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(54) **Title:** IMAGING METHODS USING BI-DIRECTIONAL COUNTERS

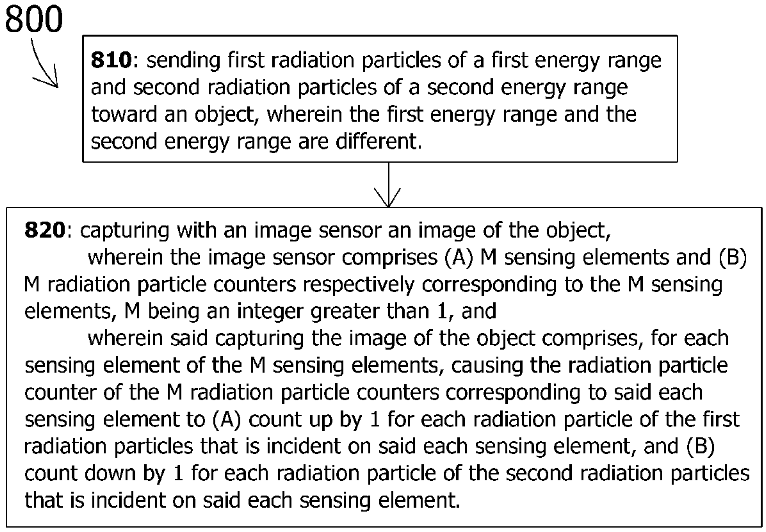

FIG. 8

(57) **Abstract:** Disclosed is an imaging method. The imaging method includes: sending first radiation particles of a first energy range and second radiation particles of a second energy range toward an object, the first energy range and the second energy range being different (810), capturing with an image sensor an image of the object, the image sensor comprising (A) M sensing elements and (B) M radiation particle counters respectively corresponding to the M sensing elements, M being an integer greater than 1, capturing the image of the object comprises, for each sensing element, causing the radiation particle counter of the M radiation particle counters corresponding to said each sensing element to (A) count up by 1 for each radiation particle of the first radiation particles that is incident on said each sensing element, and (B) count down by 1 for each radiation particle of the second radiation particles that is incident on said each sensing element (820).

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IMAGING METHODS USING BI-DIRECTIONAL COUNTERS

Background

[0001] A radiation detector is a device that measures a property of a radiation. Examples of the property may include a spatial distribution of the intensity, phase, and polarization of the radiation. The radiation measured by the radiation detector may be a radiation that has transmitted through an object. The radiation measured by the radiation detector may be electromagnetic radiation such as infrared light, visible light, ultraviolet light, X-ray, or γ-ray. The radiation may be of other types such as α-rays and β-rays. An imaging system may include one or more image sensors each of which may have one or more radiation detectors.

Summary

[0002] Disclosed herein is a method comprising: sending first radiation particles of a first energy range and second radiation particles of a second energy range toward an object, the first energy range and the second energy range being different; and capturing with an image sensor an image of the object, the image sensor comprising (A) M sensing elements and (B) M radiation particle counters respectively corresponding to the M sensing elements, M being an integer greater than 1. Said capturing the image of the object comprises, for each sensing element of the M sensing elements, causing the radiation particle counter of the M radiation particle counters corresponding to said each sensing element to (A) count up by 1 for each radiation particle of the first radiation particles that is incident on said each sensing element, and (B) count down by 1 for each radiation particle of the second radiation particles that is incident on said each sensing element.

[0003] In an aspect, the first radiation particles and the second radiation particles are X-ray photons.

[0004] In an aspect, the image of the object comprises M picture elements respectively corresponding to the M radiation particle counters, and said capturing the image of the object comprises determining a content of each picture element of the M picture elements based on a count of the radiation particle counter of the M radiation particle counters corresponding to said each picture element.

[0005] In an aspect, the content of said each picture element is equal to the count of the radiation particle counter of the M radiation particle counters corresponding to said each picture element.

[0006] In an aspect, the method further comprises introducing a contrast agent into the object before capturing the image of the object.

[0007] In an aspect, the contrast agent comprises iodine.

[0008] In an aspect, the first radiation particles as a first group and the second radiation particles as a second group are sent one group at a time.

[0009] In an aspect, each radiation particle counter of the M radiation particle counters is in a count-up state or a count-down state, while the first radiation particles are sent, the M radiation particle counters are in the count-up state, and while the second radiation particles are sent, the M radiation particle counters are in the count-down state.

[0010] In an aspect, said capturing the image of the object comprises, after a group of the first and second groups are sent and before the remaining group of the first and second groups are sent, switching the M radiation particle counters from a state of the count-up state and the count-down state to the remaining state of the count-up state and the count-down state.

[0011] In an aspect, the first radiation particles are sent from a first bombardment target which comprises a first material, the second radiation particles are sent from a second bombardment target which comprises a second material, and the first material and the second material are different.

[0012] In an aspect, the first material comprises tungsten, and the second material comprises (A) molybdenum, (B) tin, or (C) lanthanum actinium alloy.

[0013] In an aspect, said sending the first radiation particles and the second radiation particles comprises: directing an electron beam to a bombardment target of the first and second bombardment targets; and then directing the electron beam to the remaining bombardment target of the first and second bombardment targets.

[0014] In an aspect, the first energy range and the second energy range overlap.

[0015] In an aspect, the first radiation particles and the second radiation particles are sent simultaneously toward the object and toward the image sensor.

[0016] In an aspect, said capturing the image of the object comprises, for each sensing element of the M sensing elements: determining with the image sensor that a radiation particle of the first radiation particles and the second radiation particles which is incident on said each sensing element is of the first energy range; and thereby causing the radiation particle counter of the M radiation particle counters corresponding to said each sensing element to count up by 1.

[0017] In an aspect, said capturing the image of the object comprises, for each sensing element of the M sensing elements: determining with the image sensor that a radiation particle of the first radiation particles and the second radiation particles which is incident on said each sensing element is of the second energy range; and thereby causing the radiation particle counter of the M radiation particle counters corresponding to said each sensing element to count down by 1.

[0018] In an aspect, the first energy range and the second energy range do not overlap.

Brief Description of Figures

[0019] Fig. 1 schematically shows a radiation detector, according to an embodiment.

[0020] Fig. 2 schematically shows a simplified cross-sectional view of the radiation detector, according to an embodiment.

[0021] Fig. 3 schematically shows a detailed cross-sectional view of the radiation detector, according to an embodiment.

[0022] Fig. 4 schematically shows a detailed cross-sectional view of the radiation detector, according to an alternative embodiment.

[0023] Fig. 5 schematically shows a top view of a radiation detector package including the radiation detector and a printed circuit board (PCB), according to an embodiment.

[0024] Fig. 6 schematically shows a cross-sectional view of an image sensor including the packages of Fig. 5 mounted to a system PCB (printed circuit board), according to an embodiment.

[0025] Fig. 7 schematically shows an imaging system, according to an embodiment.

[0026] Fig. 8 shows a flowchart generalizing the operation of the imaging system, according to an embodiment.

Detailed Description

[0027] RADIATION DETECTOR

[0028] Fig. 1 schematically shows a radiation detector 100, as an example. The radiation detector 100 may include an array of pixels 150 (also referred to as sensing elements 150). The array may be a rectangular array (as shown in Fig. 1), a honeycomb array, a hexagonal array, or any other suitable array. The array of pixels 150 in the example of Fig. 1 has 4 rows and 7 columns; however, in general, the array of pixels 150 may have any number of rows and any number of columns.

