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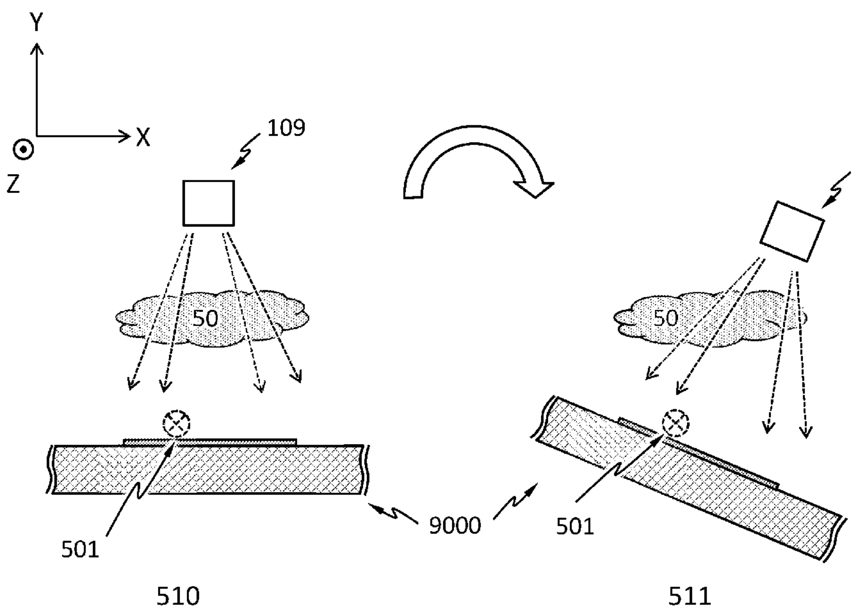

Fig. 1A

Fig. 1B

(57) **Abstract:** Disclosed herein is a method comprising: while an image sensor (9000) is at a first position (910) relative to a radiation source (109), capturing a first set of images of portions of a scene (50) respectively when the image sensor (9000) and the radiation source (109) are collectively rotated relative to the scene (50) about a first axis (501) to a plurality of rotational positions; while the image sensor (9000) is at a second position (920) relative to the radiation source (109), capturing a second set of images of portions of the scene (50) respectively when the image sensor (9000) and the radiation source (109) are collectively rotated relative to the scene (50) about the first axis (501) to the plurality of rotational positions; and forming an image of the scene (50) by stitching an image of the first set and an image of the second set.

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AN IMAGING METHOD

Background

[0001] Radiation detectors may be devices used to measure the flux, spatial distribution, spectrum or other properties of radiations.

[0002] Radiation detectors may be used for many applications. One important application is imaging. Radiation imaging is a radiography technique and can be used to reveal the internal structure of a non-uniformly composed and opaque object such as the human body.

[0003] Early radiation detectors for imaging include photographic plates and photographic films. A photographic plate may be a glass plate with a coating of light-sensitive emulsion. Although photographic plates were replaced by photographic films, they may still be used in special situations due to the superior quality they offer and their extreme stability. A photographic film may be a plastic film (e.g., a strip or sheet) with a coating of light-sensitive emulsion.

[0004] In the 1980s, photostimulable phosphor plates (PSP plates) became available. A PSP plate may contain a phosphor material with color centers in its lattice. When the PSP plate is exposed to radiation, electrons excited by radiation are trapped in the color centers until they are stimulated by a laser beam scanning over the plate surface. As the plate is scanned by laser, trapped excited electrons give off light, which is collected by a photomultiplier tube. The collected light is converted into a digital image. In contrast to photographic plates and photographic films, PSP plates can be reused.

[0005] Another kind of radiation detectors are radiation image intensifiers. Components of a radiation image intensifier are usually sealed in a vacuum. In contrast to photographic plates, photographic films, and PSP plates, Radiation image intensifiers may produce real-time images, i.e., do not require post-exposure processing to produce images. Radiation first hits an input phosphor (e.g., cesium iodide) and is converted to visible light. The visible light then hits a photocathode (e.g., a thin metal layer containing cesium and antimony compounds) and causes emission of electrons. The number of emitted electrons is proportional to the intensity of the incident Radiation. The emitted electrons are projected, through electron optics, onto an output phosphor and cause the output phosphor to produce a visible-light image.

[0006] Scintillators operate somewhat similarly to radiation image intensifiers in that scintillators (e.g., sodium iodide) absorb radiation and emit visible light, which can then be detected by a suitable image sensor for visible light. In scintillators, the visible light spreads and scatters in all directions and thus reduces spatial resolution. Reducing the scintillator thickness helps to improve the spatial resolution but also reduces absorption of radiation. A scintillator thus has to strike a compromise between absorption efficiency and resolution.

[0007] Semiconductor radiation detectors largely overcome this problem by direct conversion of radiation into electric signals. A semiconductor radiation detector may include a semiconductor layer that absorbs radiation in wavelengths of interest. When a radiation particle is absorbed in the semiconductor layer, multiple charge carriers (e.g., electrons and holes) are generated and swept under an electric field towards electric contacts on the semiconductor layer. Cumbersome heat management required in currently available semiconductor radiation detectors (e.g., Medipix) can make a detector with a large area and a large number of pixels difficult or impossible to produce.

