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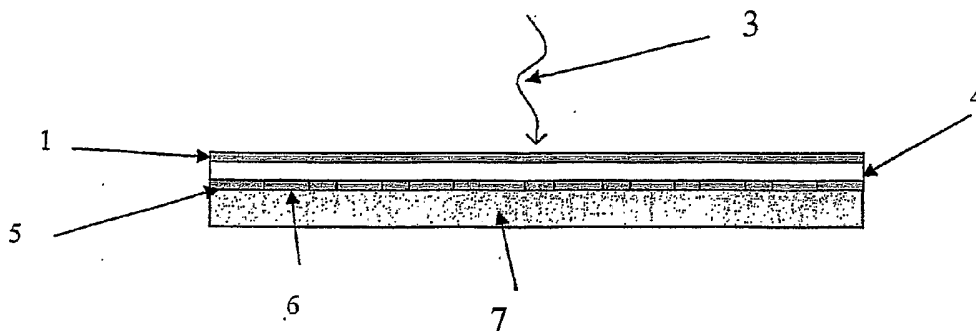
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- (71) Applicant (for all designated States except US): **NILSSON MATERIALS AB** [SE/SE]; Emdalavägen 16, S-223 69 LUND (SE).
- (72) Inventors; and
- (75) Inventors/Applicants (for US only): **JUNNO, Bert** [SE/SE]; Nybrogatan 16, S-114 39 STOCKHOLM (SE). **STÅLEMARK, Jan** [SE/SE]; Primusgatan 67, S-112 67 STOCKHOLM (SE).
- (74) Agents: **KARLSTRÖM, Lennart** et al.; NORÉNS PATENTBYRÅ AB, Box 10198, S-100 55 STOCKHOLM (SE).
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(54) Title: DETECTOR FOR IONIZING RADIATION



(57) Abstract: A detector for detecting ionising radiation comprising at least one detector arranged to be connected to a read-out arrangement for the reading-out and the evaluation of a signal from the detector, which detector comprises a carrier material and a layer (4) comprising an active detector material applied to the carrier material, which active detector material is arranged, in the event of its receiving incident ionising radiation (3) that is incident upon the said layer (4), to give rise to ionisation in the said active detector material in the said layer (4), where an electrical field is applied across the said layer (4), whereby the said ionisation gives rise to an electric current, which said read-out arrangement is arranged to detect such that it can in this way detect the said incident ionising radiation (3). The invention is characterised in that the said active detector material in the said layer contains ZnO to such an extent that ionising radiation gives rise to a detectable electric current.

Detector for Ionizing Radiation.

The present invention concerns a detector for ionising radiation.

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Examples of such radiation are X-rays used in investigations in which X-ray detectors can be used to record in an electronic manner an image of an object or a living creature. Another example are detectors used to detect gamma radiation used in for example medical materials science or security applications. However, the present detector can be used in order to detect all types of ionising radiation. Furthermore, the present detector can be used both in medical applications and in industrial applications. Within the medical field, detection can be carried out in connection with, for example, the use of gamma radiation to treat a disease, or for the use of X-rays. Within the industrial field, detection of radiation can be carried out in connection with, for example, investigation of objects within microelectronics, nanotechnology, etc.

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Thus, the present invention is not to be regarded as being limited to any one particular field of use.

25 **The Prior Art**

Different designs of digital detectors of ionising radiation are available. Some of these are based on amorphous semiconductors that create charges at the surface layer when exposed. A detector plate with a layer of amorphous semiconductor is read in a read-out arrangement, whereby an image of an object is obtained.

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Recently, digital detectors have also been developed. These are based on different technical solutions. One type of detectors has silicon in the detector. X-rays or gamma photons can in this way be directly collected in the silicon-based detector. The silicon-based detectors can either be of plate-type, i.e. a plane area of silicon with image pixels, or they can be built up from pixels comprising rods of silicon that protrude from a silicon substrate.

Another type of detectors is based on a type of detector that comprises a gas avalanche detector, in which a noble gas is used as an amplifier. A cloud of electrons is in this manner generated that can be detected by detector plates with electrodes of, for example, metal applied to a carrier.

Different types of semiconductor detectors are available for the detection of ionising radiation, such as detectors containing germanium, silicon, CdTe and HgI₂. Detectors of scintillation type can comprise an active material comprising NaI, CsI, BGO, BaF₂, plastic or fibres.