[0029] Each pixel 150 may be configured to detect radiation from a radiation source (not shown) incident thereon and may be configured to measure a characteristic (e.g., the energy of the particles, the wavelength, and the frequency) of the radiation. A radiation may include radiation particles such as photons (X-rays, gamma rays, etc.) and subatomic particles (alpha particles, beta particles, etc.) Each pixel 150 may be configured to count numbers of particles of radiation incident thereon whose energy falls in a plurality of bins of energy, within a period of time. All the pixels 150 may be configured to count the numbers of particles of radiation incident thereon within a plurality of bins of energy within the same period of time. When the incident particles of radiation have similar energy, the pixels 150 may be simply configured to count numbers of particles of radiation incident thereon within a period of time, without measuring the energy of the individual particles of radiation.

[0030] Each pixel 150 may have its own analog-to-digital converter (ADC) configured to digitize an analog signal representing the energy of an incident particle of radiation into a digital signal, or to digitize an analog signal representing the total energy of a plurality of incident particles of radiation into a digital signal. The pixels 150 may be configured to operate in parallel. For example, when one pixel 150 measures an incident particle of radiation, another pixel 150 may be waiting for a particle of radiation to arrive. The pixels 150 may not have to be individually addressable.

[0031] The radiation detector 100 described here may have applications such as in an X-ray telescope, X-ray mammography, industrial X-ray defect detection, X-ray microscopy or microradiography, X-ray casting inspection, X-ray non-destructive testing, X-ray weld inspection, X-ray digital subtraction angiography, etc. It may be suitable to use this radiation detector 100 in place of a photographic plate, a photographic film, a PSP plate, an X-ray image intensifier, a scintillator, or another semiconductor X-ray detector.

[0032] Fig. 2 schematically shows a simplified cross-sectional view of the radiation detector 100 of Fig. 1 along a line 2-2, according to an embodiment. Specifically, the radiation detector 100 may include a radiation absorption layer 110 and an electronics layer 120 (which may include one or more ASICs or application-specific integrated circuits) for processing or analyzing electrical signals which incident radiation generates in the radiation absorption layer 110. The radiation detector 100 may or may not include a scintillator (not shown). The radiation absorption layer 110 may include a semiconductor material such as silicon, germanium, GaAs, CdTe, CdZnTe, or a combination thereof. The semiconductor material may have a high mass attenuation coefficient for the radiation of interest.

[0033] Fig. 3 schematically shows a detailed cross-sectional view of the radiation detector 100 of Fig. 1 along the line 2-2, as an example. Specifically, the radiation absorption layer 110 may include one or more diodes (e.g., p-i-n or p-n) formed by a first doped region 111, one or more discrete regions 114 of a second doped region 113. The second doped region 113 may be separated from the first doped region 111 by an optional intrinsic region 112. The discrete regions 114 may be separated from one another by the first doped region 111 or the intrinsic region 112. The first doped region 111 and the second doped region 113 may have opposite types of doping (e.g., region 111 is p-type and region 113 is n-type, or region 111 is n-type and region 113 is p-type). In the example of Fig. 3, each of the discrete regions 114 of the second doped region 113 forms a diode with the first doped region 111 and the optional intrinsic region 112. Namely, in the example in Fig. 3, the radiation absorption layer 110 has a plurality of diodes (more specifically, 7 diodes corresponding to 7 pixels 150 of one row in the array of Fig. 1, of which only 2 pixels 150 are labeled in Fig. 3 for simplicity). The plurality of diodes may have an electrical contact 119A as a shared (common) electrode. The first doped region 111 may also have discrete portions.

[0034] The electronics layer 120 may include an electronic system 121 suitable for processing or interpreting signals generated by the radiation incident on the radiation absorption layer 110. The electronic system 121 may include an analog circuitry such as a filter network, amplifiers, integrators, and comparators, or a digital circuitry such as a microprocessor, and memory. The electronic system 121 may include one or more ADCs (analog to digital converters). The electronic system 121 may include components shared by the pixels 150 or components dedicated to a single pixel 150. For example, the electronic system 121 may include an amplifier dedicated to each pixel 150 and a microprocessor shared among all the pixels 150. The electronic system 121 may be electrically connected to the pixels 150 by vias 131. Space among the vias may be filled with a filler material 130, which may increase the mechanical stability of the connection of the electronics layer 120 to the radiation absorption layer 110. Other bonding techniques are possible to connect the electronic system 121 to the pixels 150 without using the vias 131.

[0035] When radiation from the radiation source (not shown) hits the radiation absorption layer 110 including diodes, particles of the radiation may be absorbed and generate one or more charge carriers (e.g., electrons, holes) by a number of mechanisms. The charge carriers may drift to the electrodes of one of the diodes under an electric field. The electric field may be an external electric field. The electrical contact 119B may include discrete portions each of which is in electrical contact with the discrete regions 114. The term “electrical contact” may be used interchangeably with the word “electrode.” In an embodiment, the charge carriers may drift in directions such that the charge carriers generated by a single particle of the radiation are not substantially shared by two different discrete regions 114 (“not substantially shared” here means less than 2%, less than 0.5%, less than 0.1%, or less than 0.01% of these charge carriers flow to a different one of the discrete regions 114 than the rest of the charge carriers). Charge carriers generated by a particle of the radiation incident around the footprint of one of these discrete regions 114 are not substantially shared with another of these discrete regions 114. A pixel 150 associated with a discrete region 114 may be an area around the discrete region 114 in which substantially all (more than 98%, more than 99.5%, more than 99.9%, or more than 99.99% of) charge carriers generated by a particle of the radiation incident therein flow to the discrete region 114. Namely, less than 2%, less than 1%, less than 0.1%, or less than 0.01% of these charge carriers flow beyond the pixel 150.

[0036] Fig. 4 schematically shows a detailed cross-sectional view of the radiation detector 100 of Fig. 1 along the line 2-2, according to an alternative embodiment. More specifically, the radiation absorption layer 110 may include a resistor of a semiconductor material such as silicon, germanium, GaAs, CdTe, CdZnTe, or a combination thereof, but does not include a diode. The semiconductor material may have a high mass attenuation coefficient for the radiation of interest. In an embodiment, the electronics layer 120 of Fig. 4 is similar to the electronics layer 120 of Fig. 3 in terms of structure and function.

[0037] When the radiation hits the radiation absorption layer 110 including the resistor but not diodes, it may be absorbed and generate one or more charge carriers by a number of mechanisms. A particle of the radiation may generate 10 to 100,000 charge carriers. The charge carriers may drift to the electrical contacts 119A and 119B under an electric field. The electric field may be an external electric field. The electrical contact 119B may include discrete portions. In an embodiment, the charge carriers may drift in directions such that the charge carriers generated by a single particle of the radiation are not substantially shared by two different discrete portions of the electrical contact 119B (“not substantially shared” here means less than 2%, less than 0.5%, less than 0.1%, or less than 0.01% of these charge carriers flow to a different one of the discrete portions than the rest of the charge carriers). Charge carriers generated by a particle of the radiation incident around the footprint of one of these discrete portions of the electrical contact 119B are not substantially shared with another of these discrete portions of the electrical contact 119B. A pixel 150 associated with a discrete portion of the electrical contact 119B may be an area around the discrete portion in which substantially all (more than 98%, more than 99.5%, more than 99.9% or more than 99.99% of) charge carriers generated by a particle of the radiation incident therein flow to the discrete portion of the electrical contact 119B. Namely, less than 2%, less than 0.5%, less than 0.1%, or less than 0.01% of these charge carriers flow beyond the pixel associated with the one discrete portion of the electrical contact 119B.

[0038] RADIATION DETECTOR PACKAGE

[0039] Fig. 5 schematically shows a top view of a radiation detector package 500 including the radiation detector 100 and a printed circuit board (PCB) 510. The term “PCB” as used herein is not limited to a particular material. For example, a PCB may include a semiconductor. The radiation detector 100 may be mounted to the PCB 510. The wiring between the radiation detector 100 and the PCB 510 is not shown for the sake of clarity. The package 500 may have one or more radiation detectors 100. The PCB 510 may include an input/output (I/O) area 512 not covered by the radiation detector 100 (e.g., for accommodating bonding wires 514). The radiation detector 100 may have an active area 190 which is where the pixels 150 (Fig. 1) are located. The radiation detector 100 may have a perimeter zone 195 near the edges of the radiation detector 100. The perimeter zone 195 has no pixels 150, and the radiation detector 100 does not detect particles of radiation incident on the perimeter zone 195.

