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Carminati et al.

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(54) **INTEGRATED ELECTRONIC MODULE FOR 3D SENSING APPLICATIONS, AND 3D SCANNING DEVICE INCLUDING THE INTEGRATED ELECTRONIC MODULE**

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CPC ***G06V 10/145*** (2022.01); ***G01S 17/894*** (2020.01); ***G06V 20/64*** (2022.01); ***G06V 40/172*** (2022.01)

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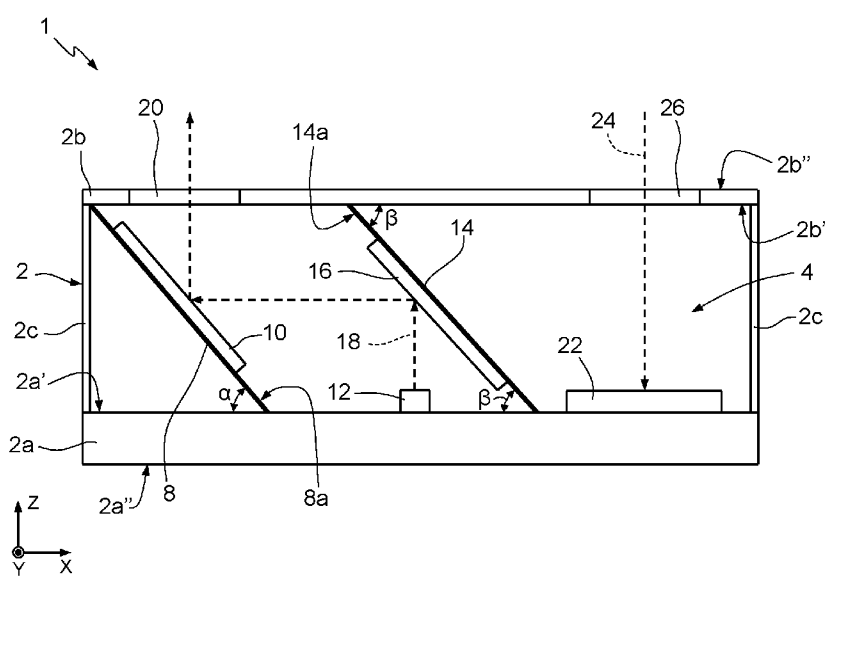
(57) **ABSTRACT**

A method of manufacturing an electronic module includes providing a base substrate having a first surface, providing a first supporting element having a first portion with an inclined top surface, and affixing the first supporting element to the first surface such that the inclined top surface is inclined with respect to the base substrate. A first reflector is coupled to the inclined top surface such that a rear surface of the first reflector is in physical contact with the inclined top surface of the first portion of the first supporting element, and a spacer structure is configured to form an interface for mounting lateral walls to the base substrate. A cap is positioned over and supported by the lateral walls to thereby define a chamber. The emitter, as well as a detector, are coupled to the first surface of the base substrate.

16 Claims, 9 Drawing Sheets



(51) **Int. Cl.**
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G06V 40/16 (2022.01)

(58) **Field of Classification Search**
CPC G01S 7/4817; G01S 7/4813; G01S 7/4814; G01S 17/894; G01S 17/89; G01S 17/42; H01L 23/04; H01L 25/165; H01L 25/167
See application file for complete search history.

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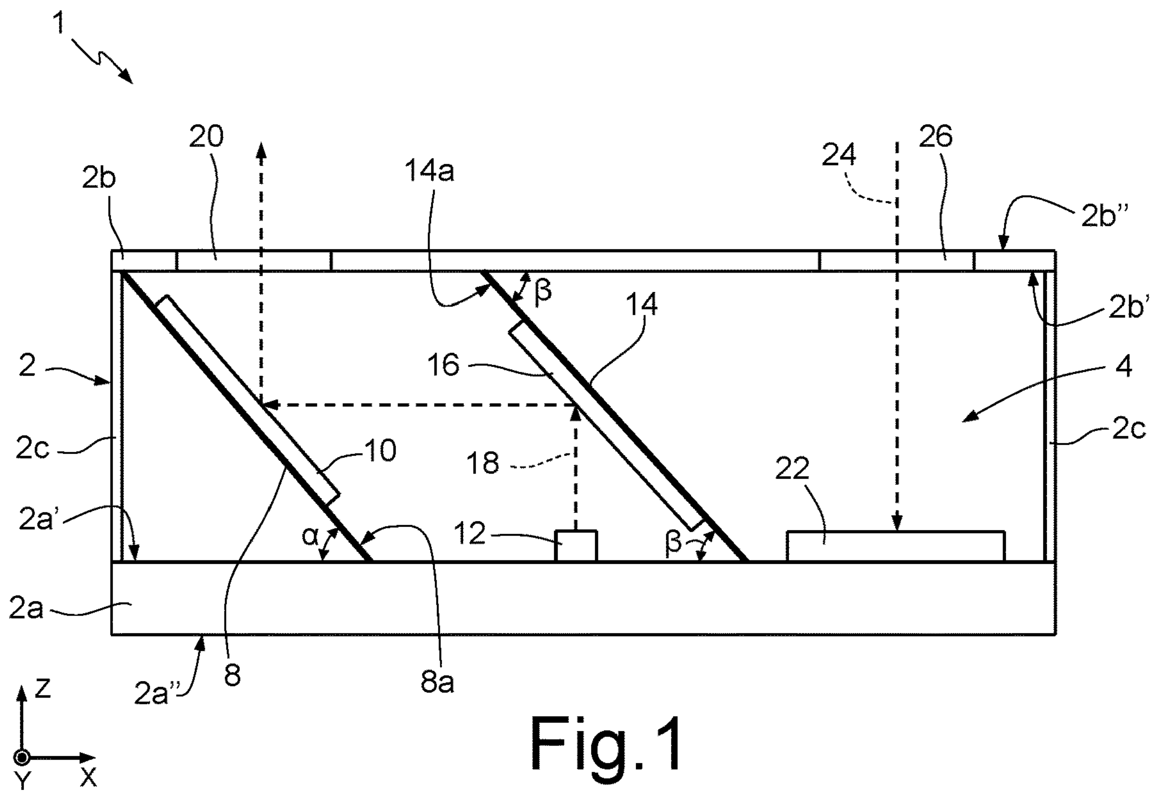
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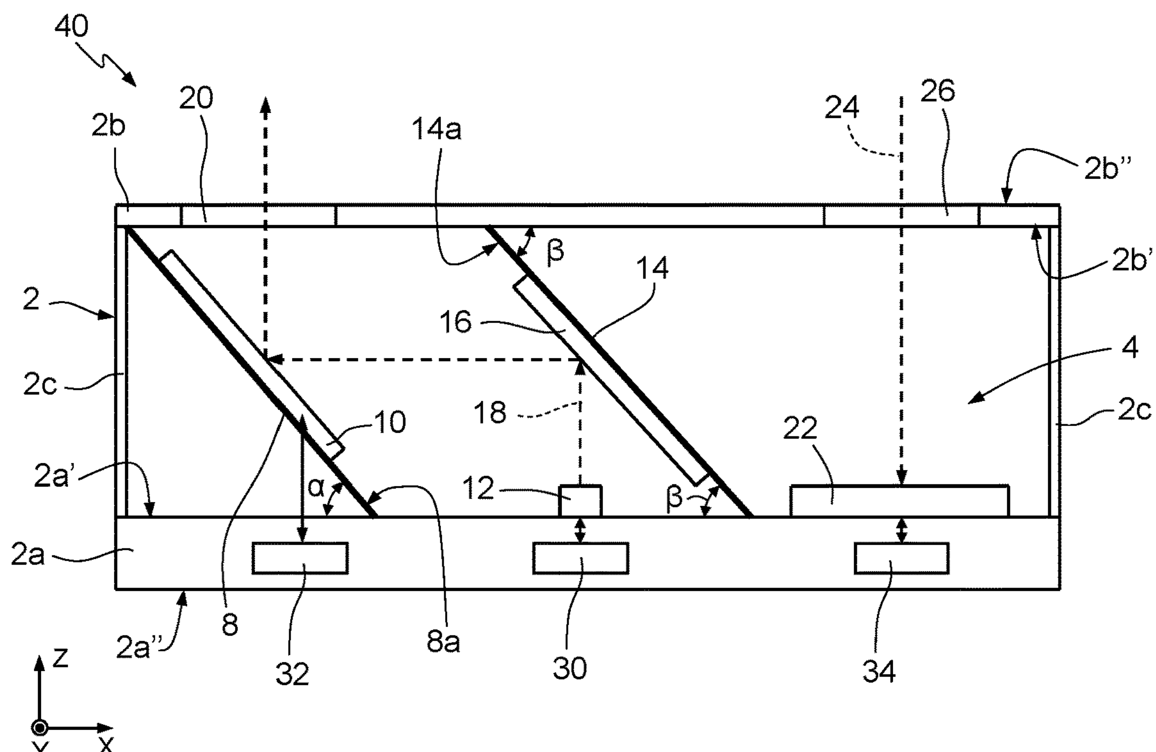
20
2b
14a
24
26
2b''
β
14
2b'
16
2
4
2c
10
2c
18
22
2a'
α
12
β
2a
2a''
8
8a
Z
Y
X