Known detectors suffer principally from the disadvantage that they are expensive. Another disadvantage is that they give rise to a relatively slow recording of the input radiation.

The present invention eliminates these disadvantages.

The costs of digital detectors are reduced through the present invention, while the performance of the detectors is at the same time increased.

The present invention thus relates to a detector for detecting ionising radiation comprising at least one detector

arranged to be connected to a read-out arrangement for the reading and the evaluation of a signal from the detector, which detector comprises a carrier material and a layer comprising an active detector material applied to this carrier material, which active detector material is arranged, in the event of its receiving ionising radiation that is incident upon the said layer, to give rise to ionisation in the said active detector material in the said layer, where an electrical field is applied across the said layer, whereby the said ionisation gives rise to an electric current, which read-out arrangement is arranged to detect such that it can in this way detect the said incident ionising radiation, and it is characterised in that the said active detector material in the said layer contains ZnO to such an extent that ionising radiation gives rise to a detectable electric current.

The present invention is described in more detail below, partly in association with an embodiment of the invention shown on the attached drawings, where

- Figure 1a shows schematically a cross-section of a detector according to a first embodiment of the present invention;
- Figure 1b and 1c illustrate the principle according to which the present invention operates;
- Figure 2 shows a detector according to a second embodiment according to the invention;
- Figure 3 shows a detector according to a third embodiment of the invention; and
- Figure 4 shows an embodiment of the invention with two levels of detectors.

The active material zinc oxide makes possible low doses of radiation and gives rapid recording, and this means that also so called moving images formed by X-rays can be generated. The invention comprises a detector or a CCD (a Charge Coupled Device), in which the detector material consists of zinc oxide in an amorphous, crystalline or nanocrystalline form, either in a pure form or doped with a dopant. The zinc oxide may be present in a p-doped, n-doped or intrinsic form. The zinc oxide is subsequently deposited onto a carrier material. This may be of various properties such as glass, quartz crystal, ceramic, polymeric, sapphire, silicon or similar. The carrier material has read-out electrodes integrated into the surface layer or in the carrier material. It is, however, important to point out that it is the pure or doped zinc oxide that is the active material for the detection of photons. Integrated with the carrier material or mounted onto the carrier material there are electronic circuits for amplification, threshold detection, signal processing and digitalisation. The zinc oxide may either be applied to one large region, which forms the complete detector, or it may be applied to subregions, which are subsequently assembled together to form a detector unit. The active material zinc oxide can be adapted to different wavelengths. Furthermore, the active material zinc oxide gives a constant response in the relevant wavelength range, and this facilitates the design of the electronic circuits used for reading-out and for detection.

Brief Description of the Drawings.

The invention will be described below with schematic drawings, where Figure 1a shows a detector for ionising radiation, where the active material zinc oxide has been

applied to the readout chip with its layer of conductor. Figures 1b and 1c illustrate the principle according to which the present invention functions.

5 Figure 2 shows how the zinc oxide has been applied to a circuit board, which then has connections to electronic circuits for reading-out and for detection. Figure 3 shows how the active material has been applied to a carrier substrate, which has electric connections such that it can be
10 connected to electronic circuits for reading-out and for detection with the aid of flip-chip technology. The connection can also be connected to other contact elements such as, for example, conducting rubber elements. Figure 4 shows a technological solution in which the detector material
15 (ZnO) has been applied to the substrate, which consists of a circuit board of a polymer material, ceramic, silicon or similar. Furthermore, a second layer of active material has been applied. This makes it possible to measure the angle of incidence of the ionising radiation.

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In addition, the energy level of the incident photons can be measured.

Detailed Description

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The invention comprises a detector or a CCD (Charge Coupled Device), in which the detector material consists of zinc oxide in amorphous, crystalline or nanocrystalline form, either in pure form or doped with a dopant. The zinc oxide
30 may be p-doped, n-doped or it may have its intrinsic form.

Figure 1a shows a detector for ionising radiation, such as X-rays or gamma rays 3, where the active material zinc oxide 4

has been applied to a read-out chip 7 provided with a conducting layer 6. A dielectric material 5 is present between the conductors in the conducting layer 6. A top electrode 1 is applied above the active material 4.

