

X-RAY IMAGE SENSOR

Background

5 The present invention relates to X-ray imaging, including dental X-ray imaging. More specifically, the invention relates to an X-ray image sensor, comprising an X-ray converter layer for converting X-rays into signals received by a semiconductor detector for sampling and detecting converted X-rays as electrical signals, and a connection substrate comprising electrical connections, the X-ray converter layer bonded to a first surface of the
10 semiconductor detector and the connection substrate arranged at a second surface of the semiconductor detector, opposite the X-ray converter layer.

Herein, the term “X-ray converter layer” covers any layer, in a particular plate-shaped element, which converts X-ray radiation into signals which can be received and detected by a
15 semiconductor material, in particular into optical radiation, i.e. radiation in the visible, UV or near IR portion of the electromagnetic spectrum, irrespective of the detailed structure and composition thereof. In particular, the term covers prior art elements which consist of a fibre (or fiber) optic plate and a scintillating layer provided thereon. The term “semiconductor detector” designates any element for detecting the signals provided by the converter layer, in
20 particular the optical radiation generated in a scintillating layer into electrical signals on a pixel-basis, i.e. comprising an array of photoelectric detector or sensor elements, respectively. Typically, the semiconductor detector converts the received signals into electrical signals. Well-known and commercially available semiconductor detectors are of the integrated silicon detector type (e.g. CCD or CMOS). The term “connection substrate” means any type of
25 substrate comprising connections and/or electronic components which are required for operating the semiconductor detector component of the sensor and providing an internal signal processing, as far as required, irrespective of the specific type and manufacturing technology of the substrate. In particular, the term covers all types of PCBs.

30 An X-ray image sensor of this type is e.g. disclosed in US 2011/0013745 A1.

Such sensor comprises, as schematically illustrated in Figs. 1A to 1D, a semiconductor detector (silicon die) 110 of basically rectangular shape, with two corners chamfered, a conventional PCB 120, and a fibre optic plate 130 with a scintillator layer 140 on that surface

which is opposite to the surface where the silicon die 110 together with the PCB 120 are bonded to the fibre optic plate 130. The fiber (or fibre) optic 130 is acting as an x-ray blocking layer to absorb the x-ray intensity after the scintillating layer to prevent direct interaction of x-rays in the silicon die 110 which would cause an undesired signal thereby degrading the performance of the sensor.

Some of the prior art sensors have been built without using a fibre optic 110 by directly placing the scintillating layer onto the silicon die 110. Older prior art sensors used the silicon die itself as a converting layer, thereby accepting the weak performance efficiency of x-ray in silicon as compared to the better efficiency of newer prior art sensors, i.e. indirect working sensors using the combination of scintillating layer 140, x-ray blocking fibre optic 130 and silicon die 110 optimized for the conversion of the optical signal generated in the scintillator by the x-ray signal. Typical prior art scintillator layers are made of thallium doped caesium iodide, which has a crystal structure and a thickness of around 100 μm . Scintillators and the interface to the fibre optic (or silicon detector) are mechanically fragile. The fibre optics used in such sensors are much more mechanical stable due to their construction and their typical thickness of one to three mm. Hence, such fibre optics are inherently much less susceptible to damage induced mechanical stress.

Wire bond connections 100 are provided to connect portions or functional elements on the light-receiving surface of the silicon die 110 to connecting points on the PCB 120, which is arranged on the opposite (back or bottom) surface of the silicon die. It can be recognized that the wire bonds 100 are provided at one of the short edges of the silicon die 110 and extend over that edge to a portion of the PCB which projects over the edge of the silicon die.

Whereas the fibre optic plate 130 with the scintillator layer 140 are basically congruent with the shape of the silicon die 110, they are slightly recessed with respect to the silicon die, such that the fibre optic plate does not interfere with the wire bonds 100, which are raised above the upper surface of the silicon die 110.

Furthermore, existing semiconductor detectors are such designed that all electrical connectivity, except the ground connection, must be implemented at one side of the detector, thereby substantially limiting the freedom of designing the device, i.e. the chip.

Summary of the invention

One challenge associated with electronic intraoral X-ray systems, more specifically with sensors as described in the above U.S. patent application, is the limited space for obtaining optimized sensor signals, i.e. images of high resolution and contrast. Insofar, for such sensors it is required to optimize the ratio between that area of the sensor which is sensitive/receptive to X-ray radiation and an inactive area which is needed for electrically contacting, isolating and mechanically protecting the sensor.

