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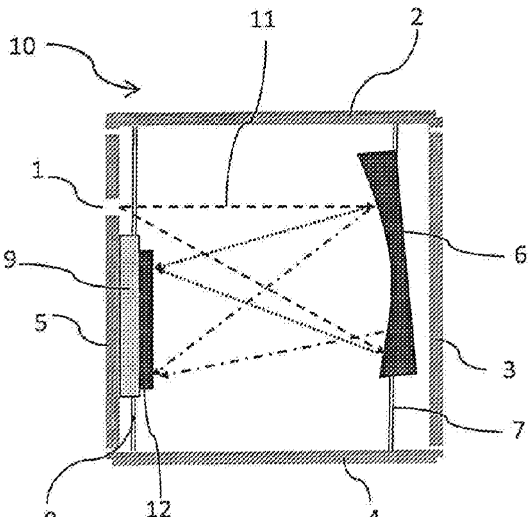

Fig. 1

(57) Abstract: The present invention relates to an optical module (10), comprising an inside volume and an optical housing enclosing said inside volume, said optical housing being, except for one or more input optical ports (1), completely non-transparent, such that light can enter said inside volume solely through said one or more input optical ports, said inside volume further comprises one or more diffractive elements (6), wherein the diffractive elements transform a portion of an input optical signal into an output optical signal according to the spectral and spatial transformation information, the input optical signal propagating within the optical housing from one or more input optical ports, the output optical signal propagating within the optical housing to an optical output region of the optical element, and at least one photo detector (12) is positioned for receiving at least a portion of the output optical signal from at least a portion of the optical output region, wherein said one or more diffractive elements are a grating assembly composed of several gratings, wherein each grating is designed for a specific wavelength range and optimum wavelength within said range, and wherein said at least one photo detector is a 2D image sensor.

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AN OPTICAL MODULE COMPRISING A GRATING ASSEMBLY AND AN IMAGE SENSOR

Description

The present invention relates to an optical module, comprising an inside volume and an optical housing enclosing said inside volume.

The optical module as referred above is used for the field of optics, more specifically to spectroscopy and corresponding equipment. Spectroscopy and spectrography are terms used to refer to the measurement of radiation intensity as a function of wavelength and are often used to describe experimental spectroscopic methods. Spectral measurement devices are referred to as spectrometers, spectrophotometers, spectrographs or spectral analyzers. In optics, especially in spectrometers, very often a diffraction grating is used as an optical component with a periodic structure, which splits and diffracts light into several beams travelling in different directions. The directions of these beams depend on the spacing of the grating and the wavelength of the light so that the grating acts as the dispersive element. Therefore, gratings are used in spectrometers.

Spectrometers are well known in the art. A traditional layout of a spectrometer consists of five separate components that must be accurately assembled and adjusted: a narrow slit at the input serving as a point source, a curved mirror (collimator) that makes the incoming beam parallel, a flat diffraction grating that deflects the colours of the incoming light at different angles (”rainbow effect”), a curved mirror (focusing mirror) that focuses the colour spectrum onto a linear detector, and a linear sensor array that converts the colour information into electrical signals.

For example International application WO2014/014415 relates to a miniaturized spectrometer module comprising a first member having a first face which is substantially planar, a second member having a second face facing said first face, a third member comprised in said first member or comprised in said second member or distinct from and located between these, which comprises an opening, a dispersive element and a position-sensitive light sensor, wherein said first member comprises one or more transparent portions through which light can pass.

In addition, US 7,330,614 relates to an optical apparatus, comprising: an optical element having a set of diffractive elements and a sample chamber; and a photo detector, wherein the diffractive elements of the set are collectively arranged so as to comprise spectral and spatial transformation information, the diffractive elements of the set are collectively arranged so as to transform a portion of an input optical signal into an output optical signal according to the spectral and spatial transformation information, the spectral and spatial transformation information varies among the diffractive elements of the set so that an optical spectrum of the output optical signal varies with spatial position at the optical output region of the optical element; at least one photodetector is positioned for receiving at least a portion of the output optical signal from at least a portion of the optical output region; and at least a portion of the sample chamber is positioned at the input optical port so that at least a portion of light emitted from the sample chamber is transmitted as the input optical signal into the optical element at the input optical port.

US Patent application number 2008/309936 relates to a spectrometric measurement apparatus for measuring intensity distributions of optical radiation, the measurement apparatus comprising: a collimator adapted to produce a beam of incident radiation, a first diffractive grating at a location where said first diffractive grating is adapted to receive a first part of said incident radiation, a second diffractive grating at a location where said second diffractive grating is adapted to receive a second part of said incident radiation at the same time when said first diffractive grating receives said first part of said incident radiation, and a detector arrangement at a location where said detector arrangement is adapted to receive radiation diffracted by said first and second diffractive gratings; wherein at least one grating parameter of the first diffractive grating is different than a corresponding grating parameter of said second diffractive grating.

US Patent application number 2007/030484 relates to a spectrograph, comprising: a radiation source that supplies radiation; a collimator that receives the radiation supplied by the radiation source and substantially collimates the radiation; and a dispersion device that receives the collimated radiation, the dispersion device comprising a plurality of segments each having a dispersion surface; wherein the segments are arranged adjacently along a plane upon which the radiation is incident; and wherein each of the segments disperses the radiation differently than adjacent segments.

International application WO94/24527 relates to an optical spectrograph, comprising: a source of a light beam to be analyzed; a two-dimensional array of opto-electric detectors; a plurality of holographic transmission optical gratings each operating on a different wavelength range; and means for directing the same aperture of the input light onto each of said gratings so as to cause said gratings to diffract at least a portion of the incident light onto said opto-electric detectors, whereby different regions of the detector array receive signals representing different portions of the spectrum encompassed in the incoming beam.

There is an increasing role for spectrometric measurement methods with important societal themes. In industrial society the contamination of the environment is becoming an increasing concern. But also contamination of food and feed, their security and safety, the sustainability of food production, processing and consumption in face of a growing world food demand have become major societal challenges. The instant availability of material compositions as parameter is a key factor for corrective and improvement actions. Many applications use spectrometry as a method to diagnose and monitor food, feed, water, air, soil, biological tissues, packaging and waste.

Traditional industries are changing from offline quality measurements towards real-time measurements at the production line. This causes a large time gap between diagnosis and corrective action. This can only be overcome by real-time measurements on the spot. Tissue and waste materials are by nature heterogeneous and cannot be fully differentiated with imaging techniques.

Most current spectrometry methods are performed through offline measurements, requiring sample preparation and analysis in a lab environment. These methods are time consuming, expensive and require users skilled in analytical spectrometry to perform the analysis. Consequence is that companies are looking for robust compact sensors and efficient data collection methods.

There is thus an increasing demand for in-line and mobile inspection of materials in food and feed safety control, waste management, health care and forensics. However, today’s technology is too complex and too expensive for wide-spread use.

The aim of the present invention is to provide user access, size and cost reduction and to bring the innovation to medium-volume production.

Another aim of the present invention is to provide a compact and robust optical module while not compromising the wavelength resolution and sensitivity over a wide wavelength range.

Another aim of the present invention is to manufacture a high-quality spectrometer module which is very compact of the order of one cubic inch, which will be a breakthrough in spectroscopy instrumentation.

Another aim of the present invention is to provide a method for manufacture a spectrometer module on a modular basis.

Another aim of the present invention is to provide a method for manufacture a spectrometer module wherein the optical performance of the spectrometer module thus manufactured can be adjusted according to the specific application or use of the spectrometer module.

The present invention thus relates to an optical module, comprising an inside volume and an optical housing enclosing said inside volume, said optical housing being, except for one or more input optical ports, completely non-transparent, such that light can enter said inside volume solely through said one or more input optical ports, said inside volume further comprises one or more diffractive elements, wherein the diffractive elements transform a portion of an input optical signal into an output optical signal according to the spectral and spatial transformation information, the input optical signal propagating within the optical housing from one or more input optical ports, the output optical signal propagating within the optical housing to an optical output region of the optical element, and at least one photo detector is positioned for receiving at least a portion of the output optical signal from at least a portion of the optical output region, characterized in that

said one or more diffractive elements are a grating assembly composed of several gratings, wherein each grating is designed for a specific wavelength range and optimum wavelength within said range, and

wherein said at least one photo detector is a 2D image sensor.

According to the present invention one or more of the present objects are achieved. Another benefit is that no time consuming assembly of the individual parts of the spectrometer is necessary. In the present optical module the adjustment and calibration is done afterwards with image processing software. In addition, a flexible and scalable manufacturing platform according to a modular concept has now become possible resulting in a reduction of assembly time and in easy configuration and upscaling to high volume.

In a preferred embodiment wavelength sections of the incoming light are diffracted from a grating assembly of stacked (concave) sub-gratings, wherein each grating is designed for a specific wavelength range and optimum wavelength within said range each is designed to give a high efficiency. The 2D image sensor is chosen such that this sensor has maximum quantum efficiency in the spectral range needed for the application. Different grating-detector combinations can be utilized for different applications. The overall result is a wide-range, high-resolution spectrometer in a small form factor for much lower cost than the traditional devices.

According to a preferred embodiment the 2D image sensor is composed of several photo detector sub-segments, wherein each sub-segment is optimized for receiving at least a portion of the segmented output signal from the grating assembly.

According to another preferred embodiment at least one photo detector is of CMOS-type, AlGaAs type, PbSe type, CCD type and/or diode array.

In order to provide a high-resolution spectrometer it is preferred that the photo detector comprises several segments, wherein each segment is preferably optimized for a specific wavelength range.

For specific applications of the present module it is preferred that segments are optimized for at least one or more wavelength segments, such as VIS1 (for example 400-570 nm), VIS2 (for example 570-814 nm), IR1 (for example 814-1180 nm), IR2 (for example 1180-1700 nm), UV1 (for example 180-270 nm) and UV2 (for example 270-400 nm).

In the present optical module it is preferred that each segment of the segmented photo detector is provided with individual electronic components for individual data processing.

The present grating assembly preferably comprises segmented gratings composed of several sub-gratings, wherein each sub-grating is designed for a specific wavelength range and optimum efficiency within said range, wherein the segmented gratings are preferably composed of several stacked sub-gratings. According to the present invention the images of the stacked partial spectra are projected on a CMOS image sensor. The total spectrum is obtained by finding the partial spectra and combining these with software using standard image processing routines. The sub-gratings are optimized for the partial spectra which will result in a higher overall efficiency across the whole range.

