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(71) Applicant: SENSINITE OY [FI/FI]; Wolffintie 36 F2, FI-65200 Vaasa (FI).

(72) Inventor: ORAVA, Risto; Dagmarinkatu 8 B 24, FI-00100 Helsinki (FI).

(74) Agent: FINNPATENT OY; Smart Chemistry Park, Raisionkaari 55, FI-21200 Raisio (FI).

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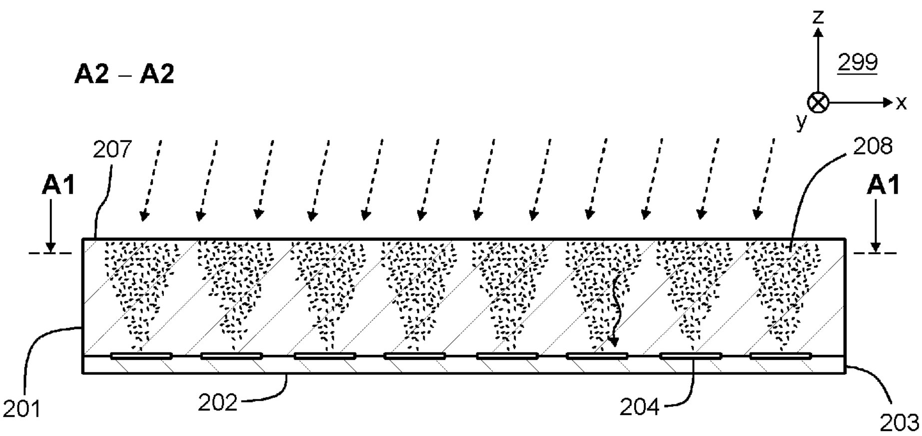

Figure 2a

(57) Abstract: An apparatus for detecting radiation comprises a radiation conversion element (101) and a photo-detector (102). The radiation conversion element comprises one or more conversion materials for converting incoming radiation at least partly to photons, where the one or more conversion materials comprise at least one scintillation material for producing the photons. The photo-detector comprises a membrane (103) attached to the radiation conversion element and provided with printed photodetector semiconductor components (104) for detecting the photons and for producing electric output signals indicative of the detected photons. The use of the printed photodetector semiconductor components makes it possible to produce radiation measuring apparatuses of different sizes, shapes, and mechanical properties, such as for example mechanical flexibility, in a cost-effective way.

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An apparatus for detecting radiation

Field of the disclosure

The disclosure relates generally to radiation detection. More particularly, the disclosure relates to an apparatus for detecting radiation.

Background

In many cases, there is a need to detect and measure radiation for example to ensure safety of people, analyze materials, and for many other purposes, too. The radiation to be detected may comprise for example gamma rays, X-rays, neutrons, alpha particles, beta particles, and/or other electrically charged or neutral particles. Radiation can be detected using radiation detectors such as for example a Geiger counter, an ionisation chamber, a scintillation detector, a neutron detector, and so forth. In a scintillation detector, energy of incoming radiation is at least partly converted into photons that are, in turn, detected with a photodetector which produces electric output signals indicative of the detected photons. The electric output signals of the photodetector are processed with an appropriate processing system to produce output data suitable for an application under consideration.

Organic and inorganic scintillator materials offer a platform for fabricating radiation detectors which can be tailored for different applications. For specifying a detector design, there are typically many aspects to define such as for example: i) characteristics of radiation to be detected such as e.g. type, energy, and expected flux, ii) mechanical constraints such as e.g. limitations of size and/or shape, mechanical stresses, and a need for mechanical flexibility, iii) electrical constraints related to e.g. powering and signal read-out, iv) functional requirements such as e.g. required detector efficiency, sensitivity, and radiation hardness, v) background conditions such as e.g. radiation background and electric noise, and vi) operating environment-related aspects such as e.g. available cooling and variations in temperature, humidity, and atmospheric pressure. Furthermore, in detector design, it is advantageous to provide for an efficient signal extraction. In case of scintillating detectors, it is a well-known practice to use different types and geometries of light guide and/or light concentrators to maximize the number of photons arriving at a photodetector which can be either a photomultiplier tube PMT or a silicon-based photodetector such as e.g. a PIN diode, avalanche P/N diode APD, or a silicon photomultiplier SiPM. The light guides/light concentrators enable larger detector areas to be read out by a photodetector with a small active surface area.

As discussed above, there are numerous aspects to be considered when constructing an apparatus for detecting radiation. Furthermore, the apparatus for detecting radiation should be as cost-effective as possible. To improve the possibilities to fulfil the numerous aspects of the kind described above, there is still a need for new ways to construct apparatuses for detecting radiation.

Summary

The following presents a simplified summary to provide a basic understanding of some aspects of various invention embodiments. The summary is not an extensive overview of the invention. It is neither intended to identify key or critical elements of the invention nor to delineate the scope of the invention. The following summary merely presents some concepts of the invention in a simplified form as a prelude to a more detailed description of exemplifying embodiments of the invention.

In this document, the word “geometric” when used as a prefix means a geometric concept that is not necessarily a part of any physical object. The geometric concept can be for example a geometric point, a straight or curved geometric line, a geometric plane, a non-planar geometric surface, a geometric space, or any other geometric entity that is zero, one, two, or three dimensional.

In accordance with the invention, there is provided a new apparatus for detecting radiation such as e.g. gamma rays, X-rays, neutrons, alpha particles, beta particles, and/or other electrically charged or neutral particles. An apparatus according to the invention comprises:

- a radiation conversion element comprising one or more conversion materials for converting radiation at least partly to photons, the one or more conversion materials comprising at least one scintillation material for producing the photons, and

- a photo-detector for detecting the photons,

wherein the photo-detector comprises a membrane attached to the radiation conversion element and provided with printed photodetector semiconductor components for detecting the photons, and wherein:

- the radiation conversion element comprises at least partially optically transparent base material and particles of the one or more conversion materials mechanically supported by the at least partially optically transparent base material,
- the particles of the one or more conversion materials are arranged to form clusters of the particles within the at least partially optically transparent base material,
- the clusters of the particles form an array of the clusters that is aligned with an array of the printed photodetector semiconductor components comprised by the membrane, and
- the clusters of the particles have a shape tapering towards the membrane comprising the printed photodetector semiconductor components.

In accordance with the invention, there is provided also another new apparatus for detecting radiation, the apparatus comprising:

- a radiation conversion element comprising one or more conversion materials for converting radiation at least partly to photons, the one or more conversion materials comprising at least one scintillation material for producing the photons, and
- a photo-detector for detecting the photons,

wherein the photo-detector comprises a membrane attached to the radiation conversion element and provided with printed photodetector semiconductor components for detecting the photons, and wherein:

- the radiation conversion element comprises a stack of sheets made of at least partially optically transparent material and provided with the one or more conversion materials printed on surfaces of the sheets,
- each of at least two of the sheets comprises an array of printed areas containing the one or more conversion materials so that the array of the printed areas is aligned with an array of the photodetector semiconductor components printed on the membrane, and
- the printed areas nearer to the membrane comprising the printed photodetector semiconductor components are smaller than the printed areas farther from the membrane comprising the printed photodetector semiconductor components.

The utilization of the printed photodetector semiconductor components makes it possible to produce radiation measuring apparatuses of different sizes, shapes, and mechanical properties in a cost-effective way. The radiation conversion element can be, for example but not necessarily, a flexible sheet of elastomer provided with particles of one or more conversion materials. Correspondingly, the membrane provided with the printed photodetector semiconductor components can be flexible as well. In this exemplifying case, the apparatus for detecting radiation is flexible so that it can be e.g. wrapped around a tube that conducts radiation emitting fluid. In addition to the above-mentioned photodetector semiconductor components, it is possible to use printed electronics for implementing amplifiers, filters, and/or other components of an apparatus for detecting radiation. It is however also possible that an apparatus for detecting radiation is connected to an external circuitry that comprises amplifiers, filters, and/or other components needed for operating the apparatus for detecting radiation.