It is a further challenge, to provide for a high mechanical stability of the sensor, under the constraints of limited space for the housing thereof and, more specifically, of limited thickness of the sensor as a whole.

Therefore, it is an object of the invention to provide an X-ray image sensor of the above type which combines high mechanical stability at low outer dimensions with an optimized ratio between the X-ray sensitive and the total area of the sensor and which allows enhanced freedom in the designing thereof.

This object is solved by an image sensor according to claim 1. Embodiments of the invention are subject of the dependent claims.

It is an aspect of the invention, that the semiconductor detector of the sensor in at least one edge portion, preferably at any side thereof, comprises vias for through-contacting detector elements formed in or on the first surface of the semiconductor detector to the connection substrate.

The embodiments of the invention hereinafter are disclosed for the case that a fibre optic is combined with a scintillator to form a fibre optic scintillating plate. However, those skilled in the art will appreciate that the fibre optic can be omitted or alternative types of scintillators may be used for achieving the intended improvements in respect of aspect ratios, easier and less costly production and mechanical stability.

In an embodiment of the invention, the image sensor has the overall shape of a plate, and the semiconductor detector comprises a detector plate, the X-ray converter layer comprises a fibre

optic scintillating plate, and the connection substrate comprises a PCB. The plate shape of the sensor components, as well as the corresponding overall shape of the sensor in its housing is, as such, a well-known configuration but is dramatically improved in its mechanical performance by applying the inventive concept.

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In an embodiment of the invention, vias and through-contacts are provided in each of the short edge portions of the semiconductor detector. Techniques for forming vias and through-contacts in a semiconductor substrate are well-known in the art, so that a detailed description of such techniques is not required.

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In a further embodiment of the invention, the semiconductor detector comprises a silicon wafer portion of basically rectangular shape, in particular with at least two corners cut-off (chamfered), preferably four corners cut-off. More specifically, in this embodiment the short edge of the rectangular side of the wafer portion, as well as two or all three edges of the chamfered-corner side are provided with vias and through-contacts.

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In another embodiment, the through-contacted detector elements are connected to the PCB/substrate by wire bonds. Besides wire bonding, other well-established IC connecting techniques can be used to provide the required electrical connections between the detector elements and the associated connection points on the PCB/substrate, including but not limited to ball bonding, soldering and galvanic techniques.

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In another embodiment, the semiconductor detector and the PCB/substrate are geometrically similar, wherein the semiconductor detector is slightly larger than the PCB/substrate, or are basically congruent. Here, "basically congruent" means that the circumferential shape of the semiconductor detector and the PCB/substrate appear as identical, although minor local deviations may exist. In this embodiment, it is important that the PCB/substrate is not larger than the semiconductor detector, i.e. the edges of the PCB/substrate do not project over the corresponding edges of the semiconductor detector, which eliminates a drawback of prior art sensor arrangements.

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In a further, closely related embodiment the X-ray converter layer, e.g. scintillating plate, and the semiconductor detector are geometrically similar, wherein the scintillating plate is slightly larger than the semiconductor detector and arranged such that none of the edges of the

semiconductor detector projects over a corresponding edge of the scintillating plate. In this embodiment, the scintillating plate protects the semiconductor detector from external mechanical forces, which helps to avoid damage of the fragile and expensive semiconductor detector (specifically silicon wafer plate).

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More specifically, in a further embodiment the X-ray converter layer, e.g. the scintillating plate, is self-supporting and supports and provides mechanical integrity to the semiconductor detector, which is tightly bonded to the scintillating plate and to the PCB/substrate. The tight bonding of the semiconductor detector to the scintillating plate, notwithstanding the above mentioned slightly larger dimensions of the scintillating plate, becomes possible, or is at least facilitated, by the vias and through-contacts in the edge portions of the semiconductor detector.

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In a further embodiment, the X-ray converter layer, e.g. scintillating plate, the semiconductor detector and the PCB/substrate are, as an integral mechanical unit, encapsulated in a housing, the inner walls of the housing preferably tightly fitting to the outer edges of the scintillating plate. In this embodiment, the total area of the sensor, including its housing, is being minimized without increasing the risk of mechanical damage of the semiconductor detector and/or the PCB/substrate. Instead, the optimized adapted housing of this embodiment guides mechanical impacts or stress to the robust scintillating plate.