Fig.1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2c
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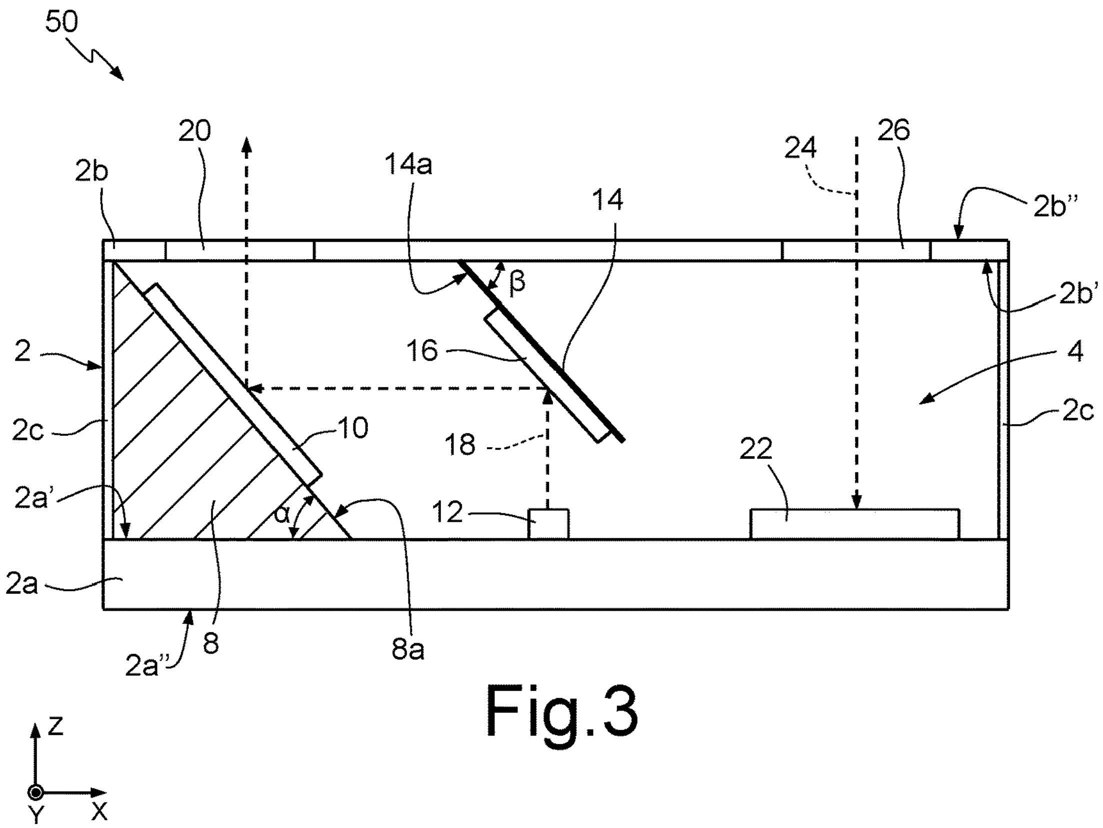
2a'
α
12
β
2a
2a''
8
8a
32
30
34
Z
Y
X

Fig.2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β
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2
16
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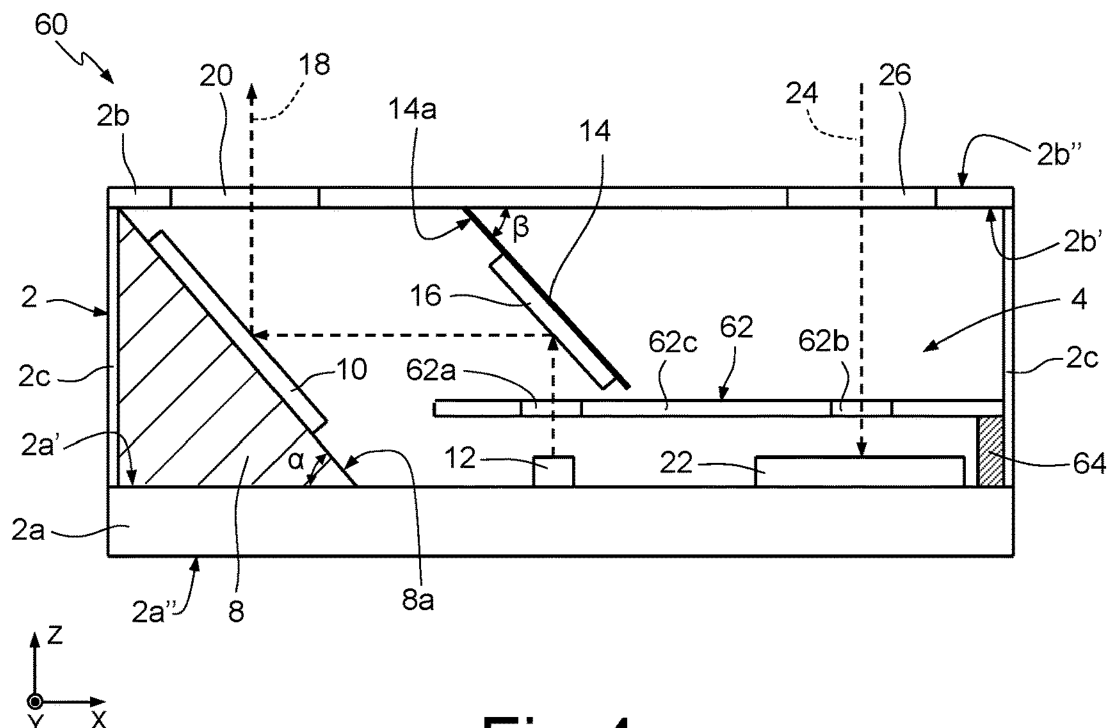
α
12
2a
2a''
8
8a
Z
X
Y

Fig.3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24
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2b''
14
β
2b'
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4
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62
62b
2c
2c
10
62a
2a'
α
12
22
64
2a
2a''
8
8a
Z
X
Y