5

Figure 1b shows a detector with, when traversed from the top downwards, a top electrode, a dielectric layer, the active detector material, a conducting layer with electrical conductors surrounded by a dielectric material, and a carrier layer. A Schottky contact may be formed in the top electrode instead of a dielectric layer under the top electrode. The lower dielectric material can, in a similar manner, be replaced by a Schottky contact. Photons that are incident on and stopped by the detector volume of ZnO are converted into an electron-hole pair, which in turn relax their excess energy in such a manner that further electron-hole pairs are formed. The free charge-carriers are subsequently accelerated in an applied electric field and the electrons collect in limited and isolated read-out islands of metal, which read-out islands are connected to read-out contacts. An electric field is applied between the top electrode and the read-out islands and this field thus lies principally across the detector volume characterised by a capacitance C_d , see Figure 1c. This capacitance C_d is significantly smaller than a capacitance C_s between the read-out contacts and earth. A signal is extracted via a conductor from between the capacitance C_s and earth to the read-out electronics.

According to one preferred embodiment, the said active material comprises p-doped ZnO with up to 5% nitrogen (N), arsenic (As) or phosphorus (P).

30

According to another preferred embodiment, the said active material comprises n-doped ZnO with up to 5% aluminium (Al), indium (In) or gallium (Ga).

5 The conducting layer 6, located under the layer 4 of active detector material, comprises according to one preferred embodiment an electrically conducting layer comprising one or more of the metals titanium (Ti), aluminium (Al), platinum (Pt), gold (Au) and silver (Ag).

10

An electrically conducting layer I in the form of a top electrode 1 is located above the layer of an active detector material, which comprises one or several of the metals titanium (Ti), aluminium (Al), platinum (Pt), gold (Au) or
15 silver (Ag).

15

The said active detector material is arranged to supply the said detectable electrical current for incident electromagnetic radiation with an energy level in the
20 interval 1 KeV and 20 MeV.

20

Figure 2 shows a detector, according to a second embodiment, for ionising radiation 3. According to this embodiment, the active material zinc oxide 4 has been applied onto a
25 conducting layer 11, that lies on a circuit board 9, for example, a printed circuit board. The conducting layer comprises electrical conductors with a dielectric medium 8 between the conductors. The conductors have electrical connections 10 to suitable known electronic circuits for the
30 present type of detector, not shown in the drawing, for reading-out and for detection. The top electrode 1 is applied above the active material 4. This design of detector ensures that it is possible to spread out the connections 10 such

30

that mounting onto the read-out and detection chip is facilitated. Efficient mounting methods such as, for example, wire bonding can then be used.

5 Figure 3 shows a detector for ionising radiation 3 according to a third embodiment. The active material zinc oxide 4 has been applied to a carrier substrate 12, which has electrical connections 16 such that it can be connected to read-out islands 17 on the electronic circuits 14 for read-out and
10 detection with the aid of flip-chip technology with BGA (Ball Grid Array) technology. The connection may also be made using other contact elements such as, for example, conducting rubber elements. A circuit board or substrate 12 with a conducting layer has been applied on top of the active
15 material 4, as has been described above. The top electrode 1 has been applied on top of the circuit board or substrate 12.

Figure 4 shows a detector for ionising radiation according to a fourth embodiment.

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According to this embodiment, a second equivalent detector arrangement is arranged under a first detector arrangement comprising a top electrode, an active layer and an electrically conducting layer, whereby the incident radiation
25 is incident first upon the upper active material and subsequently upon the lower active material, where a read-out circuit is present for each layer of active material.

The active material zinc oxide 4 is applied to a carrier
30 substrate 23 with read-out islands. The carrier substrate 23, with the read-out islands, consists of a circuit board of polymer material, ceramic, silicon or similar material.

Furthermore, a second layer 22 of active material including a top electrode 18 is applied under the carrier substrate 23. A carrier substrate 19 is present under the second active layer, with read-out islands, which also consists of a circuit board of polymer material, ceramic, silicon or similar material.

The lower active layer 22 is sectioned into pixels.

According to one preferred embodiment, in the case in which several detectors are placed onto the same substrate, a dielectric material is placed between different parts of the said electrically conducting material under the layer of the active material in order to form separated electrical conductors in the electrically conducting layer.

Figure 4 shows electrical connections, known as "vias", 20 and 24, drawn through the relevant substrate in order to be able to provide connections to the read-out and detection chip.