[0040] IMAGE SENSOR

[0041] Fig. 6 schematically shows a cross-sectional view of an image sensor 600, according to an embodiment. The image sensor 600 may include one or more radiation detector packages 500 of Fig. 5 mounted to a system PCB 650. The electrical connection between the PCBs 510 and the system PCB 650 may be made by bonding wires 514. In order to accommodate the bonding wires 514 on the PCB 510, the PCB 510 may have the I/O area 512 not covered by the radiation detectors 100. In order to accommodate the bonding wires 514 on the system PCB 650, the packages 500 may have gaps in between. The gaps may be approximately 1 mm or more. Particles of radiation incident on the perimeter zones 195, on the I/O area 512, or on the gaps cannot be detected by the packages 500 on the system PCB 650. A dead zone of a radiation detector (e.g., the radiation detector 100) is the area of the radiation-receiving surface of the radiation detector, on which incident particles of radiation cannot be detected by the radiation detector. A dead zone of a package (e.g., package 500) is the area of the radiation-receiving surface of the package, on which incident particles of radiation cannot be detected by the radiation detector or detectors in the package. In this example shown in Fig. 5 and Fig. 6, the dead zone of the package 500 includes the perimeter zones 195 and the I/O area 512. A dead zone (e.g., 688) of an image sensor (e.g., image sensor 600) with a group of packages (e.g., packages 500 mounted on the same PCB and arranged in the same layer or in different layers) includes the combination of the dead zones of the packages in the group and the gaps between the packages.

[0042] In an embodiment, the radiation detector 100 (Fig. 1) operating by itself may be considered an image sensor. In an embodiment, the package 500 (Fig. 5) operating by itself may be considered an image sensor.

[0043] The image sensor 600 including the radiation detectors 100 may have the dead zone 688 among the active areas 190 of the radiation detectors 100. However, the image sensor 600 may capture multiple partial images of an object or scene (not shown) one by one, and then these captured partial images may be stitched to form a stitched image of the entire object or scene.

[0044] The term “image” in the present application (including the claims) is not limited to spatial distribution of a property of a radiation (such as intensity). For example, the term “image” may also include the spatial distribution of density of a substance or element.

[0045] IMAGING SYSTEM

[0046] Fig. 7 schematically shows an imaging system 700, according to an embodiment. In an embodiment, the imaging system 700 may include a radiation source 710 and the image sensor 600 of Fig. 6. In an embodiment, an object 720 may be positioned between the radiation source 710 and the image sensor 600.

[0047] In an embodiment, the radiation source 710 may send a radiation beam 712 toward the object 720 and toward the image sensor 600. In an embodiment, the radiation beam 712 may include first radiation particles and second radiation particles (not shown). The first radiation particles may be of a first energy range (i.e., each of the first radiation particles has an energy in the first energy range); and the second radiation particles may be of a second energy range (i.e., each of the second radiation particles has an energy in the second energy range). For example, the first energy range may be 20 keV – 60 keV; and the second energy range may be 30 keV – 80 keV.

[0048] The words “first”, “second”, and other ordinal numerals in the present patent application (including the claims) are used only for easy reference and do not imply any chronological order.

[0049] In an embodiment, the first energy range and the second energy range may be different (i.e., at least an energy level is in one range and is not in the other range). For example, the first energy range of 20 keV – 60 keV and the second energy range of 30 keV – 80 keV are different because 70 keV is in the second energy range and is not in the first energy range.

[0050] In an embodiment, the first radiation particles and the second radiation particles may be X-ray photons.

[0051] In an embodiment, the image sensor 600 may include (A) multiple sensing elements 150 and (B) a radiation particle counter (not shown) for each of the multiple sensing elements 150. For example, the image sensor 600 may include a radiation detector 100 of Fig. 1 – Fig. 4. As a result, the image sensor 600 has 28 sensing elements 150 and 28 radiation particle counters. In an embodiment, the 28 radiation particle counters may be part of the electronics layer 120 of the radiation detector 100.

[0052] OPERATION OF IMAGING SYSTEM

[0053] In an embodiment, with reference to Fig. 7, while the radiation source 710, the image sensor 600, and the object 720 are arranged as shown in Fig. 7, the image sensor 600 may capture an image of the object 720 by using, inter alia, the radiation of the radiation beam 712 that has transmitted through the object 720.

[0054] In an embodiment, during the capturing of the image of the object 720, the first radiation particles as a first group and second radiation particles as a second group may be sent from the radiation source 710 one group at a time. For example, the second radiation particles may be sent after the first radiation particles are sent. Alternatively, the first radiation particles may be sent after the second radiation particles are sent.

[0055] In an embodiment, for each sensing element 150 of the image sensor 600, the radiation particle counter corresponding to said each sensing element 150 may (A) count up by 1 for each radiation particle of the first radiation particles that is incident on said each sensing element, and (B) count down by 1 for each radiation particle of the second radiation particles that is incident on said each sensing element 150.

[0056] For example, assume the first radiation particles are sent first (i.e., sent before the second radiation particles are sent). Assume further that a radiation particle of the first radiation particles is incident on a particular sensing element 150 of the image sensor 600. As a result, the radiation particle counter corresponding to that particular sensing element 150 counts up by 1, thereby increasing the count of the radiation particle counter from 0 to 1.

[0057] Assume that later another radiation particle of the first radiation particles is incident on that particular sensing element 150 of the image sensor 600. As a result, the radiation particle counter corresponding to that particular sensing element 150 counts up by 1, thereby increasing the count of the radiation particle counter from 1 to 2.

[0058] Assume that later while the second radiation particles are being sent, a radiation particle of the second radiation particles is incident on that particular sensing element 150 of the image sensor 600. As a result, the radiation particle counter corresponding to that particular sensing element 150 counts down by 1, thereby decreasing the count of the radiation particle counter from 2 to 1.

[0059] In an embodiment, with the image sensor 600 having 28 sensing elements 150 and 28 radiation particle counters, the image of the object 720 captured by the image sensor 600 may have 28 picture elements respectively corresponding to the 28 radiation particle counters. In an embodiment, the content of each picture element of the 28 picture elements may be determined based on the count of the radiation particle counter corresponding to said each picture element. In other words, the 28 contents of the 28 picture elements of the image of the object 720 are determined based respectively on the 28 counts of the 28 radiation particle counters.

[0060] In an embodiment, the content of said each picture element may be equal to the count of the radiation particle counter corresponding to said each picture element. For example, if the count of a radiation particle counter is 5, then the content of the picture element corresponding to that radiation particle counter is also 5.

[0061] FLOWCHART GENERALIZING OPERATION OF IMAGING SYSTEM

[0062] Fig. 8 shows a flowchart 800 generalizing the operation of the imaging system 700. Step 810 includes sending first radiation particles of a first energy range and second radiation particles of a second energy range toward an object, where the first energy range and the second energy range are different. For example, in the embodiments described above, with reference to Fig. 7, the first radiation particles of the first energy range (20 keV – 60 keV) and the second radiation particles of the second energy range (30 keV – 80 keV) are sent toward the object 720, where the first energy range and the second energy range are different (70 keV is in the second energy range and is not in the first energy range).

[0063] Step 820 includes capturing with an image sensor an image of the object. For example, in the embodiments described above, with reference to Fig. 7, the image sensor 600 captures the image of the object 720.