Fig.4

Fig.5A

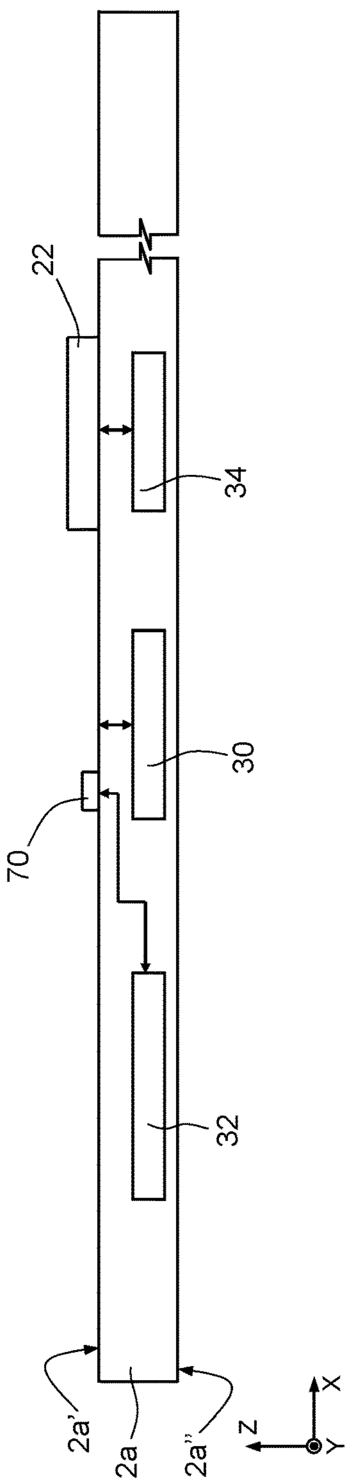


Fig.5B

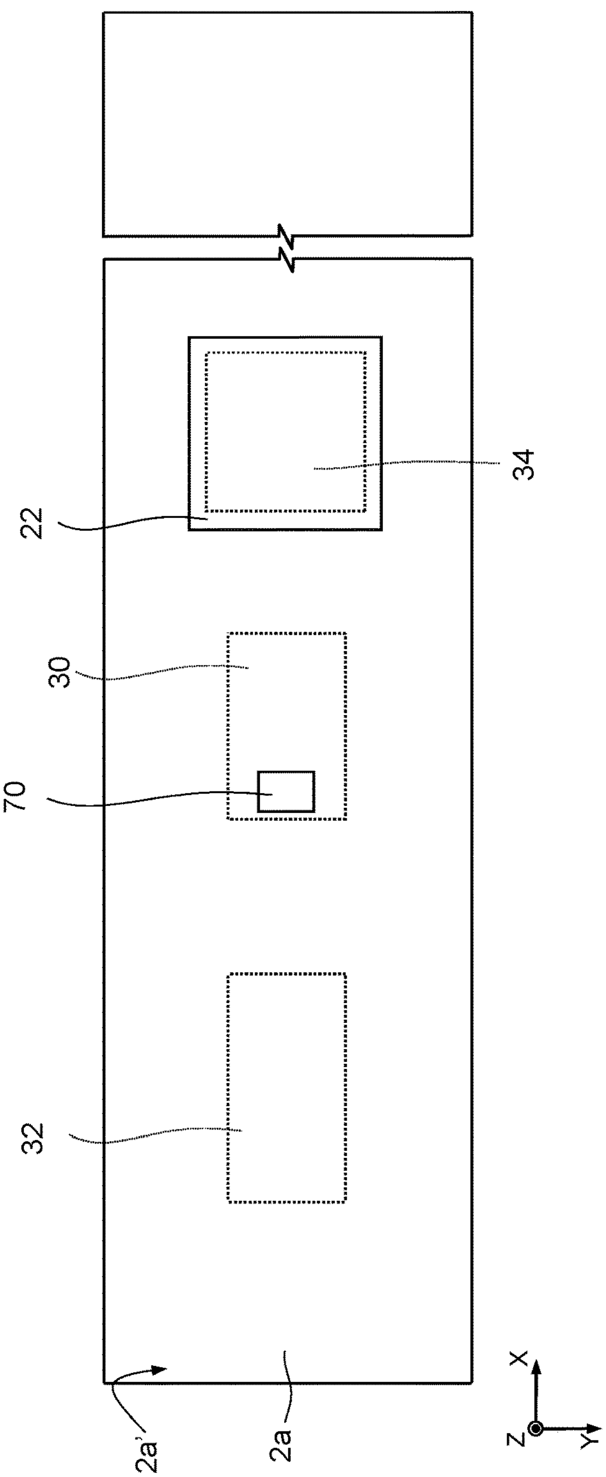


Fig.6A

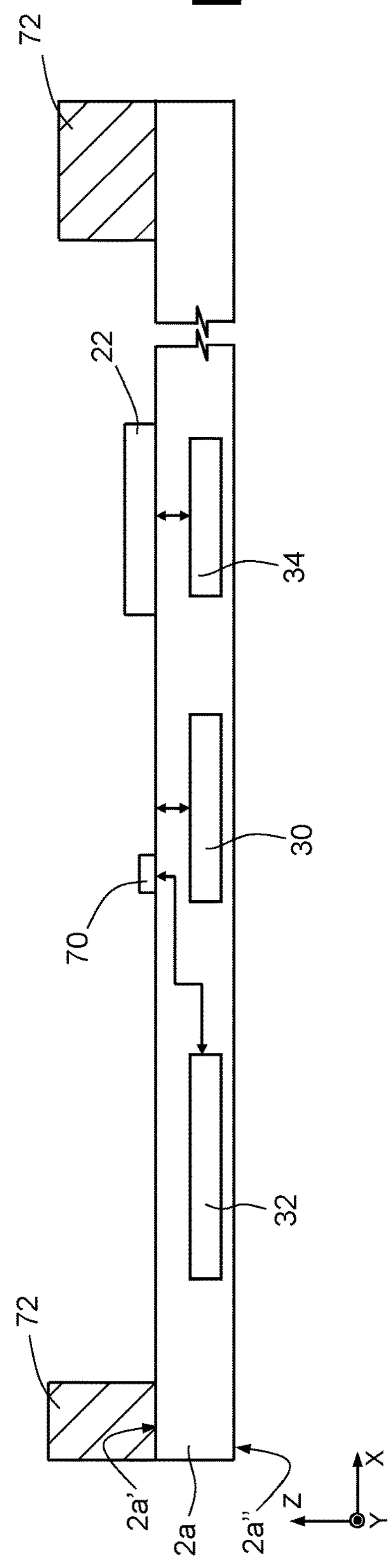
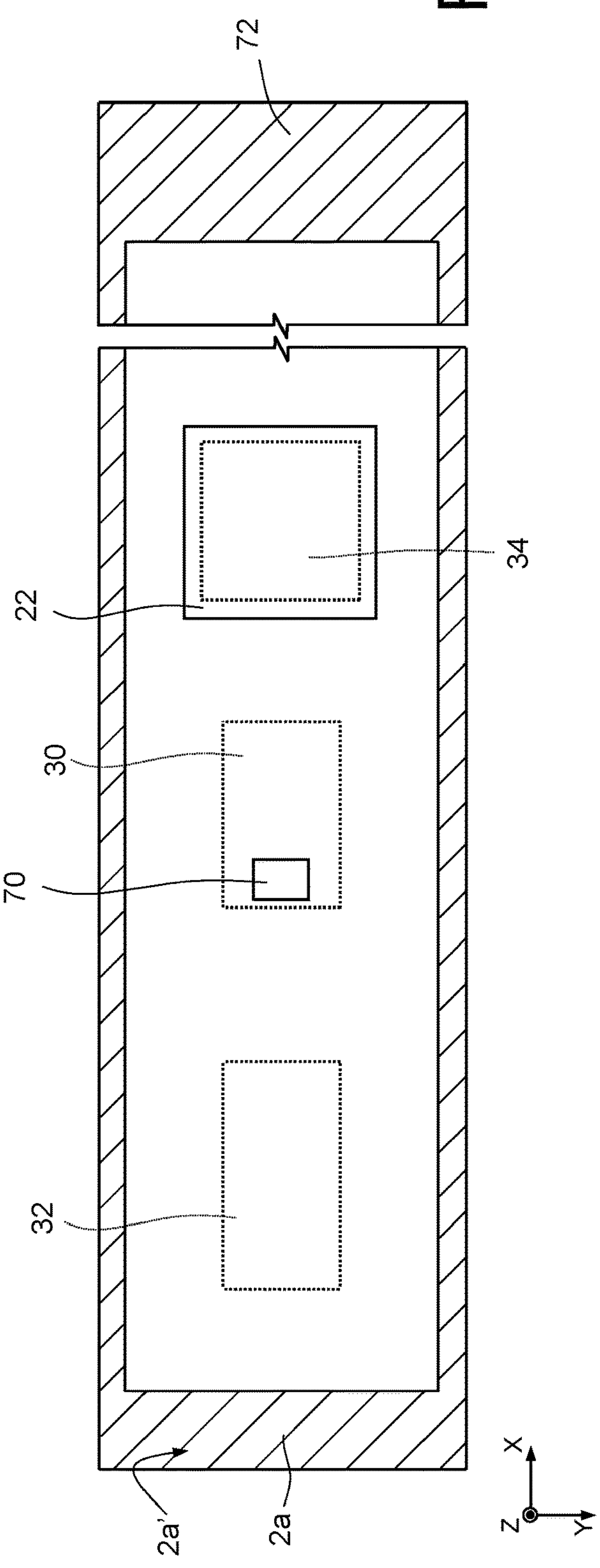
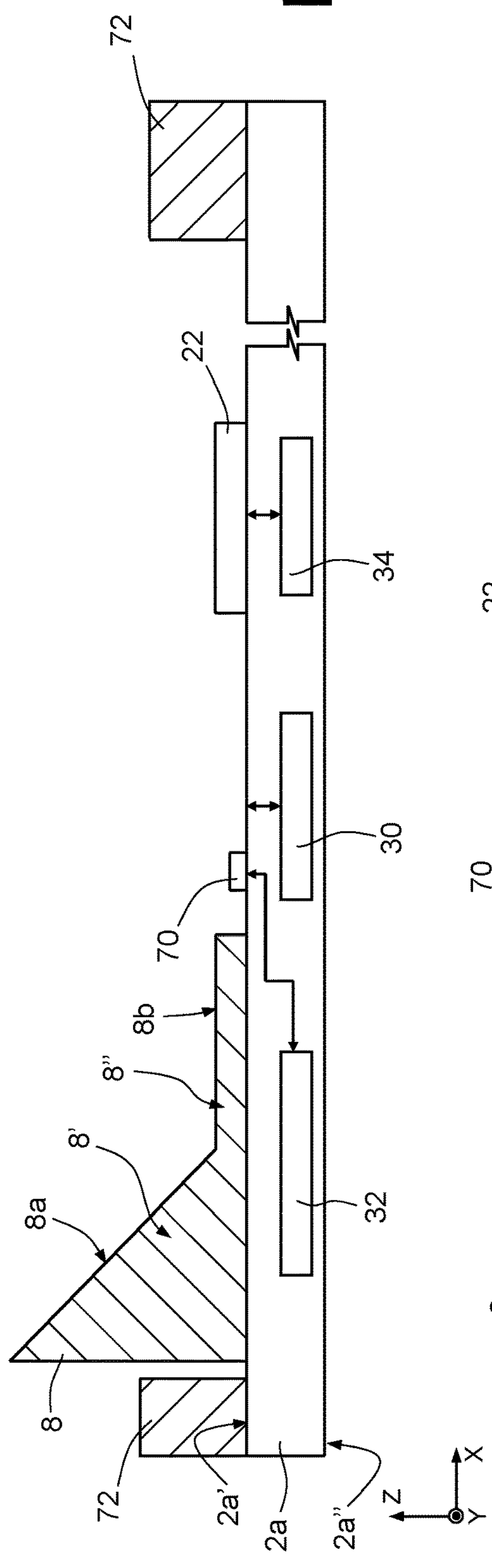


Fig.6B

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22
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70
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8''
8'
8a
32
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72
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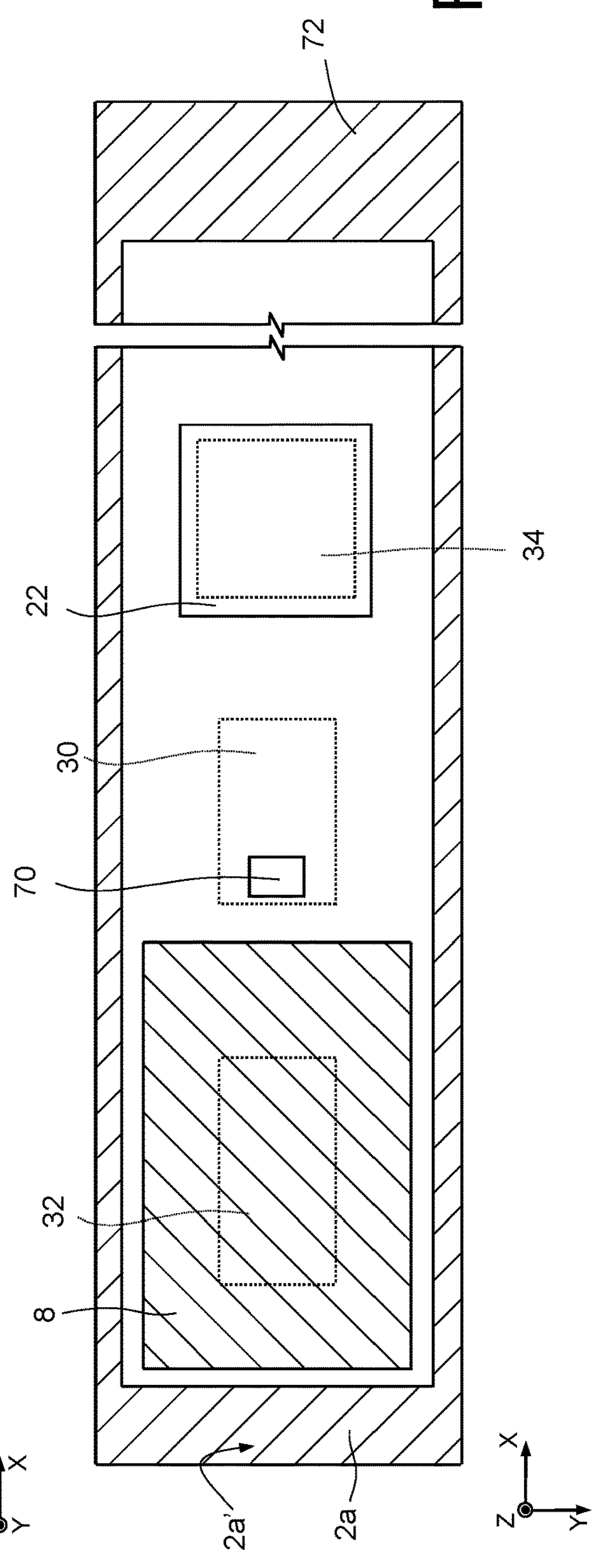
2a
2a''
Z
X
Y