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At least in some embodiments, the image sensor according to the present invention has an improved ratio between the active, i.e. X-ray sensitive area and the total sensor area, due to the replacement of standard wire connections at edges of the semiconductor detector (silicon detector) with vias and through-contacts, which makes it possible to reduce the dimensions of the PCB below those of the semiconductor detector and, at the same time, to increase the dimensions of the scintillating plate to conform to those of the semiconductor detector. Furthermore, at least in some embodiments of the invention the mechanical integrity and robustness of the image sensor are improved, due to the fact that the provision of vias and through-contacts makes it possible that the scintillating plate dominates the geometrical configuration of the sensor and at the same time provides a new dimension of mechanical integrity to the semiconductor detector and PCB, which can now tightly be bonded to the scintillating plate. Furthermore, at least in embodiments of the invention even the replacement of the mechanically fragile “classical” wire bonds, bridging the edge of the semiconductor

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detector down to the PCB and insofar exposed to mechanical impacts and stress, with embedded through-contacts results in improved mechanical properties and reliability of the image sensor.

5 Brief description of the drawings

Figs. 1A to 1C are schematic illustrations of a plate-shaped X-ray image sensor, wherein Fig. 1A is a top view of the semiconductor detector and PCB, Fig. 1B is a side view of the semiconductor detector and PCB, and Fig. 1C is a side-view including a scintillating plate
10 comprising a fibre optic and a scintillating layer located on the top e.g. towards the x-ray source of the fibre optic.

Figs. 2A to 2C are schematic illustrations of a plate-shaped X-ray image sensor according to a first embodiment of the invention, wherein Fig. 2A is a top view of the semiconductor
15 detector and PCB, Fig. 2B is a side view of the semiconductor detector and PCB, and Fig. 2C is a side-view including a scintillating plate.

Figs. 3A and 3B are schematic illustrations of a plate-shaped X-ray image sensor according to a second embodiment of the invention, wherein Fig. 3A is a top view and Fig. 3B is a side
20 view of the semiconductor detector and PCB.

Figs. 4A to 4D are schematic illustrations of a plate-shaped X-ray image sensor according to a third embodiment of the invention, wherein Fig. 4A is a top view of the semiconductor detector and PCB, Fig. 4B is a side view of the semiconductor detector, Fig. 4C is a top view
25 and Fig. 4D is a side-view of the sensor including a scintillating plate.

Fig. 5 is a schematic cross-sectional view of a further embodiment of the invention, showing a stack of scintillating plate, semiconductor detector and PCB encapsulated in a two-part plastic housing.

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Detailed description

Figs. 2A to 2C illustrate, in a similar manner as Figs. 1A to 1C explained further above, an X-ray image sensor according to an embodiment of the invention. This sensor comprises, as

schematically illustrated in Figs. 1A to 1D, a semiconductor detector (silicon die) 210 of basically rectangular shape, with two corners chamfered, a conventional PCB 220, and a fibre optic plate 230 with a scintillator layer 240 on that surface which is opposite to the surface where the silicon die 210 together with the PCB 220 are bonded to the fibre optic plate 230.

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Both at the short edge of the rectangular left portion of the silicon die 210 and in the chamfered portions and at the remaining short edge in the right portion thereof, vias 200, 201, 202 and 203, respectively, and through-contacts are provided. As best can be seen in Fig. 2B, at the bottom side of the silicon die 210, at the respective ends of the vias, wire bonds 100 are provided for contacting the ends of the through-contacts to connecting points on the PCB 220. It should be emphasized that this is just an exemplary connecting scheme, whereas further options for implementing the connections on the bottom surface of the silicon die are available and may, under certain conditions, be advantageous over the illustrated wire bonds.

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What also becomes apparent from the figures, are the specific geometrical relationships between the relevant plate-shaped elements, i.e. the fibre optic/scintillator plate 230/240, the semiconductor detector 210 and the PCB 220: Different from the conventional arrangement in Figs. 1A to 1C, the dimensions of the PCB, as compared to the semiconductor detector, are reduced, whereas the dimensions of the fibre optic/scintillator plate are increased, to make the outer edges of the latter to be at least congruent with or slightly project over the semiconductor detector. As at the light receiving surface of the semiconductor detector there are no longer any wire bonds, the fibre optic/scintillator plate 230/240 can be made as large as to cover the full adjoining surface of the semiconductor detector, and a full-surface tight bond (e.g. by means of a transparent adhesive) can be provided between them. This guarantees highest possible protection of the fragile semiconductor detector against mechanical impact or stress and high reliability, even when the sensor is applied for dental purposes, where movements, dropping, or accidental or desired biting on the sensor is likely to occur.