The membrane attached to the radiation conversion element may comprise, for example, a two-dimensional array i.e. a matrix, of photodetector semiconductor components. In this exemplifying case, the printed photodetector semiconductor components can be arranged to cover a large area. Therefore, by integrating printed photodetector electronics within an appropriate radiation conversion of the kind mentioned above, an efficient composite radiation detector can be manufactured for a variety of detector modalities, including large area position sensitive imagers.

There are different methods for producing the membrane provided with the printed photodetector semiconductor components. For example, the photodetector semiconductor components can be pre-manufactured elements that are capsuled in the membrane. For another example, the photodetector semiconductor components can be formed by printing on the membrane using suitable printing fluids having affinity to the membrane.

Exemplifying and non-limiting embodiments of the invention are described in accompanied dependent claims.

Various exemplifying and non-limiting embodiments of the invention both as to constructions and to methods of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific exemplifying and non-limiting embodiments when read in conjunction with the accompanying drawings.

The verbs “to comprise” and “to include” are used in this document as open limitations that neither exclude nor require the existence of un-recited features. The features recited in dependent claims are mutually freely combinable unless otherwise explicitly stated. Furthermore, it is to be understood that the use of “a” or “an”, i.e. a singular form, throughout this document does not exclude a plurality.

Brief description of the figures

Exemplifying and non-limiting embodiments and their advantages are explained in greater detail below in the sense of examples and with reference to the accompanying drawings, in which:

figures 1a and 1b illustrate an apparatus for detecting radiation,

figures 2a and 2b illustrates an apparatus according to another exemplifying and non-limiting embodiment for detecting radiation, figure 3 illustrates an apparatus according to an exemplifying and non-limiting embodiment for detecting radiation,

figures 4a and 4b illustrate an apparatus for detecting radiation,

figure 5 illustrates an apparatus according to an exemplifying and non-limiting embodiment for detecting radiation, and

figure 6 shows a high-level flowchart of a method for manufacturing an apparatus according to an exemplifying and non-limiting embodiment for detecting radiation.

In the accompanying drawings, an underlined reference number is employed to represent an item over which the underlined number is positioned. A non-underlined reference number relates to an item identified by a line linking the non-underlined number to the item. When a reference number is non-underlined and accompanied by an associated arrow not in contact with any item, the non-underlined reference number is used to identify a general item towards which the arrow is pointing. When a reference number is non-underlined and accompanied by an associated arrow in contact with an item, the non-underlined reference number is used to identify a surface of the item.

Description of exemplifying and non-limiting embodiments

The specific examples provided in the description below should not be construed as limiting the scope and/or the applicability of the accompanied claims. All lists and groups of examples provided in the description are not exhaustive unless otherwise explicitly stated.

Figures 1a and 1b show schematic section views of an apparatus for detecting radiation. The section plane related to figure 1a is parallel with the xz-plane of a coordinate system 199, and the section plane related to figure 1b is parallel with the xy-plane of the coordinate system 199. The apparatus comprises a radiation conversion element 101 comprising one or more conversion materials for converting incoming radiation at least partly to photons. The one or more conversion materials comprise at least one scintillation material for producing the photons. In figure 1a, the incoming radiation is depicted with dashed line arrows and some of the photons are depicted with wavy line arrows. In the exemplifying case illustrated in figures 1a and 1b, the radiation conversion element 101 is a single piece of scintillation material. The scintillation material may comprise for example organic scintillator material such as for example polyethylene napthalate PEN, polyethylene terepthalate PET, polyvinyltoluene PVT containing napthalate, or polystyrene PS containing napthalate. Organic scintillator materials are typically low atomic number materials, i.e. low-Z materials, with densities in the range of about 1 g/cm^3. Most of the organic scintillators are doped, and there is a wide choice of signal photon wavelengths. However, e.g. polyethylene napthalate PEN is an intrinsic scintillator, and there is no need for activation components, leading to a highly competitive pricing of the scintillator material. The organic scintillator materials are relatively radiation hard. For example, polyethylene napthalate PEN has excellent radiation hardness, up to 1 MGy/year. The radiation to be detected may comprise for example gamma rays, X-rays, neutrons, alpha particles, beta particles, and/or other electrically charged or neutral particles. The scintillation material is selected based on the type or types of the radiation to be detected. Information about plastic scintillators fabricated by a polymerization reaction are presented e.g. by Cheol Ho Lee, et al.: Characteristics of Plastic Scintillators Fabricated by a Polymerization Reaction, Department of Nuclear Engineering, Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul 04763, South Korea, Nuclear Engineering and Technology 49, 2017, pp. 592-597.

The apparatus further comprises a photo-detector 102 for detecting the photons produced by the radiation conversion element 101. The photo-detector 102 comprises a membrane 103 attached to the radiation conversion element and provided with printed photodetector semiconductor components for detecting the photons. When the radiation conversion element 101 is made with injection molding, the membrane 103 can be attached to the radiation conversion element 101 for example with the overmolding technique where the radiation conversion element 101 is fused to the membrane 103 with heat. In figures 1a and 1b, one of the photodetector semiconductor components is denoted with a reference 104. In the exemplifying apparatus illustrated in figures 1a and 1b, the photodetector semiconductor components are arranged to constitute a two-dimensional array. The photo-detector 102 comprises wirings 105 and 106 for powering and signal read-out. Electrical signals on the wirings 105 indicate one or more columns of the above-mentioned array on which there are one or more photodetector semiconductor components activated by photons. Correspondingly, electrical signals on the wirings 106 indicate one or more rows of the above-mentioned array on which there are one or more photodetector semiconductor components activated by photons. It is worth noting that the wiring arrangement shown in figure 1b is a non-limiting example only. It is also possible that each of the photodetector semiconductor components has separate wires connected to the photodetector semiconductor component under consideration. For, example there can be two component-specific wires to each photodetector semiconductor component though which the photodetector semiconductor component is powered and its response to photons is read out. Each of the photodetector semiconductor components can be for example an avalanche photo-diode, a PIN-diode, or a photo-transistor. A PIN-diode is a diode with a wide, undoped intrinsic semiconductor region between a P-type semiconductor region and an N-type semiconductor region.

In addition to the above-mentioned photodetector semiconductor components, it is possible to use printed electronics for implementing amplifiers, filters, and/or other components. In an exemplifying apparatus, the membrane 103 further comprises printed electronic components, e.g. transistors et al., arranged to constitute amplifiers and/or filters for processing the electrical signals produced by the photodetector semiconductor components, and/or voltage- and/or current-regulators for controlling energy supply of the photodetector semiconductor components.

Figures 2a and 2b show schematic section views of an apparatus according to an exemplifying and non-limiting embodiment for detecting radiation. The section plane related to figure 2a is parallel with the xz-plane of a coordinate system 299, and the section plane related to figure 2b is parallel with the xy-plane of the coordinate system 299. The apparatus comprises a radiation conversion element 201 for converting incoming radiation at least partly to photons. In this exemplifying case, the radiation conversion element 201 comprises at least partially optically transparent base material 207 and particles of one or more conversion materials, where the one or more conversion materials comprise at least one scintillation material for producing the photons. The particles are mechanically supported by the base material 207. In figures 2a and 2b, some of the particles are denoted with a reference 208. The base material 207 can be for example polymer or elastomer such as e.g. polydimethylsiloxane PDMS. Thus, the apparatus for detecting radiation can be flexible so that it can be e.g. wrapped around a tube that conducts radiation emitting fluid.