According to a preferred embodiment the segmented gratings are curved. In a specific embodiment of the present optical module the grating assembly is tilted backwards such that stray light will be drastically reduced at the at least one photo detector.

In addition, the inside volume further comprises one or more mirrors, especially mirrors of the concave type. In another embodiment the segmented gratings are flat, i.e. its surface is flat and there is no curved shape. The inside volume further comprises a circuit board to which said at least one photo detector is operationally connected. In yet another embodiment a circuit board to which said at least one photo detector is operationally connected is positioned outside the optical module. Such an “external” circuit board can be beneficial for cooling purposes.

For assembly purposes and miniaturization the inside volume preferably comprises one or more slots for inserting the individual elements, such as diffractive element, photo detector, mirror, lenses, apertures, e.g. pupils, light blocking elements, e.g. baffles, and circuit board. These mirrors and gratings also include segmented mirrors and segmented gratings.

In some embodiments at least one or more of said slots are tilted. Such a construction of at least one or more of the slots allow a tilt of one or more of the components inside said housing, for example 2D sensor, grating, mirror. A preferred range of tilting is about 1-10 degrees, typically 5 – 7 degrees.

The present optical housing is preferably manufactured via precision extrusion techniques. Such a technique enables high volume production with maintaining high precision and low cost. Other manufacturing techniques for include injection molding and 3D printing techniques.

In specific embodiments the optical housing comprises one or more baffles for attenuating or blocking light inside said optical housing.

In specific embodiments the optical housing comprises one or more slots located on the exterior of said optical housing. These slots enable a connection with other optical elements, such as external wavelength splitters, or one or more other optical housings, for example optical housings of the same kind as the present optical module.

In the present optical module the input optical signal is transmitted into said optical module by at least one of a channel waveguide, an optical fibre, a surface mounted prism, an optical port, and free-space propagation.

According to a specific embodiment the input optical signal is subdivided into two or more different wavelength ranges, wherein said thus subdivided light is propagated within the optical housing, wherein such a step of subdividing said input optical signal into two or more different wavelength ranges is carried out by using a set of mirrors and spectral filters, or other spectral selective elements. It is preferred that the input optical signal is subdivided such that higher-order diffraction spectra will not occur in said two or more different wavelength ranges.

The step of subdividing said input optical signal into two or more different wavelength ranges may take place within said optical housing. However, in another embodiment it is also possible to manufacture another optical housing provided with a set of mirrors, filters or other dispersive elements and to carry out the step of subdividing the input optical signal into two or more different wavelength ranges in such a separate optical housing. The output optical signals originating from that separate optical housing are transferred to the input optical port(s) of the present optical module. In that construction it is preferred to provide the optical housing with one or more slots on the exterior part of the housing for an accurate positioning of the separate optical housing on the other optical housing.

The present invention thus enables a more efficient, affordable, and more wide-spread use of spectroscopic technologies for the analysis of materials. The present module is the core of an optical spectrometer and preferably consists of a replicated segmented grating, and one or two CMOS image sensors, and, depending on its application, electronic circuitry for detecting transient spectra in the microsecond range. Examples of such applications are Laser Induced Breakdown Spectroscopy (LIBS) and time-resolved Raman Spectroscopy. The present modules are designed as a plug-in module with a USB3.0 interface for the spectrometer software. Other types of interfacing are also possible, such as Thunderbolt, GigE or any other camera interface protocol.

Typical applications for the present optical module are in the field of disease screening and diagnostics applications in healthcare, food safety, lifestyle, process analysis and industrial process control, in the field of targeting waste reduction, such as waste electronics and waste metals. But the present optical module will also enable the development of new applications with system integrators and application developers for spectroscopy key-components and thus open new markets for spectroscopy.

According to the present invention the optical modules result in spectrometers providing the powerful analytical possibilities of materials analysis in a novel compact architecture, wherein spectral analysis can be performed in real-time over a broad spectral range, from UV (180 nm) to SWIR (1700 nm and beyond), time-gated measurement is enabled by the use of CMOS image-sensors. In addition spectrometers can be configured by the end user for his specific applications by software. And portability is enabled through considerable size reduction and through the robust design of the module.

A wavelength splitter can also be an element that disperses the light into its wavelength components by dispersion, e.g. by a glass wedge, by diffraction on a periodic structure, such as a grating, or by wavelength selective optical filters.

The present invention furthermore relates to a method for manufacturing an optical module as discussed above, the method comprising the following:

i) providing optical components and, optionally, electronic components;

ii) providing a housing for one or more of the components of i), the interior of said housing being provided with one or more slots for accurately mounting said one or more components;

iii) inserting said one or more components into said one or more slots within said housing for obtaining said optical module.

Such a method allows for manufacturing optical modules in a versatile way. The presence of slots within the housing, i.e. the interior thereof, enables to use optical components of different optical quality and performance. In addition, for a specific application of the present optical module only several slots in the housing are provided with optical elements, whereas for other applications of the optical module different types of optical components will be used. This means that some of the slots inside the housing are merely optional for some applications or uses. In addition, the accurate position of the optical components in the housing is very critical. By the provision of well-defined and dimensioned slots in the interior of the housing the accuracy of the output is guaranteed and the output signal adjustment and calibration is done afterwards with image processing software. The present method provides thus a robust and reliable method for manufacturing an optical module,

In an embodiment of the present method for manufacturing the optical module the housing including its interior is manufactured via (precision) extrusion, injection molding or 3D printing techniques. These techniques allow a precise, accurate and complex structure of the optical module.

In order to obtain a well-defined position of an optical element in the interior of the housing the slots are preferably provided with local stop features for positioning said component at a desired height into said slot.

Such local stop features can be obtained by a method chosen from the group of bending, pinching, welding, screwing and applying a bead of glue.

In the optical housing according to the present invention some slots are positioned parallel to the wall of the housing but other slots need to be constructed in a certain angle relative to the wall of the housing. Thus, one or more slots in the interior of said housing allow a tilted configuration of said one or more slots thereby positioning said component in a desired angle and/or height in the interior of said housing. In an embodiment the step of allowing a tilted configuration of one or more slots comprises a step of bending a part of said slot.

Examples of the components of step i) are segmented gratings, detectors, segmented mirrors, lenses, apertures (pupils), light blocking elements (baffles) and circuit boards. The term gratings and mirrors also includes segmented gratings and segmented mirrors. It is to be noted that one or more of these elements may be pre-shaped in a somewhat tilted fashion, for example when complex dimensional shapes have been manufactured through 3 D printing technique. This means that an element as such is to be inserted in the relevant slot into the optical housing thereby directly obtaining an optical element in a tilted fashion. This implies that a further step of bending of the element is not necessary.

The present method further comprises a step of secure mounting of the components thus inserted in the interior of said housing, said step of secure mounting being chosen from the group of clamping, gluing, (laser) welding, soldering and screwing.

In another embodiment step ii) further comprises the provision of one or more slots located at the exterior of said housing. In some applications or uses these external slots will not be used, i.e. the redundant slots will remain “empty”.

The present method can be further carried out by assembling one or more optical modules obtained in step iii) with one or more other optical components chosen from the group of spectrometers and wavelength splitter blocks.

The interior of the present optical housing is preferably provided with light absorbing material at specific places. Such light absorbing material functions to absorb unwanted stray light inside the optical housing.

Objects and advantages pertaining to integrated spectrometers incorporating diffractive element sets may become apparent upon referring to the exemplary embodiments illustrated in the drawings and disclosed in the following written description and/or claims.

Fig. 1 is a schematic side view of an optical module according to the present invention.

Fig. 2A is a schematic side view of another optical module according to the present invention.

Fig. 2B is a schematic side view of a wavelength splitter module according to the present invention.

Fig. 3 is a schematic view of a concave grating element.

Fig. 4 is a schematic view of light propagating in the inside of an optical module comprising a mirror element according to the present invention.

Fig. 5 is a schematic plan view of a wavelength splitter block according to the present invention.

Fig. 6 shows the housing of an optical module according to the present invention.

Fig. 7 is another schematic view of light rays within an optical module according to the present invention.

Fig. 8A and 8B show an embodiment of an optical module according to the present invention in combination with an external wavelength splitter block.

Fig. 9 shows an example of a housing of a wavelength splitter block according to the present invention.

Fig. 10 shows an arrangement of the present optical module and a wavelength splitter block.

Fig. 11 shows another arrangement of the present optical module and a wavelength splitter block.

Fig. 12 shows a sub-mount for an optical element to be inserted into the interior of the present optical module.

Fig. 13 shows another embodiment of an optical element to be inserted into the interior of the present optical module.

Fig. 1 is a schematic side view of an optical module 10 according to the present invention. Optical module 10 comprises a housing of a block type, consisting of six walls or sides. In Figure 1 walls 3 and 5 are shown, as well as upper side 2 and bottom side 4. Optical module 10 also comprises a back wall and a front wall (not shown). Optical module 10 thus comprises an inside volume and an optical housing enclosing the inside volume. The optical housing is, except for one or more input optical ports 1, completely non-transparent, such that light can enter said inside volume solely through the one or more input optical ports 1. In figure 1 only one input optical port 1 has been shown but the present optical module 10 is not restricted to a specific number of input optical ports. The inside volume of optical module 10 comprises a concave grating 6, a 2D image sensor 12 and circuit board 9. Within optical module 10 concave grating 6 is positioned such that light 11 entering optical module through input optical port 1 is split and diffracted into several beams travelling in the direction of the 2D image sensor 12. The 2D image sensor 12 provides output signals that are further processed by circuit board 9. Within the optical housing concave grating 6 is positioned within slots 7. The 2D image sensor 12 and circuit board 9 are positioned within slots 8. Slots 7, 8 are configured in such a way that both 2D image sensor 12 and concave grating 6 can be positioned in a tilted fashion, in relation to the walls 3, 5 and upper side 2 and a bottom side 4, i.e. in the x, y and z direction of the optical module.