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In Figs. 3A and 3B, a modified embodiment of the invention is illustrated, wherein at the remaining shorter edge in the chamfered portion of the silicon die 310 no vias and through-contacts are provided. Except this difference, the arrangement is similar to the embodiment of Figs. 2A to 2C.

In Figs. 4A to 4D, a further embodiment is illustrated, the semiconductor detector 310 of which is similar to the semiconductor detector 310 in Figs. 3A and 3B. However, in the present embodiment there are no wire bond connections between the semiconductor detector 310 and the (modified) PCB 321. These are replaced with soldered connections 400, 401 which e.g. can be produced by means of a reflow soldering technique or, just to mention one of the available alternatives, by means of conductive paste screen printing. This embodiment has the additional advantage that no fragile wire bonds exist at all, not even on the bottom surface of the silicon die. In Fig. 4C and 4D, it can be seen that on the semiconductor detector 310 a slightly larger integrated fibre optic/scintillator plate 500 is mounted, which plate has slightly convex edges in the chamfered portions of the plate stack. This provides some additional mechanical protection for these edge portions and the vias and through-contacts 201, 203 provided therein.

Fig. 5 illustrates, in a schematical cross-sectional view, the plate stack of the X-ray image sensor according to Figs. 4C and 4D in an optimized housing 601. The two parts of the housing 601 are adapted to the circumferential shape of the fibre optic/scintillator plate 500, which is the largest part of the plate stack, such as to minimize the overall dimensions of the sensor in its housing and to guide mechanical impacts or stress to the robust fibre optic/scintillator plate. In this arrangement, any mechanical contact between inner walls of the housing and the more fragile silicon die is, in normal usage of the sensor, excluded.

Various features and advantages of the invention are set forth in the following claims.

Claims

1. An X-ray image sensor, comprising:
an X-ray converter layer for converting X-rays into signals to be received by a semiconductor
5 detector for sampling and detecting converted X-rays as electrical signals, and
a connection substrate comprising electrical connections,
the X-ray converter layer bonded to a first surface of the semiconductor detector and the
connection substrate arranged at a second surface of the semiconductor detector, opposite the
X-ray converter layer,
10 wherein the semiconductor detector in at least one edge portion comprises vias for through-
contacting detector elements formed in or on the first surface of the semiconductor detector to
the connection substrate.
2. The image sensor of claim 1 having the overall shape of a plate and wherein the
15 semiconductor detector comprises a detector plate, the X-ray converter layer comprises a fibre
optic scintillating plate, and the connection substrate comprises a PCB.
3. The image sensor of claim 1 or 2, wherein vias and through-contacts are provided in
each of the short edge portions of the semiconductor detector.
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4. The image sensor of one of the preceding claims, wherein the through-contacted
detector elements are connected to the connection substrate by wire bonds.
5. The image sensor of one of the preceding claims, wherein the semiconductor detector
25 comprises a silicon wafer portion of basically rectangular shape, in particular with at least two
corners cut-off.
6. The image sensor of one of the preceding claims, wherein the semiconductor detector
and the connection substrate are geometrically similar, wherein the semiconductor detector is
30 slightly larger than the connection substrate, or are basically congruent.
7. The image sensor of one of the preceding claims, wherein the X-ray converter layer
and the semiconductor detector are geometrically similar, wherein the X-ray converter layer is

slightly larger than the semiconductor detector and arranged such that none of the edges of the semiconductor detector projects over a corresponding edge of the X-ray converter layer.

8. The image sensor of one of the preceding claims, wherein the X-ray converter layer is
5 self-supporting and supports and provides mechanical integrity to the semiconductor detector, which is tightly bonded to the X-ray converter layer and to the connection substrate.

9. The image sensor of one of the preceding claims, wherein the X-ray converter layer,
the semiconductor detector and the connection substrate are, as an integral mechanical unit,
10 encapsulated in a housing, the inner walls of the housing tightly fitting to the outer edges of the X-ray converter layer.