This design makes possible the measurement of the angle of incidence of the incident radiation 3. The angle of incidence of the photons is determined with the aid of the read-out electronic circuits, which interact both with the read-out islands in the detector plane in which detection takes place and with islands in other planes. With exact time determination of events down to a precision of microseconds or with shorter time intervals, the cloud of electrons that is created by one photon can be detected in several layers with at least two different read-out islands in different planes that interact. The angle of incidence can be

calculated from this information arising from single-photon events.

Furthermore, the energy level of the incident photons can be measured. The energy level is determined through two or more layers of the detector electrodes discriminating between radiation with different energies. Photons that have been able to penetrate the first detector volume with a maximum energy E_1 are detected in an upper layer of detector material. Photons with an energy that is greater than E_1 are detected in an underlying layer. If more than two detector layers are used, radiation from several energy intervals can be discriminated and used to provide an X-ray image with an artificial "colour depth".

Three-dimensional and real-colour X-ray images can in this way be realised.

It is preferred according to all embodiments that what are known as "TFTs" (Thin Film Transistors) are formed either in or on the said electrically conducting layer in order to read the active detector material.

According to an alternative preferred embodiment, what are known as "CCD elements" (Charged Coupled Device elements) are formed either in or on the said electrically conducting layer in order to read the active detector material.

According to a further alternative preferred embodiment, what are known as "ROICs" (Read Out Integrated Circuits) are formed either in or on the said electrically conducting layer in order to read the active detector material.

According to all embodiments described above, the thickness of the active layer is between 10 and 10,000 micrometers.

According to one preferred embodiment, the dimensions of the
5 detector in its own plane are up to 1 X 1 meter.

A number of embodiments have been described above. It is, however, apparent that a detector according to the present invention can be modified by one skilled in the arts with
10 respect to the design of the detector layer in its own plane and with respect to the design of the conducting layers.

The present invention for this reason is not to be regarded as limited to the embodiments specified above, but can be
15 varied within the scope of the attached claims.

Claims

1. A detector for detecting ionising radiation comprising at least one detector arranged to be connected to a read-out arrangement for the reading-out and the evaluation of a signal from the detector, which detector comprises a carrier material and a layer (4) comprising an active detector material applied to the carrier material, which active detector material is arranged, in the event of its receiving ionising radiation (3) that is incident upon the said layer (4), to give rise to ionisation in the said active detector material in the said layer (4), where an electrical field is applied across the said layer (4), whereby the said ionisation gives rise to an electric current, which said read-out arrangement is arranged to detect such that it can in this way detect the said incident ionising radiation (3), characterised in that the said active detector material in the said layer contains ZnO to such an extent that ionising radiation gives rise to a detectable electric current.

2. A detector according to claim 1, characterised in that the said active detector material comprises ZnO in amorphous, crystalline or nanocrystalline form.

3. A detector according to claim 1 or 2, characterised in that the said active material comprises p-doped ZnO with up to 5% nitrogen (N), arsenic (As) or phosphorus (P).

4. A detector according to claim 1 or 2, characterised in that the said active material comprises n-doped ZnO with up to 5% aluminium (Al), indium (In) or gallium (Ga).

5. A detector according to claim 1 or 2, characterised in that the said active material comprises ZnO in its intrinsic form.

5 6. A detector according to claim 1, 2, 3, 4 or 5, characterised in that the said active detector material is arranged to give the said detectable electrical current for an incident electromagnetic radiation with an energy level within the interval between 1 KeV and 20 MeV.

10

7. A detector according to any one of the preceding claims, characterised in that an electrically conducting layer comprising one or more of the metals titanium (Ti), aluminium (Al), platinum (Pt), gold (Au) and silver (Ag) is present
15 under the layer of active detector material.

8. A detector according to any one of the preceding claims, characterised in that an electrically conducting layer in the form of a top electrode comprising one or more of the
20 metals titanium (Ti), aluminium (Al), platinum (Pt), gold (Au) and silver (Ag) is present above the layer of active detector material.

9. A detector according to any one of the preceding claims,
25 characterised in that the detector with the said three layers, namely the active layer and a layer above and below the active layer, is built up on a substrate of polymer material, ceramic material or a silicon material.

30 10. A detector according to claim 9, characterised in that in the case in which several detectors are located on the same substrate, a dielectric material is located between different parts of the said electrically conducting material

under the layer of the active material in order to form separated electrical conductors in the electrically conducting layer.

5 11. A detector according to any one of the preceding claims, characterised in that what are known as "TFTs" (Thin Film Transistors) are formed in or on the said electrically conducting layer in order to read out the active detector material.