Fig. 2A is a schematic side view of another optical module 20 according to the present invention. Optical module 20 comprises a housing of a block type, consisting of six walls or sides. In Figure 2 walls 3 and 5 are shown, as well as upper side 2 and bottom side 4. Optical module 20 also comprises a back wall and a front wall (not shown).Optical module 20 thus comprises an inside volume and an optical housing enclosing the inside volume. The optical housing is, except for one or more input optical ports 1, completely non-transparent, such that light can enter said inside volume solely through the one or more input optical ports 1. In figure 2 only one input optical port 1 has been shown but the present optical module 20 is not restricted to a specific number of input optical ports. The inside volume of optical module 20 comprises a grating 25, a mirror 26, a 2D image sensor 12 and circuit board 9. Within optical module 10 mirror 26 is positioned such that light 11 entering optical module through input optical port 1 is reflected by mirror 26. The light thus reflected travels to grating 25 and is split and diffracted into several beams travelling in the direction of mirror 26. Mirror 26 reflects light beams into the direction of the 2D image sensor 12 and the light thus reflected impinges on 2D image sensor 12. The 2D image sensor 12 provides output signals that are further processed by circuit board 9. Within the optical housing a mirror 26 is positioned within slots 7, whereas grating 25 is positioned within slots 14. The 2D image sensor 12 and circuit board 9 are positioned within slots 8. The slots 7, 8, 14 are configured in such a way that grating 25, 2D image sensor 12 and mirror 26 can be positioned in a tilted fashion, in relation to each other. The tilted fashion can take place in any direction, i.e. in the x, y and z direction of the optical module. The presence of slots 7, 8, 14 enables an easy manufacturing of the present module. In the present optical module the adjustment and calibration is done afterwards with image processing software. A specific wavelength splitter module 160 is positioned in the interior of optical module 20. This wavelength splitter module 160 is an optional element and in another embodiment such a wavelength splitter module is positioned outside the optical module 20. The functioning of wavelength splitter module 160 will be explained in Fig. 2B.

Fig. 2B is a schematic side view of a wavelength splitter module according to the present invention. The wavelength splitter module 160 has an inlet port 165 for the incident light 161, for example light in a wavelength range of 400 nm – 1700 nm. Low-pass dichroic mirror 169 reflects light having a wavelength > 850 nm and light having a wavelength < 850 nm, i.e. light having a wavelength range of 400 nm – 850 nm will leave wavelength splitter module 160 via outlet port 166. This outlet port 166 can be seen as Channel 1. The light exiting Channel 1 is light 164 having a wavelength range of 400 nm – 850 nm. Light 162 reflected by low-pass dichroic mirror 169 will impinge on reflective mirror 168, i.e. a 100% reflective mirror, and the light thus reflected will leave wavelength splitter module 160 via outlet port

167. This outlet port 167 can be seen as Channel 2. The light exiting Channel 2 is light 163 having a wavelength range of 850 nm – 1700 nm. Please note that the wavelength ranges mentioned here are for illustrative purposes only.

The construction of both Figure 2A and 2B has to be interpreted in such a way that the dotted rectangle 160 in Fig. 2A indicates the area where the light is parallel to Channel 1 after reflection from (concave) mirror 26. In this area sub-module 160 is inserted, which sub-module 160 is, as discussed above, a wavelength splitter module that allows the passage of short-wave light (Channel 1) and directs the long-wave light to a second spectrometer module (Channel 2) which is located beneath optical module 20. Thus, the construction shown in Figure 2A and 2B operates perpendicular to the drawing. It should be noted that instead of using a low-pass dichroic mirror 169, one can also use a corresponding high-pass filter at this position, then the wavelength ranges of light 163 and light 164 will be exchanged.

Fig. 3 is a schematic view of a concave grating element 30 according to the present invention. Concave grating element 30 comprises multiple zones or segments 31, 32, 33 and 34. The number of zones or segments is not limited and only four have been shown here. Each grating segment 31, 32, 33 and 34 is designed for a maximum diffraction efficiency in this specific wavelength range and an optimum wavelength within said range. Each grating segment 31, 32, 33 and 34 is preferably supported by a common substrate.

Fig. 4 is a schematic view of light propagating in the inside of an optical module 40 comprising a grating element 42 according to the present invention. In figure 4 the housing of the optical module 40 has been left out. Optical module 40 comprises four different input optical ports 48, 49. Light 46 entering the optical module 40 through input optical port 48 is reflected by mirror 41. In a specific embodiment mirror 41 comprises several individual zones, each designed for a specific wavelength range and optimum wavelength within said range, for example by special reflective coating materials. For example, the optical module comprises four different input optical ports, each port defined by a specific wavelength. For example, light of a specific wavelength range, e.g. of VIS1 (for example 400-570 nm) enters one input optical port, whereas light of another specific wavelength range, e.g. VIS2 (for example 570-814 nm) enters another input optical port. The same applies for example light in a wave range of IR1 (for example 814-1180 nm) and IR2 (for example 1180-1700 nm). Thus light of a total wavelength range of 400 – 1700 nm is sub-divided into four different wavelength ranges, each entering a specific input optical port. Please note that such a specific subdivision of wavelength ranges, i.e. number of ranges and the width of the ranges, is not restricted to a specific value but depends on the intended application of the present optical module. From mirror 41 the reflected light travels to a grating 42. In this embodiment grating 42 is composed of several segments or zones, each designed for a maximum diffraction efficiency in this specific wavelength range and optimum wavelength within said range. Image sensor wavelength ranges are preferably located on a common pixel map of the same sensor, or if necessary, on two or more separate sensors. This is because IR sensors operate with a different technology with different substrates (InGaAs instead of silicon). The light thus split and diffracted by grating 42 travels in the direction mirror 41 and is reflected as light 47. Light 47 travels in the direction of a 2D image sensor 43. The 2D image sensor 43 is composed of four photo detector sub-segments 44, 45, wherein each sub-segment is optimized for receiving at least a portion of the segmented output signal from the grating-mirror assembly. The number of sub-segments of the 2D image sensor 43 is not limited to a total of four as shown here. Depending on the application and the resolution of the optical module a different number of sub-segments of the 2D image sensor 43 can be used, for example one, two, three or even more sub-segments.

Fig. 5 is a schematic plan view of a wavelength splitter block 50 according to the present invention. The function of the wavelength splitter block 50 is to split light into different wavelength ranges. In this embodiment the incoming light 62 is split into four wavelength ranges 72, 74, 65 and 67. However, the number of output optical signals is not restricted to a number of four. Wavelength splitter block 50 comprises several slots 58, 59, 61, 75 into which optical elements can be positioned. Embodiments of optical elements are mirrors 55, 56 and filters 53, 54, 57. Incoming light 62 travels through optical inlet port 52 to filter 53, positioned in slots 58, 61. Some parts of light 62 passes filter 53 as light 64. Some parts of light 62 are reflected by filter 53 as light 63. Light 63 travels in the direction of filter 57, positioned in slots 75, 59. Some parts of light 63 passes filter 57 as light 72. Some parts of light 63 are reflected by filter 57 as light 73. Light 73 travels in the direction of mirror 56 and is reflected by mirror 56 as light 74. Light 64 from filter 53 travels in the direction of filter 54, positioned in slots 58, 59. Some parts of light 64 passes through filter 54 as light 66. Some parts are reflected by filter 54 as light 65. Light 66 is further propagated in the direction of mirror 55, positioned in slots 58, 59. Light reflected by mirror 55 leaves wavelength splitter block 50 as light 67. Thus incoming light 62 is split into different wavelength ranges. In this embodiment the incoming light 62 is split into four wavelength ranges 72, 74, 65 and 67, each wavelength range leaving wave splitter block 50 via output ports 68, 69, 70, 71 respectively. The combination and selection of mirrors and filters is such that incoming light is spit into the required wavelength ranges. In his embodiment of the wavelength splitter block 50 there are four outlet ports.

Fig. 6 shows the housing of an optical module according to the present invention. This extrusion profile shows slots for the main components of the present optical module. The housing 20 shown here refers to the housing shown in Figure 2, comprising slots 7, 8, 14 for mirror 26, 2D sensor 12 and grating 25, respectively.

Fig. 7 is another schematic view of light rays within an optical module 80 according to the present invention. Four input optical ports 81, 82 provide light rays travelling onto a mirror comprising four segments 83, 84, 85 and 86. Only light 87 originating from input optical port 81 is shown here. The light thus reflected by the segmented mirror travels into the direction of a segmented grating 88 comprising segments of different gratings (not shown here). The light thus split and diffracted by segmented grating 88 travels to the segmented mirror and is eventually reflected as light 90 onto photo detector 89, namely a 2D image sensor. This 2D image sensor comprises segments 91, 92, 93 and 94 wherein each segment is preferably optimized for a specific wavelength range. The optical module 80 is not restricted to a specific number of input optical ports, neither to a grating comprising four segments, nor to a 2D image sensor comprising four segments.

Fig. 8A shows an arrangement of a combination of a wavelength splitter block and an optical module according to the present invention. Light from an optical source 91, for example an optical fibre is split in wavelength splitter block 92. Wavelength splitter block 92 is connected to detector-grating module 93 inside the optical housing of the invention. In wavelength splitter block 92 light 94 is split into four different wavelength ranges 95, 96, 97 and 98. The output signal of wavelength splitter block 92 comprises thus four different wavelength ranges 95, 96, 97 and 98 and each specific wavelength range 95, 96, 97 and 98 is sent to a specific grating 99, 100, 101 and 102, respectively. Each specific grating 99, 100, 101 and 102 is designed for a specific wavelength range and optimum wavelength within said range. The resulting light 105, 106, 107 and 108 is sent to a 2D image sensor. The 2D image sensor is preferably composed of several photo detector sub-segments 103, 104, wherein each sub-segment is optimized for receiving at least a portion of the segmented output signal from the grating assembly 99, 100, 101 and 102. For example photo detector 103 is an InGaAs 2D sensor (wavelength range: 1.0 – 1.7 micrometres), and photo detector 104 is a CMOS 2D sensor (wavelength range: 0.4 – 1.0 micrometres). Please note that the wavelength ranges mentioned here are for illustrative purposes only. For example InGaAs 2D sensor can also be for a wavelength range of 1.0 – 2.0 micrometres. Also the detector arrays can be of any number of pixels, or any size or shape of the pixels. In this embodiment wavelength splitter block 92 is shown as an element separate from the detector-grating module 93 but in a specific embodiment both elements can be incorporated into one single module.

Fig. 8B shows wavelength splitter block 92 of Figure 8A without its internal elements but with an optical input port 650. The output signal of wavelength splitter block 92 leaves wavelength splitter block 92 via port 660 and enters optical module 93, comprising mirror 700, grating 710 and 2D sensor 720, via optical input port 670. For reasons of legibility electronic components and circuitry (optical module), mirrors and spectral filters (wavelength splitter block) have been left out here. The wavelength splitter block can also be arranged at another wall of housing 93, and the position of entry port 670 can be at another wall of the housing.