10. Use of an image sensor of one of the preceding claims in medical imaging, in particular dental imaging.

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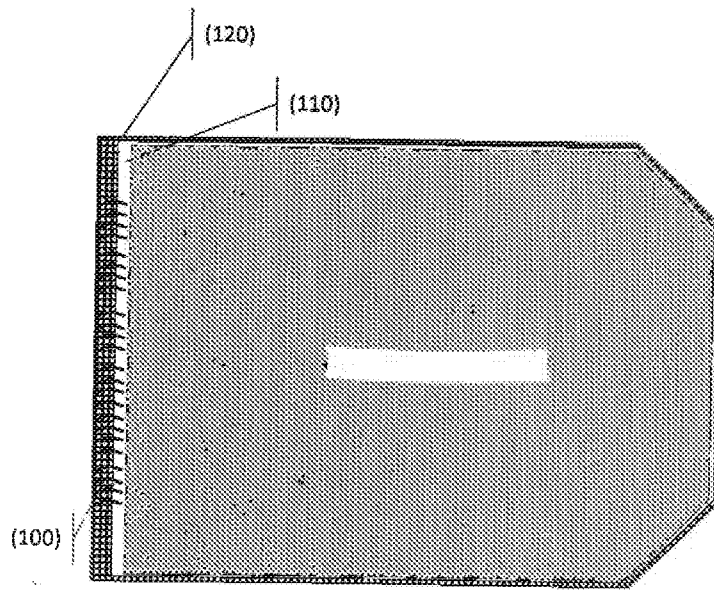


Fig. 1A



Fig. 1B

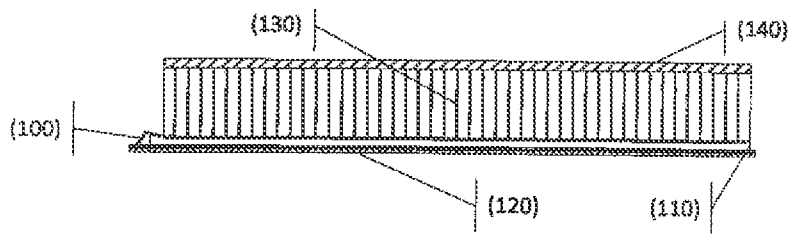


Fig. 1C

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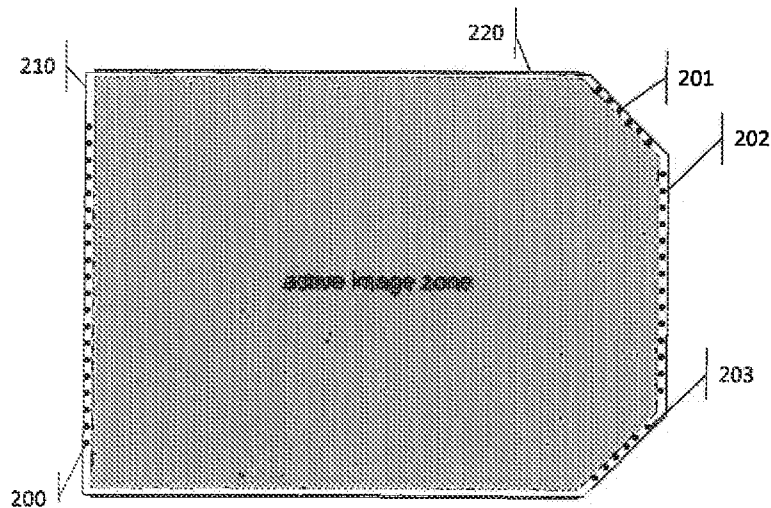