Fig.7A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70
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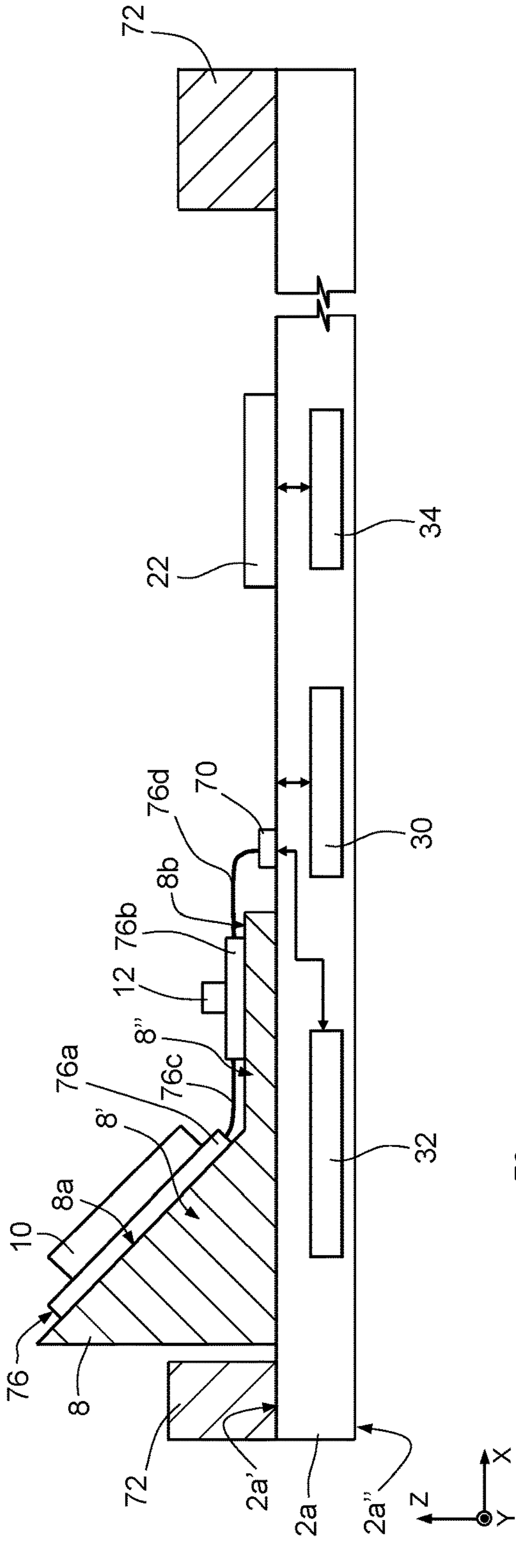
8
2a'
2a
X
Z
Y

Fig.7B

Fig.8A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8b
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8''
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76c
8'
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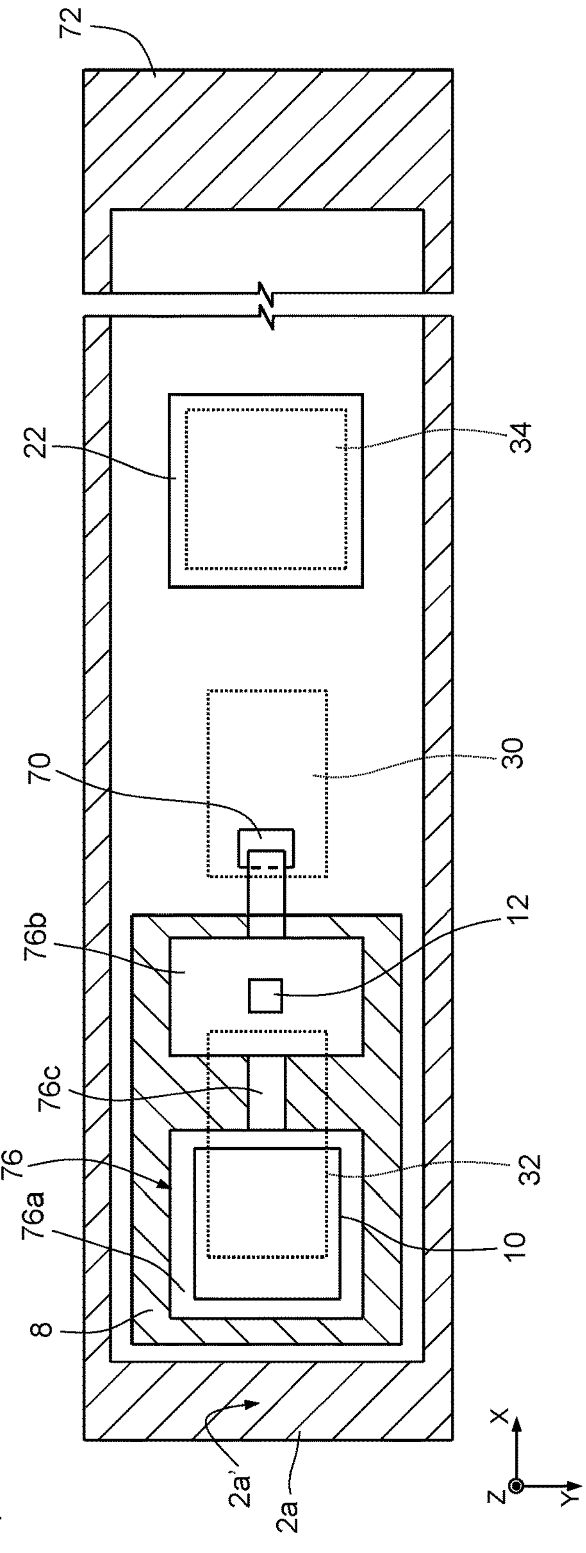
8a
10
76
8
72
2a'
2a
2a''
Z
X
Y

Fig.8B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76
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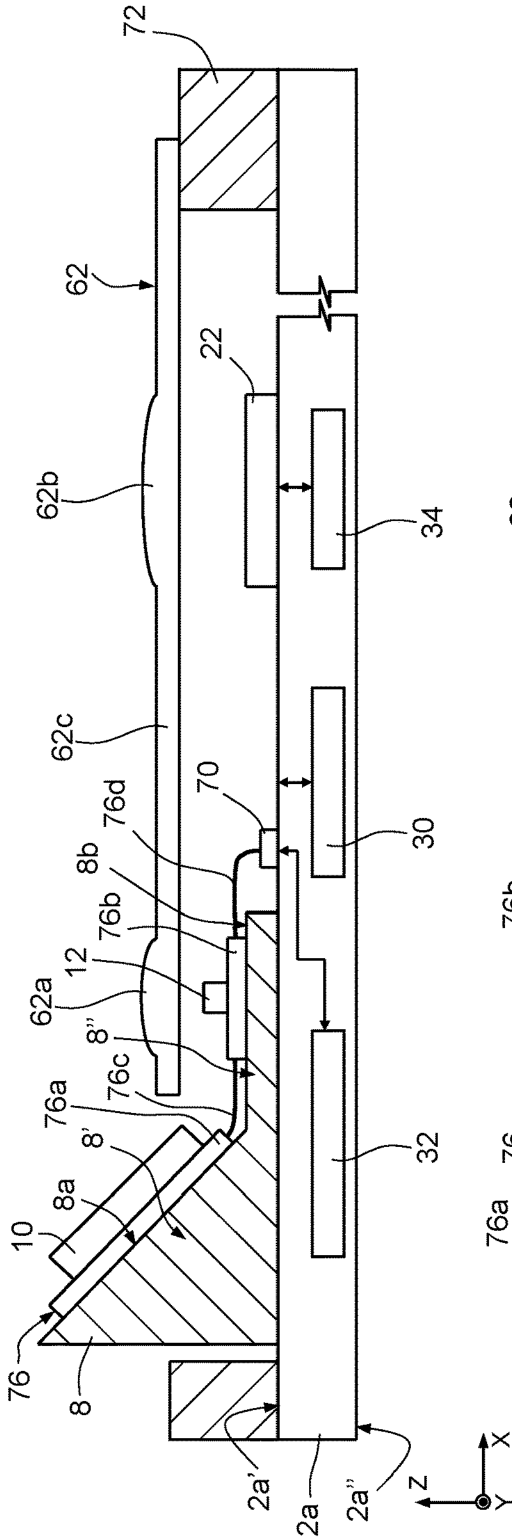
Z
Y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62c
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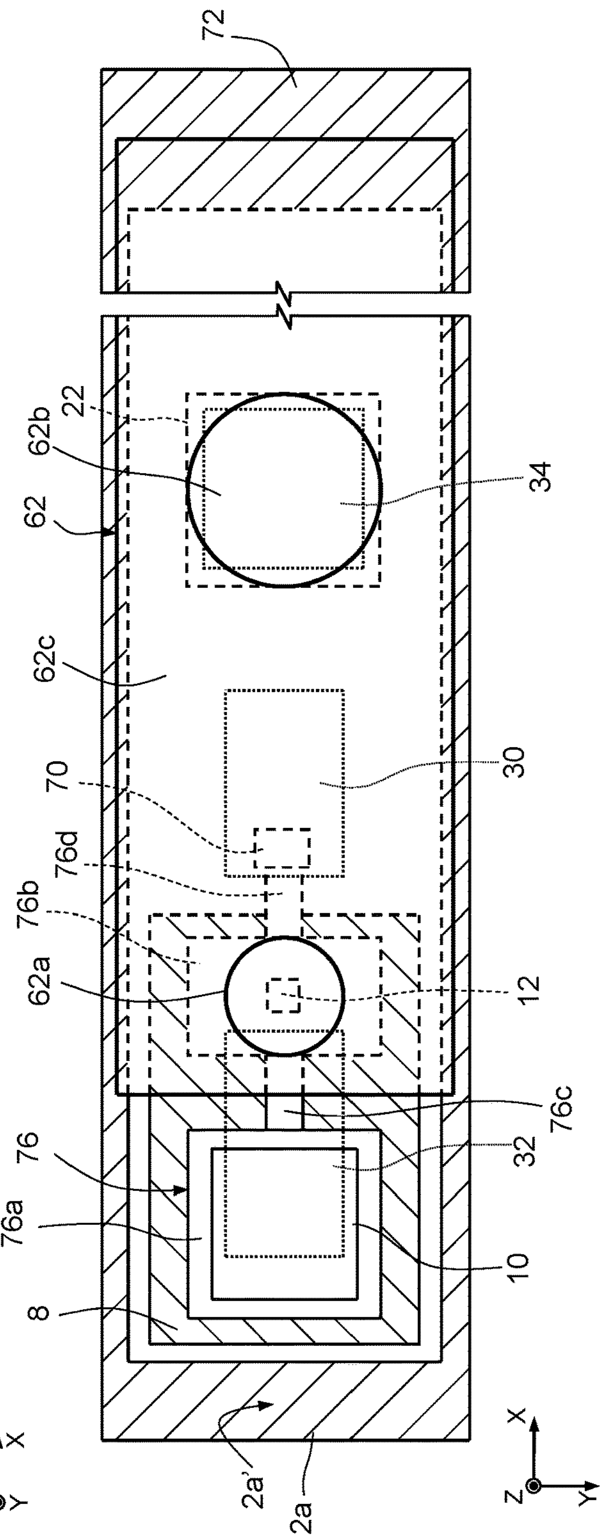
76d
8b
76b
12
62a
8''
76c
76a
8'
8a
10
76
8
32
2a'
2a
2a''
Z
Y
X