Fig. 9 shows an example of a housing 110 of a wavelength splitter block according to the present invention. Housing 110 is an extrusion molded part provided with multiple slots 115, 116, 117, 118, 119, 120, 121, 122, 123, and 124 where mirrors and spectral filters can be inserted. Housing 110 is also provided with an input optical port located on the front plane (not shown here) and output optical ports 111, 112, 113 and 114. The input optical port located on the front plane has been shown in Figure 5 as reference number 62. Filters and mirrors of a wavelength splitter block (see Figure 5) may also be mounted in a similar housing adjacent to the spectrometer module housing 110. Both wavelength splitter block (see Figure 5) and spectrometer module housing 110 may share the wall with the holes entering the spectrometer modules 110. Holes for light sources, i.e. input optical ports 111, 112, 113 and 114, are preferably drilled after extrusion or are made simultaneously in case of injection moulding. In a similar way multiple spectrometer modules 110 may share a common wall.

Fig. 10 shows an arrangement of the present optical module and a wavelength splitter block. The arrangement comprises two optical modules 200, 210 coupled with an eight port (two x four) wavelength splitter block 260, 270. Optical modules 200, 210 comprise optical input port 280, 290, respectively. In addition optical modules 200, 210 further comprise mirror 300, 330, grating 310, 340 and 2D sensor 320, 350. Light enters light input port 230 and is subdivided into several wavelengths by wavelength splitter blocks 260, 270. The light thus subdivided leaves wavelength splitter blocks 260, 270 via port 240, 250 and enters optical modules 200, 210 via optical input port 280, 290. For reasons of legibility electronic components and circuitry (optical module), mirrors and spectral filters (wavelength splitter block) have been left out here.

Fig. 11 shows another arrangement of the present optical module and a wavelength splitter block. The arrangement 500 comprises four optical modules 510, 520, 530, 540 coupled with a sixteen port (four x four) wavelength splitter block 550. Each optical module 510, 520, 530, 540 comprises mirror 700, grating 710 and 2D sensor 720. Light enters light input port 560 and is subdivided into several wavelengths by wavelength splitter block 550. The light thus subdivided leaves wavelength splitter block 550 via port 570, 580, 590, 600 and enters optical modules 510, 520, 530, 540 via optical input port 610, 620, 630, 640. It is to be noted that the specific configuration of each individual component within the optical modules 510, 520, 530, 540 can be different from each other. In other words, the configuration of the 2D sensor in optical module 520 can be different from the 2D sensor in optical module 530. The same applies for the mirror 700 and the grating 710. For reasons of legibility electronic components and circuitry (optical module), mirrors and spectral filters (wavelength splitter block) have been left out here.

Fig. 12 shows a sub-mount for an optical element to be inserted into the interior of the present optical module. Sub-mount 136 consists of a frame having two standoffs 131 and 133 between a plane 134 is positioned. Plane 134 can be positioned in the same horizontal plane as standoffs 131 and 133, i.e. a flat construction of the frame being obtained. The presence of bending line 132, said bending line 132 extending over the whole length of plane 134 perpendicular on standoffs 131 and 133, facilitates the adjustment of the angle of plane 134 relative to the position of standoffs 131 and 133. In the construction shown in Figure 12 plane 134 is positioned in a tilted fashion. Sub-mount 136 can be inserted via standoffs 131 and 133 into the slots of the present optical housing. The exact position, i.e. the height of optical element in the present optical housing, can be adjusted by reducing the length of standoffs 131 and 133. The tilted construction of plane 134 can be realised before the step of inserting optical element into the slots of the present optical housing, or can be realised afterwards.

Fig. 13 shows another embodiment of an optical element to be inserted into the interior of the present optical module. Optical element 130 shown in Figure 13 is different from 136 shown in Figure 12 because plane 134 is now provided with apertures 135. Optical element 130 consists of a frame having two standoffs 131 and 133 between a plane 134 is positioned. Plane 134 can be positioned in the same horizontal plane as standoffs 131 and 133, i.e. a flat construction of the frame being obtained. The presence of bending line 132, said bending line 132 extending over the whole length of plane 134 perpendicular on standoffs 131 and 133, facilitates the adjustment of the angle of plane 134 relative to the position of standoffs 131 and 133. In the construction shown in Figure 13 plane 134 is positioned in a tilted fashion. The function of apertures 135 is to reduce stray light. The shape of apertures 135 is not restricted to a round shape and any shape, such as elliptic or rectangular, can be applied here. Optical element 130 can be inserted via standoffs 131 and 133 into the slots of the present optical housing. The exact position, i.e. the height of optical element in the present optical housing, can be adjusted by reducing the length of standoffs 131 and 133. The tilted construction of plane 134 can be realised before the step of inserting the optical element into the slots of the present optical housing, or can be realised afterwards.

The present invention enables the construction of several spectrometer configurations, i.e. optical blocks as shown in figures 1 and 2. In such a configuration it is possible to combine for example two separate optical modules with one wavelength splitter block as shown in figure 5. In other words, the combination of a wavelength splitter block 92 and a detector-grating module 93 (see Figure 8) can be such that a specific wavelength splitter block only provides two optical output signals, wherein these optical output signals are used as optical input signal for another wavelength splitter block. And the optical output signals created by that another wavelength splitter block is used as optical input signals for the detector-grating module. In such a situation an optimum subdivision of specific wavelength ranges for a specific application is possible. It is also possible to connect even more detector-grating modules to one or more one wavelength splitter blocks, each designed for processing a specific wavelength and optimum wavelength within said range.

The present inventors found that by using the optical module according to the present invention no higher orders within a wavelength segment exist. This lack of higher orders will result in less scattering, The advantage thereof is that no order sorting filter is necessary for the detector, whereas such a filter is an essential element for the traditional optical modules. In addition, the stray light is drastically reduced compared to the traditional spectrometer designs.

In addition, the present inventors also found that by optimal choice of the geometry of the grating a significant reduction in stray light inside one optical module can be realised. A preferred geometry of the grating is wherein the grating is tilted backwards, by typically 5 – 7 degrees, as illustrated in figure 8B.

CLAIMS

1. An optical module, comprising an inside volume and an optical housing enclosing said inside volume, said optical housing being, except for one or more input optical ports, completely non-transparent, such that light can enter said inside volume solely through said one or more input optical ports, said inside volume further comprises one or more diffractive elements, wherein the diffractive elements transform a portion of an input optical signal into an output optical signal according to the spectral and spatial transformation information, the input optical signal propagating within the optical housing from one or more input optical ports, the output optical signal propagating within the optical housing to an optical output region of the optical element, and at least one photo detector is positioned for receiving at least a portion of the output optical signal from at least a portion of the optical output region, characterized in that

said one or more diffractive elements are a grating assembly composed of several gratings, wherein each grating is designed for a specific wavelength range and optimum wavelength within said range, and

wherein said at least one photo detector is a 2D image sensor.

2. An optical module according to claim 1, wherein said 2D image sensor is composed of several photo detector sub-segments, wherein each sub-segment is optimized for receiving at least a portion of the segmented output signal from the grating assembly.

3. An optical module according to any one or more of the preceding claims, wherein said at least one photo detector is of CMOS-type, AlGaAs type, PbSe type, CCD type and/or diode array.

4. An optical module according to any one or more of the preceding claims, wherein said photo detector comprises several segments, wherein each segmented is preferably optimized for a specific wavelength range.

5. An optical module according to claim 4, wherein said segments are optimized for at least one or more of VIS1 (for example 400-570 nm), VIS2 (for example 570-814 nm), IR1 (for example 814-1180 nm), IR2 (for example 1180-1700 nm), UV1 (for example 180-270 nm) and UV2 (for example 270-400 nm).

6. An optical module according to any one or more of claims 4-5, wherein each segment of said segmented photo detector is provided with individual electronic components for individual data processing.

7. An optical module according to any one or more of the preceding claims, wherein said grating assembly comprises segmented gratings composed of several sub-gratings, wherein each sub-grating is designed for a specific wavelength range and optimum wavelength within said range.

8. An optical module according to claim 7, wherein said segmented gratings are composed of several stacked sub-gratings.

9. An optical module according to any one or more of claims 7-8, wherein said segmented gratings are curved.

10. An optical module according to any one or more of the preceding claims, wherein said grating assembly is tilted backwards such that stray light will be drastically reduced at said at least one photo detector.

11. An optical module according to any one or more of the preceding claims, wherein said inside volume further comprises a circuit board to which said at least one photo detector is operationally connected.

12. An optical module according to any one or more of the preceding claims, wherein said inside volume further comprises one or more mirrors, especially mirrors of the concave type.

13. An optical module according to any one or more of the preceding claims, wherein said inside volume comprises one or more slots for inserting the individual elements, such as diffractive element, photo detector, mirror, lens, light blocking element and circuit board.

14. An optical module according claim 13, wherein at least one or more of said slots allow a tilt of one or more of the components inside said housing.

15. An optical module according claim 14, wherein the tilt of one or more of said slots is realized by mechanical deformation of the slot(s) concerned.

16. An optical module according to any one or more of the preceding claims, wherein said optical housing is manufactured via extrusion techniques.

17. An optical module according to any one or more of the preceding claims, wherein said optical housing comprises on or more baffles for attenuating or blocking light inside said optical housing.

18. An optical module according to any one or more of the preceding claims, wherein said input optical signal is transmitted into said optical module by at least one of a channel waveguide, an optical fiber, a surface mounted prism, a surface coupling grating, an optical port, and free-space propagation.

19. An optical module according to any one or more of the preceding claims, wherein said input optical signal is subdivided into two or more different wavelength ranges, wherein said thus subdivided light is propagated within the optical housing.

20. An optical module according to claim 19, wherein said input optical signal is subdivided such that higher-order diffraction spectra will not occur in said two or more different wavelength ranges.

21. An optical module according to any one of claims 19-20, wherein said step of subdividing said input optical signal into two or more different wavelength ranges is carried out by using a set of mirrors.

22. An optical module according to any one of claims 19-21, wherein said step of subdividing said input optical signal into two or more different wavelength ranges takes place within said optical housing.

23. A method for manufacturing an optical module according to any one or more of the preceding claims, said method comprising the following:

i) providing optical components and, optionally, electronic components;

ii) providing a housing for one or more of the components of i), the interior of said housing being provided with one or more slots for accurately mounting said one or more components;

iii)inserting said one or more components into said one or more slots within said housing for obtaining said optical module.

24. A method according to claim 23, wherein said housing including its interior is manufactured via precision extrusion, injection molding or 3D printing techniques.

25. A method according to any one or more of claims 23-24, wherein said one or more slots in the interior of said housing are provided with local stop features for positioning said component at a desired height into said slot.