Summary

[0008] Disclosed herein is method comprising: while an image sensor is at a first position relative to a radiation source, capturing a first set of images of portions of a scene respectively when the image sensor and the radiation source are collectively rotated relative to the scene about a first axis to a plurality of rotational positions; while the image sensor is at a second position relative to the radiation source, capturing a second set of images of portions of the scene respectively when the image sensor and the radiation source are collectively rotated relative to the scene about the first axis to the plurality of rotational positions; and forming an image of the scene by stitching an image of the first set and an image of the second set.

[0009] According to an embodiment, the method further comprises moving the image sensor from the first position relative to the radiation source to the second position relative to the radiation source by translating or rotating the image sensor relative to the radiation source.

[0010] According to an embodiment, the first axis is near or on a radiation-receiving surface of the image sensor.

[0011] According to an embodiment, the image sensor is configured to move relative to the radiation source by translating along a first direction relative to the radiation source.

[0012] According to an embodiment, the first direction is parallel to a radiation-receiving surface of the image sensor.

[0013] According to an embodiment, the image sensor is configured to move relative to the radiation source by translating along a second direction relative to the radiation source; wherein the second direction is different from the first direction.

[0014] According to an embodiment, the image sensor is configured to move relative to the radiation source by rotating about a second axis.

[0015] According to an embodiment, the image sensor is configured to move relative to the radiation source by rotating about a third axis; wherein the third axis is different from the second axis.

[0016] According to an embodiment, the image sensor comprises a first radiation detector and a second radiation detector.

[0017] According to an embodiment, the first radiation detector and the second radiation detector respectively comprise a planar surface configured to receive the radiation from the radiation source.

[0018] According to an embodiment, the planar surface of the first radiation detector and the planar surface of the second radiation detector are not parallel.

[0019] According to an embodiment, the first axis is near or on the planar surface of the first radiation detector.

[0020] According to an embodiment, a relative position of the first radiation detector with respect to the second radiation detector remains the same.

[0021] According to an embodiment, the first radiation detector and the second radiation detector are configured to move relative to the radiation source by translating along a first direction relative to the radiation source.

[0022] According to an embodiment, the first direction is parallel to the planar surface of the first radiation detector but not parallel to the planar surface of the second radiation detector.

[0023] According to an embodiment, the first radiation detector and the second radiation detector are configured to move relative to the radiation source by translating along the second direction relative to the radiation source; wherein the second direction is different from the first direction.

[0024] According to an embodiment, the first radiation detector and the second radiation detector are configured to move relative to the radiation source by rotating about a second axis, wherein the radiation source is on the second axis.

[0025] According to an embodiment, the first radiation detector and the second radiation detector are configured to move relative to the radiation source by rotating about a third axis; wherein the third axis is different from the second axis.

[0026] According to an embodiment, the first radiation detector and the second radiation detector each comprise an array of pixels.

[0027] According to an embodiment, the first radiation detector is rectangular in shape.

[0028] According to an embodiment, the first radiation detector is hexagonal in shape.

Brief Description of Figures

[0029] Fig. 1A-Fig.1H schematically show a method of imaging a scene, according to an embodiment.

[0030] Fig. 2A schematically shows a portion of an image sensor, according to an embodiment.

[0031] Fig. 2B schematically shows another view of the image sensor of Fig. 2A.

[0032] Fig. 3A schematically shows a cross-sectional view of a radiation detector, according to an embodiment.

[0033] Fig. 3B schematically shows a detailed cross-sectional view of the radiation detector, according to an embodiment.

[0034] Fig. 3C schematically shows an alternative detailed cross-sectional view of the radiation detector, according to an embodiment.

[0035] Fig. 4 schematically shows that the radiation detector may have an array of pixels, according to an embodiment.

[0036] Fig. 5 schematically shows a functional block diagram of the image sensor, according to an embodiment.

[0037] Fig. 6 schematically shows the image sensor capturing images of portions of a scene, according to an embodiment.

[0038] Fig. 7A-7C schematically show arrangements of the radiation detectors in the image sensor, according to some embodiments.

[0039] Fig. 8 schematically shows an image sensor with plurality of radiation detectors that are hexagonal in shape, according to an embodiment.

[0040] Fig. 9 schematically shows a system comprising the image sensor described herein, suitable for medical imaging such as chest Radiation radiography, abdominal Radiation radiography, etc., according to an embodiment

[0041] Fig. 10 schematically shows a system comprising the image sensor described herein suitable for dental Radiation radiography, according to an embodiment.

[0042] Fig. 11 schematically shows another cargo scanning or non-intrusive inspection (NII) system comprising the image sensor described herein, according to an embodiment.

[0043] Fig. 12 schematically shows a full-body scanner system comprising the image sensor described herein, according to an embodiment.

[0044] Fig. 13 schematically shows a radiation computed tomography (Radiation CT) system comprising the image sensor described herein, according to an embodiment.

[0045] Fig. 14A and Fig. 14B each show a component diagram of an electronic system of the radiation detector in Fig. 3A, Fig. 3B and Fig. 3C, according to an embodiment.

[0046] Fig. 15 schematically shows a temporal change of the electric current flowing through an electrode (upper curve) of a diode or an electric contact of a resistor of a radiation absorption layer exposed to radiation, the electric current caused by charge carriers generated by a radiation particle incident on the radiation absorption layer, and a corresponding temporal change of the voltage of the electrode (lower curve), according to an embodiment.