[0064] In addition, in step 820, the image sensor comprises (A) M sensing elements and (B) M radiation particle counters respectively corresponding to the M sensing elements, M being an integer greater than 1. For example, in the embodiments described above, with reference to Fig. 7, the image sensor 600 includes (A) 28 sensing elements 150 and (B) 28 radiation particle counters respectively corresponding to the 28 sensing elements 150.

[0065] In addition, in step 820, said capturing the image of the object comprises, for each sensing element of the M sensing elements, causing the radiation particle counter of the M radiation particle counters corresponding to said each sensing element to (A) count up by 1 for each radiation particle of the first radiation particles that is incident on said each sensing element, and (B) count down by 1 for each radiation particle of the second radiation particles that is incident on said each sensing element.

[0066] For example, in the embodiments described above, with reference to Fig. 7, for the particular sensing element 150 mentioned above, the radiation particle counter corresponding to that particular sensing element 150 (A) counts up by 1 for each radiation particle of the first radiation particles that is incident on that particular sensing element 150, and (B) counts down by 1 for each radiation particle of the second radiation particles that is incident on that particular sensing element 150.

[0067] OTHER EMBODIMENTS

[0068] CONTRAST AGENT

[0069] In an embodiment, with reference to step 820 of Fig. 8, before the image of the object is captured, a contrast agent (not shown) may be introduced into the object. For example, with reference to Fig. 7, a contrast agent may be introduced into the object 720 before the image sensor 600 captures the image of the object 720. In an embodiment, the contrast agent may include iodine.

[0070] SWITCHING STATE OF COUNTER WHEN CHANGING GROUPS

[0071] In an embodiment, with reference to step 820 of Fig. 8, each radiation particle counter of the M radiation particle counters may be in a count-up state or a count-down state. If a radiation particle counter is in the count-up state, then the radiation particle counter counts up by 1 when a radiation particle is incident on the sensing element corresponding to the radiation particle counter. If a radiation particle counter is in the count-down state, then the radiation particle counter counts down by 1 when a radiation particle is incident on the sensing element corresponding to the radiation particle counter.

[0072] In an embodiment, with the first radiation particles (i.e., the first group) and the second radiation particles (i.e., the second group) being sent one group at a time, (A) while the first radiation particles are being sent, the M radiation particle counters may be in the count-up state, and (B) while the second radiation particles are being sent, the M radiation particle counters may be in the count-down state.

[0073] In an embodiment, with reference to step 820 of Fig. 8, said capturing the image of the object may include, after a group of the first and second groups are sent and before the remaining group of the first and second groups are sent, switching the M radiation particle counters from a state of the count-up state and the count-down state to the remaining state of the count-up state and the count-down state.

[0074] For example, assume the first group (i.e., the first radiation particles) are sent first. While the first group are being sent, the 28 radiation particle counters of the image sensor 600 are in the count-up state. Then, after the first group are sent and before the second group (i.e., the second radiation particles) are sent, the 28 radiation particle counters of the image sensor 600 are switched from the count-up state to the count-down state. Then, while the second group are being sent, the 28 radiation particle counters of the image sensor 600 are in the count-down state.

[0075] DIFFERENT BOMBARDMENT TARGETS FOR DIFFERENT GROUPS

[0076] In an embodiment, with reference to Fig. 7, the radiation source 710 may include (A) a first bombardment target (not shown) which includes a first material, and (B) a second bombardment target (not shown) which includes a second material. In an embodiment, the first radiation particles may be sent from the first bombardment target; and the second radiation particles may be sent from the second bombardment target. In an embodiment, the first material and the second material may be different. For example, the first material may be tungsten; and the second material may be (A) molybdenum, (B) tin, or (C) lanthanum actinium alloy.

[0077] In an embodiment, the first radiation particles and the second radiation particles may be sent by (A) directing an electron beam (not shown) to a bombardment target of the first and second bombardment targets; and then (B) directing the electron beam to the remaining bombardment target of the first and second bombardment targets. In other words, the electron beam is directed to one bombardment target at a time, thereby generating and sending the first and second groups respectively from the first and second bombardment targets one group at a time.

[0078] FIRST AND SECOND ENERGY RANGES OVERLAP

[0079] In an embodiment, the first energy range of the first radiation particles and the second energy range of the second radiation particles may overlap. For example, the first energy range of 20 keV – 60 keV and the second energy range of 30 keV – 80 keV mentioned above overlap.

[0080] ALTERNATIVE EMBODIMENTS

[0081] SENDING TWO GROUPS SIMULTANEOUSLY

[0082] In the embodiments described above, with reference to Fig. 7, during the capturing of the image of the object 720, the first group (i.e., the first radiation particles) and the second group (i.e., the second radiation particles) are sent one group at a time. In an alternative embodiment, during the capturing of the image of the object 720, the first and second groups may be sent simultaneously from the radiation source 710. Accordingly, in an embodiment, the first energy range and the second energy range may not overlap (i.e., no energy level is in both energy ranges). For example, the first energy range may be 120 keV – 140 keV; and the second energy range may be 150 keV – 180 keV.

[0083] Accordingly, in an embodiment, with reference to Fig. 7, the image sensor 600 may capture the image of the object 720 as follows. During the capturing of the image of the object 720, with the first and second groups being sent simultaneously, for each sensing element 150 of the image sensor 600, when a radiation particle is incident on said each sensing element 150, (A) if the image sensor 600 determines that the incident radiation particle is of the first energy range, then the radiation particle counter corresponding to said each sensing element 150 may count up by 1, and (B) if the image sensor 600 determines that the incident radiation particle is of the second energy range, then the radiation particle counter corresponding to said each sensing element 150 may count down by 1.

[0084] Then, in an embodiment, the contents of the picture elements of the image of the object 720 may be determined based on the counts of the radiation particle counters of the image sensor 600. For example, if the image sensor 600 has 28 sensing elements and 28 radiation particle counters, then the contents of the 28 picture elements of the image of the object 720 may be determined respectively based on the 28 counts of the 28 radiation particle counters of the image sensor 600.

[0085] While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

What is claimed is:

1. A method, comprising:

sending first radiation particles of a first energy range and second radiation particles of a second energy range toward an object, wherein the first energy range and the second energy range are different; and

capturing with an image sensor an image of the object,

wherein the image sensor comprises (A) M sensing elements and (B) M radiation particle counters respectively corresponding to the M sensing elements, M being an integer greater than 1, and

wherein said capturing the image of the object comprises, for each sensing element of the M sensing elements, causing the radiation particle counter of the M radiation particle counters corresponding to said each sensing element to (A) count up by 1 for each radiation particle of the first radiation particles that is incident on said each sensing element, and (B) count down by 1 for each radiation particle of the second radiation particles that is incident on said each sensing element.

2. The method of claim 1, wherein the first radiation particles and the second radiation particles are X-ray photons.

3. The method of claim 1,

wherein the image of the object comprises M picture elements respectively corresponding to the M radiation particle counters, and

wherein said capturing the image of the object comprises determining a content of each picture element of the M picture elements based on a count of the radiation particle counter of the M radiation particle counters corresponding to said each picture element.

4. The method of claim 3, wherein the content of said each picture element is equal to the count of the radiation particle counter of the M radiation particle counters corresponding to said each picture element.

5. The method of claim 1, further comprising introducing a contrast agent into the object before capturing the image of the object.

6. The method of claim 5, wherein the contrast agent comprises iodine.

7. The method of claim 1, wherein the first radiation particles as a first group and the second radiation particles as a second group are sent one group at a time.

8. The method of claim 7,

wherein each radiation particle counter of the M radiation particle counters is in a count-up state or a count-down state,

wherein while the first radiation particles are sent, the M radiation particle counters are in the count-up state, and

wherein while the second radiation particles are sent, the M radiation particle counters are in the count-down state.