Fig. 2A

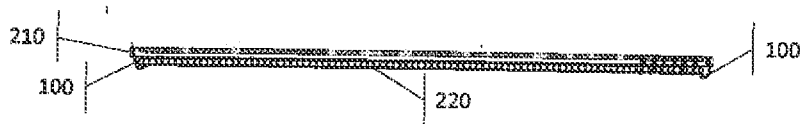


Fig. 2B

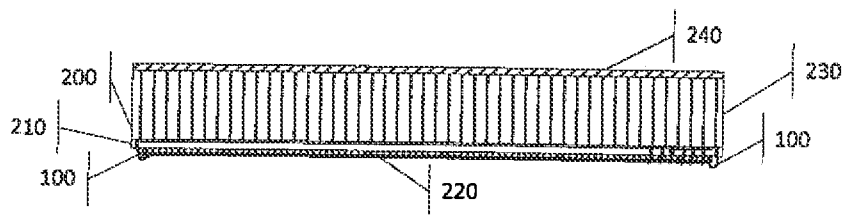


Fig. 2C

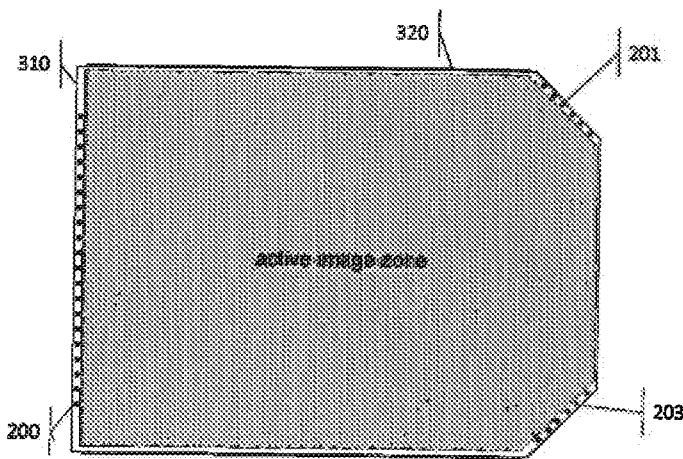


Fig. 3A

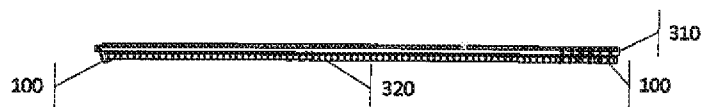


Fig. 3B

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Fig. 4A

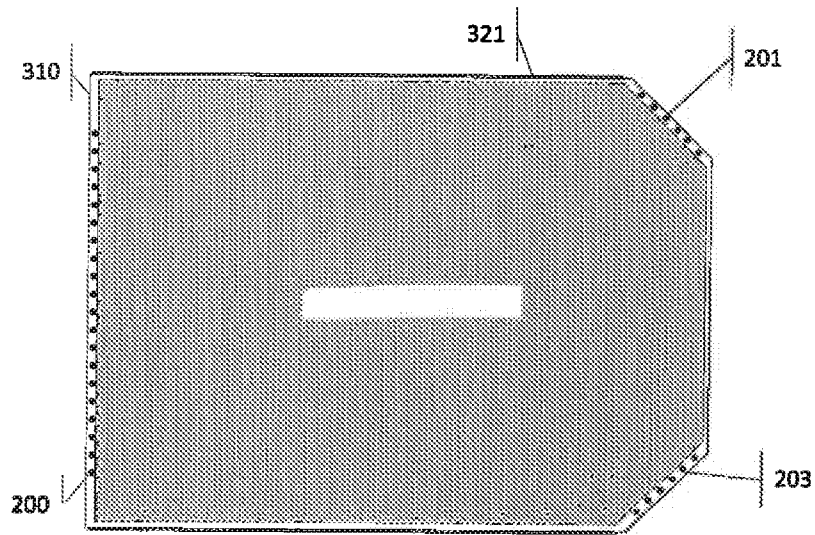


Fig. 4B

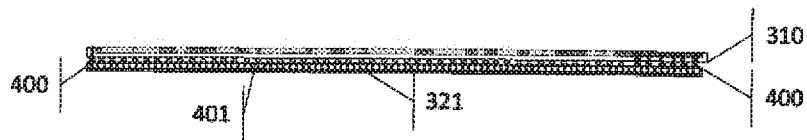


Fig. 4C

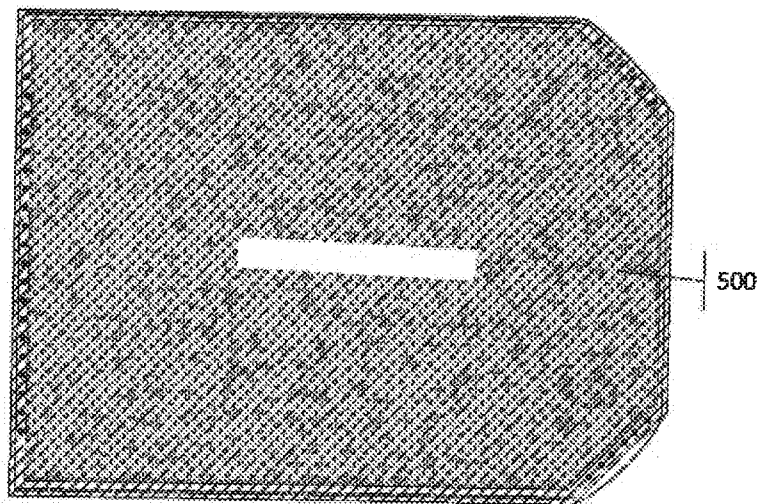


Fig. 4D



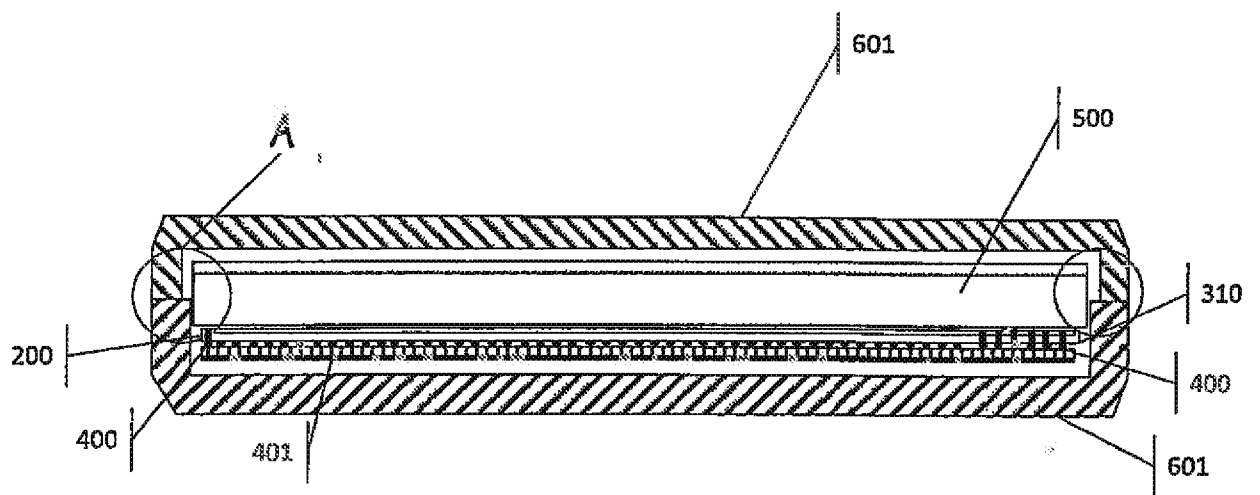


Fig. 5

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 12/42887

A. CLASSIFICATION OF SUBJECT MATTER IPC(8) - G01T 1/24 (2012.01) USPC - 250/370.09 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) USPC: 250/370.09 IPC(8): G01T 1/24 (2012.01)		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched IPC: G01T1/24; USPC: 250/370.09, 370.11, 773, 774, 784; 378/38, 62 (keyword limited; terms below)		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) PubWEST (USPT, PGPB, EPAB, JPAB); Google Scholar; Google Patents Search terms used: X-ray image sensor; semiconductor; converter layer; connection layer; vias; detector; printed circuit board; fiber optic scintillating plate x-radiation etc.		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2009/0224161 A1 (FRITSCH et al.) 10 September 2009 (10.09.2009), entire document, especially Fig 1, 7-9; para [0002], [0004], [0009], [0017], [0018], [0034], [0043]-[0046], [0048], [0049], [0053]	1-3
Y	US 2005/0018065 A1 (TASHIRO et al.) 27 January 2005 (27.01.2005), Fig 4, 5, 10; para [0009], [0019], [0051], [0053], [0073]-[0079]	1-3
Y	US 2004/0007671 A1 (SIPILA et al.) 15 January 2004 (15.01.2004), Fig 4, 6; para [0006], [0031], [0038]	2, 3/2
Y	US 2007/0248306 A1 (KAJIWARA et al.) 25 October 2007 (25.10.2007), Fig 2, 3; para [0004], [0035], [0139], [0140]	2, 3/2
A	US 5,528,043 A (SPIVEY et al.) 18 June 1996 (18.06.1996), entire document	1, 2, 3/(1,2)
A	US 2009/0242779 A1 (DE GODZINSKY) 01 October 2009 (01.10.2009), entire document	1, 2, 3/(1,2)
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/>		
* 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 15 August 2012 (15.08.2012)		Date of mailing of the international search report 14 SEP 2012
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201		Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 12/42887

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.: 4-10
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:

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 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.:
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.