Detailed Description

[0047] Fig. 1A-Fig. 1H schematically show a method of imaging a scene 50, according to an embodiment. A plurality of sets of images of portions of the scene 50 may be captured when an image sensor 9000 and a radiation source 109 are collectively rotated to a plurality of rotational positions about a first axis 501 relative to the scene 50.

[0048] Fig. 1A and Fig. 1B each schematically show that the image sensor 9000 and the radiation source 109 are collectively at two different rotational positions relative to the scene 50, and that the image sensor 9000 is at the first position (e.g., 910 in Fig. 1C) relative to the radiation source 109. The first axis 501 is near or on a radiation-receiving surface of the image sensor 9000. Fig. 1A schematically shows the radiation source 109 and the image sensor 9000 at the first rotational position 510. Fig. 1B schematically shows that the radiation source 109 and the image sensor 9000 are collectively rotated to a second rotational position 511 about the first axis 501 relative to the scene 50, from the first rotational position 510. The image sensor 9000 may remain at the first position relative to the radiation source 109 during this collective rotation. The first axis 501 may be stationary relative to the scene 50. At the first rotational position 510 and the second rotational position 511, the radiation from the radiation source 109 may pass through different portions of the scene 50. A first set of images of portions of the scene 50 are captured respectively when the radiation source 109 and the image sensor 9000 are collectively rotated to a plurality of rotational positions about the first axis 501 relative to the scene 50, while the image sensor 9000 is at the first position relative to the radiation source 109. For example, the first set of images may include an image the image sensor 9000 captured at the first rotational position 510 shown in Fig. 1A or an image the image sensor 9000 captured at the second rotational position 511 shown in Fig. 1B.

[0049] The image sensor 9000 may be moved from the first position relative to the radiation source 109 to a second position relative to the radiation source 109. Fig. 1C schematically shows that image sensor 9000 may move relative to the radiation source 109 by translating relative to the radiation source 109, according to an embodiment. In the example shown in Fig. 1C, the image sensor 9000 may move from the first position 910 relative to the radiation source 109 to a second position 920 relative to the radiation source 109 by translating along a first direction 904 relative to the radiation source 109. The first direction 504 may be parallel to a radiation-receiving surface of the image sensor 9000.

[0050] Fig. 1C also shows that the image sensor 9000 may move from the first position 910 relative to the radiation source 109 to a third position 930 relative to the radiation source 109 by translating along a second direction 905 relative to the radiation source 109. The second direction 905 is different from the first direction 904.

[0051] Fig. 1D and Fig. 1E each schematically show that the image sensor 9000 and the radiation source 109 are collectively at two different rotational positions relative to the scene 50 after the image sensor 9000 has moved to the second position (e.g., 920 in Fig. 1C) relative to the radiation source 109 by translating relative to the radiation source 109. Fig. 1D schematically shows the radiation source 109 and the image sensor 9000 at the first rotational position 510. Fig. 1E schematically shows that the radiation source 109 and the image sensor 9000 are collectively rotated to the second rotational position 511 about the first axis 501 relative to the scene 50, from the first rotational position 510. The image sensor 9000 may remain at the second position relative to the radiation source 109 during this collective rotation. A second set of images of portions of the scene 50 are captured respectively when the radiation source 109 and the image sensor 9000 are collectively rotated to a plurality of rotational positions about the first axis 501 relative to the scene 50, while the image sensor 9000 is at the second position relative to the radiation source 109. For example, the second set of images may include an image the image sensor 9000 captured at the first rotational position 510 shown in Fig. 1D or an image the image sensor 9000 captured at the second rotational position 511 shown in Fig. 1E.

[0052] Fig. 1F schematically shows that the image sensor 9000 may move relative to the radiation source 109 by rotating relative to the radiation source 109, according to an embodiment. In the example shown in Fig. 1F, the image sensor 9000 may move from the first position 910 relative to the radiation source 109 to a fourth position 940 relative to the radiation source 109 by rotating about a second axis 902 relative to the radiation source 109. The second axis 902 may be parallel to a radiation-receiving surface of the image sensor 9000. The radiation source 109 may be on the second axis 902.

[0053] Fig. 1F also shows that the image sensor 9000 may move from the first position 910 relative to the radiation source 109 to a fifth position 950 relative to the radiation source 109 by rotating about a third axis 903 relative to the radiation source 109. The third axis 903 is different from the second axis 902. For example, the third axis 903 may be perpendicular to the second axis 902. The radiation source 109 may be on the third axis 903.

[0054] Fig. 1G and Fig. 1H each schematically show that the image sensor 9000 and the radiation source 109 are collectively at two different rotational positions relative to the scene 50 after the image sensor 9000 has moved to the fourth position (e.g., 940 in Fig. 1F) relative to the radiation source 109 by rotating relative to the radiation source 109. Fig. 1G schematically shows the radiation source 109 and the image sensor 9000 at the first rotational position 510. Fig. 1H schematically shows that the radiation source 109 and the image sensor 9000 are collectively rotated to the second rotational position 511 about the first axis 501 relative to the scene 50, from the first rotational position 510. The image sensor 9000 may remain at the fourth position relative to the radiation source 109 during this collective rotation. A second set of images of portions of the scene 50 are captured respectively when the radiation source 109 and the image sensor 9000 are collectively rotated to a plurality of rotational positions about the first axis 501 relative to the scene 50, while the image sensor 9000 is at the fourth position relative to the radiation source 109. For example, the second set of images may include an image the image sensor 9000 captured at the first rotational position 510 shown in Fig. 1G or an image the image sensor 9000 captured at the second rotational position 511 shown in Fig. 1H.