9. The method of claim 8, wherein said capturing the image of the object comprises, after a group of the first and second groups are sent and before the remaining group of the first and second groups are sent, switching the M radiation particle counters from a state of the count-up state and the count-down state to the remaining state of the count-up state and the count-down state.

10. The method of claim 7,

wherein the first radiation particles are sent from a first bombardment target which comprises a first material,

wherein the second radiation particles are sent from a second bombardment target which comprises a second material, and

wherein the first material and the second material are different.

11. The method of claim 10,

wherein the first material comprises tungsten, and

wherein the second material comprises (A) molybdenum, (B) tin, or (C) lanthanum actinium alloy.

12. The method of claim 10, wherein said sending the first radiation particles and the second radiation particles comprises:

directing an electron beam to a bombardment target of the first and second bombardment targets; and then

directing the electron beam to the remaining bombardment target of the first and second bombardment targets.

13. The method of claim 7, wherein the first energy range and the second energy range overlap.

14. The method of claim 1, wherein the first radiation particles and the second radiation particles are sent simultaneously toward the object and toward the image sensor.

15. The method of claim 14, wherein said capturing the image of the object comprises, for each sensing element of the M sensing elements:

determining with the image sensor that a radiation particle of the first radiation particles and the second radiation particles which is incident on said each sensing element is of the first energy range; and thereby

causing the radiation particle counter of the M radiation particle counters corresponding to said each sensing element to count up by 1.

16. The method of claim 15, wherein said capturing the image of the object comprises, for each sensing element of the M sensing elements:

determining with the image sensor that a radiation particle of the first radiation particles and the second radiation particles which is incident on said each sensing element is of the second energy range; and thereby

causing the radiation particle counter of the M radiation particle counters corresponding to said each sensing element to count down by 1.