10

12. A detector according to any one of claims 1-10, characterised in that what are known as "CCD elements" (Charge Coupled Device elements) are formed in or on the said electrically conducting layer in order to read out the active
15 detector material.

13. A detector according to any one of claims 1-10, characterised in that what are known as "ROICs" (Read Out Integrated Circuits) are formed in or on the said
20 electrically conducting layer in order to read out a signal from the active detector material.

14. A detector according to any one of the preceding claims, characterised in that the thickness of the active
25 layer is between 10 and 10,000 micrometers.

15. A detector according to any one of the preceding claims, characterised in that the dimensions of the detector in its own plane are up to 1 X 1 meter.

30

16. A detector according to any one of the preceding claims, characterised in that a second corresponding detector arrangement is arranged under a first detector arrangement

comprising a top electrode, an active layer and an electrically conducting layer, whereby incident radiation is incident first upon the upper active material and subsequently upon the lower active material and in that a
5 read-out circuit is present for each layer of active material.

Fig. 1a

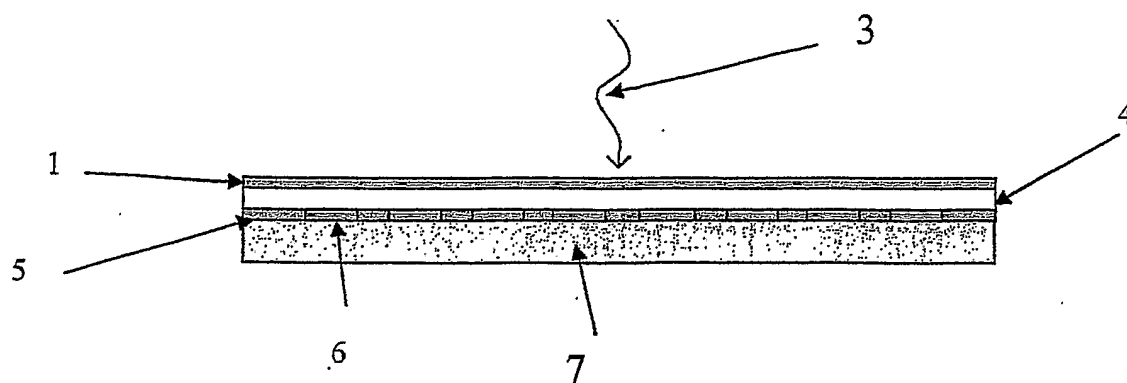


Fig. 1b.