Fig.9A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62c
70
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76a
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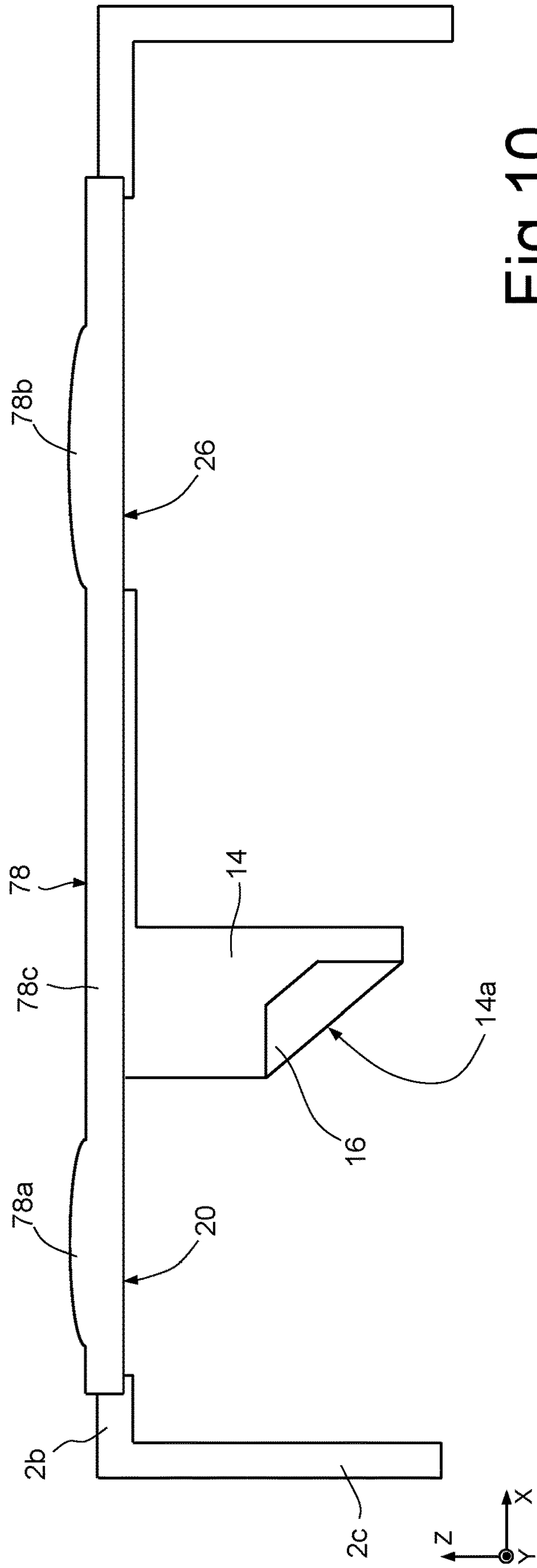
8
2a'
2a
X
Z
Y

Fig.9B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14
14a
16
78a
20
2b
2c
Z
X
Y

Fig.10

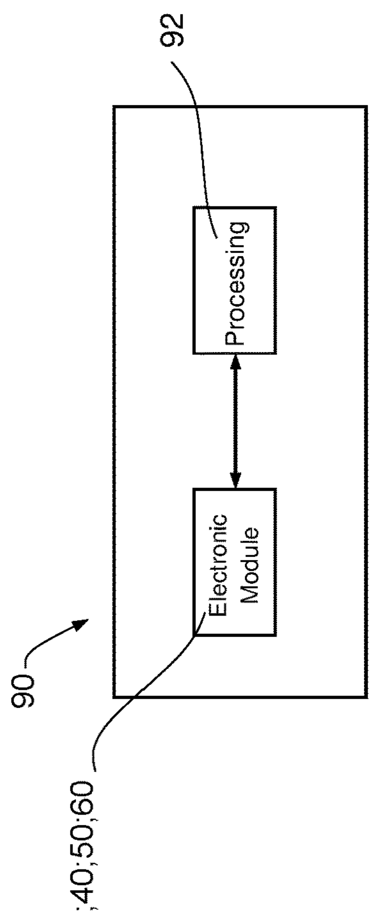
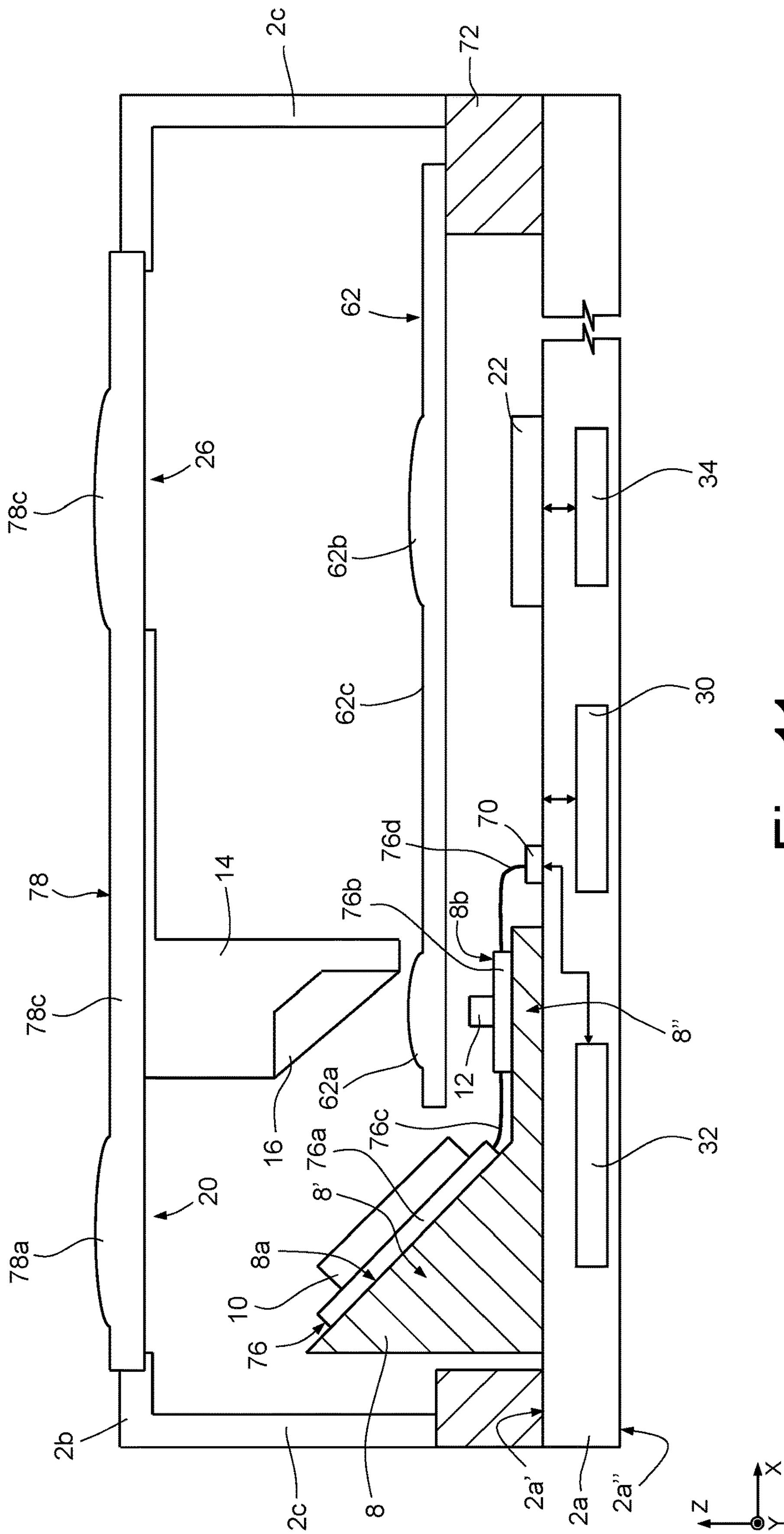

92
Processing
Electronic Module
90
1;40;50;60

Fig.12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22
26
78c
34
62b
62c
30
78
14
70
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76b
8b
78c
8''
12
62a
16
76a
76c
32
20
8'
78a
8a
10
76
8
2b
2c
2a'
2a
2a''
Z
X
Y

Fig.11

INTEGRATED ELECTRONIC MODULE FOR 3D SENSING APPLICATIONS, AND 3D SCANNING DEVICE INCLUDING THE INTEGRATED ELECTRONIC MODULE

PRIORITY CLAIM

This application is a continuation of U.S. application patent Ser. No. 16/826,983, filed Mar. 23, 2020, which claims the priority benefit of Italian Application for Patent No. 102019000004197, filed on Mar. 22, 2019, the contents of which are hereby incorporated by reference in their entireties to the maximum extent allowable by law.

TECHNICAL FIELD

This disclosure relates to an electronic module, to be used for three dimensional (3D) sensing applications, and to a 3D scanning device including the integrated electronic module.

BACKGROUND

With the introduction of the depth-sensing technology, the usage of 3D sensing is now widely used on smartphones and portable devices in general. In particular, the technology is expected to innovate the security methods through face recognition.

One of the known methods to implement 3D sensing is based on a time-of-flight (ToF) approach. A typical ToF architecture includes an infrared (IR) source configured to generate an IR light pulse towards an object (emitted beam). A beam reflected by the object is received by a detector. Depth is calculated by measuring the time (direct ToF) or the phase shift (indirect ToF) between the emitted and the reflected beam. This approach has several advantages, among which a longer range with higher accuracy and less required power, low processing requirements, accurate minimum object distance (MOD) thanks to higher angular resolution, and high immunity to blare effect (in case of objects in motion). However, it is sensitive to reflections and scattering phenomena.

Another known method to implement 3D sensing is based on structured light. In this case, a known pattern is projected onto an object; the pattern thus projected is distorted by the object, and an analysis of the distortion of the light pattern can be used to calculate a depth value and achieve a geometric reconstruction of the object's shape. This technique has the advantages of being less sensitive to reflection and scattering and to allow the implementation of high volume solutions with an ongoing cost-optimization path. However, it requires heavy processing, complex component assembly and the resolution is limited by the component's resolution.

It is known to implement the systems discussed above with a split projection/detection scheme, such as a solution where the projector and the detector are each contained within their own package and physically separated from each other, even though they might be mounted on a same printed-circuit board. In particular, the projector typically includes a LASER source and a micro-mirror manufactured in microelectromechanical system (MEMS) technology; the LASER source is oriented so that a beam is directed towards the micro-mirror, and the micro-mirror is controlled in oscillation to direct the beam towards a target. The main limitation of this approach is the system complexity and the need to cooperate with partners that can design and manufacture opto-mechanical solutions. Moreover, by having the projector and the detector mounted as separate modules, the integration is reduced and the size of the final module increased. Smaller dimensions can be achieved to the detriment of the system performance.

There is therefore a need in the art for a technical solution the overcomes the above issues and drawbacks of the known art without having an impact on the performance.