26. A method according to claim 25, wherein said local stop features are obtained by a method chosen from the group of bending, pinching, welding, screwing and applying a bead of glue.

27. A method according to any one or more of claims 23-26, wherein said one or more slots in the interior of said housing allow a tilted configuration of said one or

more slots thereby positioning said component in a desired angle and/or height in the interior of said housing.

28. A method according to claim 27, wherein said step of allowing a tilted configuration of said one or more slots comprises a step of bending a part of said slot.

29. A method according to any one or more of claims 23-28, wherein said components of step i) are chosen from the group of (segmented) gratings, photo detectors, (segmented) mirrors, lenses, apertures, light shielding elements and circuit boards.

30. A method according to any one or more of claims 23-29, wherein said step iv) further comprises a step of secure mounting of the components thus inserted in the interior of said housing, said step of secure mounting being chosen from the group of clamping, gluing, (laser) welding, soldering and screwing.

31. A method according to any one or more of claims 23-29, wherein said housing provided in step ii) further comprises one or more slots located at the exterior of said housing.

32. A method according to any one or more of claims 23-29, further comprising assembling one or more optical modules obtained in step iii) with one or more other optical components chosen from the group of spectrometers and wavelength splitter blocks.

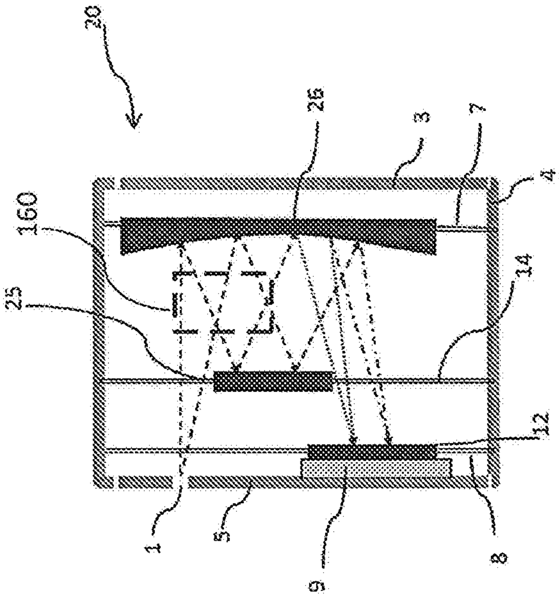

Fig. 2A

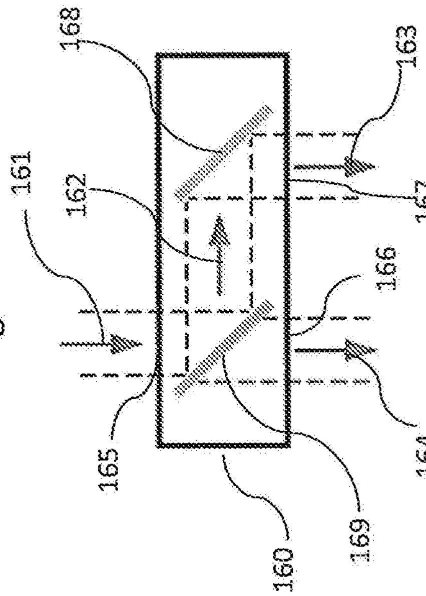

Fig. 2B

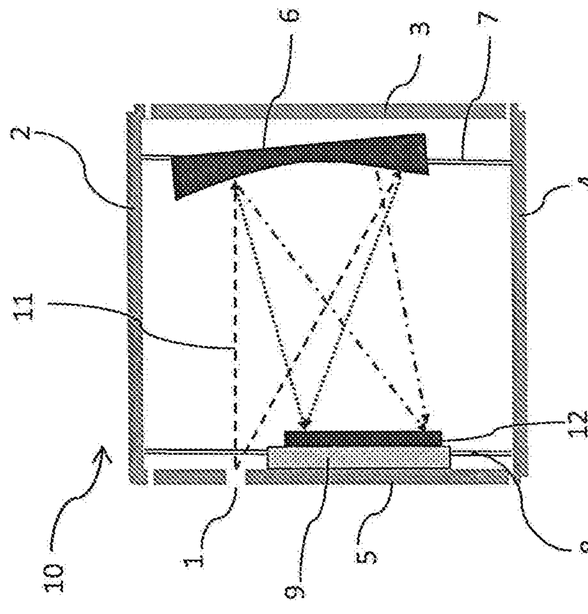

Fig. 1

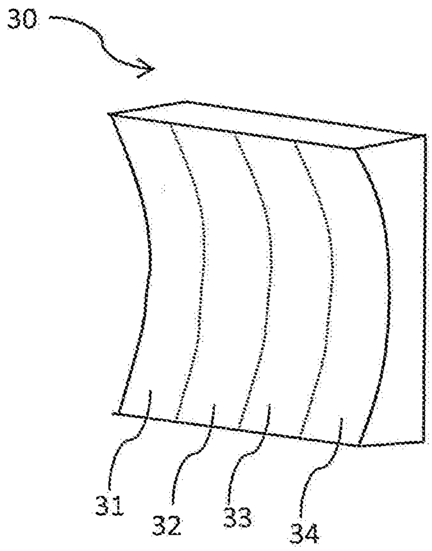

Fig. 3

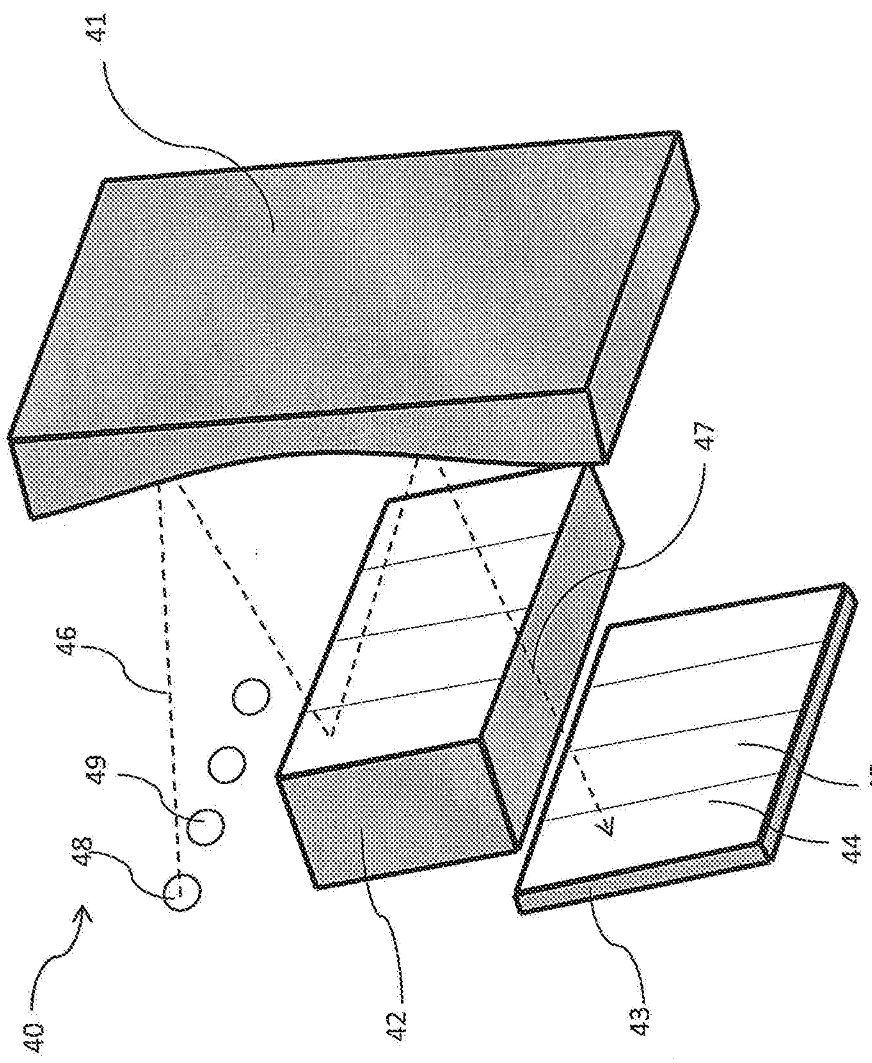

Fig. 4

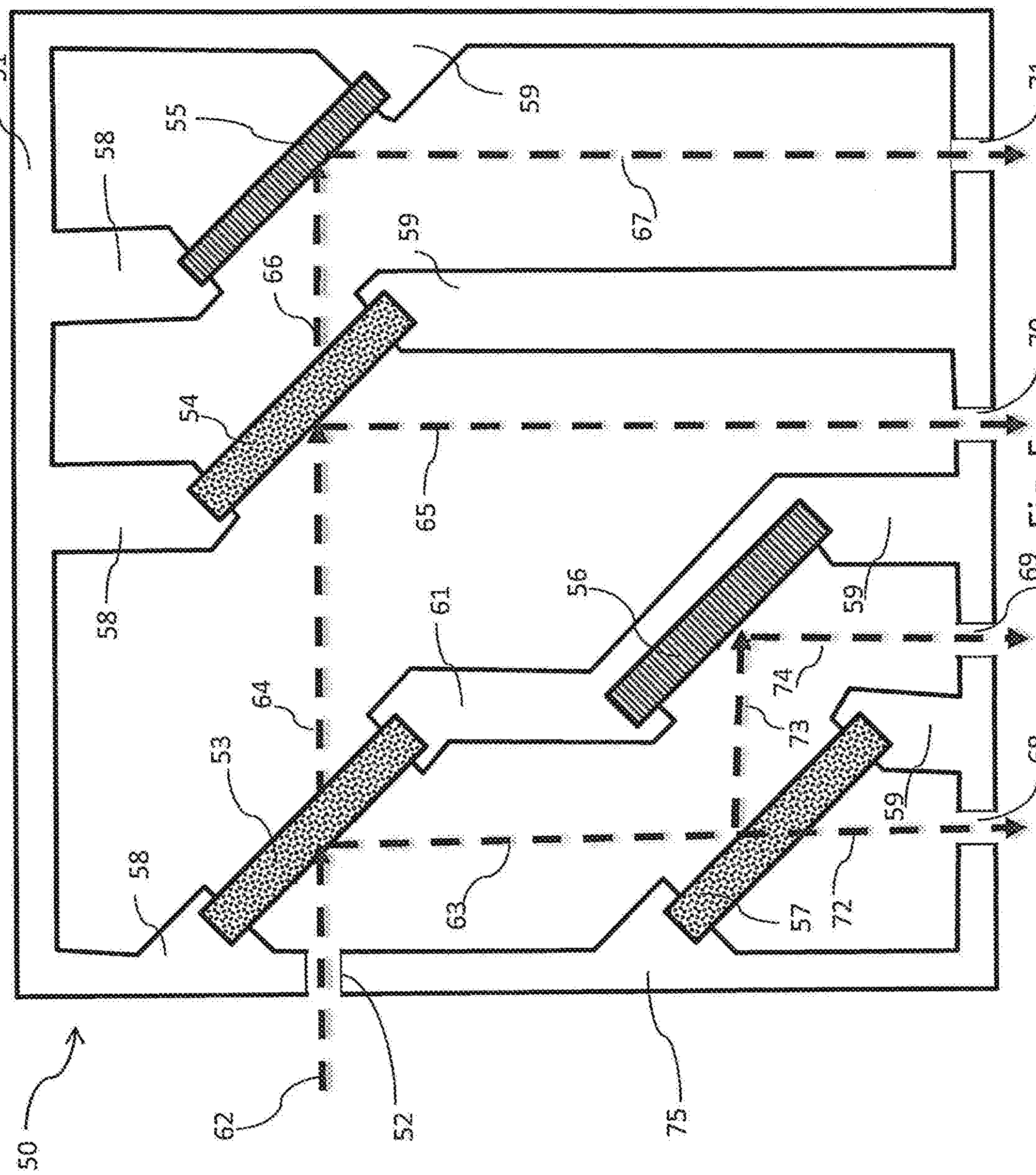
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Fig. 5