The above-mentioned particles of the conversion materials may comprise for example particles of one or more primary conversion materials for emitting charged particles such as e.g. electrons, alpha particles, Li-ions, or other charged particles in response to the incoming radiation and particles of one or more inorganic scintillation materials for producing photons in response to the charged particles. The one or more primary conversion materials may comprise for example: Boron B isotope-10 for detecting neutrons, Lithium Li isotope-6 for detecting neutrons, Gadolium Gd natural or enriched with isotope-157 for detecting neutrons, tungsten W for detecting gamma radiation and beta radiation, lead Pb for detecting gamma radiation and beta radiation, iron Fe for detecting gamma radiation and beta radiation, copper Cu for detecting gamma radiation and beta radiation, zinc sulfide ZnS for detecting charged particles having a mass at least the mass of a proton, and/or zinc selenium ZnSe for detecting charged particles having a mass at least the mass of a proton. The one or more inorganic scintillation materials may comprise for example: cesium iodide CsI, sodium iodide containing thallium NaI:T, lithium iodide LiI, Cadmium telluride CdTe, cadmium zinc telluride CdZnTe, zinc sulfide containing thallium ZnS:T, and/or zinc selenium containing thallium ZnSe:T.

Other inorganic scintillation materials are for example: $AgGd(PO_3)_4$:Ce, Ba_2GdCl_7:Ce, $BaGdCl_5$:Ce, CdS:Te, $CdWO_4$, $CdWO_4$, $Cs_2LiGdBr_6$:Ce, $CsGd(PO_3)_4$:Ce, $Gd_3Al_2Ga_3O_{12}$:Ce known as GAGG, $Gd_3Al_3Ga_2O_{12}$:Ce, $Gd_3Y_3Al_{10}O_{24}$:Ce known as GYAG, $GdBO_3$:Ce, $GdBr_3$, $GdCl_3$:Ce, GdI_3:Ce, GdOBr:Ce, GdOCl:Ce, K_2LiYBr_6:Ce, $KGd(PO_3)_4$:Ce, $Li_{12}LuGd(BO_3)_6$, Li_2NaYBr_6:Ce, Li_3TaO_4, $Li_6Gd(BO_3)_3$:Ce, $LiGdCl_4$, $LiGdCl_4$:Ce, $Lu_{(2-2x)}Gd_{(2x)}SiO_5$:Ce known as LGSO, $Lu_{(x)}Gd_{(1-x)}I_3$:Ce, $NaGd(PO_3)_4$:Ce, $NaGdCl_4$:Ce, Rb_2LiYI_6:Ce, Rb_2LiYI_6:Ce, Rb_2LiYI_6:Ce, $RbGd_2Br_7$:Ce, $RbGd_2Br_7$:Ce, and $RbGd_2Br_7$:Ce.

The apparatus further comprises a photo-detector 202 for detecting the photons produced by the radiation conversion element 201. The photo-detector 202 comprises a membrane 203 attached to the radiation conversion element and provided with printed photodetector semiconductor components for detecting the photons. In figure 2a, one of the photodetector semiconductor components is denoted with a reference 204. Each photodetector semiconductor component can be e.g. an avalanche photo-diode, a PIN-diode, or a photo-transistor. The photo-detector 202 can be e.g. similar to the photo-detector 102 illustrated in figures 1a and 1b.

In the exemplifying apparatus illustrated in figures 2a and 2b, the particles of the one or more conversion materials are arranged to form clusters within the at least partially optically transparent base material 207. In figure 2b, one of the clusters is denoted with a reference 209. As shown in figure 2b, the clusters are arranged to form, in a geometric plane parallel with the membrane 203, a two-dimensional array of the clusters. In the exemplifying case illustrated in figures 2a and 2b, the clusters form an 8 × 8 -array. The printed photodetector semiconductor components may form an 8 × 8 -array in the same way as illustrated in figure 1b. In this exemplifying case, the 8 × 8 -array of the clusters can be aligned with the 8 × 8 -array of the printed photodetector semiconductor components. This arrangement facilitates producing a pixelized image representing the incoming radiation, i.e. provides a better space resolution than an apparatus having evenly distributed conversion material. It is to be noted that the above-mentioned 8 × 8 -arrays represent a mere non-limiting example and many different patterns of clusters and printed photodetector semiconductor components are possible.

In the exemplifying apparatus illustrated in figures 2a and 2b, the clusters of the particles have a shape tapering towards the membrane 203 comprising the printed photodetector semiconductor components. This spatial arrangement has an advantage that photons emitted by the particles of scintillation material have a better probability of reaching the photodetector semiconductor components than e.g. in a case where the clusters have a cylindrical shape because the tapering shape reduces the risk that a photon emitted by one of the particles is absorbed by another of the particles. The tapering shape can be e.g. a conical shape. If the above-mentioned shape were cylindrical there would be a higher risk that a photon would be captured by conversion material whose refractive index is typically greater than that of the surrounding material.

Figure 3 shows a schematic perspective view of an apparatus according to an exemplifying and non-limiting embodiment for detecting radiation. The apparatus comprises a radiation conversion element 301 for converting incoming radiation at least partly to photons. In this exemplifying case, the radiation conversion element 301 is a three-dimensional array of cubicles each of which comprises one or more conversion materials selected based on the type or types of radiation to be detected. In figure 3, three of the cubicles are denoted with a reference 321. The apparatus further comprises a photo-detector 302 for detecting the photons produced by the radiation conversion element 301. In this exemplifying case, the photo-detector 302 comprises planar membranes provided with printed photodetector semiconductor components. The planar membranes can be e.g. such as the membrane 103 shown in figures 1a and 1b. In figure 3, one of the planar membranes is denoted with a reference 303a. The photo-detector 302 further comprises strip membranes provided with printed photodetector semiconductor components. In figure 3, one of the strip membranes is denoted with a reference 303b. The planar membranes and the strip membranes comprise wirings for powering and signal read-out of the printed photodetector semiconductor components. The wirings make it possible to detect which rows of the three-dimensional array in the x-, y-, and z-directions of a coordinate system 399 comprise cubicles activated by the incoming radiation. Thus, it is possible to detect the arrival direction of the incoming radiation.

Figure 4a shows a schematic section view of an apparatus for detecting radiation. The section plane is parallel with the xz-plane of a coordinate system 499. Figure 4b shows a top view of the apparatus. The viewing direction related to figure 4b is illustrated with the coordinate system 499. The apparatus comprises a radiation conversion element 401 for converting incoming radiation at least partly to photons. In this exemplifying case, the radiation conversion element 401 comprises a sheet 430 made of at least partially optically transparent material. One or more conversion materials are printed on a surface of the sheet 430. Particles of the one or more conversion materials can be e.g. mixed with suitable printing fluid that is capable of attaching on the surface of the sheet 430.

The apparatus further comprises a photo-detector 402 for detecting photons produced by the radiation conversion element 401. The photo-detector 402 comprises a membrane 403 attached to the radiation conversion element and provided with printed photodetector semiconductor components for detecting the photons. In figure 4a, one of the photodetector semiconductor components is denoted with a reference 404. The photo-detector 402 can be e.g. similar to the photo-detector 102 illustrated in figures 1a and 1b.

In the exemplifying apparatus illustrated in figures 4a and 4b, the sheet 430 comprises an array of printed areas containing the one or more conversion materials so that the array of the printed areas is aligned with an array of the photodetector semiconductor components printed on the membrane 403. In figures 4a and 4b, one of the printed areas is denoted with a reference 431. This arrangement facilitates producing a pixelized image representing the incoming radiation, i.e. provides a better space resolution than an apparatus having evenly distributed conversion material. It is to be noted that the 8 × 8 -array illustrated in figure 4b represents a mere non-limiting example and many different patterns formed by the printed one or more conversion materials and the printed photodetector semiconductor components are possible.

Figure 5 shows a schematic section view of an apparatus according to an exemplifying and non-limiting embodiment for detecting radiation. The section plane is parallel with the xz-plane of a coordinate system 599. The apparatus comprises a radiation conversion element 501 for converting incoming radiation at least partly to photons. In this exemplifying case, the radiation conversion element 501 comprises a stack 532 of sheets made of at least partially optically transparent material. One or more conversion materials are printed on surfaces of the sheets. Particles of the one or more conversion materials can be e.g. mixed with suitable printing fluid that is capable of attaching on the surfaces of the sheets.