SUMMARY

Disclosed herein is a method of manufacturing an electronic module, including: integrating electronic circuitry for controlling an emitter and electronic circuitry for processing a detector output signal into a base substrate having a first surface; providing a first supporting element formed from a solid body of metal acting as a heat-sink and having a first portion with an inclined top surface, and affixing the first supporting element to the first surface of the base substrate such that the inclined top surface of the first supporting element is inclined with respect to the base substrate; coupling a first reflector to the inclined top surface of the first portion of the first supporting element such that a rear surface of the first reflector is in physical contact with the inclined top surface of the first portion of the first supporting element; configuring a spacer structure to form an interface for mounting lateral walls to the base substrate, and positioning a cap over and supported by the lateral walls to thereby define a chamber; coupling the emitter to the first surface of the base substrate in a fashion such that the emitter is connected to the electronic circuitry for controlling the emitter; and affixing a detector to the first surface of the base substrate in a fashion such that the detector is connected to the electronic circuitry for controlling the detector.

The first supporting element may be affixed to the first surface of the base substrate by gluing the first supporting element to the first surface of the base substrate.

The first supporting element may be formed from the solid body of metal to have a second portion extending parallel to the base substrate when the first supporting element is affixed to the first surface of the base substrate.

The emitter may be coupled to the first surface of the base substrate by coupling the emitter to the second portion of the first supporting element.

The first supporting element may be formed from the solid body of metal such that the first and second portions of the first supporting element are integrally formed.

The first supporting element may be formed from the solid body of metal such that the first and second portions of the first supporting element are separate from one another and spaced apart from one another.

The method may further include: thermally coupling a rigid-flex circuit to the inclined top surface of the first supporting element by thermally coupling a first rigid portion of the rigid-flex circuit to the first portion of the first supporting element, thermally coupling a second rigid portion of the rigid-flex circuit to the second portion of the first supporting element, and connecting the first and second rigid portions of the rigid-flex circuit using a flexible portion, the flexible portion extending at an intersection between the first rigid portion and the second rigid portion such that it follows a change in slope between the first and second portions of the first supporting element; wherein the emitter is coupled to the second portion of the first supporting element by affixing the emitter to the second rigid portion of the rigid-flex circuit; and wherein the first reflector is coupled to the first portion of the first supporting element by affixing the first reflector to the first rigid portion of the rigid-flex circuit.

The electronic circuitry for controlling the emitter may be integrated into the second rigid portion of the rigid-flex circuit.

The method may also include connecting a first end of a further flexible portion of the rigid-flex circuit to the second rigid portion and connecting a second end of the further flexible portion of the rigid-flex circuit to one or more pads for supplying driving signals and power supply to the first reflector.

The spacer structure may also be configured to completely surround a region of the base substrate in which the first supporting element, first reflector, emitter, and detector are located.

The method may also include providing the spacer structure to be made from plastic material, metallic material, and/or semiconductor material; and further comprising providing the base substrate to be made from an organic material, plastic material, and/or semiconductor material.

The method may also include providing the cap to include a second supporting element extending from an interior surface of the cap toward the emitter; and further comprising affixing a second reflector to the second supporting element.

Also disclosed herein is a method of manufacturing an electronic module, including: integrating electronic circuitry for controlling an emitter and electronic circuitry for processing a detector output signal into a base substrate having a first surface; coupling a first reflector to a first surface of the base substrate; configuring a spacer structure to form an interface for mounting lateral walls to the base substrate, and positioning a cap over and supported by the lateral walls to thereby define a chamber; coupling the emitter to the first surface of the base substrate in a fashion such that the emitter is connected to the electronic circuitry for controlling the emitter; affixing a detector to the first surface of the base substrate in a fashion such that the detector is connected to the electronic circuitry for controlling the detector; providing a lens module including first and second lenses; and positioning the lens module within the chamber such that it is supported by the spacer structure and extends therefrom parallel to the substrate such that the first lens is operatively coupled to the emitter and the second lens is operatively coupled to the detector.

The spacer structure may also be configured to surround a region of the base substrate in which the first reflector, emitter, and detector are located.

The method may also include providing the spacer structure to be made from plastic material, metallic material, and/or semiconductor material, and providing the base substrate to be made from an organic material, plastic material, and/or semiconductor material.

The method may include providing the cap to include a second supporting element extending from an interior surface of the cap toward the emitter, and affixing a second reflector to the second supporting element.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding, preferred embodiments thereof are now described purely by way of non-limiting example with reference to the attached drawings, wherein:

FIGS. **1** to **4** show respective cross-sectional views of electronic modules according to respective embodiments;

FIG. **5A-10** show a cross-sectional and top-plan views of an electronic module during manufacturing steps;

FIG. **11** shows the electronic module manufactured according to the steps of FIGS. **5A-10**; and

FIG. **12** schematically shows a system including the electronic module using any of the embodiments of FIGS. **1-4** and **11**.

DETAILED DESCRIPTION

FIG. **1** shows, in a Cartesian (triaxial) reference system of axis X, Y, Z, an electronic module **1** to be used for 3D-sensing applications, according to an embodiment.

The electronic module **1** includes a package **2** formed by a base substrate **2***a* and a cap **2***b*. The base substrate **2***a* has a first surface **2***a*' opposite to a second surface **2***a*". In the reference system of FIG. **1**, the first and the second surfaces **2***a*', **2***a*" are parallel to one another and to the XY plane. Analogously, the cap **2***b* has a first surface **2***b*' opposite to a second surface **2***b*". In the reference system of FIG. **1**, also the first and the second surfaces **2***b*', **2***b*" are parallel to one another and to the XY plane.

According to an embodiment, the base substrate **2***a* includes, or is mechanically and/or electrically coupled to, a printed-circuit board (PCB) configured to support electronic components and to provide the required routing for the signals received and generated by the electronic components, in a per se known way. In particular, the printed-circuit board is arranged to directly face the chamber **4** so that such electronic components can be housed within the chamber **4**.

The PCB may be a rigid circuit board, a flexible circuit board or a rigid-flex circuit board, according to the needs and is coupled directly to the base substrate **2***a* or, alternatively, through an interface element such as a heat exchanger.

The cap **2***b* is coupled to the base substrate **2***a* by means of lateral walls **2***c* extending between the cap **2***b* and the base substrate **2***a*, so that an inner chamber **4** of the package **2** is formed. The lateral walls **2***c* may be either integral with the cap **2***b* or the base substrate **2***a* (and coupled, for example glued, to the other among the cap **2***b* and the base substrate **2***a*); alternatively the lateral walls **2***c* can be a separate element, coupled (for example, glued) to both the cap **2***b* and the base substrate **2***a*.

The first surface **2***a*' of the base substrate **2***a* directly faces the chamber **4** (in particular, the first surface **2***a*' is in the chamber **4**); analogously, the first surface **2***b*' of the cap **2***b* directly faces the chamber **4** (in particular, the first surface **2***b*' is in the chamber **4**).

A first supporting element **8** extends within the chamber **4** and has a surface **8***a* defining a supporting plane that forms an angle of incline α with the first surface **2***a*' of the base substrate **2***a*. The value of the angle α is in the range of 25-65 degrees, in particular 45 degrees (where α=0 degrees means that the surface **8***a* is parallel to the first surface **2***a*' and α=90 degrees means that the surface **8***a* is orthogonal to the first surface **2***a*').

Coupled to the surface **8***a* of the supporting element **8**, there is a first reflector **10**, in particular a reflector manufactured in MEMS technology (also known as micro-mirror). The first reflector **10** is in particular a MEMS reflector of a resonant type, configured to be coupled to an actuation system that, when operated, causes oscillation of the MEMS reflector in a substantially periodic way around a resting position. This is also known in the art as a "MEMS scanner". Micro-mirrors, or MEMS scanners, of this type are, for example, disclosed in U.S. Pat. No. 9,843,779, and in U.S. Application for Patent No. 2018/0180873 (both incorporated herein by reference). Other types of reflectors or micro-mirrors can be used, as apparent to the skilled person in the art.

The first reflector **10** can be coupled to the supporting element **8** by means of glue or other means such as soldering regions, die-attach film, etc.

The first supporting element **8** is, according to an embodiment, made of thermally-conductive material such as metal. In this case, the first supporting element **8** has also the function of being a heat-sink, for favoring heat dispersion of the first reflector **10** when it is in the form of a MEMS micro-mirror or MEMS scanner and is biased, during use, through electric signals that cause temperature increase by Joule effect.

Coupled to the first surface **2***a*' of the base substrate **2***a* there is an emitter **12**, in particular a Vertical-Cavity Surface-Emitting LASER (VCSEL). The emitter **12** is coupled to the base substrate **2***a* through the PCB, in a per se known way. In an embodiment, the emitter **12** is an infrared (IR) emitter, configured to emit an IR radiation.

A second supporting element **14** extends within the chamber **4** and has a surface **14***a* defining a supporting plane that forms an angle of incline β with the first surface **2***a*' of the base substrate **2***a*. The value of the angle β is in the range 25-65 degrees, in particular 45 degrees (where β=0 degrees means that the surface **14***a* is parallel to the first surface **2***a*' and (β=90 degrees means that the surface **14***a* is orthogonal to the first surface **2***a*'). It is noted that the same angle of incline is formed at the intersection between the surface **14***a* and the first surface **2***b*' of the cap **2***b* (where β=0 degrees means that the surface **14***a* is parallel to the first surface **2***b*' and β=90 degrees means that the surface **14***a* is orthogonal to the first surface **2***b*').

In the embodiment of FIG. **1**, the surfaces **8***a* and **14***a* of the first and, respectively, second supporting elements **8**, **14** are parallel to one another.

Coupled to the surface **14***a* of the supporting element **14**, there is a second reflector **16**, in particular a mirror of a fixed type (such that it does not oscillate like the first reflector **10**).

The first supporting element **8** (with the first reflector **10**) and the second supporting element **14** (with the second reflector **16**) are arranged in the chamber **4** in such a way that, when the electronic module **1** is considered in lateral cross section as in FIG. **1**, the emitter **12** is arranged between the first supporting element **8** and the second supporting element **14**. Furthermore, the surface **8***a* and the surface **14***a* face one another, so that also the first and second reflectors **10**, **16** face one another.

The cap **2***b* is provided with a first window **20**, arranged above, and at a distance from, the first reflector **10**. In particular, the first window **20** is superposed (or at least partially aligned along Z axis) to the first reflector **10**. However, as is apparent from the previous description, the first window **20** lies on a plane parallel to the XY plane, while the first reflector **10** lies on a plane inclined 45 degrees with respect to the XY plane.