17. The method of claim 1, wherein the first energy range and the second energy range do not overlap.

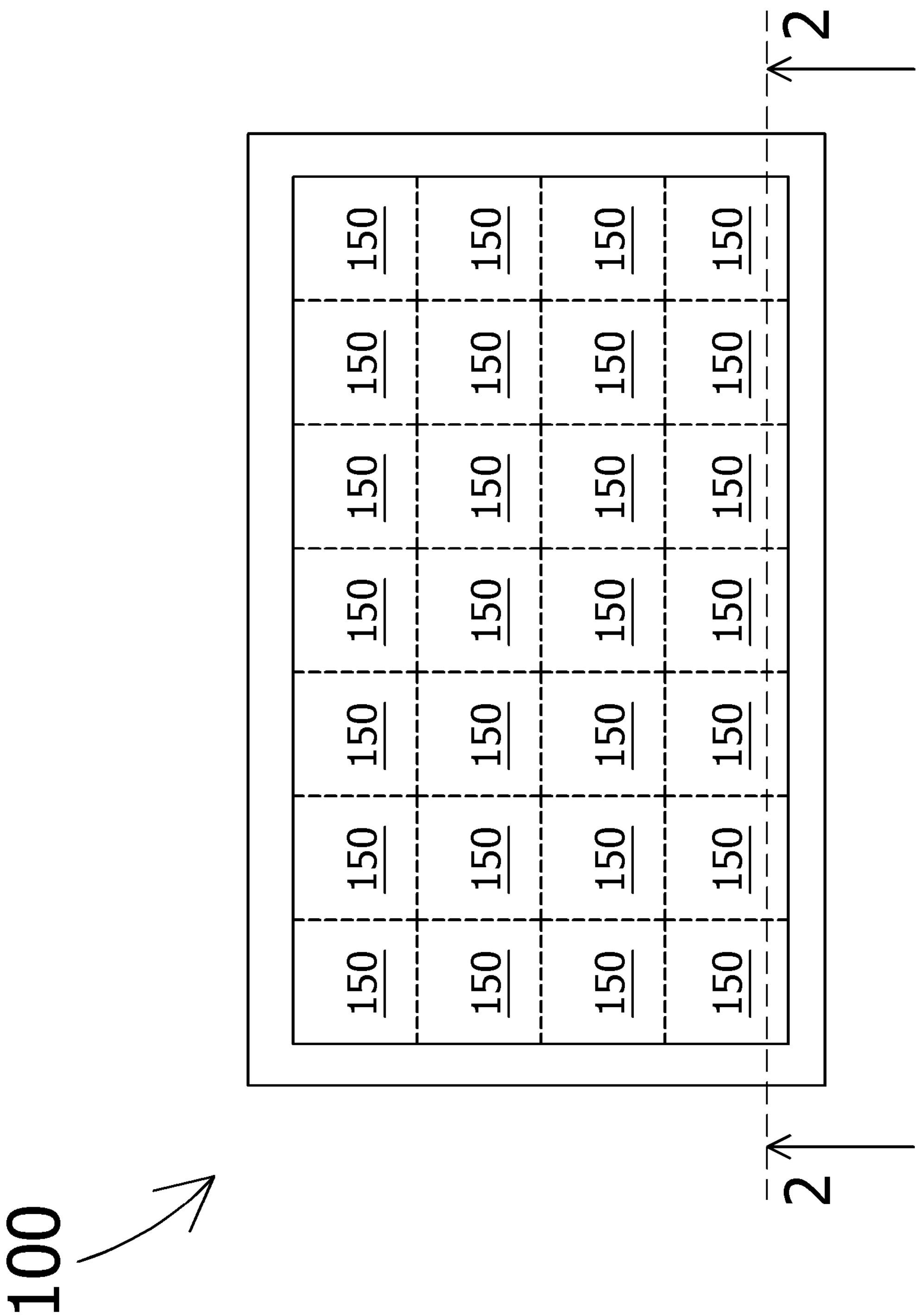

FIG. 1

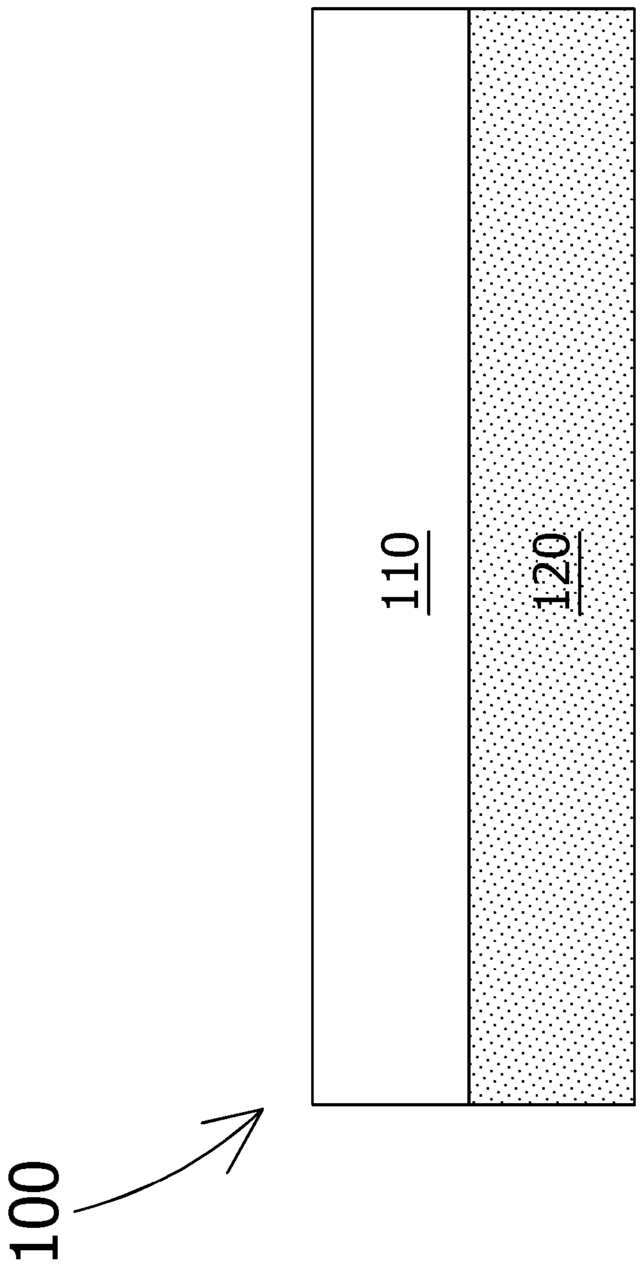

FIG. 2

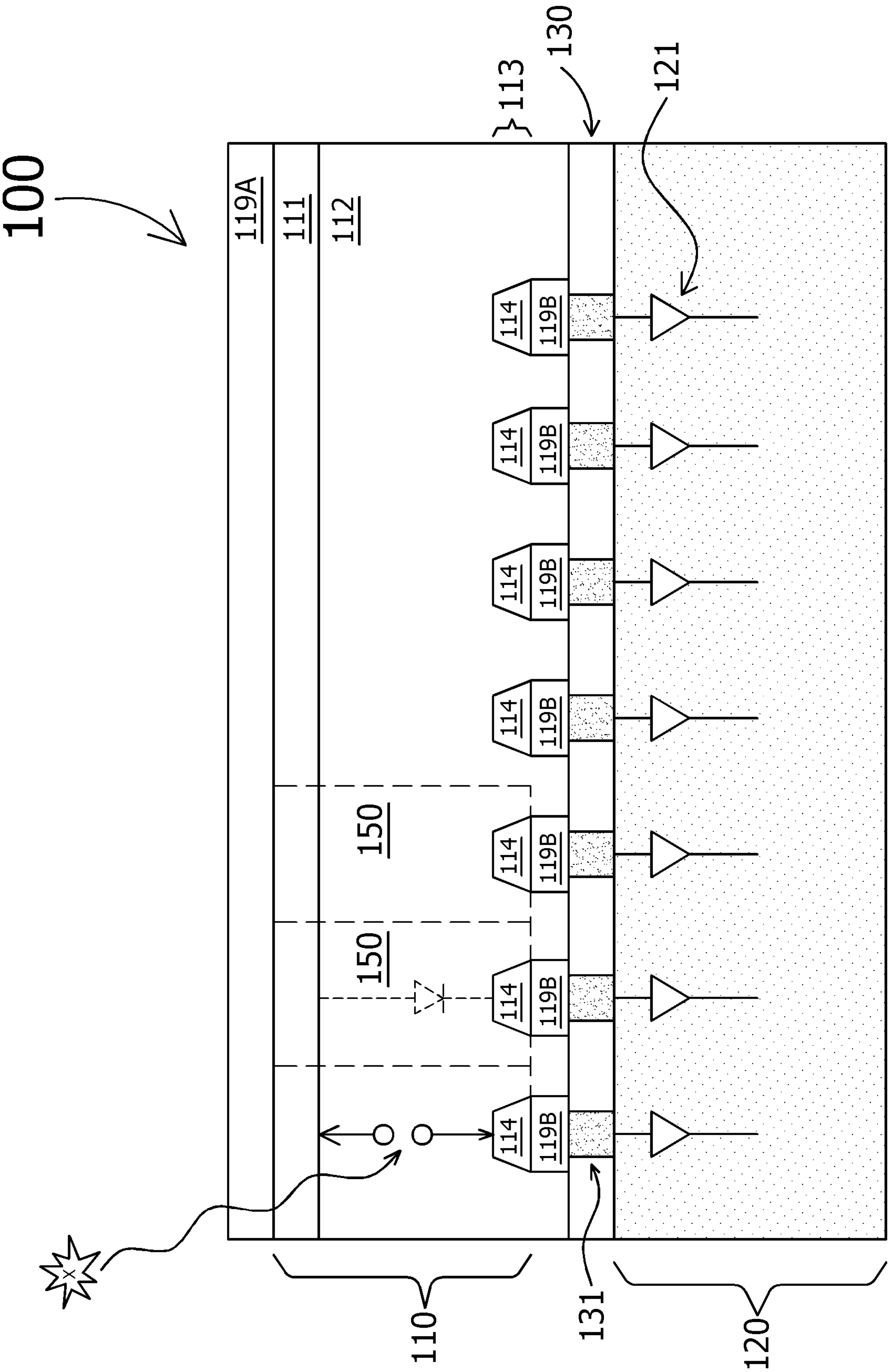

FIG. 3

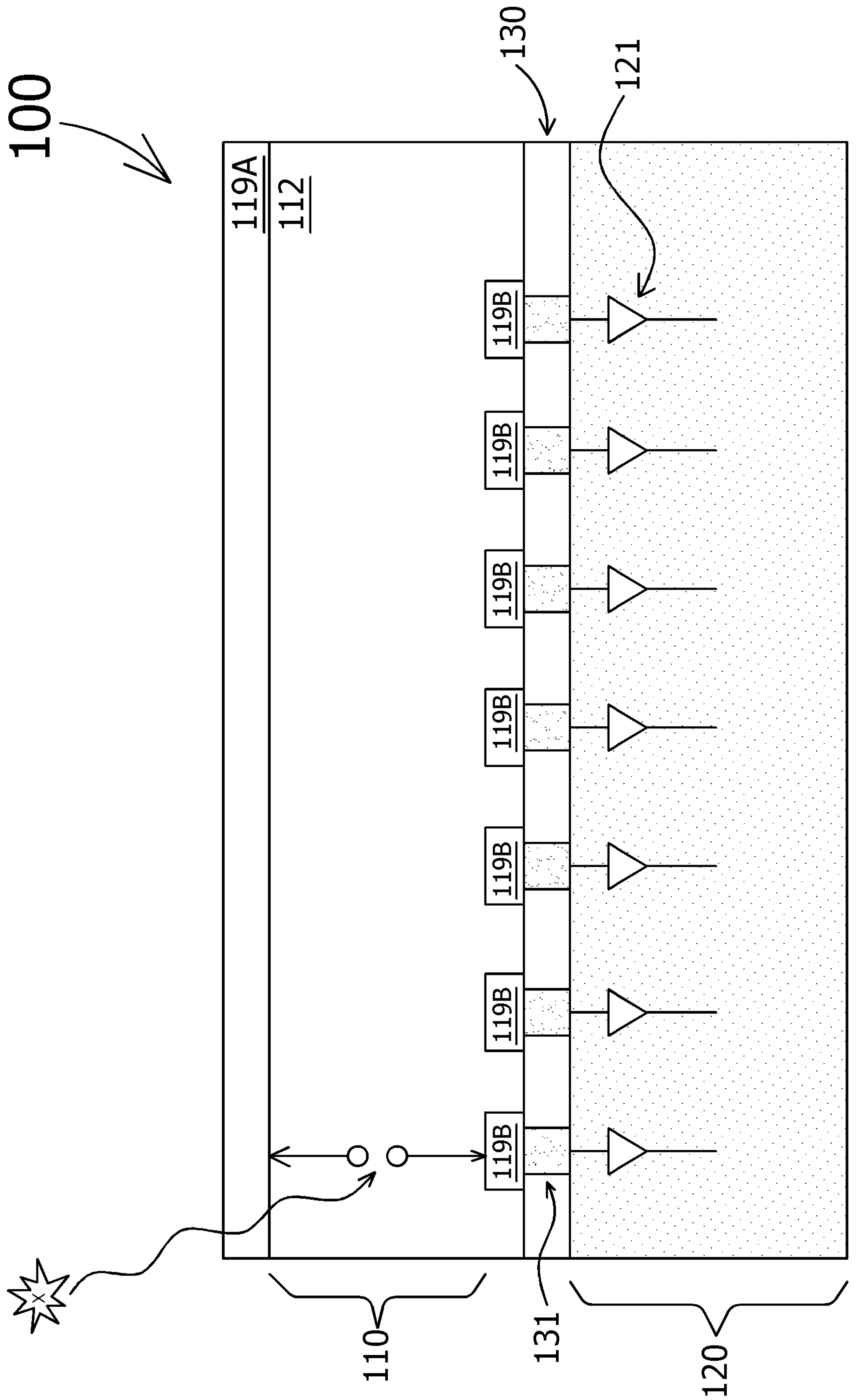
100
130
121
119A
112
119B
119B
119B
119B
119B
119B
119B
110
131
120