The apparatus further comprises a photo-detector 502 for detecting photons produced by the radiation conversion element 501. The photo-detector 502 comprises a membrane 503 attached to the radiation conversion element and provided with printed photodetector semiconductor components for detecting the photons. In figure 5, one of the photodetector semiconductor components is denoted with a reference 504. The photo-detector 502 can be e.g. similar to the photo-detector 102 illustrated in figures 1a and 1b.

In the exemplifying apparatus illustrated in figure 5, each sheet of the radiation conversion element 501 comprises an array of printed areas containing the one or more conversion materials so that the array of the printed areas is aligned with an array of the photodetector semiconductor components printed on the membrane 503. In figure 5, one of the printed areas is denoted with a reference 531. In this exemplifying case, a printed area that is nearer to the membrane 503 is smaller than a printed area that is farther from the membrane 503. This spatial arrangement has an advantage that photons emitted by one or more scintillation materials contained by the printed areas have a better probability of reaching the photodetector semiconductor components than e.g. in a case where the printed areas at different distances from the membrane 503 have equal sizes because the spatial arrangement shown in figure 5 reduces the risk that a photon emitted by one of the printed areas is absorbed by another of the printed areas.

The radiation conversion element 501 shown in figure 5 is a mere non-limiting example of radiation conversion elements based on stacked sheets and printed conversion materials. A radiation conversion element may comprise for example sheets having one or more printed conversion materials and sheets without printed conversion material. A sheet without printed conversion material can be made of e.g. organic scintillation material. It is also possible that a sheet is made of organic scintillation material and one or more primary conversion materials for emitting charged particles in response to incoming radiation are printed on a surface of the sheet.

The powering and signal read-out of the radiation detection apparatuses illustrated in figures 1a, 1b, 2a, 2b, 3, 4, and 5 can be carried out with a processing system connected to wirings of an apparatus under consideration. The processing system may comprise for example driver circuits, analogue-to-digital converters, and one or more digital processing circuits. Each digital processing circuit can be a programmable processor circuit provided with appropriate software, a dedicated hardware processor such as for example an application specific integrated circuit “ASIC”, or a configurable hardware processor such as for example a field programmable gate array “FPGA”. Furthermore, the processing system may comprise one or more memory circuits each of which can be for example a Random-Access Memory “RAM” circuit.

Figure 6 shows a high-level flowchart of a method for manufacturing an apparatus according to an exemplifying and non-limiting embodiment for detecting radiation. The method comprises the following actions:

- action 601: obtaining a radiation conversion element comprising one or more conversion materials for converting radiation at least partly to photons, the one or more conversion materials comprising at least one scintillation material for producing the photons,

- action 602: obtaining a membrane provided with printed photodetector semiconductor components for detecting the photons, and

- action 603: attaching the membrane provided with the printed photodetector semiconductor components to the radiation conversion element.

Each of the above-mentioned printed photodetector semiconductor components can be for example an avalanche photo-diode, a PIN-diode, or a photo-transistor.

In an exemplifying method, the conversion materials comprise primary conversion material for emitting charged particles in response to the radiation and the at least one scintillation material for producing the photons in response to the charged particles.

In an exemplifying method, the at least one scintillation material comprises at least one organic scintillation material.

In an exemplifying method, the at least one scintillation material comprises at least one inorganic scintillation material.

In an exemplifying method, the radiation conversion element comprises at least partially optically transparent base material and particles of the one or more conversion materials mechanically supported by the base material.

In an exemplifying method, the particles of the one or more conversion materials are arranged to form clusters of the particles within the base material.

In an exemplifying method, the clusters of the particles form an array of the clusters and the array of the clusters is aligned with an array of the photodetector semiconductor components printed on the membrane.

In an exemplifying method, the clusters of the particles have a shape tapering towards the membrane comprising the printed photodetector semiconductor components.

In an exemplifying method, the base material comprises elastomer, e.g. polydimethylsiloxane PDMS.

A manufacturing process of the above-mentioned radiation conversion element comprising the clusters of the particles of the one or more conversion materials may comprise for example the following actions:

- arranging granules of the at least partially optically transparent base material, e.g. polymer granules, on a supporting surface to form a sheet of the granules,
- covering the sheet of the granules with a stencil comprising openings arranged at a distance from each other,
- arranging the particles on top of the stencil to enable mixing of the particles with the granules exposed via the openings of the stencil to create the clusters of the particles, and
- forming the radiation conversion element by applying a suitable amount of heat for an appropriate duration of time.

In an exemplifying method, the radiation conversion element comprises a sheet made of at least partially optically transparent material and the one or more conversion materials are printed on a surface of the sheet.

In an exemplifying method, the sheet comprises an array of printed areas containing the one or more conversion materials, and the array of the printed areas is aligned with an array of the photodetector semiconductor components printed on the membrane.

In an exemplifying method, the radiation conversion element comprises a stack of sheets made of at least partially optically transparent material and the one or more conversion materials are printed on surfaces of the sheets.

In an exemplifying method, each of at least two of the sheets comprises an array of printed areas containing the one or more conversion materials, and the array of the printed areas is aligned with an array of the photodetector semiconductor components printed on the membrane. In a method according to an exemplifying and non-limiting embodiment, a printed area nearer to the membrane comprising the photodetector semiconductor components is smaller than a printed area farther from the membrane comprising the printed photodetector semiconductor components.

In an exemplifying method, the radiation conversion element is made with injection molding and the membrane is attached to the radiation conversion element with the overmolding technique.

The specific examples provided in the description given above should not be construed as limiting the scope and/or the applicability of the appended claims. Lists and groups of examples provided in the description given above are not exhaustive unless otherwise explicitly stated.

What is claimed is:

1. An apparatus for detecting radiation, the apparatus comprising:

- a radiation conversion element (101, 201, 301, 401, 501) comprising one or more conversion materials for converting radiation at least partly to photons, the one or more conversion materials comprising at least one scintillation material for producing the photons, and

- a photo-detector (102, 202, 302, 402, 502) for detecting the photons,

wherein the photo-detector comprises a membrane (103, 203, 303a, 303b, 403, 503) attached to the radiation conversion element and provided with printed photodetector semiconductor components (104, 204, 404, 504) for detecting the photons, and wherein:

- the radiation conversion element (201) comprises at least partially optically transparent base material (207) and particles (208) of the one or more conversion materials mechanically supported by the at least partially optically transparent base material,

- the particles (208) of the one or more conversion materials are arranged to form clusters (209) of the particles within the at least partially optically transparent base material, and

- the clusters (209) of the particles form an array of the clusters that is aligned with an array of the printed photodetector semiconductor components (204) comprised by the membrane,

characterized in that the clusters of the particles have a shape tapering towards the membrane (203) comprising the printed photodetector semiconductor components (204).

2. An apparatus for detecting radiation, the apparatus comprising:

- a radiation conversion element (101, 201, 301, 401, 501) comprising one or more conversion materials for converting radiation at least partly to photons, the one or more conversion materials comprising at least one scintillation material for producing the photons, and

- a photo-detector (102, 202, 302, 402, 502) for detecting the photons,

wherein the photo-detector comprises a membrane (103, 203, 303a, 303b, 403, 503) attached to the radiation conversion element and provided with printed photodetector semiconductor components (104, 204, 404, 504) for detecting the photons, and wherein:

- the radiation conversion element (501) comprises a stack (532) of sheets made of at least partially optically transparent material and provided with the one or more conversion materials printed on surfaces of the sheets, and

- each of at least two of the sheets comprises an array of printed areas (531) containing the one or more conversion materials so that the array of the printed areas is aligned with an array of the photodetector semiconductor components (504) printed on the membrane (503),

characterized in that the printed areas nearer to the membrane (503) comprising the printed photodetector semiconductor components are smaller than the printed areas farther from the membrane comprising the printed photodetector semiconductor components.