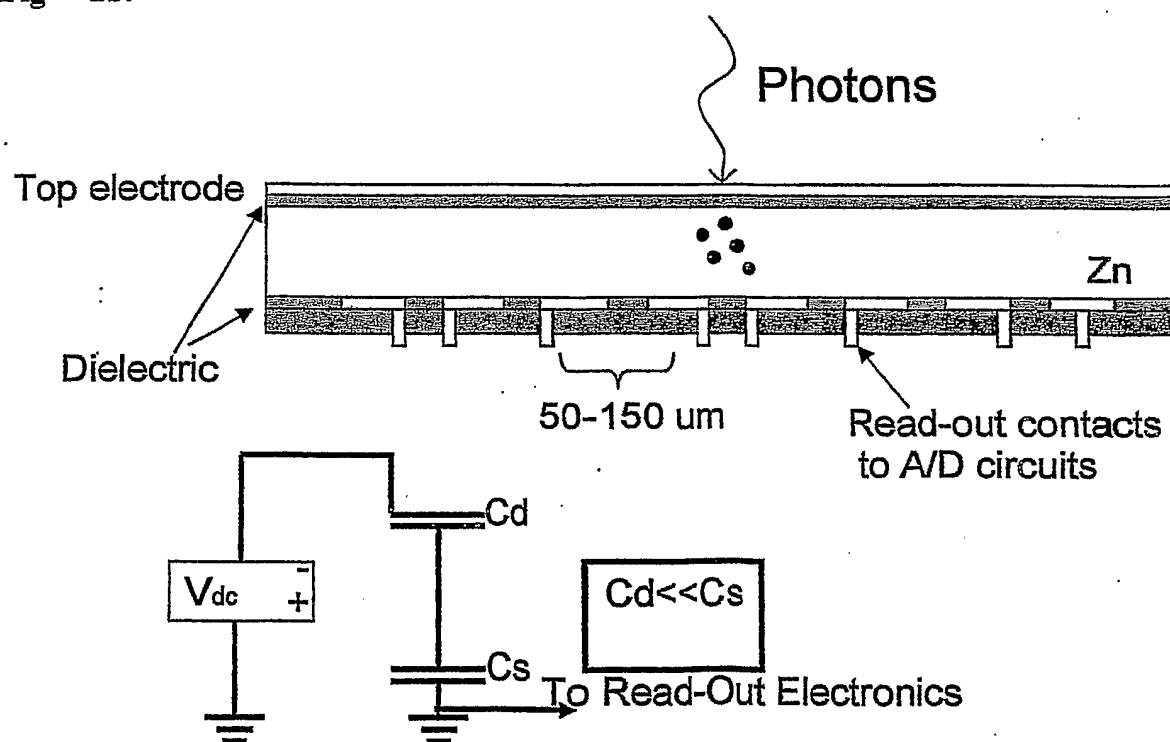


Fig. 1c

Fig . 2

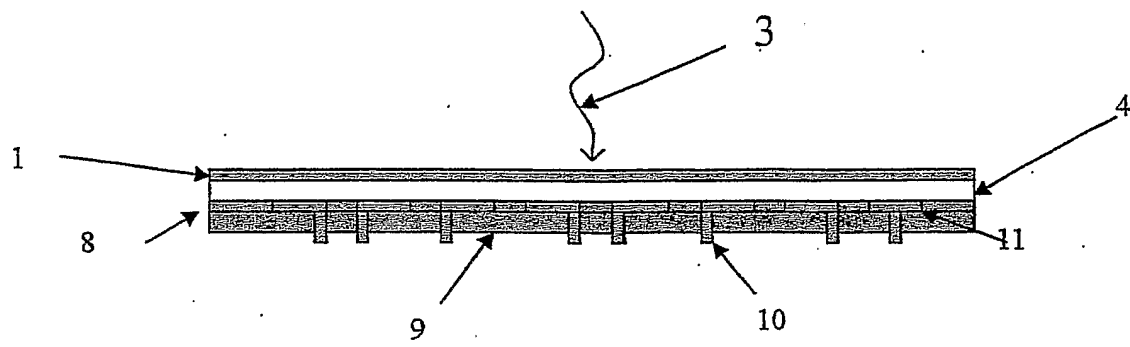


Fig. 3

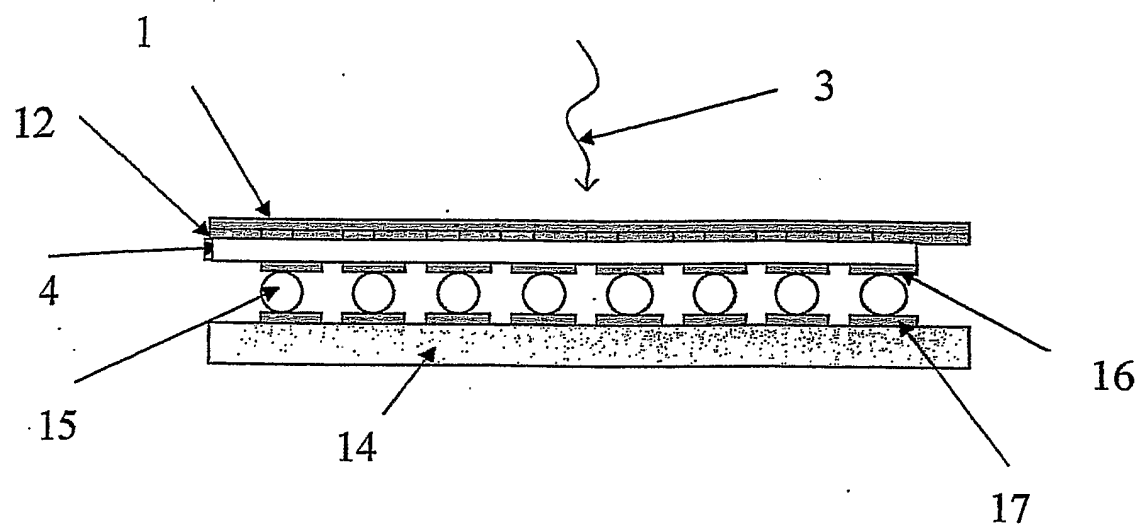
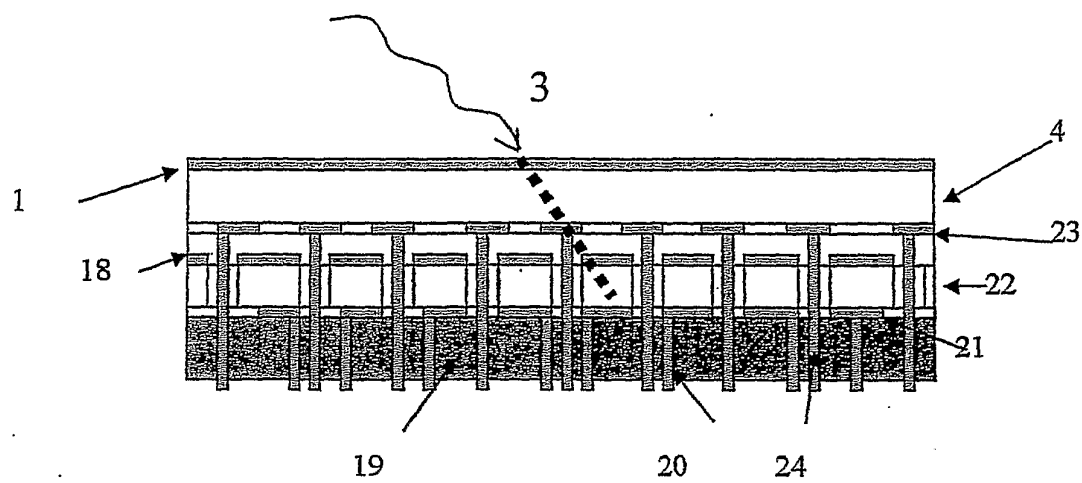