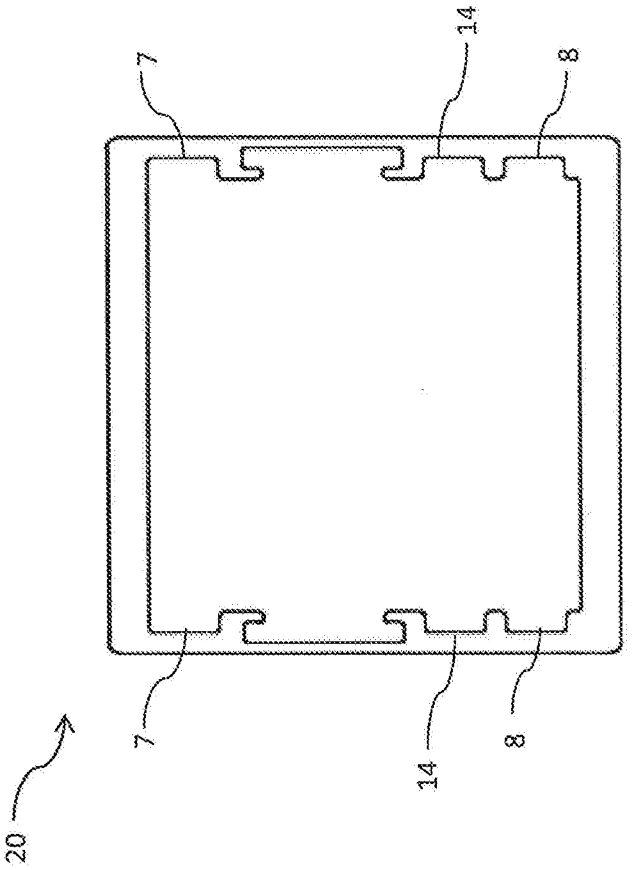

Fig. 6

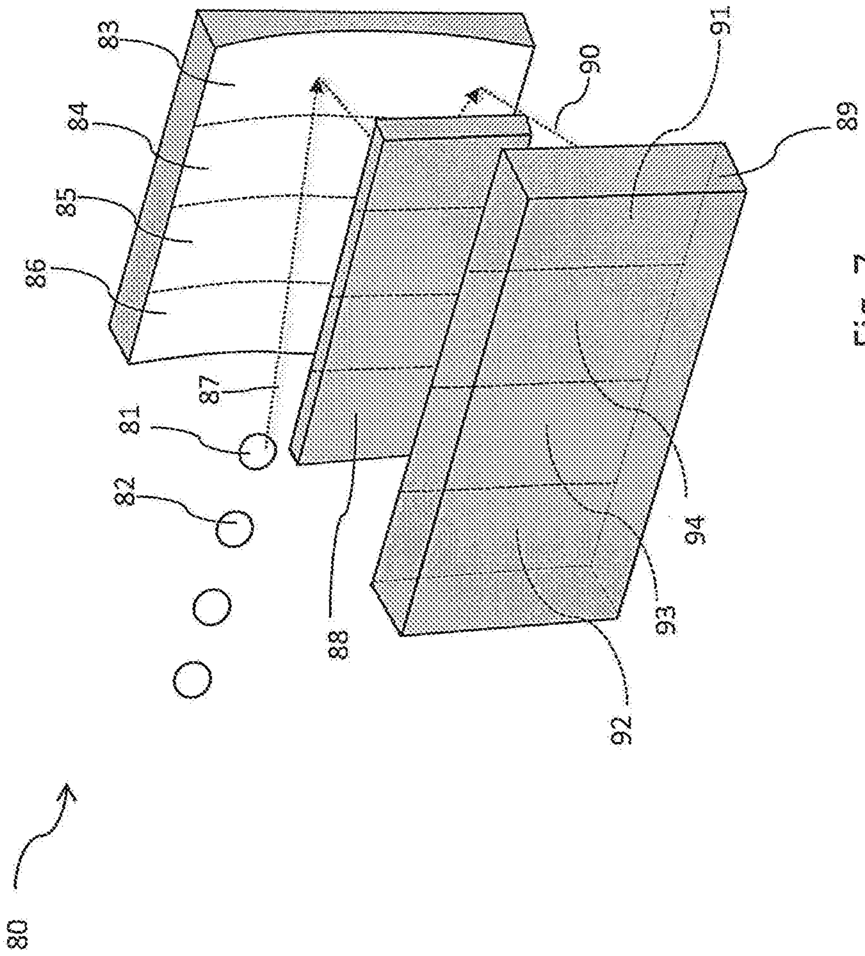

Fig. 7

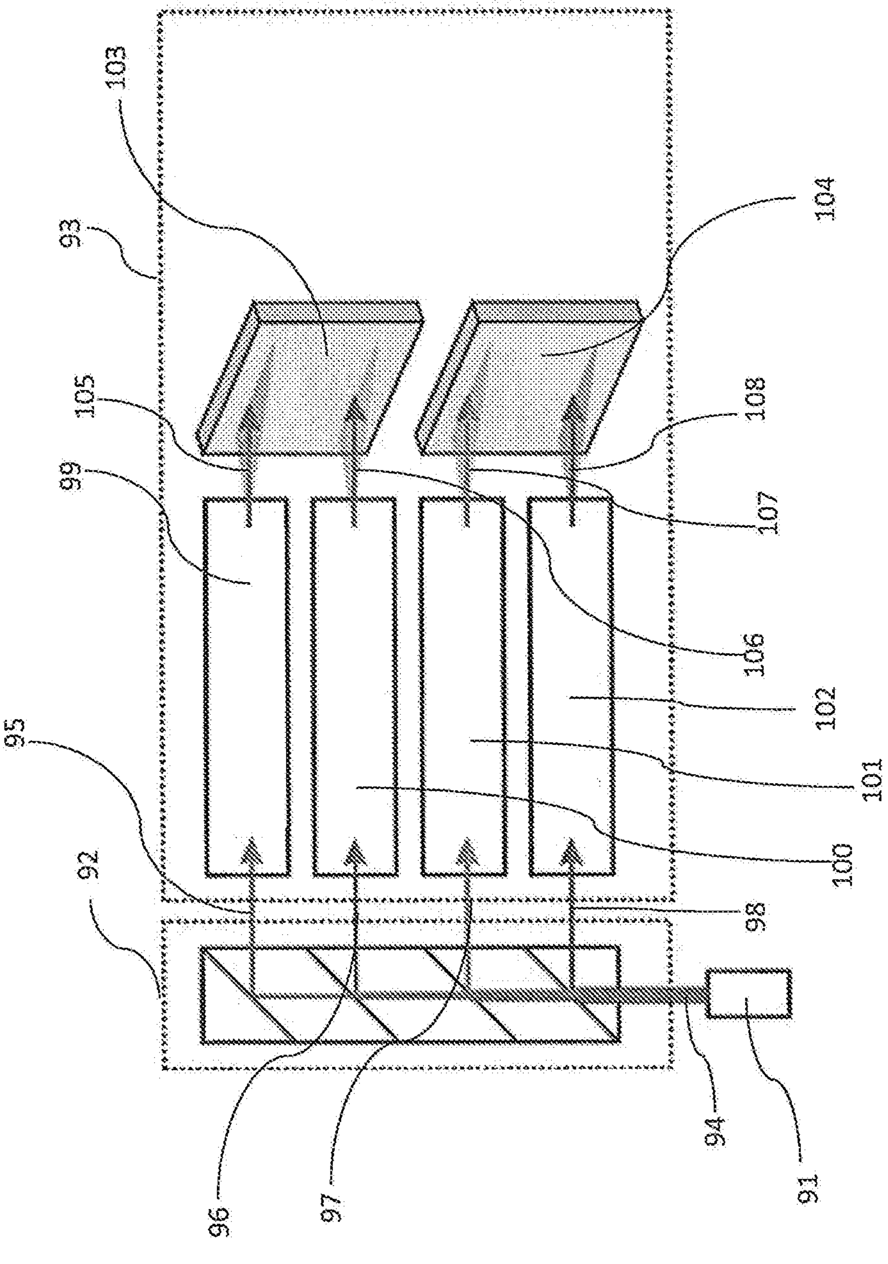

Fig. 8 A

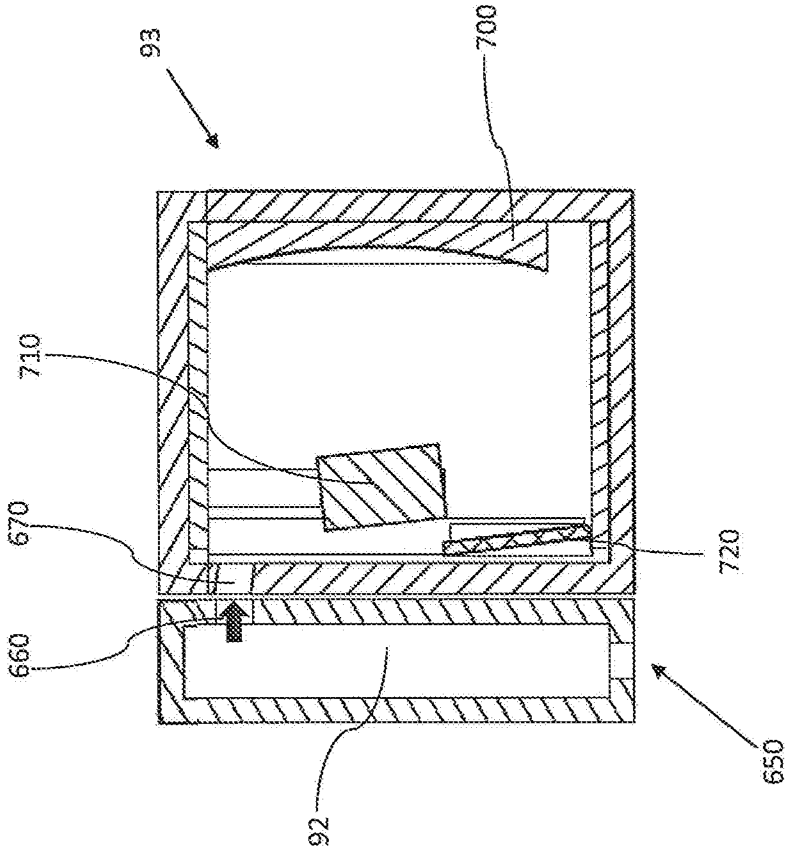

Fig. 8 B