3. An apparatus according to claim 1 or 2, wherein the conversion materials comprise primary conversion material for emitting charged particles in response to the radiation and the at least one scintillation material for producing the photons in response to the charged particles.

4. An apparatus according to claim 3, wherein the primary conversion material comprises at least one of the following: Boron isotope-10 for detecting neutrons, Lithium isotope-6 for detecting neutrons, Gadolium natural or enriched with isotope-157 for detecting neutrons, tungsten for detecting gamma radiation and beta radiation, lead for detecting gamma radiation and beta radiation, iron for detecting gamma radiation and beta radiation, copper for detecting gamma radiation and beta radiation, zinc sulfide ZnS for detecting charged particles having a mass at least a

mass of a proton, zinc selenium ZnSe for detecting charged particles having a mass at least a mass of a proton.

5. An apparatus according to any of claims 1-4, wherein the at least one scintillation material comprises at least one organic scintillation material.

6. An apparatus according to claim 5, wherein the at least one organic scintillation material comprises at least one of the following: polyethylene napthalate PEN, polyethylene terepthalate PET, polystyrene PS containing napthalate, polyvinyltoluene PVT containing napthalate.

7. An apparatus according to any of claims 1-6, wherein the at least one scintillation material comprises at least one inorganic scintillation material.

8. An apparatus according to claim 7, wherein the at least one inorganic scintillation material comprises at least one of the following: cesium iodide CsI, sodium iodide containing thallium NaI:T, lithium iodide LiI, Cadmium telluride CdTe, cadmium zinc telluride CdZnTe, zinc sulfide containing thallium ZnS:T, zinc selenium containing thallium ZnSe:T.

9. An apparatus according to claim 1, wherein the at least partially optically transparent base material (207) comprises elastomer.

