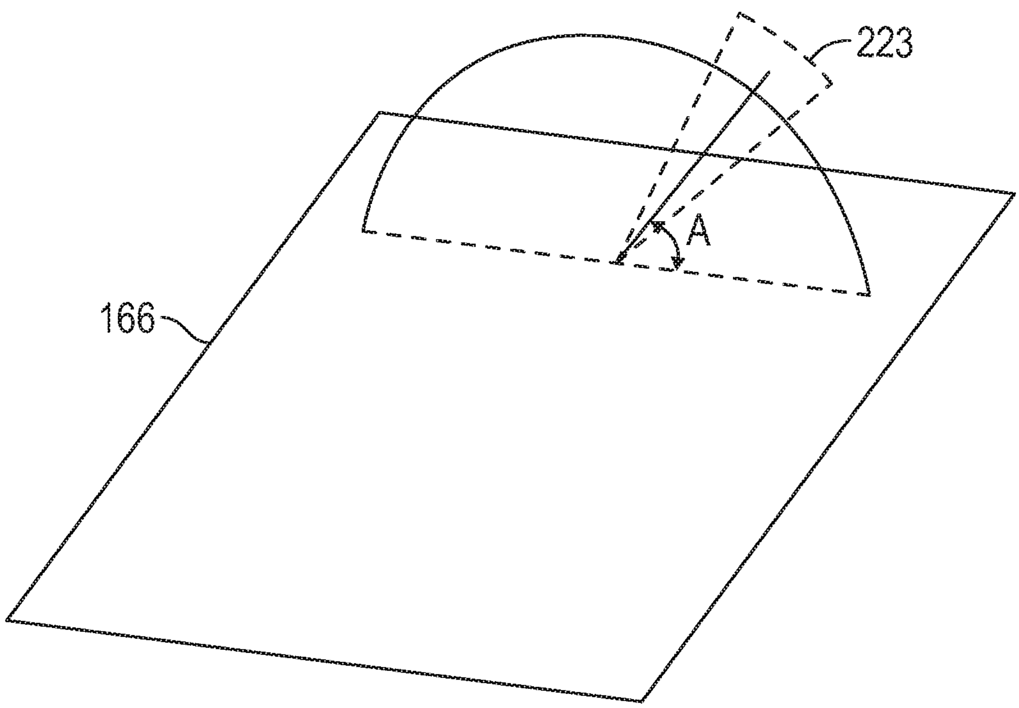
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FIG. 9A