[0055] Fig. 2A schematically shows that the image sensor 9000 may have a plurality of radiation detectors (e.g., a first radiation detector 100A, a second radiation detector 100B). The image sensor 9000 may have a support 107 with a curved surface 102. The plurality of radiation detectors may be arranged on the support 107, for example, on the curved surface 102, as shown in the example of Fig. 2A. The first radiation detector 100A may have a first planar surface 103A configured to receive radiation from a radiation source 109. A second radiation detector 100B may have a second planar surface 103B configured to receive the radiation from the radiation source 109. The first planar surface 103A of the first radiation detector 100A and the second planar surface 103B of the second radiation detector 100B may be not parallel. The radiation from the radiation source 109 may have passed through the scene 50 (e.g., a portion of a human body) before reaching the first radiation detector 100A or the second radiation detector 100B.

[0056] Fig. 2B schematically shows a perspective view of the image sensor 9000 depicted in Fig. 2A, with respect to the scene 50 and the radiation source 109.

[0057] The first axis 501 may be parallel to the first planar surface 103A of the first radiation detector 100A and the second planar surface 103B of the second radiation detector 100B. The first axis 501 may be near or on the planar surface of the first radiation detector 100A. A relative position of the first radiation detector 100A with respect to the second radiation detector 100B may remain unchanged when the image sensor 9000 moves relative to the radiation source 109 and when the image sensor 9000 and the radiation source 109 collectively rotate relative to the scene 50. The first radiation detector 100A and the second radiation detector 100B remain stationary relative to the image sensor 9000. Therefore, the first radiation detector 100A and the second radiation detector 100B may move relative to the radiation source 109 with the image sensor 9000 by translating along the first direction 904 or the second direction 905 relative to the radiation source 109 or by rotating about the second axis 902 or the third axis 903 relative to the radiation source 109. The first direction 904 or the second direction 905 may be parallel to both, either or neither of the first planar surface 103A and the second planar surface 103B. For example, the first direction 904 may be parallel to the first planar surface 103A, but not parallel to the second planar surface 103B.

[0058] Fig. 3A schematically shows a cross-sectional view of a radiation detector 100, according to an embodiment. The radiation detector 100 may be used in the image sensor 9000, for example as the first radiation detector 100A or the second radiation detector 100B. The radiation detector 100 may include a radiation absorption layer 110 and an electronics layer 120 (e.g., an ASIC) for processing or analyzing electrical signals incident radiation generates in the radiation absorption layer 110. In an embodiment, the radiation detector 100 does not comprise a scintillator. The radiation absorption layer 110 may include a semiconductor material such as, silicon, germanium, GaAs, CdTe, CdZnTe, or a combination thereof. The semiconductor may have a high mass attenuation coefficient for the radiation energy of interest. The surface 103 of the radiation absorption layer 110 distal from the electronics layer 120 is configured to receive radiation.

[0059] As shown in a detailed cross-sectional view of the radiation detector 100 in Fig. 3B, according to an embodiment, 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 the intrinsic region 112. The discrete regions 114 are 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 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 in Fig. 2B, 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. 2B, the radiation absorption layer 110 has a plurality of diodes having the first doped region 111 as a shared electrode. The first doped region 111 may also have discrete portions.

[0060] When a radiation particle hits the radiation absorption layer 110 including diodes, the radiation particle may be absorbed and generate one or more charge carriers by a number of mechanisms. A radiation particle may generate 10 to 100000 charge carriers. The charge carriers may drift to the electrodes of one of the diodes under an electric field. The field may be an external electric field. The electric contact 119B may include discrete portions each of which is in electrical contact with the discrete regions 114. In an embodiment, the charge carriers may drift in directions such that the charge carriers generated by a single radiation particle 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 radiation particle 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 radiation particle incident therein at an angle of incidence of 0° 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.

[0061] As shown in an alternative detailed cross-sectional view of the radiation detector 100 in Fig. 3C, according to an embodiment, 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 may have a high mass attenuation coefficient for the radiation energy of interest.

[0062] When a radiation particle hits the radiation absorption layer 110 including a resistor but not diodes, it may be absorbed and generate one or more charge carriers by a number of mechanisms. A radiation particle may generate 10 to 100000 charge carriers. The charge carriers may drift to the electric contacts 119A and 119B under an electric field. The field may be an external electric field. The electric contact 119B includes discrete portions. In an embodiment, the charge carriers may drift in directions such that the charge carriers generated by a single radiation particle are not substantially shared by two different discrete portions of the electric 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 radiation particle incident around the footprint of one of these discrete portions of the electric contact 119B are not substantially shared with another of these discrete portions of the electric contact 119B. A pixel 150 associated with a discrete portion of the electric 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 radiation particle incident at an angle of incidence of 0° therein flow to the discrete portion of the electric 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 electric contact 119B.