Fig. 4



PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference 050030PC	FOR FURTHER ACTION see Form PCT/ISA/220 as well as, where applicable, item 5 below.	
International application No. PCT/SE 2005/001228	International filing date (<i>day/month/year</i>) 23 August 2005	(Earliest) Priority Date (<i>day/month/year</i>) 23 August 2004
Applicant Nilsson, Materials AB et al		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 3 sheets.

☐ It is also accompanied by a copy of each prior art document cited in this report.

1. Basis of the report

a. With regard to the **language**, the international search was carried out on the basis of:

- ☒ the international application in the language in which it was filed
☐ a translation of the international application into _____, which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b))

b. ☐ With regard to any nucleotide and/or amino acid sequence disclosed in the international application, see Box No. I.

2. ☐ Certain claims were found unsearchable (see Box No. II)

3. ☐ Unity of invention is lacking (see Box No. III)

4. With regard to the **title**,

- ☒ the text is approved as submitted by the applicant.
☐ the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,

- ☒ the text is approved as submitted by the applicant.
☐ the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box No. IV. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. With regard to the **drawings**,

- a. the figure of the drawings to be published with the abstract is Figure No. 1a
☒ as suggested by the applicant.
☐ as selected by this Authority, because the applicant failed to suggest a figure.
☐ as selected by this Authority, because this figure better characterizes the invention.
- b. ☐ none of the figures is to be published with the abstract.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 2005/001228

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: G01T 1/24, H01L 31/115

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)

IPC7: G01T, H01L

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

SE,DK,FI,NO classes as above

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

EPO-INTERNAL, WPI DATA, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	MOON, TAE-HYOUNG ET AL: "The fabrication and characterization of ZnO UV detector", Applied Surface Science 240 (2005), pages 280-285. (available online since 4 august 2004) Available at www.sciencedirect.com See the whole document --	1-4,7-16
X	PURICA, MUNIZER ET AL: "ZnO thin films on semiconductor substrate for large area photodetector applications". Thin Solid Films, Vol. 383, Issues 1-2, pages 284-286, 15 February 2001 See the whole document --	1-5,7-16

☒ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

* Special categories of cited documents:	"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
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
"E" earlier application or patent but published on or after the international filing date	"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
"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)	"&" document member of the same patent family
"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	

Date of the actual completion of the international search	Date of mailing of the international search report
10 November 2005	10 -11- 2005

Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Erik Miliander /LR Telephone No. +46 8 782 25 00
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INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 2005/001228

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GEORGOBANI, A N ET AL: "p-Type ZnO:N obtained by ion implantation of nitrogen with post-implantation annealing in oxygen radicals". Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Vol. 514, Issues 1-3, pages 117-121, 21 November 2003 See the whole document -- -----	1-5,7-16