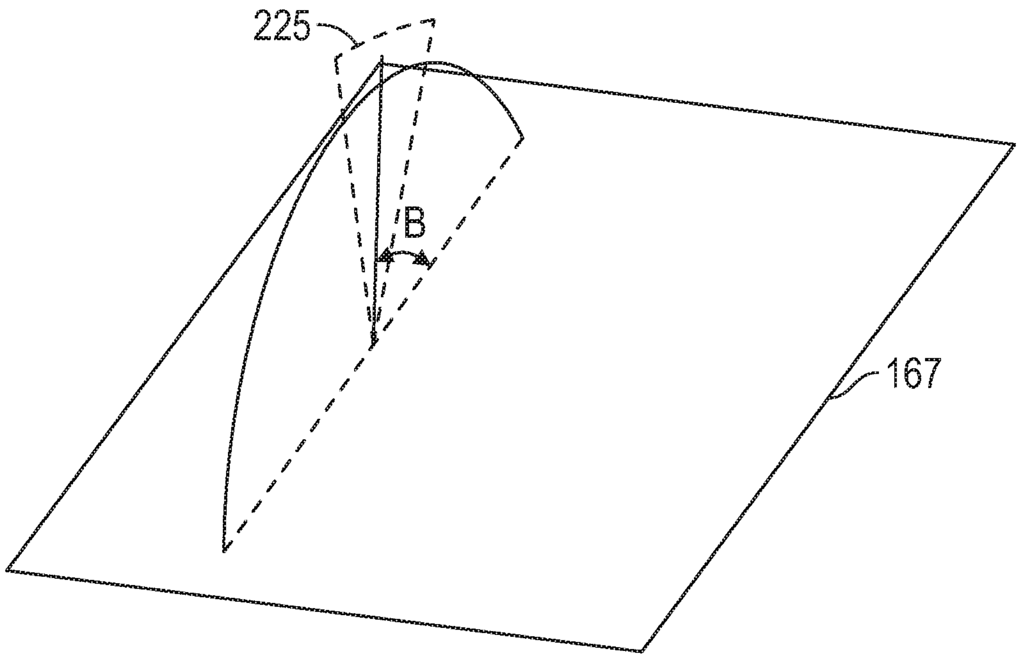


FIG. 9B

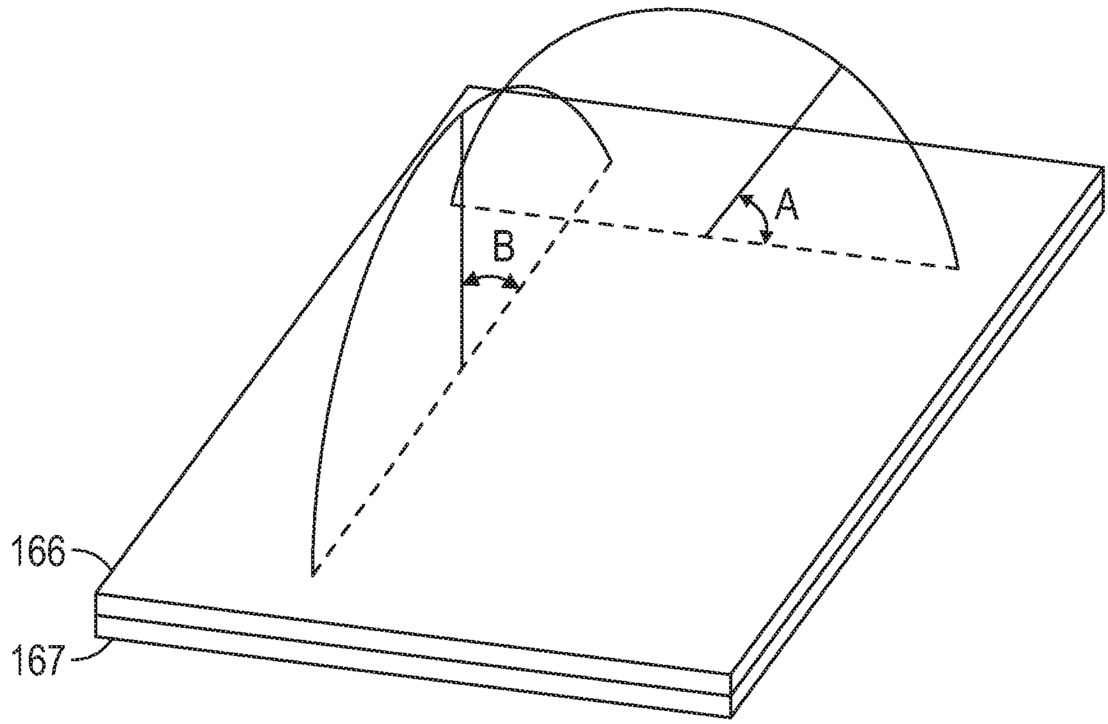
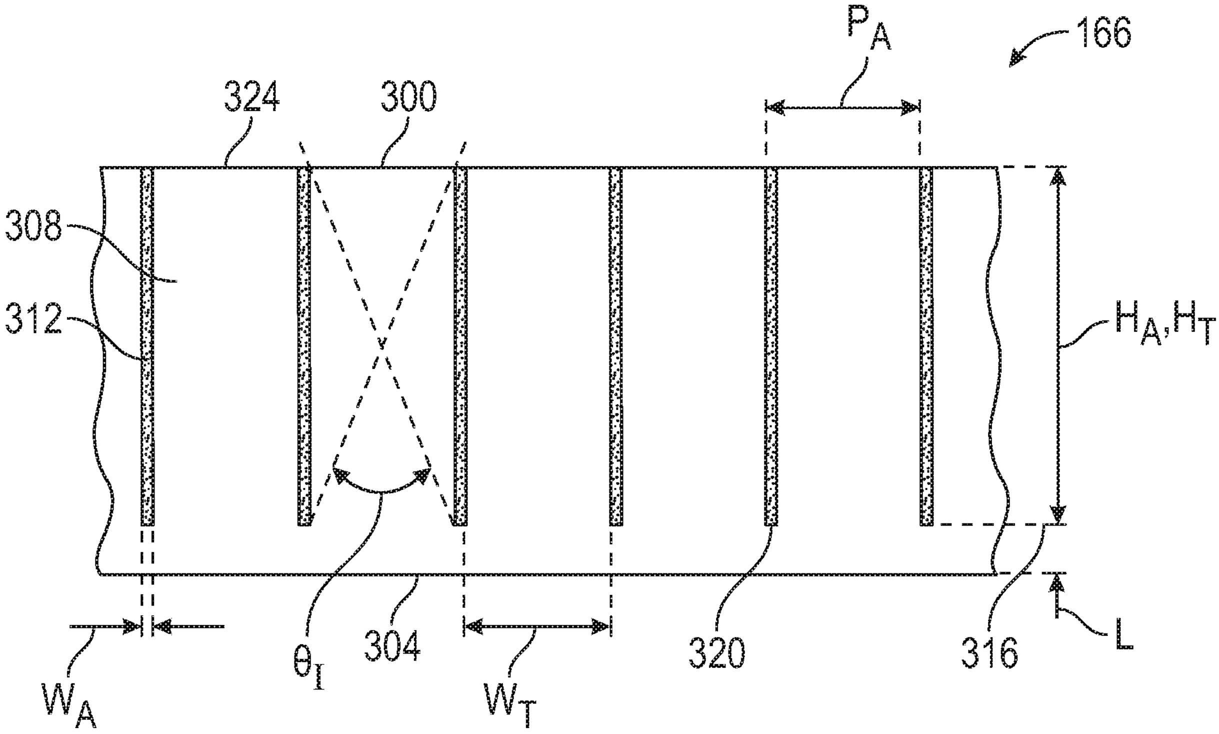