[0063] The electronics layer 120 may include an electronic system 121 suitable for processing or interpreting signals generated by radiation particles 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 components shared by the pixels or components dedicated to a single pixel. For example, the electronic system 121 may include an amplifier dedicated to each pixel and a microprocessor shared among all the pixels. The electronic system 121 may be electrically connected to the pixels 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 without using vias.

[0064] Fig. 4 schematically shows that the radiation detector 100 may have an array of pixels 150. The array may be a rectangular array, a honeycomb array, a hexagonal array or any other suitable array. Each pixel 150 may be configured to detect a radiation particle incident thereon, measure the energy of the radiation particle, or both. For example, each pixel 150 may be configured to count numbers of radiation particles incident thereon whose energy falls in a plurality of bins, within a period of time. All the pixels 150 may be configured to count the numbers of radiation particles incident thereon within a plurality of bins of energy within the same period of time. Each pixel 150 may have its own analog-to-digital converter (ADC) configured to digitize an analog signal representing the energy of an incident radiation particle into a digital signal. The ADC may have a resolution of 10 bits or higher. Each pixel 150 may be configured to measure its dark current, such as before or concurrently with each radiation particle incident thereon. Each pixel 150 may be configured to deduct the contribution of the dark current from the energy of the radiation particle incident thereon. The pixels 150 may be configured to operate in parallel. For example, when one pixel 150 measures an incident radiation particle, another pixel 150 may be waiting for another radiation particle to arrive. The pixels 150 may be but do not have to be individually addressable.

[0065] In an embodiment, the radiation detectors 100 (e.g., 100A and 100B) of the image sensor 9000 can move to multiple positions, relative to the radiation source 109. The image sensor 9000 may use the radiation detectors 100 and with the radiation from the radiation source 109 to capture images of multiple portions of the scene 50 respectively at the multiple positions. The image sensor 9000 can stitch these images to form an image of the entire scene 50. As shown in Fig. 5, according to an embodiment, the image sensor 9000 may include an actuator 500 configured to move the radiation detectors 100 to the multiple positions. The actuator 500 may include a controller 600. The image sensor may include a collimator 200 that only allows radiation to reach active area of the radiation detectors 100. Active areas of the radiation detectors 100 are areas of the radiation detectors 100 that are sensitive to the radiation. The actuator 500 may move the collimator 200 together with the radiation detectors 100. The positions may be determined by the controller 600.

[0066] Fig. 6 schematically shows capturing images of portions of the scene 50 by the image sensor 9000. In the example shown in Fig. 6, the radiation detectors 100 move to three positions relative to the radiation source 109, for example, the first position 510, the second position 520, for example, by using the actuator 500. Respectively at the positions 510, 520, the image sensor 9000 captures a first set of image 51A, a second set of images 51B of portions of the scene 50 when the image sensor 9000 and the radiation source 109 are collectively rotated relative to the scene 50 about a first axis 501 to a plurality of rotational positions (e.g., 511, 521). The image sensor 9000 can stitch the image of the first set 51A and the image of the second set 51B of the portions to form an image of the scene 50. The images 51A, 51B of the portions may have overlap among one another to facilitate stitching. Every portion of the scene 50 may be in at least one of the images captured when the detectors are at the multiple positions. Namely, the images of the portions when stitched together may cover the entire scene 50.

[0067] The radiation detectors 100 may be arranged in a variety of ways in the image sensor 9000. Fig. 7A schematically shows one arrangement, according to an embodiment, where the radiation detectors 100 are arranged in staggered rows. For example, radiation detectors 100A and 100B are in the same row, aligned in the Y direction, and uniform in size; radiation detectors 100C and 100D are in the same row, aligned in the Y direction, and uniform in size.

Radiation detectors 100A and 100B are staggered in the X direction with respect to radiation detectors 100C and 100D. According to an embodiment, a distance X2 between two neighboring radiation detectors 100A and 100B in the same row is greater than a width X1 (i.e., dimension in the X direction, which is the extending direction of the row) of one radiation detector in the same row and is less than twice the width X1. Radiation detectors 100A and 100E are in a same column, aligned in the X direction, and uniform in size; a distance Y2 between two neighboring radiation detectors 100A and 100E in the same column is less than a width Y1 (i.e., dimension in the Y direction) of one radiation detector in the same column. This arrangement allows imaging of the scene as shown in Fig. 6, and an image of the scene may be obtained from stitching three images of portions of the scene captured at three positions spaced apart in the X direction.

[0068] Fig. 7B schematically shows another arrangement, according to an embodiment, where the radiation detectors 100 are arranged in a rectangular grid. For example, the radiation detectors 100 may include radiation detectors 100A, 100B, 100E and 100F as arranged exactly in Fig. 7A, without radiation detectors 100C, 100D, 100G, or 100H in Fig. 8A. This arrangement allows imaging of the scene by taking images of portions of the scene at six positions. For example, three positions spaced apart in the X direction and another three positions spaced apart in the X direction and spaced apart in the Y direction from the first three positions.

[0069] Other arrangements may also be possible. For example, in Fig. 7C, the radiation detectors 100 may span the whole width of the image sensor 9000 in the X-direction, with a distance Y2 between two neighboring radiation detectors 100 being less than a width of one radiation detector Y1. Assuming the width of the detectors in the X direction is greater than the width of the scene in the X direction, the image of the scene may be stitched from two images of portions of the scene captured at two positions spaced apart in the Y direction.