FIG. 4

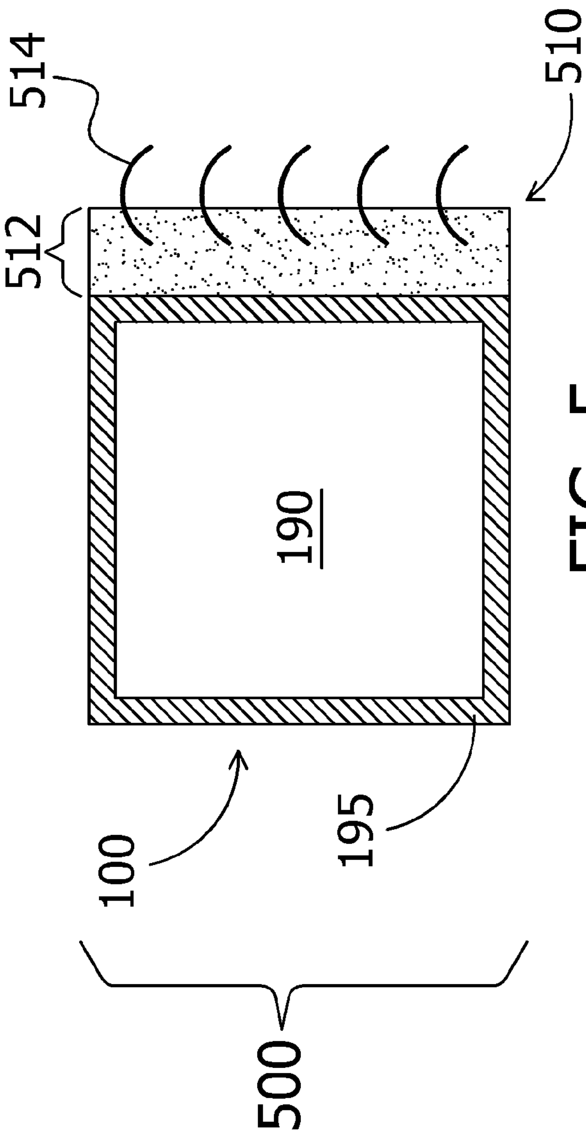
514
510
512
190
100
195
500

FIG. 5

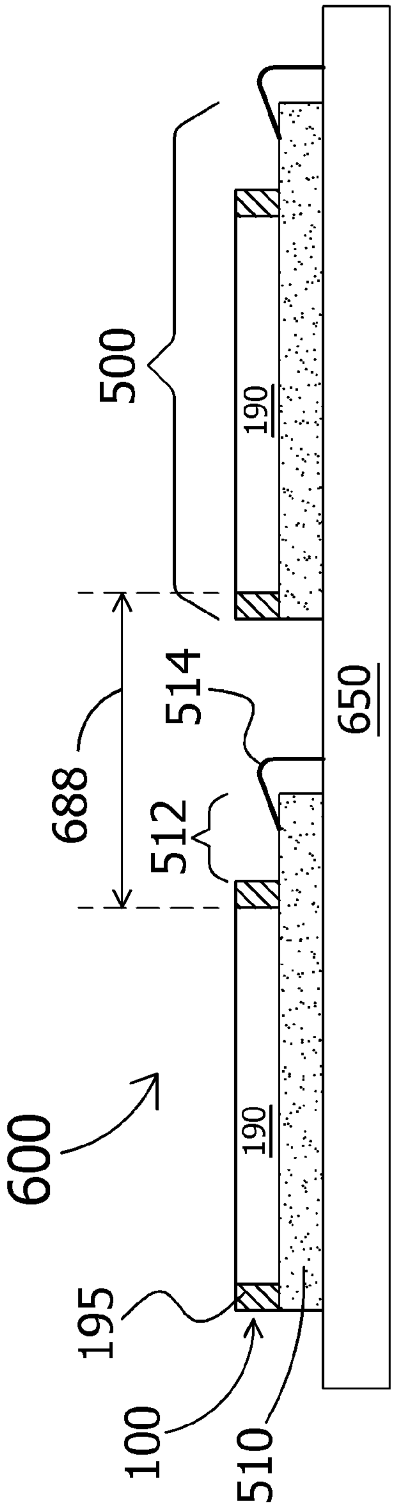
500
190
688
514
512
650
600
190
195
100
510