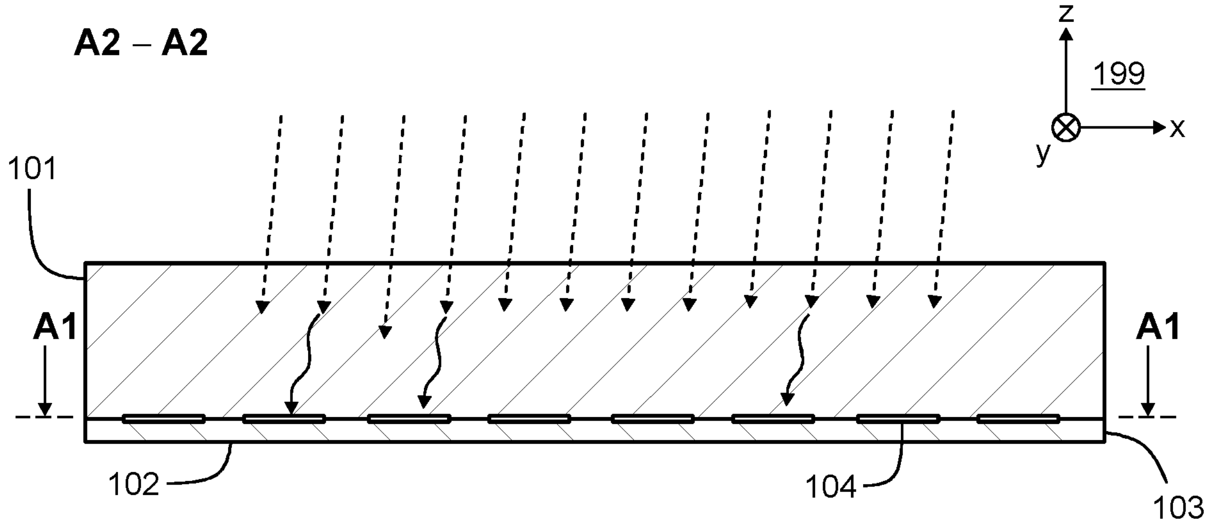

Figure 1a

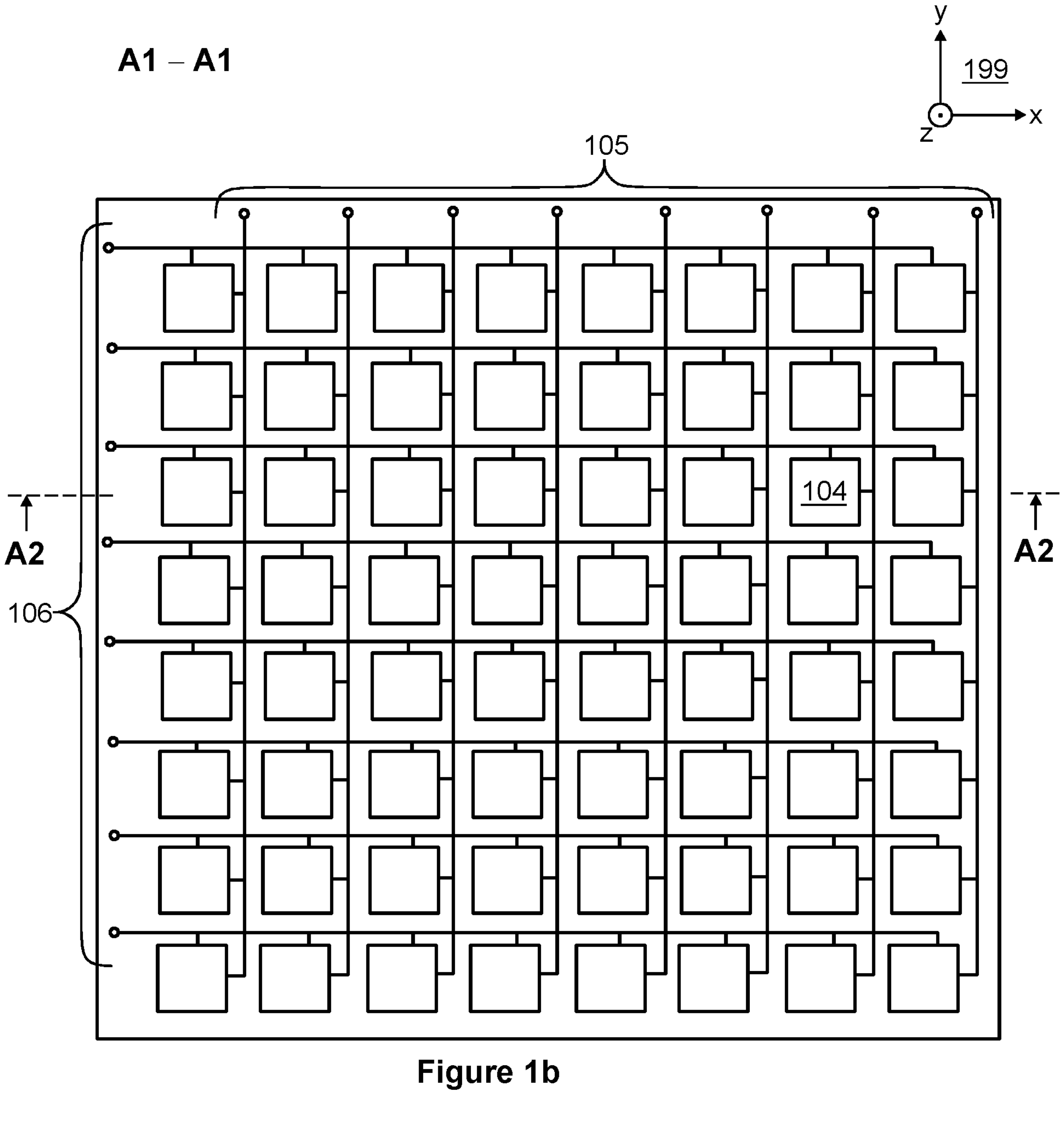

Figure 1b

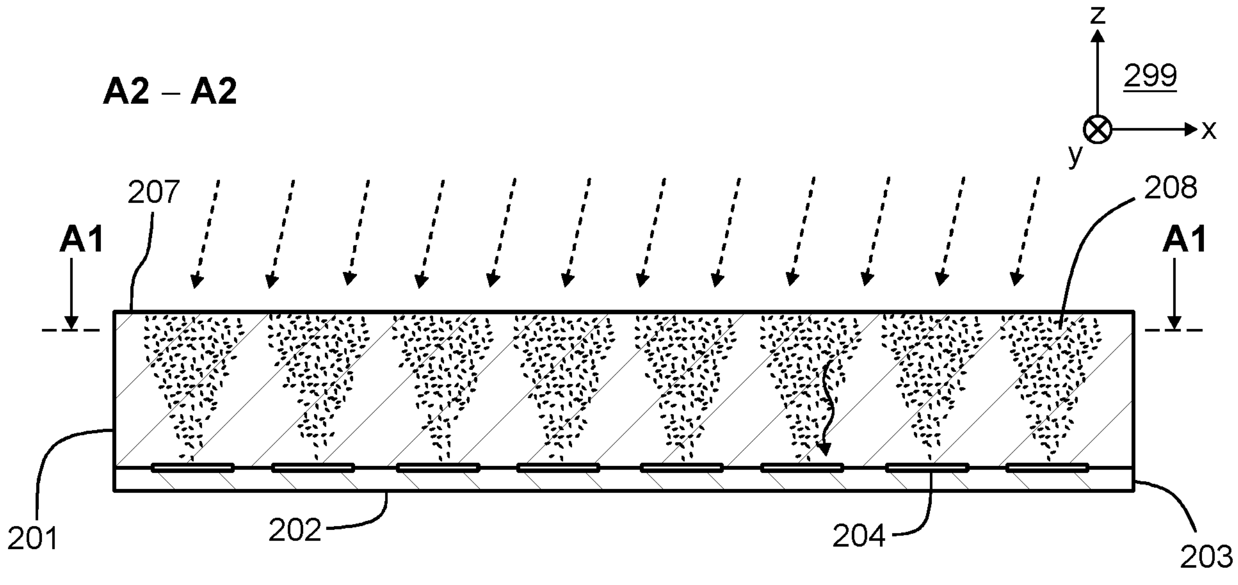

Figure 2a

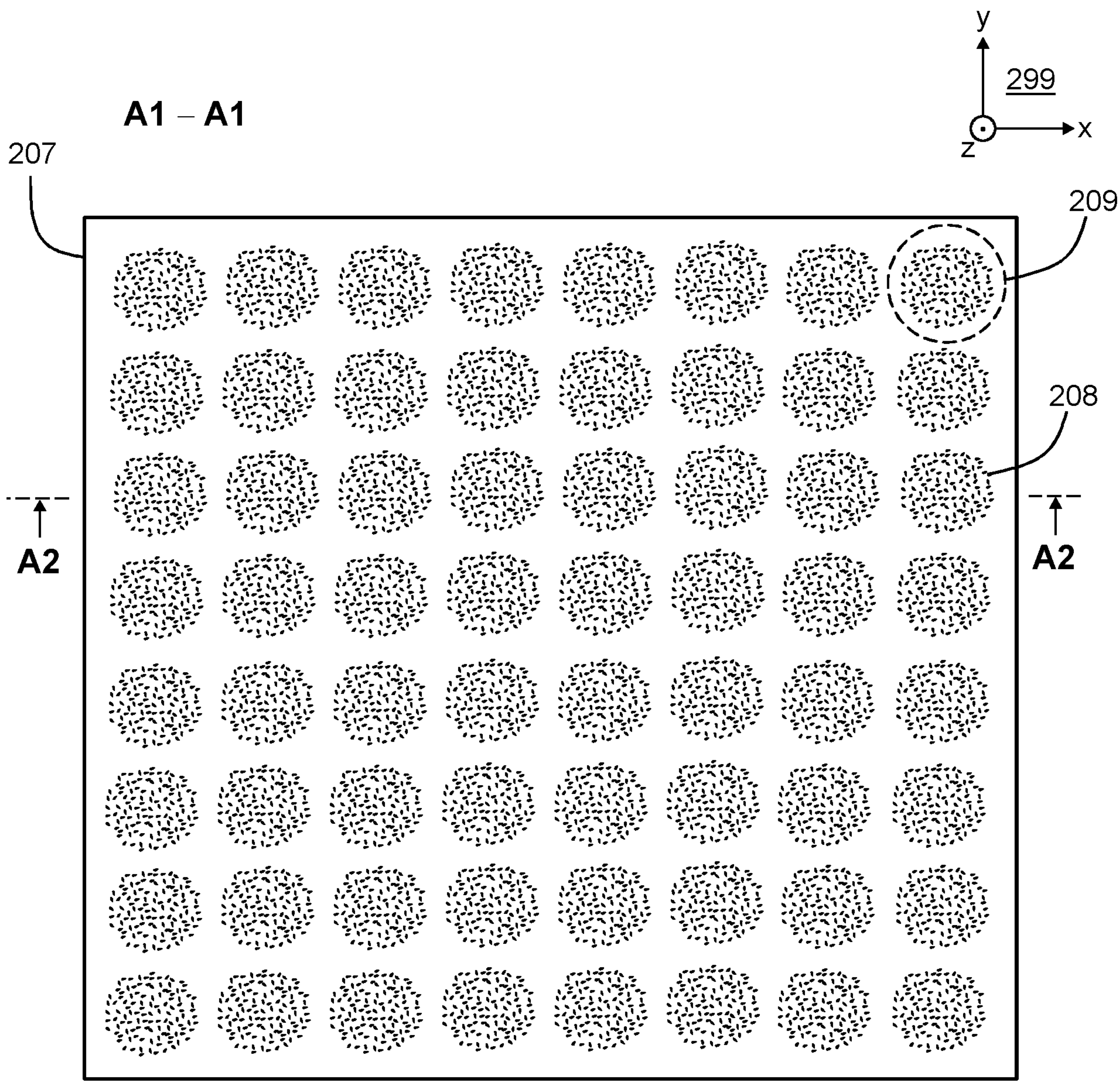

Figure 2b

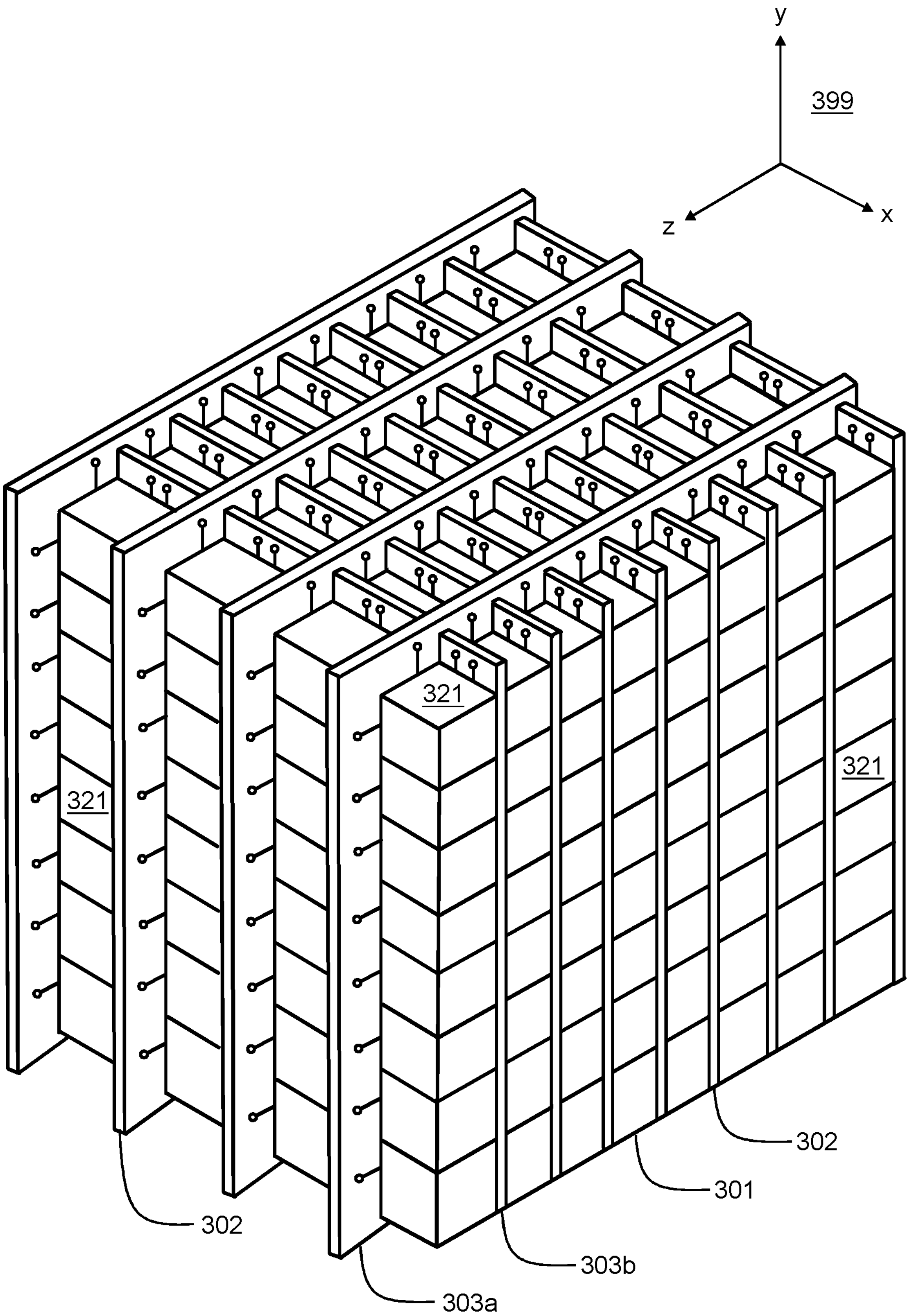

Figure 3

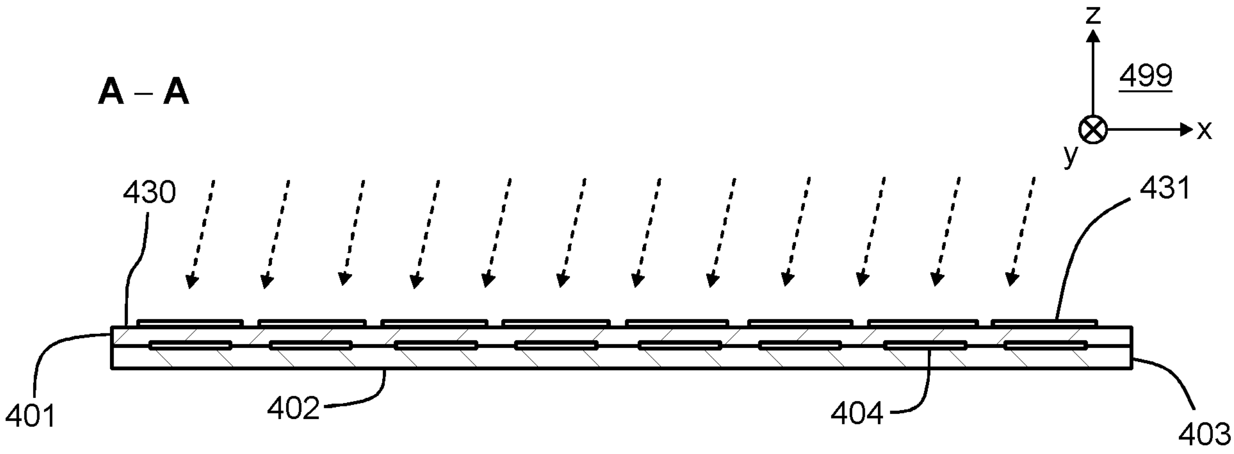

Figure 4a

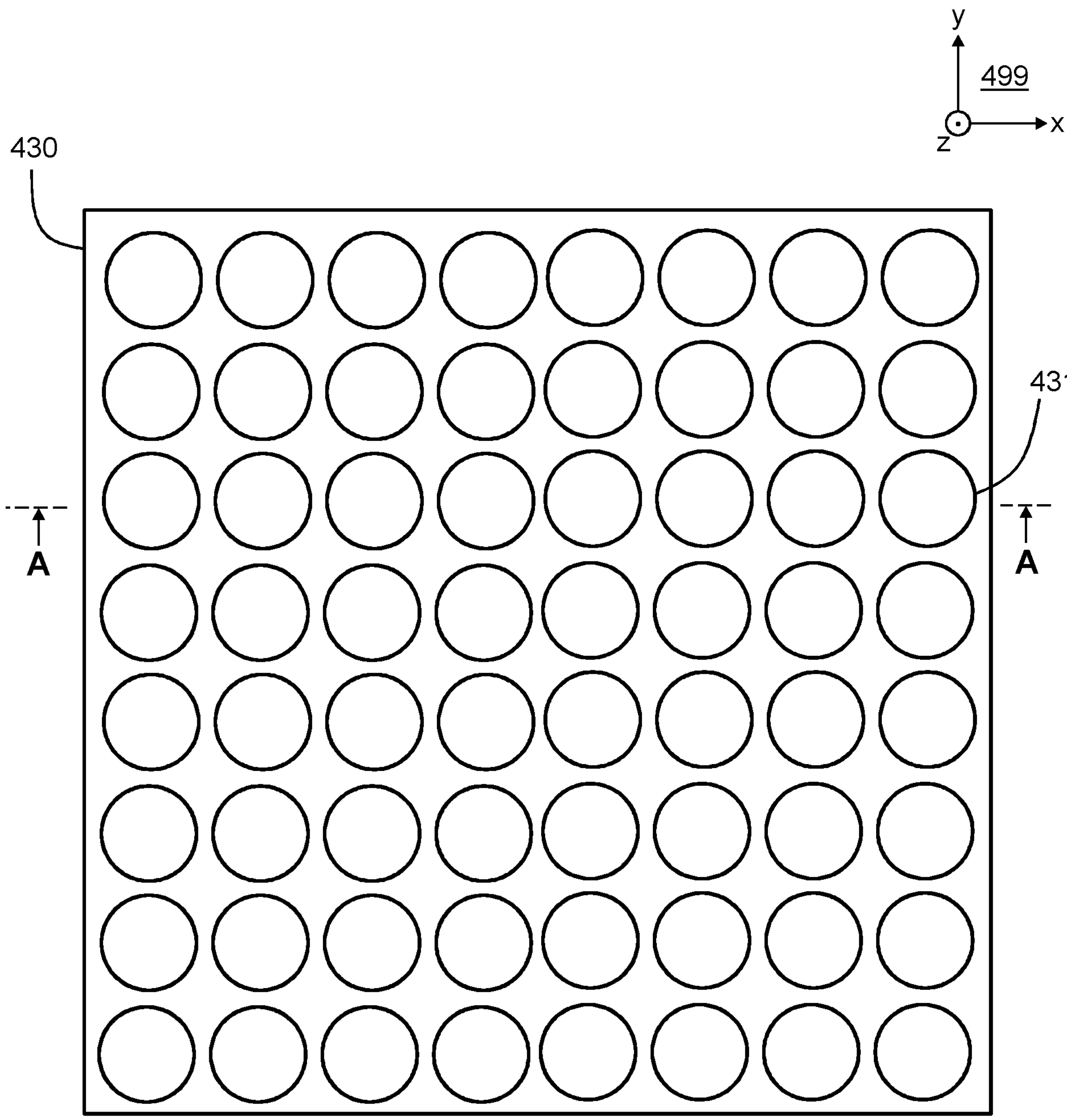

Figure 4b

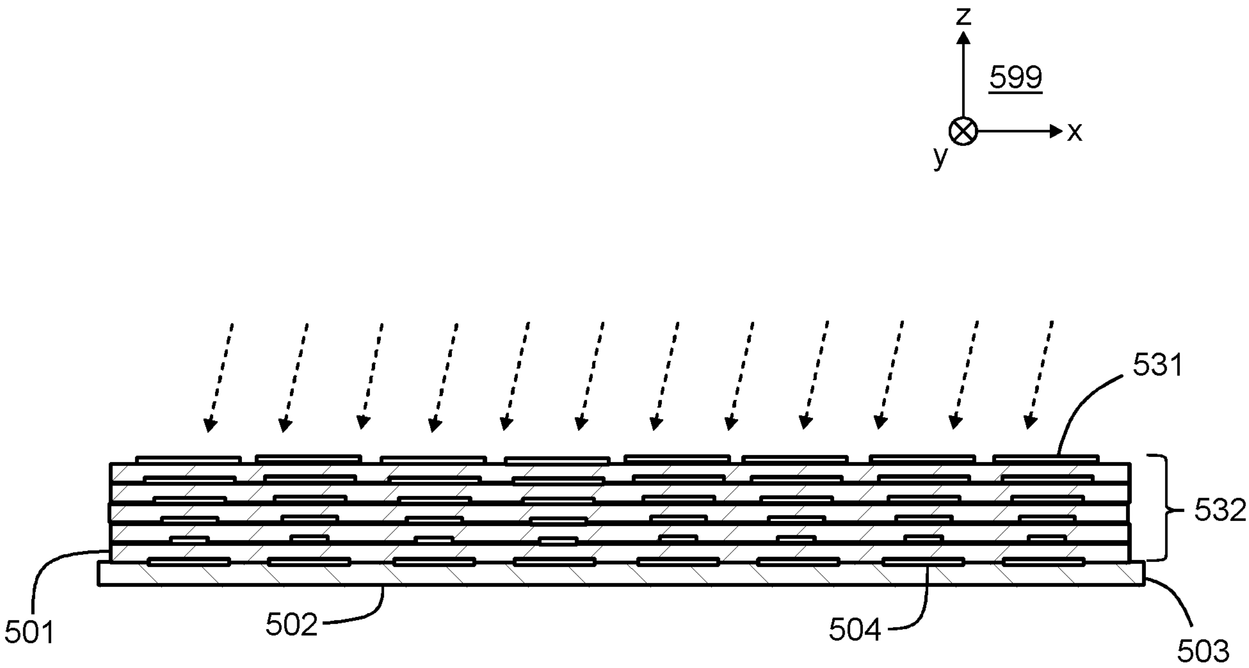

Figure 5

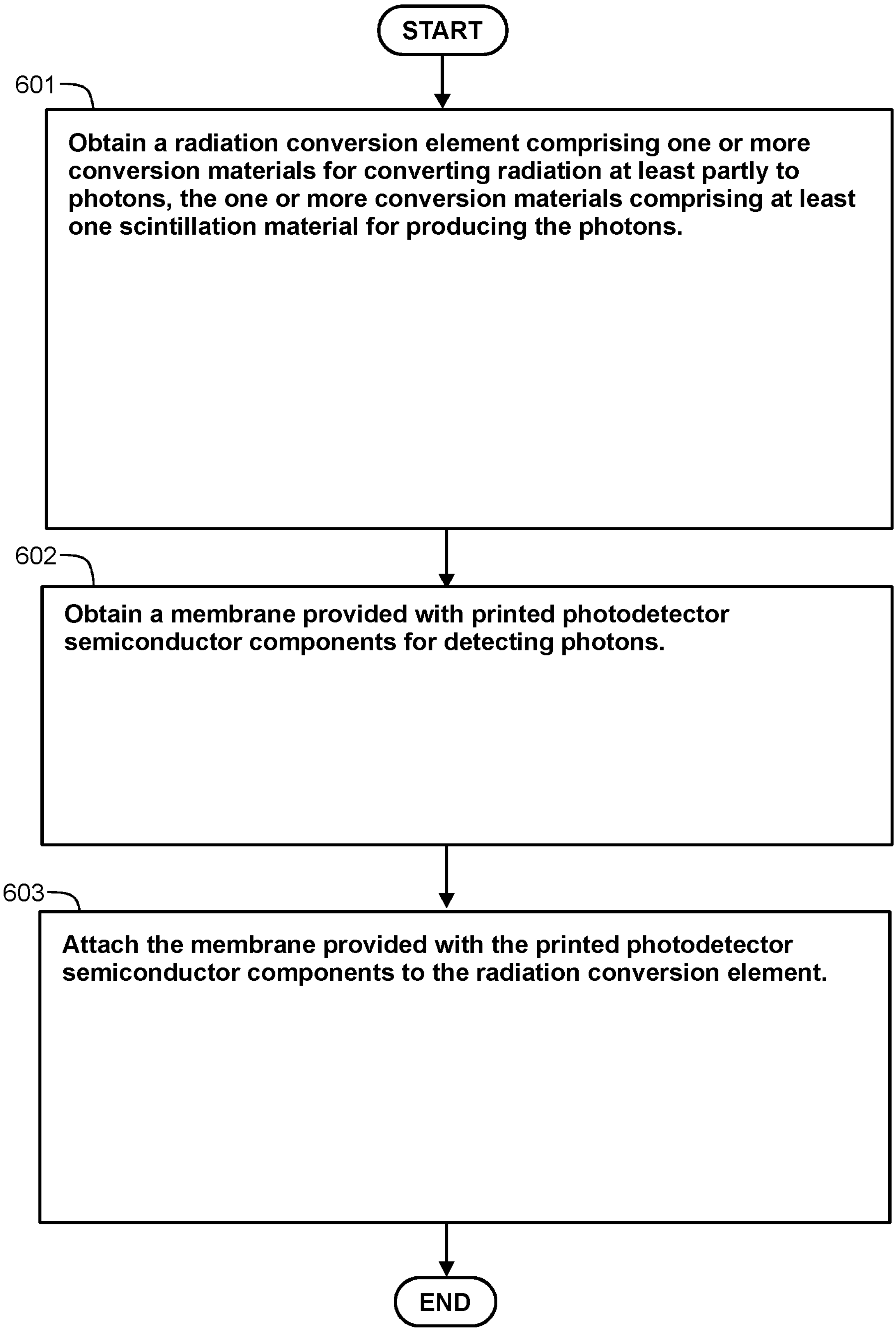
START
601
Obtain a radiation conversion element comprising one or more conversion materials for converting radiation at least partly to photons, the one or more conversion materials comprising at least one scintillation material for producing the photons.
602
Obtain a membrane provided with printed photodetector semiconductor components for detecting photons.
603
Attach the membrane provided with the printed photodetector semiconductor components to the radiation conversion element.
END

Figure 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/FI2019/050645

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01T1/20
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01T

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	WO 2017/025888 A1 (KONINKLIJKE PHILIPS NV [NL]) 16 February 2017 (2017-02-16) page 4, line 17 - page 5, line 3 page 7, lines 19-25 figures 1,7,8	1,3-9 2
A	JP H05 188148 A (HAMAMATSU PHOTONICS KK) 30 July 1993 (1993-07-30) paragraphs [0006], [0010], [0011], [0016], [0018] figures 1-3	1-9
A	WO 2015/158646 A1 (KONINKL PHILIPS NV [NL]) 22 October 2015 (2015-10-22) page 3, lines 23-24 page 8, lines 14-26 figures 1,2	1-9

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

☒ See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 November 2019	26/11/2019

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Wulveryck, J

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/FI2019/050645

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		WO 2015158646 A1	22-10-2015