[0070] The radiation detectors 100 described above may be provided with any suitable size and shapes. According to an embodiment (e.g., in Fig. 7), at least some of the radiation detectors are rectangular in shape. According to an embodiment, as shown in Fig. 8, at least some of the radiation detectors are hexagonal in shape.

[0071] The image sensor 9000 described above may be used in various systems such as those provided below.

[0072] Fig. 9 schematically shows a system comprising the image sensor 9000 as described in relation to Fig. 1-Fig.8. The system may be used for medical imaging such as chest radiation radiography, abdominal radiation radiography, etc. The system comprises a radiation source 1201. Radiation emitted from the Radiation source 1201 penetrates an object 1202 (e.g., a human body part such as chest, limb, abdomen), is attenuated by different degrees by the internal structures of the object 1202 (e.g., bones, muscle, fat and organs, etc.), and is projected to the image sensor 9000. The image sensor 9000 forms an image by detecting the intensity distribution of the radiation.

[0073] Fig. 10 schematically shows a system comprising the image sensor 9000 as described in relation to Fig. 1-Fig. 8. The system may be used for medical imaging such as dental Radiation radiography. The system comprises a radiation source 1301. Radiation emitted from the Radiation source 1301 penetrates an object 1302 that is part of a mammal (e.g., human) mouth. The object 1302 may include a maxilla bone, a palate bone, a tooth, the mandible, or the tongue. The Radiation is attenuated by different degrees by the different structures of the object 1302 and is projected to the image sensor 9000. The image sensor 9000 forms an image by detecting the intensity distribution of the Radiation. Teeth absorb Radiation more than dental caries, infections, periodontal ligament. The dosage of radiation received by a dental patient is typically small (around 0.150 mSv for a full mouth series).

[0074] Fig. 11 schematically shows another cargo scanning or non-intrusive inspection (NII) system comprising the image sensor 9000 as described in relation to Fig. 1-Fig. 8. The system may be used for luggage screening at public transportation stations and airports. The system comprises a radiation source 1501. Radiation emitted from the radiation source 1501 may penetrate a piece of luggage 1502, be differently attenuated by the contents of the luggage, and projected to the image sensor 9000. The image sensor 9000 forms an image by detecting the intensity distribution of the transmitted radiation. The system may reveal contents of luggage and identify items forbidden on public transportation, such as firearms, narcotics, edged weapons, flammables.

[0075] Fig. 12 schematically shows a full-body scanner system comprising the image sensor 9000 as described in relation to Fig. 1-Fig. 8. The full-body scanner system may detect objects on a person’s body for security screening purposes, without physically removing clothes or making physical contact. The full-body scanner system may be able to detect non-metal objects. The full-body scanner system comprises a radiation source 1601. Radiation emitted from the radiation source 1601 may backscatter from a human 1602 being screened and objects thereon, and be projected to the image sensor 9000. The objects and the human body may backscatter Radiation differently. The image sensor 9000 forms an image by detecting the intensity distribution of the backscattered radiation. The image sensor 9000 and the radiation source 1601 may be configured to scan the human in a linear or rotational direction.

[0076] Fig. 13 schematically shows a radiation computed tomography (Radiation CT) system. The Radiation CT system uses computer-processed radiations to produce tomographic images (virtual “slices”) of specific areas of a scanned object. The tomographic images may be used for diagnostic and therapeutic purposes in various medical disciplines, or for flaw detection, failure analysis, metrology, assembly analysis and reverse engineering. The Radiation CT system comprises the image sensor 9000 as described in relation to Fig. 1-Fig. 8 and a radiation source 1701. The image sensor 9000 and the radiation source 1701 may be configured to rotate synchronously along one or more circular or spiral paths.

[0077] The image sensor 9000 described here may have other applications such as in a radiation telescope, radiation mammography, industrial radiation defect detection, radiation microscopy or microradiography, radiation casting inspection, radiation non-destructive testing, radiation weld inspection, radiation digital subtraction angiography, etc. It may be suitable to use the image sensor 9000 in place of a photographic plate, a photographic film, a PSP plate, a radiation image intensifier, a scintillator, or another semiconductor radiation detector.

[0078] Fig. 14A and Fig. 14B each show a component diagram of the electronic system 121, according to an embodiment. The electronic system 121 may include a first voltage comparator 301, a second voltage comparator 302, a counter 320, a switch 305, an optional voltmeter 306 and a controller 310.

[0079] The first voltage comparator 301 is configured to compare the voltage of at least one of the electric contacts 119B to a first threshold. The first voltage comparator 301 may be configured to monitor the voltage directly, or calculate the voltage by integrating an electric current flowing through the electrical contact 119B over a period of time. The first voltage comparator 301 may be controllably activated or deactivated by the controller 310. The first voltage comparator 301 may be a continuous comparator. Namely, the first voltage comparator 301 may be configured to be activated continuously and monitor the voltage continuously. The first voltage comparator 301 may be a clocked comparator. The first threshold may be 5-10%, 10%-20%, 20-30%, 30-40% or 40-50% of the maximum voltage one incident particle of radiation may generate on the electric contact 119B. The maximum voltage may depend on the energy of the incident particle of radiation, the material of the radiation absorption layer 110, and other factors. For example, the first threshold may be 50 mV, 100 mV, 150 mV, or 200 mV.