FIG. 6

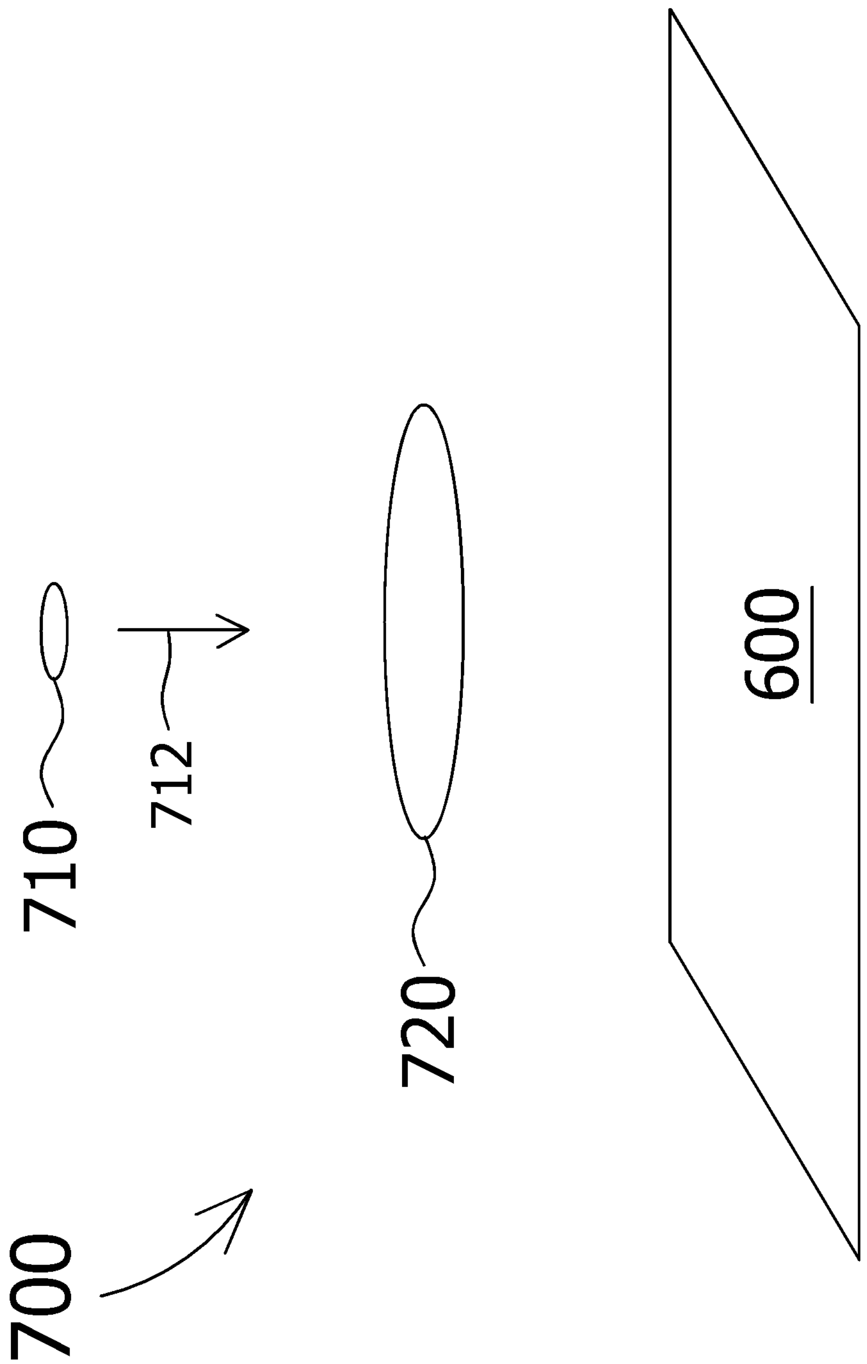

FIG. 7

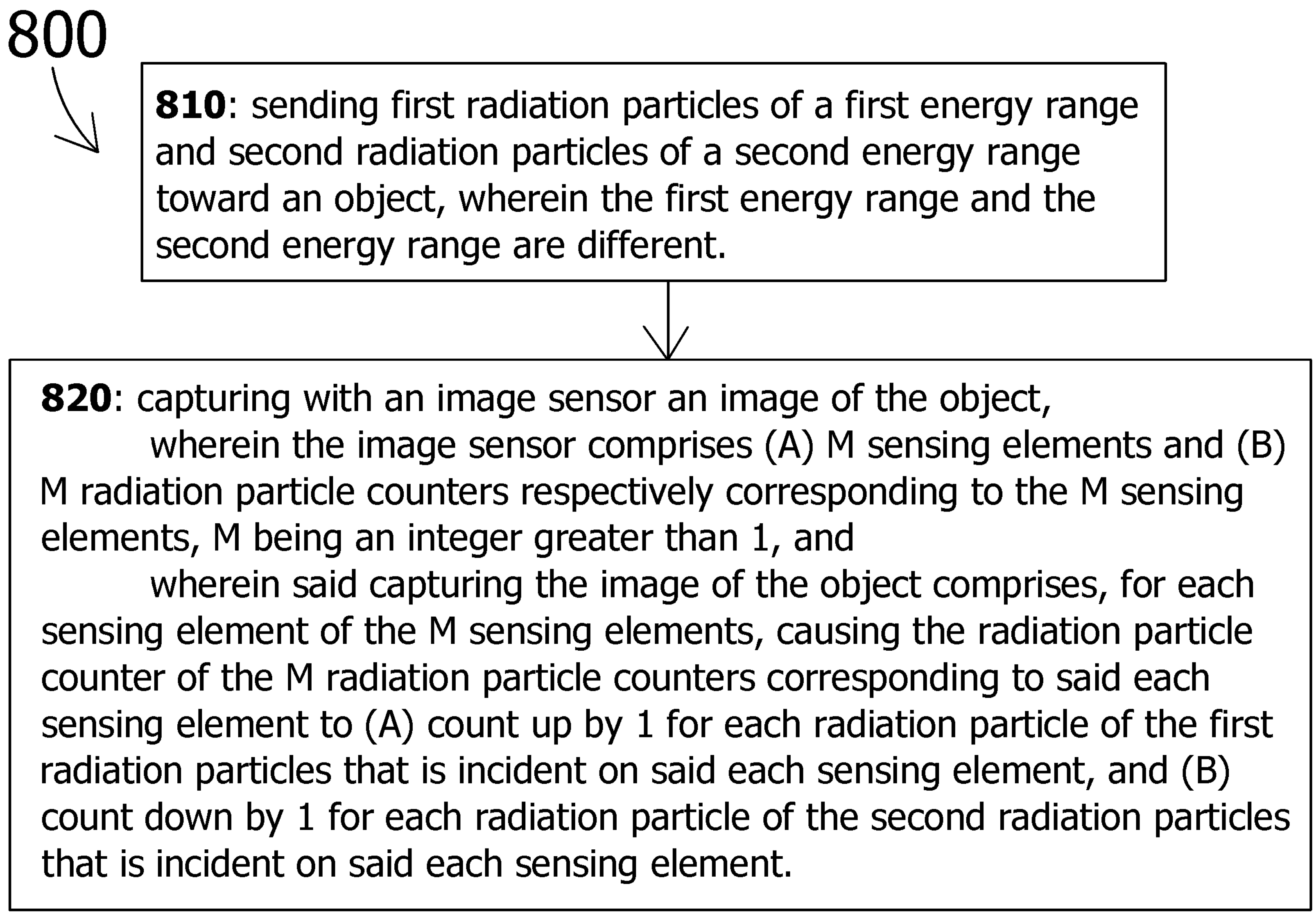
800
810: sending first radiation particles of a first energy range and second radiation particles of a second energy range toward an object, wherein the first energy range and the second energy range are different.
820: capturing with an image sensor an image of the object,
wherein the image sensor comprises (A) M sensing elements and (B) M radiation particle counters respectively corresponding to the M sensing elements, M being an integer greater than 1, and
wherein said capturing the image of the object comprises, for each sensing element of the M sensing elements, causing the radiation particle counter of the M radiation particle counters corresponding to said each sensing element to (A) count up by 1 for each radiation particle of the first radiation particles that is incident on said each sensing element, and (B) count down by 1 for each radiation particle of the second radiation particles that is incident on said each sensing element.

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2021/143485

A. CLASSIFICATION OF SUBJECT MATTER

G01T 1/161(2006.01)i; A61B 6/00(2006.01)i; H04N 5/32(2006.01)i; G01T 1/36(2006.01)i

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,A61B,H04N

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)

CNPAT, WPI, EPODOC, CNKI: SHENZHEN XPECTVISION TECHNOLOGY, CAO Peiyan, LIU Yurun, radiation, particle, energy, imag+, counter?, up, add+, down, decreas+, reduc+

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 111587084 A (SHENZHEN XPECTVISION TECHNOLOGY CO., LTD.) 25 August 2020 (2020-08-25) paragraphs [0029]-[0068]	1-17
A	JP 2000069369 A (FUJI PHOTO FILM CO., LTD.) 03 March 2000 (2000-03-03) the whole document	1-17
A	CN 110178053 A (SHENZHEN XPECTVISION TECHNOLOGY CO., LTD.) 27 August 2019 (2019-08-27) the whole document	1-17
A	JP 2004325183 A (M & C K.K.) 18 November 2004 (2004-11-18) the whole document	1-17
A	WO 2019186976 A1 (HITACHI HIGH-TECHNOLOGIES CORPORATION) 03 October 2019 (2019-10-03) the whole document	1-17
A	US 2001040214 A1 (FRIEDMAN, Jacob A. et al.) 15 November 2001 (2001-11-15) the whole document	1-17

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

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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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
06 September 2022	**26 September 2022**
Name and mailing address of the ISA/CN **National Intellectual Property Administration, PRC** **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088, China** Facsimile No. **(86-10)62019451**	Authorized officer **SUN,Yuhan** Telephone No. **86-(10)-53962497**

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4345153 A (THE UNITED STATES OF AMERICA AS REPRESENTED BY THE ADMINISTRATOR OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION) 17 August 1982 (1982-08-17) the whole document	1-17
A	CN 105282463 A (UNIV. TIANJIN) 27 January 2016 (2016-01-27) the whole document	1-17

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2021/143485

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CN	111587084	A	25 August 2020	None			
JP	2000069369	A	03 March 2000	None			
CN	110178053	A	27 August 2019	US	2019094396	A1	28 March 2019
				WO	2018133085	A1	26 July 2018
				TW	201827852	A	01 August 2018
				EP	3571530	A1	27 November 2019
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				JP	S5757271	A	06 April 1982
				CA	1171185	A	17 July 1984
CN	105282463	A	27 January 2016	None			