The emitter **12** is furthermore arranged in such a way that a beam **18** emitted, during use, by the emitter **12** is directed towards the second reflector **16**. The second reflector **16** is arranged in such a way that the beam **18** is reflected towards the first reflector **10**. The first reflector **10** is arranged in such a way that the beam **18** thus received is reflected towards the first window **20**. This condition is verified, for example, when the following conditions are verified: (i) the first and second reflectors **10**, **16** are arranged on the respective supporting elements **8**, **14** inclined by 45 degrees with respect to the XY plane (as discussed above); and (ii) the beam **18** emitted by the emitter **12** is directed along the Z axis (which is orthogonal to the XY plane). Other respective arrangements of the emitter **12** (beam **18**), first reflector **10** and second reflector **16** may be used, provided that the beam **18** is reflected by the first reflector **10** towards the first window **20**.

The first window **20** includes an aperture through the cap **2***b* to which is optionally coupled a lens (for example used to magnify the beam reflected by the first reflector **10**). Such lens is, for example, based on Wafer-Level Optics (WLO) technology, which enables the design and manufacture of miniaturized optics at the wafer level using semiconductor-like techniques.

Alternatively, when a lens is not provided, another protection element may be present at the first window **20**, to prevent particulate, dust, etc. to enter within the chamber **4** and compromise the functioning of the electronic module **1**. In general, such lens/protection element is of a material that allows the beam **18** to pass through it and exit from the chamber **4**, so that a beam is generated as output from the electronic module **1**.

The chamber **4** further houses a detector **22**, configured to detect a received beam **24** from an environment external to the chamber **4**. The detector **22** is, for example, mechanically coupled to the first surface **2***a*' of the base substrate **2***a*, in a per se known way.

According to an embodiment, the detector **22** is an IR detector configured to detect a received IR radiation. In particular, a Single-Photon Avalanche Diode (SPAD) can be used as detector **22**.

The cap **2***a* further comprises a second window **26**, that includes an aperture through the cap **2***b*, to which is optionally coupled a respective lens (for example to focus the received beam **24** and/or to correct aberration).

When a lens is not present at the second window **26**, another respective protection element may be present to prevent particulate, dust, etc. to enter within the chamber **4** and compromise the functioning of the electronic module **1**. In general, the lens/protection element coupled to the second window **26** is of a material that allows the received beam **24** to pass through it and enter the chamber **4**, so that the received beam **24** is an input to the electronic module **1**.

The second window **26** is above, and at least partially aligned along Z axis to, the detector **22** (the second window **26** is in particular superposed to the detector **22**, at a distance from the detector **22**, or in contact with it). In particular, the second window **26** and the detector **22** are reciprocally arranged such that the received beam **24** passing through the second window **26** is directed towards a sensing portion of the detector **22**, to be detected.

The proposed architecture allows the integration in a same package of VCSEL laser diode as light source (generally, an emitter) and a SPAD (generally, a detector), with significant impact on the reduction of costs and dimensions. By integrating all the components in a package-level module, the volumes of the module are reduced and optimized. By reducing the dimensions, the proposed solution enables better integration of 3D sensing applications into portable devices and mobile phones.

FIG. **2** shows an electronic module **40** according to a further embodiment. Features of the electronic module **40** common to the electronic module **1** are identified with the same reference numerals, and not further described. In the electronic module **40** of FIG. **2**, one or more among electronic circuitry **30** for controlling the emitter **12** (for controlling the generation of the beam **18**), electronic circuitry **32** for driving the micro-mirror **10** and electronic circuitry

34 for processing the signal transduced by the detector 22 are integrated within the base substrate 2*a*. Further circuitry, configured to carry out further computation required by a specific application, may also be integrated within the base substrate 2*a*. Accordingly, the integration level is still further enhanced. The use of a MEMS scanner for implementing the first reflector 10 allows to reduce and to compact the dimensions and to achieve at the same time a high resolution.

It is noted that the supporting elements 8 and 14 may either be mechanically coupled, or fixed, to the base substrate 2*a*, the cap 2*b* or to both the base substrate 2*a* and the cap 2*b*.

FIG. 3 shows an electronic module 50 according to a further embodiment. Features of the electronic module 50 common to the electronic module 1 and/or 40 are identified with the same reference numerals, and not further described.

The electronic module 50 includes a first supporting element 8 having a wedge-like shape, that rests on, and is fixed to, the base substrate 2*a* only (at the first surface 2*a*'). The first supporting element 8 may or may not reach the first surface 2*b*' of the cap 2*b*. The second supporting element 14 is an inclined wall fixed to the cap 2*b* only (at the first surface 2*b*') and may or may not reach the first surface 2*a*' of the base substrate 2*a*.

In particular, in FIG. 3, the second supporting element 14 does not reach (is not in contact with) the base substrate 2*a*.

The first supporting element 8 may be formed integral with the base substrate 2*a*, or as a separate body coupled to the base substrate 2*a* by means of glue, soldering paste, or other mechanical means, for example, screws. Analogously, the second supporting element 14 may be formed integral with the cap 2*b*, or as a separate body coupled to the cap 2*b* by means of glue, soldering paste, or other mechanical means, for example screws.

The electronic circuitry 30-34 described with reference to FIG. 2 can be part of the embodiment of FIG. 3, or it may be absent (it is not shown in FIG. 3).

FIG. 4 shows a further embodiment, illustrating an electronic module 60. Features of the electronic module 60 common to the electronic module 1 or 40 or 50 are identified with the same reference numerals, and not further described.

The electronic module 60 further comprises, with respect to the embodiment of FIG. 3, a lens module 62 arranged within the chamber 4 and provided with a first lens 62*a* operatively coupled to the emitter 12 and a second lens 62*b* operatively coupled to the detector 22. To this end, a frame structure 62*c* surrounds and sustain the lenses 62*a*, 62*b*. The frame structure 62*c* can be coupled to the base substrate 2*a* within the chamber 4 through a supporting element 64 arranged next to the lateral walls 2*c*. The supporting element 64 may also be formed in a different way, for example as disclosed with reference to FIGS. 6A, 6B and FIGS. 9A, 9B.

The first lens 62*a* is made of, for example, glass or plastic, and is configured to focus onto the second reflector 16 the beam 18 generated by the emitter 12. The second lens 62*b* is made of, for example, glass or plastic, and is configured to focus the incoming beam 24 onto the detector 22. The lenses 62*a* and 62*b* are, for example, based on Wafer-Level Optics (WLO) technology.

The first supporting element 8 corresponds to that already described with reference to FIG. 3, but it may also be replaced by that of FIG. 1 or FIG. 2. The second supporting element 14 corresponds to that described with reference to FIG. 3, such that the lens module 62 extends between the base substrate 2*a* (above the emitter 12 and the detector 22) and the supporting element 14.

The electronic circuitry 30-34 described with reference to FIG. 2 can be part of the embodiment of FIG. 4, or it may be absent (not shown in FIG. 4). Also, the wedge-shaped supporting element 8 of FIG. 3 can be part of the embodiment of FIG. 4, or supporting element 8 may be manufactured in a different way, for example as shown in FIG. 1.

FIGS. 5A-11 illustrates a method for manufacturing (specifically, assembling) an electronic module 80 (shown in FIG. 11 at the end of manufacturing steps).

With reference to FIG. 5A, which is a lateral cross-sectional view (on plane XZ), the base substrate 2*a* is provided. Here, the base substrate 2*a* is in particular an organic substrate with ICs laminated inside. A laminated material such as FR-4 or BT (bismaleimide triazine) can be used. Alternatively, the base substrate 2*a* is of plastic material or of semiconductor material.

The base substrate 2*a* integrates the electronic circuitry 30 for controlling the emitter 12, the electronic circuitry 32 for driving the micro-mirror 10 and the electronic circuitry 34 for processing the signal transduced by the detector 22. On the first surface 2*a*' of the base substrate 2*a* one or more pads 70 are provided for supplying the driving signals for the first reflector 10 in case the latter is implemented by means of a micro-mirror or MEMS scanner. The one or more pads 70 are electrically coupled to the electronic circuitry 32 through metallic routing path(s) provided within the substrate 2*a*.

On the first surface 2*a*' of the base substrate 2*a* the detector 22 is coupled, for example by means of glue, die attach film, solder joints, etc. The detector 22 is electrically coupled to the electronic circuitry 34 through metallic routing path(s) provided within the substrate 2*a*, for receiving the signals transduced by the detector 22.

The reciprocal arrangement of the elements shown in FIG. 5A is for illustrative purpose only, and is not limitative of this disclosure.

FIG. 5B is a top-plan view (on XY plane) of FIG. 5A.

Then, as shown in FIG. 6A, a spacer structure 72, configured to form an interface for mounting the lateral walls 2*c* and the cap 2*b* on the base substrate 2*a*, is coupled to the base substrate 2*a*, in particular at peripheral portions of the base substrate 2*a*. As it can be appreciated in the following, the spacer structure 72 is configured to sustain the lateral walls 2*c* and the cap 2*b*, and at the same time has the function of the supporting element 64 described with reference to FIG. 4.

As it can be appreciated from the top-plan view of FIG. 6B, the spacer structure 72 completely surrounds a superficial region of the base substrate 2*a* where the detector 22 is located and where, during successive steps of manufacturing, the first supporting element 8 and the emitter 12 will be arranged.

With reference to FIG. 7A the first supporting element 8 is coupled to the base substrate 2*a* through a layer of glue.

FIG. 7B is a top-plan view (on XY plane) of FIG. 7A.

The first supporting element 8 is, in particular, a solid body of metal material having the further function of heat-sink for the first reflector 10, as already discussed previously. Furthermore, in the embodiment of FIG. 7A, the supporting element 8 is provided with a first portion 8' including the inclined surface 8*a*, and with a second portion 8" extending in continuity with the first portion 8' and having a respective surface 8*b* parallel to the XY plane. The second portion 8" is configured to, and has the function of, supporting the emitter 12 and operates as a heat-sink for the emitter 12.

In FIGS. 7A, 7B, the first and second portions **8'**, **8"** are integral with one another; however, according to a different embodiment, the first and second portions **8'**, **8"** may be two separate elements.

With reference to FIG. **8**A, a PCB **76**, in particular a rigid-flex circuit, is coupled to the supporting element **8**, for example by means of thermally conductive glue.