[0080] The second voltage comparator 302 is configured to compare the voltage to a second threshold. The second voltage comparator 302 may be configured to monitor the voltage directly or calculate the voltage by integrating an electric current flowing through the diode or the electrical contact over a period of time. The second voltage comparator 302 may be a continuous comparator. The second voltage comparator 302 may be controllably activate or deactivated by the controller 310. When the second voltage comparator 302 is deactivated, the power consumption of the second voltage comparator 302 may be less than 1%, less than 5%, less than 10% or less than 20% of the power consumption when the second voltage comparator 302 is activated. The absolute value of the second threshold is greater than the absolute value of the first threshold. As used herein, the term “absolute value” or “modulus” $|x|$ of a real number x is the non-negative value of x without regard to its sign. Namely, $|x| =$

$\begin{cases} x, \text{if } x \geq 0 \\ -x, \text{if } x \leq 0 \end{cases}$. The second threshold may be 200%-300% of the first threshold. The second threshold may be at least 50% of the maximum voltage one incident particle of radiation may generate on the electric contact 119B. For example, the second threshold may be 100 mV, 150 mV, 200 mV, 250 mV or 300 mV. The second voltage comparator 302 and the first voltage comparator 310 may be the same component. Namely, the system 121 may have one voltage comparator that can compare a voltage with two different thresholds at different times.

[0081] The first voltage comparator 301 or the second voltage comparator 302 may include one or more op-amps or any other suitable circuitry. The first voltage comparator 301 or the second voltage comparator 302 may have a high speed to allow the electronic system 121 to operate under a high flux of incident particles of radiation. However, having a high speed is often at the cost of power consumption.

[0082] The counter 320 is configured to register at least a number of particles of radiation incident on the pixel 150 encompassing the electric contact 119B. The counter 320 may be a software component (e.g., a number stored in a computer memory) or a hardware component (e.g., a 4017 IC and a 7490 IC).

[0083] The controller 310 may be a hardware component such as a microcontroller and a microprocessor. The controller 310 is configured to start a time delay from a time at which the first voltage comparator 301 determines that the absolute value of the voltage equals or exceeds the absolute value of the first threshold (e.g., the absolute value of the voltage increases from below the absolute value of the first threshold to a value equal to or above the absolute value of the first threshold). The absolute value is used here because the voltage may be negative or positive, depending on whether the voltage of the cathode or the anode of the diode or which electrical contact is used. The controller 310 may be configured to keep deactivated the second voltage comparator 302, the counter 320 and any other circuits the operation of the first voltage comparator 301 does not require, before the time at which the first voltage comparator 301 determines that the absolute value of the voltage equals or exceeds the absolute value of the first threshold. The time delay may expire before or after the voltage becomes stable, i.e., the rate of change of the voltage is substantially zero. The phase “the rate of change of the voltage is substantially zero” means that temporal change of the voltage is less than 0.1%/ns. The phase “the rate of change of the voltage is substantially non-zero” means that temporal change of the voltage is at least 0.1%/ns.

[0084] The controller 310 may be configured to activate the second voltage comparator during (including the beginning and the expiration) the time delay. In an embodiment, the controller 310 is configured to activate the second voltage comparator at the beginning of the time delay. The term “activate” means causing the component to enter an operational state (e.g., by sending a signal such as a voltage pulse or a logic level, by providing power, etc.). The term “deactivate” means causing the component to enter a non-operational state (e.g., by sending a signal such as a voltage pulse or a logic level, by cut off power, etc.). The operational state may have higher power consumption (e.g., 10 times higher, 100 times higher, 1000 times higher) than the non-operational state. The controller 310 itself may be deactivated until the output of the first voltage comparator 301 activates the controller 310 when the absolute value of the voltage equals or exceeds the absolute value of the first threshold.

[0085] The controller 310 may be configured to cause at least one of the number registered by the counter 320 to increase by one, if, during the time delay, the second voltage comparator

302 determines that the absolute value of the voltage equals or exceeds the absolute value of the second threshold.

[0086] The controller 310 may be configured to cause the optional voltmeter 306 to measure the voltage upon expiration of the time delay. The controller 310 may be configured to connect the electric contact 119B to an electrical ground, so as to reset the voltage and discharge any charge carriers accumulated on the electric contact 119B. In an embodiment, the electric contact 119B is connected to an electrical ground after the expiration of the time delay. In an embodiment, the electric contact 119B is connected to an electrical ground for a finite reset time period. The controller 310 may connect the electric contact 119B to the electrical ground by controlling the switch 305. The switch may be a transistor such as a field-effect transistor (FET).

[0087] In an embodiment, the system 121 has no analog filter network (e.g., a RC network). In an embodiment, the system 121 has no analog circuitry.

[0088] The voltmeter 306 may feed the voltage it measures to the controller 310 as an analog or digital signal.

[0089] The electronic system 121 may include an integrator 309 electrically connected to the electric contact 119B, wherein the integrator is configured to collect charge carriers from the electric contact 119B. The integrator 309 can include a capacitor in the feedback path of an amplifier. The amplifier configured as such is called a capacitive transimpedance amplifier (CTIA). CTIA has high dynamic range by keeping the amplifier from saturating and improves the signal-to-noise ratio by limiting the bandwidth in the signal path. Charge carriers from the electric contact 119B accumulate on the capacitor over a period of time (“integration period”).