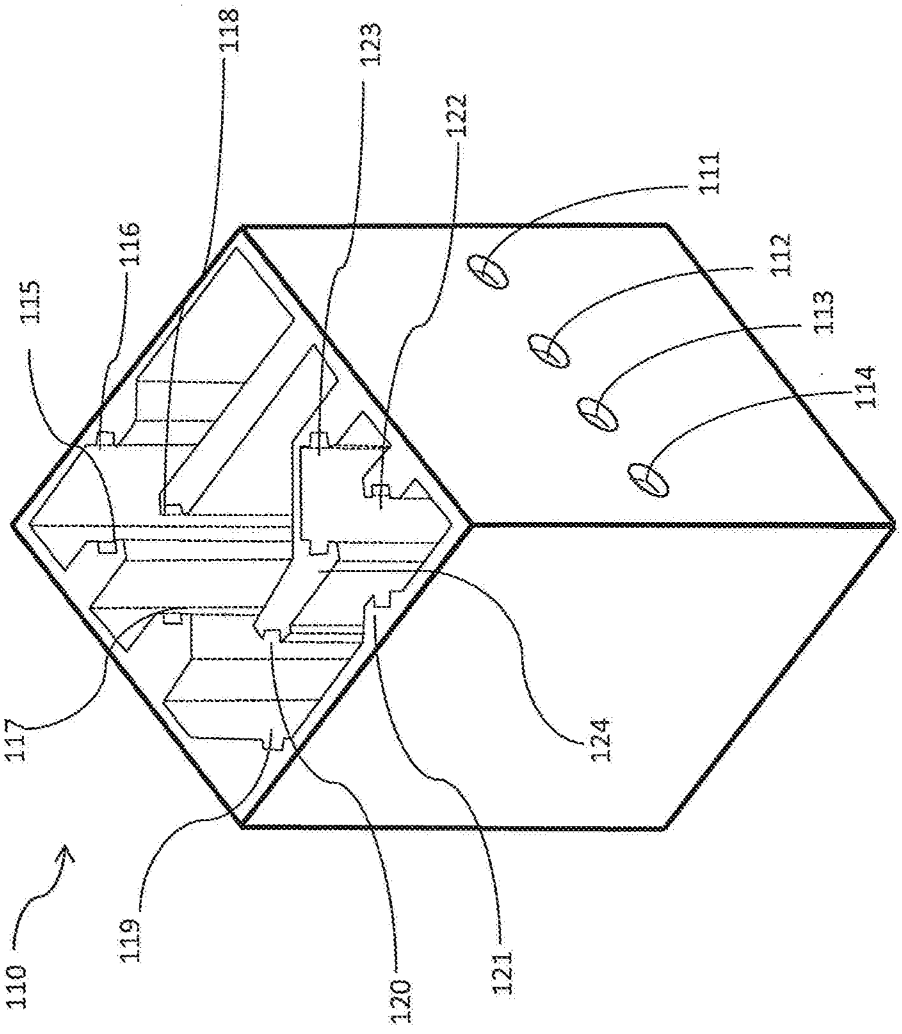

Fig. 9

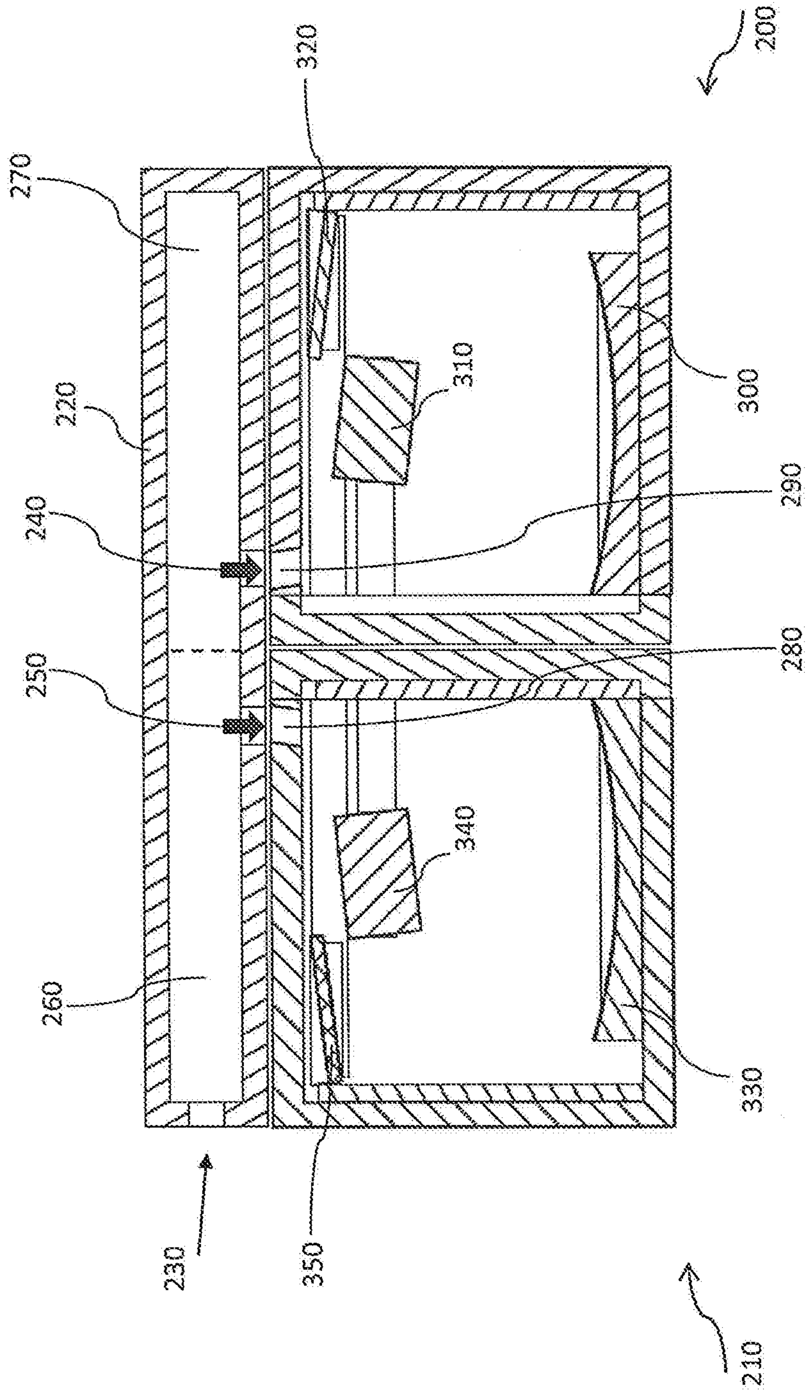

Fig. 10

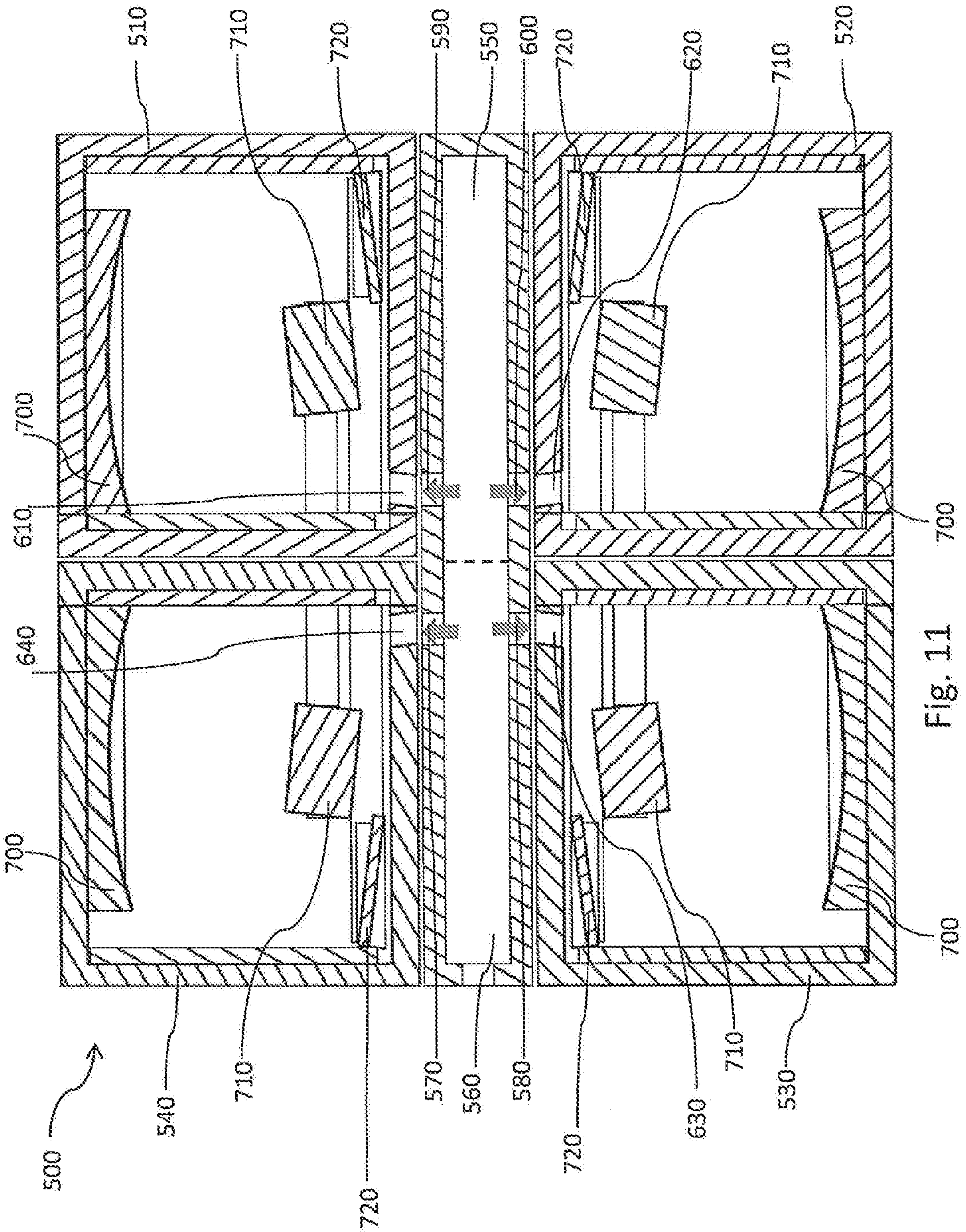
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Fig. 11