The rigid-flex circuit **76** includes a first rigid portion **76***a* coupled to the first portion **8'** of the supporting element **8** and a second rigid portion **76***b* coupled to the second portion **8"** of the supporting element **8**. A flexible portion **76***c* connects the first rigid portion **76***a* to the second rigid portion **76***b*. The flexible portion **76***c* extends at the intersection between the first portion **8'** and the second portion **8"**, so that it can follow the change in slope between the first portion **8'** and the second portion **8"**. The first rigid portion **76***a* carries the first reflector **10** and the second rigid portion **76***b* carries the emitter **12**. Alternatively to the embodiment shown in the drawings, the electronics **34** that controls/drives the emitter **12** is not integrated within the base substrate **2***a*, but it can be integrated into, or mechanically coupled to, the second rigid portion **76***b*.

A further flexible portion **76***d* is connected at one end to the second rigid portion **76***b* and at another end to the pad(s) **70**, for supplying the driving signals and the power supply to the first reflector **10** and to the emitter **12**. Other means alternative to, or in addition to, the flexible portion **76***c* can be provided, for example wire bonding.

FIG. **8**B is a top-plan view (on XY plane) of FIG. **8**A.

With reference to FIG. **9**A, the lens module **62** disclosed with reference to FIG. **4** is provided and arranged in such a way that the first lens **62***a* is operatively coupled to the emitter **12** and the second lens **62***b* is operatively coupled to the detector **22**. The frame structure **62***c* is coupled to, and sustained by, the spacer structure **72**.

FIG. **9**B is a top-plan view (on XY plane) of FIG. **9**A.

FIG. **10** shows, in a lateral cross-sectional view taken on XZ plane, of the cap **2***b*, which is formed integral with the lateral walls **2***c*. Integral with the cap **2***b* is also present the second supporting element **14**, with the second reflector **16** coupled to it. The extension, measured along the Z-axis, of the second supporting element **14**, is less than the extension, measured along the Z-axis, of the lateral walls **2***c*, so that when the cap **2***b* is mounted on the base substrate **2***a* the second supporting element **14** is at a distance from the lens module **62**.

The cap **2***b* is here provided with the first and second window **20**, **26**, to which, in turn, a further lens module **78** is coupled. In particular, the lens module **78** includes a first lens **78***a* and a second lens **78***b*. The first lens **78***a* is operatively coupled (and aligned) to the first reflector **10** to receive the beam reflected by the first reflector **10**, while the second lens **78***b* is operatively coupled (and aligned along the Z axis) to the detector **22**. The first lens **78***a* is made of glass or plastic and is configured to magnify the output radiation **18** (for example it is a divergent lens). The second lens **78***b* is made of glass or plastic, and is configured to focus the incoming beam **24** on the detector **22** and/or correct aberrations of the incoming beam **24**. The lenses **78***a* and **78***b* are, for example, based on Wafer-Level Optics (WLO) technology.

A frame structure **78***c* surrounds and holds the lenses **78***a*, **78***b*. The frame structure **78***c* is, for example, coupled on top of the cap **2***b*.

The lateral walls **2***c* can be coupled to the spacer structure **72** through a coupling region made of at least one among glue, solder paste.

The cap **2***b* and the lateral walls **2***c* are made of at least one among: plastic material, metallic material, semiconductor material.

FIG. **11** shows, in a lateral cross-sectional view taken on XZ plane, the cap **2***b* of FIG. **10** coupled to the structure of FIG. **9**A, to form the electronic module **80** according to the respective embodiment.

The electronic module **1**, **40**, **50**, **60** disclosed, with reference to the respective embodiments of FIGS. **1**-**4** and FIG. **11**, can be used as a time-of-flight device/camera to perform 3D sensing, for example for smartphones applications, such as face recognition. In this context, direct or sinusoidal short light flashes (beam **18**) are emitted by the emitter **12**; the beam outputted from the first window **20** impinges onto an object, is reflected back, and enters the chamber **4** through the second window **26**. The received beam **24** is then captured by the detector **22**. The travel time of the light from the emitter **12** to the object and back to the detector **22** is calculated by a computing circuit (for example, a processor, or processing unit). The computing circuit may be either integrated within the base substrate **2***a* or provided external to the electronic module **80**. The measured coordinates then generate a 3D picture of the object. The processing details and calculation of the time of flight is understood by those of ordinary skill in the art and therefore will not be described in detail herein.

The electronic module **80** can also be used in the context of structured light applications for 3D sensing. In this case, the detector **22** is preferentially a CMOS sensor formed by a matrix of pixels, configured to detect an image from the incoming beam **24**. Processing algorithms, known in the art, can be used to acquire information from the detected image to perform 3D sensing, such as face recognition.

FIG. **12** schematically shows a system **90**, in particular a 3D scanning device or 3D scanner, including at least one electronic module **1**, **40**, **50**, **60**, according to the respective embodiment, operatively coupled to a processing unit **92** that is configured to perform 3D sensing based on a structured light approach, a time-of-flight approach, or the like. As an example, in case of time-of-flight approach, the processing unit **92** is configured to calculate a travel time between a first time instant, corresponding to generation of the first radiation **18** by the emitter **12**, and a second time instant, corresponding to the detection of the second radiation **24** by the detector **22**, so as to determine the travel time of the beam from the emitter **12** to the object and back to the detector **22**. Irrespective of the approach used, a 3D image of the object can be reconstructed by the processing unit **92**, in a per se known way.

The processing unit **92** can be integrated in the base substrate **2***a* or be external to the electronic module **1**, **40**, **50**, **60**. The system **90** implements 3D sensing application(s), in particular for face recognition. The system **90** is, generally, an electronic device, more in particular a portable electronic device, such as a smartphone, a tablet, a notebook; or, alternatively, a desktop computer.

From an examination of the characteristics of this disclosure provided according to the present disclosure, the advantages that it affords are evident.

The proposed architecture allows the integration of a light source (emitter, in particular a VCSEL laser diode), with significant impact on lowering of cost and dimensions.

By integrating all the components in a package level module, the volumes of the solution is reduced and optimized. By reducing the dimensions, the proposed solution enables the integration into portable devices and mobile phones.

Finally, it is clear that modifications and variations may be made to what has been described and illustrated herein, without thereby departing from the sphere of protection of this disclosure, as defined in the annexed claims.

The invention claimed is:

1. A method of manufacturing an electronic module, comprising:

integrating electronic circuitry for controlling an emitter and electronic circuitry for processing a detector output signal into a base substrate having a first surface;

providing a first supporting element formed from a solid body of metal acting as a heat-sink and having a first portion with an inclined top surface, and affixing the first supporting element to the first surface of the base substrate such that the inclined top surface of the first supporting element is inclined with respect to the base substrate;

coupling a first reflector to the inclined top surface of the first portion of the first supporting element such that a rear surface of the first reflector is in physical contact with the inclined top surface of the first portion of the first supporting element;

configuring a spacer structure to form an interface for mounting lateral walls to the base substrate, and positioning a cap over and supported by the lateral walls to thereby define a chamber;

coupling the emitter to the first surface of the base substrate in a fashion such that the emitter is connected to the electronic circuitry for controlling the emitter; and

affixing a detector to the first surface of the base substrate in a fashion such that the detector is connected to the electronic circuitry for controlling the detector.

2. The method of claim **1**, wherein affixing the first supporting element comprises gluing the first supporting element to the first surface of the base substrate.

3. The method of claim **1**, wherein the first supporting element is formed from the solid body of metal to have a second portion extending parallel to the base substrate when the first supporting element is affixed to the first surface of the base substrate.

4. The method of claim **3**, wherein coupling the emitter comprises coupling the emitter to the second portion of the first supporting element.

5. The method of claim **4**, wherein the first supporting element is formed from the solid body of metal such that the first and second portions of the first supporting element are integrally formed.

6. The method of claim **4**, wherein the first supporting element is formed from the solid body of metal such that the first and second portions of the first supporting element are separate from one another and spaced apart from one another.

7. The method of claim **4**, further comprising thermally coupling a rigid-flex circuit to the inclined top surface of the first supporting element by:

thermally coupling a first rigid portion of the rigid-flex circuit to the first portion of the first supporting element;

thermally coupling a second rigid portion of the rigid-flex circuit to the second portion of the first supporting element; and

connecting the first and second rigid portions of the rigid-flex circuit using a flexible portion;

wherein the flexible portion extends at an intersection between the first rigid portion and the second rigid portion such that it follows a change in slope between the first and second portions of the first supporting element;

wherein coupling the emitter comprises affixing the emitter to the second rigid portion of the rigid-flex circuit; and

wherein coupling the first reflector comprises affixing the first reflector to the first rigid portion of the rigid-flex circuit.

8. The method of claim **7**, wherein the electronic circuitry for controlling the emitter is integrated into the second rigid portion of the rigid-flex circuit.

9. The method of claim **7**, further comprising connecting a first end of a further flexible portion of the rigid-flex circuit to the second rigid portion and connecting a second end of the further flexible portion of the rigid-flex circuit to one or more pads for supplying driving signals and power supply to the first reflector.

10. The method of claim **1**, wherein the spacer structure is also configured to completely surround a region of the base substrate in which the first supporting element, first reflector, emitter, and detector are located.

11. The method of claim **1**, further comprising providing the spacer structure to be made from plastic material, metallic material, and/or semiconductor material; and further comprising providing the base substrate to be made from an organic material, plastic material, and/or semiconductor material.

12. The method of claim **1**, further comprising providing the cap to include a second supporting element extending from an interior surface of the cap toward the emitter; and further comprising affixing a second reflector to the second supporting element.

13. A method of manufacturing an electronic module, comprising:

integrating electronic circuitry for controlling an emitter and electronic circuitry for processing a detector output signal into a base substrate having a first surface;

coupling a first reflector to a first surface of the base substrate;

configuring a spacer structure to form an interface for mounting lateral walls to the base substrate, and positioning a cap over and supported by the lateral walls to thereby define a chamber;

coupling the emitter to the first surface of the base substrate in a fashion such that the emitter is connected to the electronic circuitry for controlling the emitter;

affixing a detector to the first surface of the base substrate in a fashion such that the detector is connected to the electronic circuitry for controlling the detector;

providing a lens module including first and second lenses; and

positioning the lens module within the chamber such that it is supported by the spacer structure and extends therefrom parallel to the substrate such that the first lens is operatively coupled to the emitter and the second lens is operatively coupled to the detector.

14. The method of claim **13**, wherein the spacer structure is also configured to completely surround a region of the base substrate in which the first reflector, emitter, and detector are located.

15. The method of claim **13**, further comprising providing the spacer structure to be made from plastic material, metallic material, and/or semiconductor material; and further comprising providing the base substrate to be made from an organic material, plastic material, and/or semiconductor material.

16. The method of claim **13**, further comprising providing the cap to include a second supporting element extending from an interior surface of the cap toward the emitter; and further comprising affixing a second reflector to the second supporting element.

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