FIG. 9C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W_A
θ_I
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W_T
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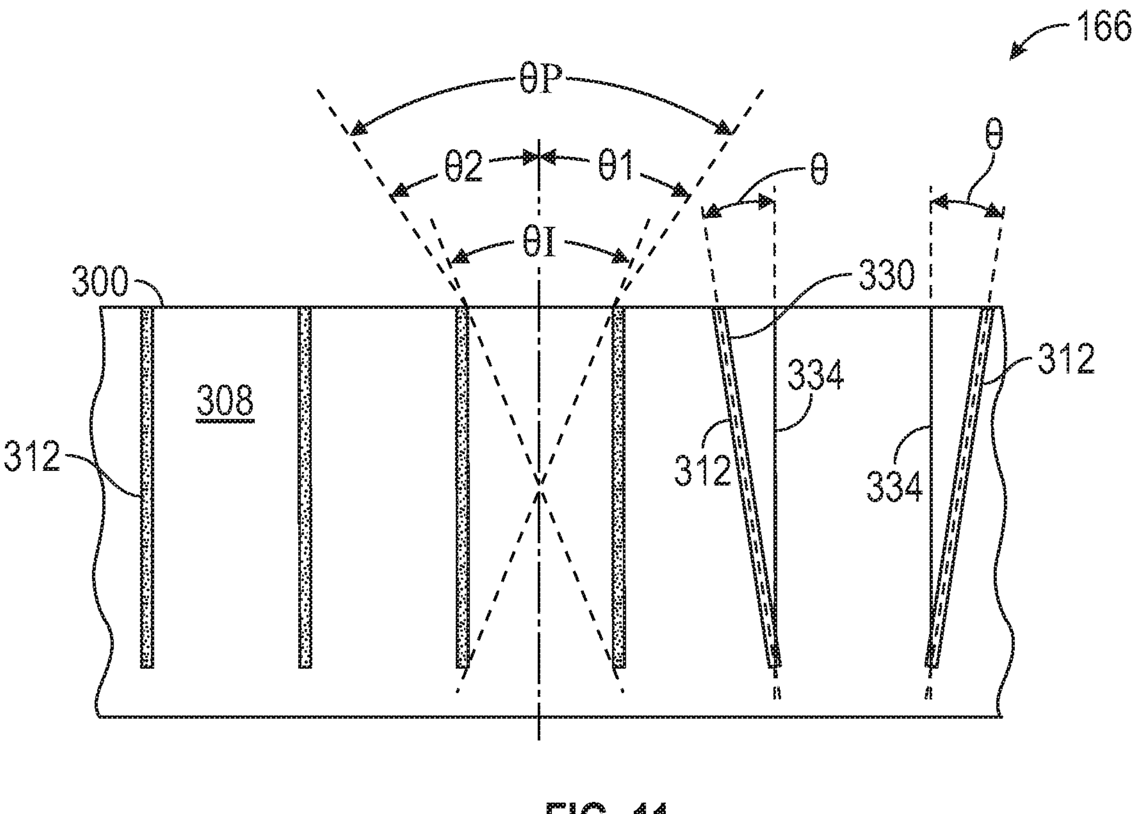
L

FIG. 10


166
θP
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θ1
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θ
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312

FIG. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2020/053107

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01J3/02 G01J3/28 G01J3/12 G02B5/12 G02B5/20
H01L31/0216
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 G02B H01L

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.
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X	EP 3 128 301 A2 (VIAVI SOLUTIONS INC [US]) 8 February 2017 (2017-02-08) paragraphs [0002] - [0004], [0065] - [0071]; figures 1, 8	6,11
X	WO 2014/089120 A1 (INTEGRATED PLASMONICS CORP [US]) 12 June 2014 (2014-06-12) paragraphs [0022], [0041]; figures 1, 3	6,11
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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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

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 May 2020	19/05/2020

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	Haan, Martine

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	DE 103 62 349 B3 (SICK AG [DE]) 8 May 2014 (2014-05-08) paragraph [0062]	1-5
A	WO 2018/097841 A1 (3M INNOVATIVE PROPERTIES CO [US]) 31 May 2018 (2018-05-31) figure 11	1-5
A	US 2012/153133 A1 (NELSON EDWARD T [US] ET AL) 21 June 2012 (2012-06-21) paragraph [0030]	10
A	US 2017/122807 A1 (KASAHARA HIDEAKI [JP] ET AL) 4 May 2017 (2017-05-04) paragraph [0192]	10
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2020/053107

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