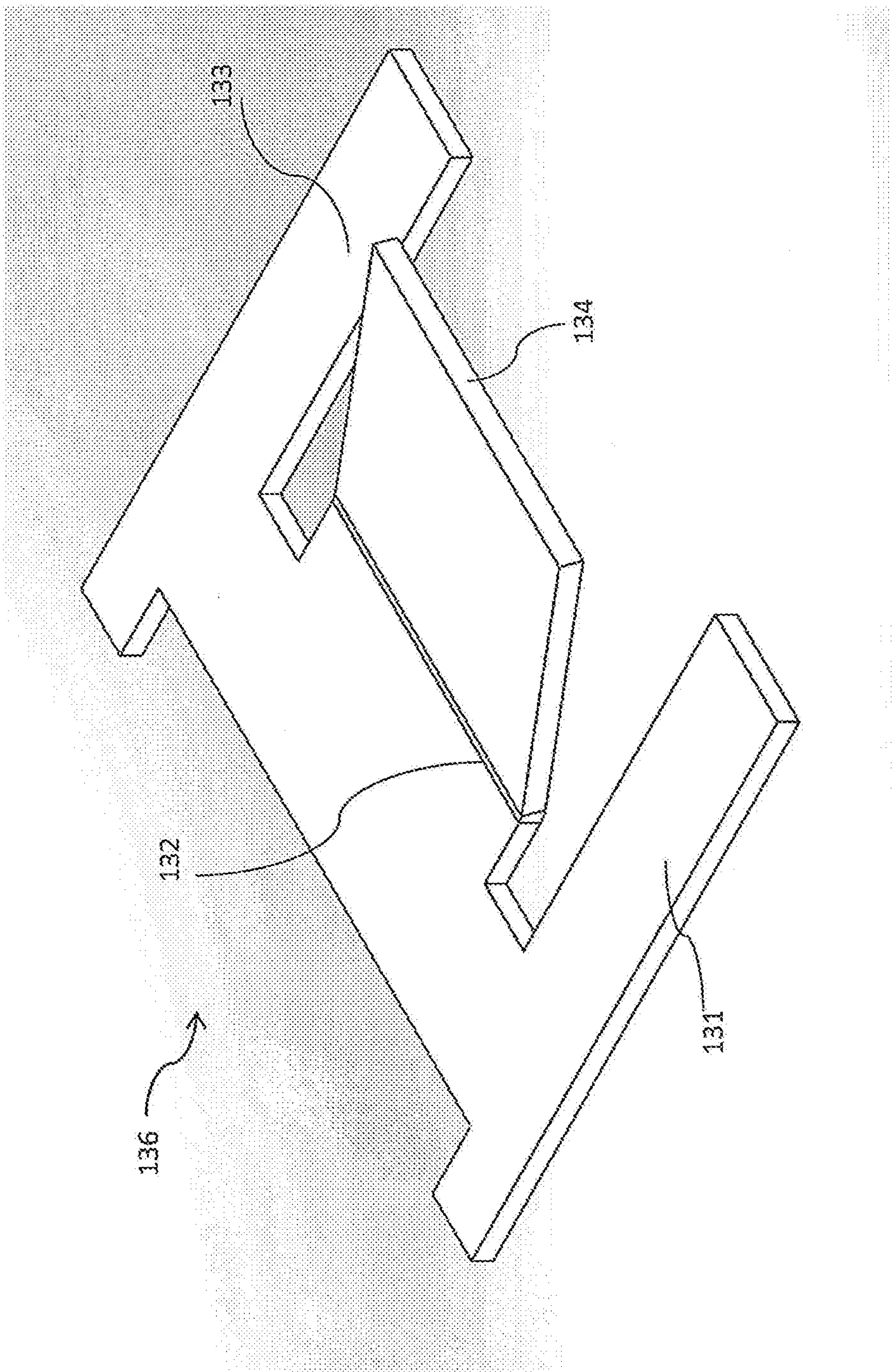

Fig. 12

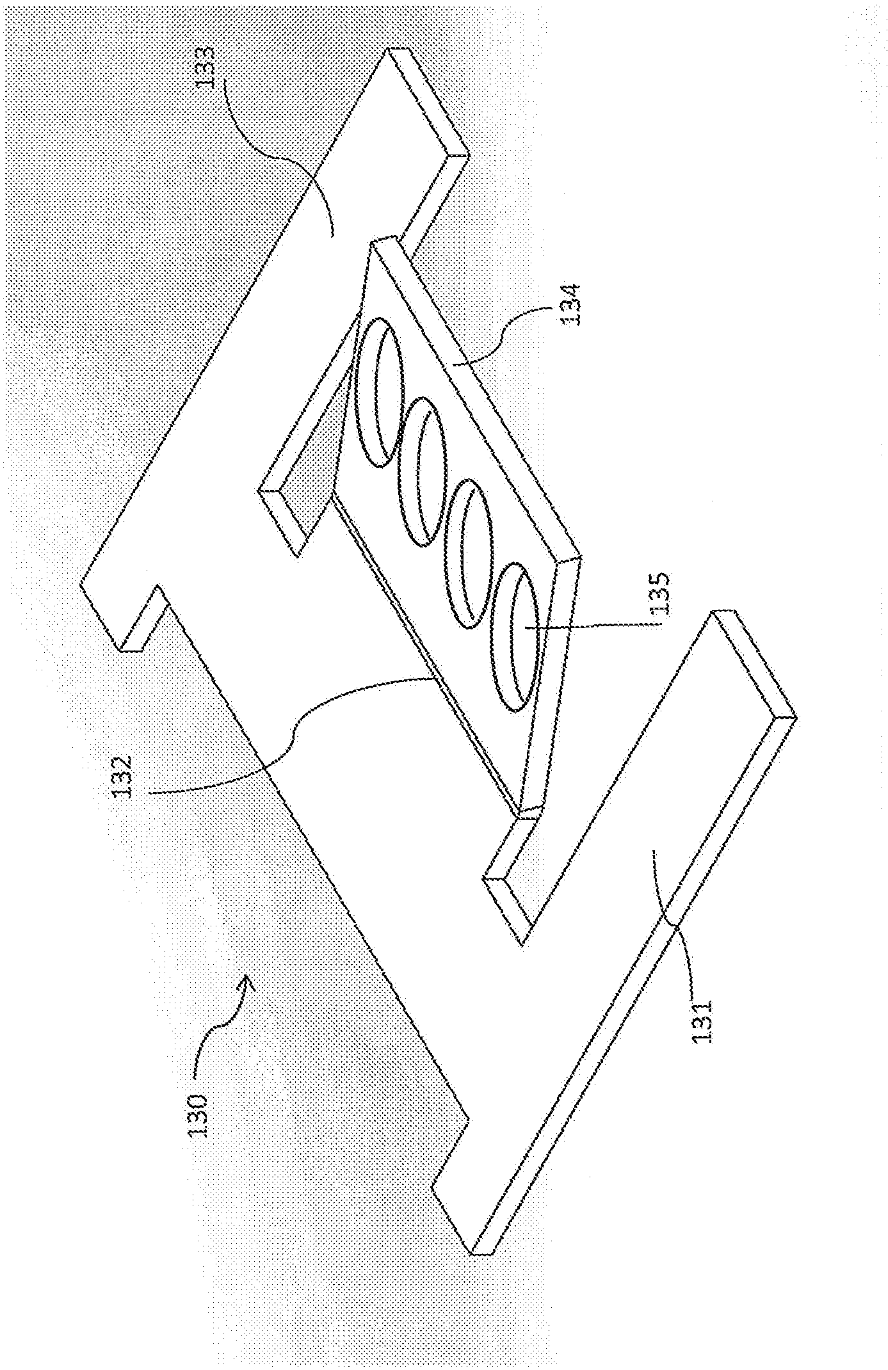

Fig. 13

INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2016/050921

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01J3/02 G01J3/18 G01J3/28 G01J3/36
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 2007/019194 A1 (CHEN LIANGYAO [CN] ET AL) 25 January 2007 (2007-01-25) figure 1 -----	1-12 13-17, 23-32
X	US 2008/309936 A1 (KRAPU MIKKO [FI]) 18 December 2008 (2008-12-18) cited in the application figure 8 -----	1
Y	US 2002/051357 A1 (TRUTTMANN-BATTIG ELISABETH [CH]) 2 May 2002 (2002-05-02) figure 2 -----	13-17, 23-32
Y	US 4 810 092 A (AUTH GERALD L [US]) 7 March 1989 (1989-03-07) figures 1, 6, 7 -----	13-17, 23-32

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

☒ See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 April 2017	24/04/2017

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	Rödig, Christoph

3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NL2016/050921

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☒ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

1-17, 23-32

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☒ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/NL2016/050921

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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US 2008309936 A1	18-12-2008	NONE	
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FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-12

   details of the optical elements in the sensor module

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2. claims: 13-17, 23-32

   details of the housing and mounting structure of the sensor module

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3. claims: 18-22

   details regarding the coupling of light to the spectrometer input port

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