After the integration period has expired, the capacitor voltage is sampled and then reset by a reset switch. The integrator 309 can include a capacitor directly connected to the electric contact 119B.

[0090] Fig. 15 schematically shows a temporal change of the electric current flowing through the electric contact 119B (upper curve) caused by charge carriers generated by a particle of radiation incident on the pixel 150 encompassing the electric contact 119B, and a corresponding temporal change of the voltage of the electric contact 119B (lower curve). The voltage may be an integral of the electric current with respect to time. At time t_0, the particle of radiation hits pixel 150, charge carriers start being generated in the pixel 150, electric current starts to flow through the electric contact 119B, and the absolute value of the voltage of the electric contact 119B starts to increase. At time t_1, the first voltage comparator 301 determines that the absolute value of the voltage equals or exceeds the absolute value of the first threshold V1, and the controller 310 starts the time delay TD1 and the controller 310 may deactivate the first voltage comparator 301 at the beginning of TD1. If the controller 310 is deactivated before t_1, the controller 310 is activated at t_1. During TD1, the controller 310 activates the second voltage comparator 302. The term “during” a time delay as used here means the beginning and the expiration (i.e., the end) and any time in between. For example, the controller 310 may activate the second voltage comparator 302 at the expiration of TD1. If during TD1, the second voltage comparator 302 determines that the absolute value of the voltage equals or exceeds the absolute value of the second threshold V2 at time t_2, the controller 310 waits for stabilization of the voltage to stabilize. The voltage stabilizes at time t_e, when all charge carriers generated by the particle of radiation drift out of the radiation absorption layer 110. At time t_s, the time delay TD1 expires. At or after time t_e, the controller 310 causes the voltmeter 306 to digitize the voltage and determines which bin the energy of the particle of radiation falls in. The controller 310 then causes the number registered by the counter 320 corresponding to the bin to increase by one. In the example of Fig. 9, time t_s is after time t_e; namely TD1 expires after all charge carriers generated by the particle of radiation drift out of the radiation absorption layer 110. If time t_e cannot be easily measured, TD1 can be empirically chosen to allow sufficient time to collect essentially all charge carriers generated by a particle of radiation but not too long to risk have another incident particle of radiation. Namely, TD1 can be empirically chosen so that time t_s is empirically after time t_e. Time t_s is not necessarily after time t_e because the controller 310 may disregard TD1 once V2 is reached and wait for time t_e. The rate of change of the difference between the voltage and the contribution to the voltage by the dark current is thus substantially zero at t_e. The controller 310 may be configured to deactivate the second voltage comparator 302 at expiration of TD1 or at t_2, or any time in between.

[0091] The voltage at time t_e is proportional to the amount of charge carriers generated by the particle of radiation, which relates to the energy of the particle of radiation. The controller 310 may be configured to determine the energy of the particle of radiation, using the voltmeter 306.

[0092] After TD1 expires or digitization by the voltmeter 306, whichever later, the controller 310 connects the electric contact 119B to an electric ground for a reset period RST to allow charge carriers accumulated on the electric contact 119B to flow to the ground and reset the voltage. After RST, the electronic system 121 is ready to detect another incident particle of radiation. If the first voltage comparator 301 has been deactivated, the controller 310 can activate it at any time before RST expires. If the controller 310 has been deactivated, it may be activated before RST expires.

[0093] 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:

while an image sensor is at a first position relative to a radiation source, capturing a first set of images of portions of a scene respectively when the image sensor and the radiation source are collectively rotated relative to the scene about a first axis to a plurality of rotational positions;

while the image sensor is at a second position relative to the radiation source, capturing a second set of images of portions of the scene respectively when the image sensor and the radiation source are collectively rotated relative to the scene about the first axis to the plurality of rotational positions; and

forming an image of the scene by stitching an image of the first set and an image of the second set.

2. The method of claim 1, further comprising moving the image sensor from the first position relative to the radiation source to the second position relative to the radiation source by translating or rotating the image sensor relative to the radiation source.

3. The method of claim 1, wherein the first axis is near or on a radiation-receiving surface of the image sensor.

4. The method of claim 1, wherein the image sensor is configured to move relative to the radiation source by translating along a first direction relative to the radiation source.

5. The method of claim 4, wherein the first direction is parallel to a radiation-receiving surface of the image sensor.

6. The method of claim 1, wherein the image sensor is configured to move relative to the radiation source by translating along a second direction relative to the radiation source; wherein the second direction is different from the first direction.

7. The method of claim 1, wherein the image sensor is configured to move relative to the radiation source by rotating about a second axis.

8. The method of claim 7, wherein the image sensor is configured to move relative to the radiation source by rotating about a third axis; wherein the third axis is different from the second axis.

9. The method of claim 1, wherein the image sensor comprises a first radiation detector and a second radiation detector.

10. The method of claim 9, wherein the first radiation detector and the second radiation detector respectively comprise a planar surface configured to receive the radiation from the radiation source.

11. The method of claim 10, wherein the planar surface of the first radiation detector and the planar surface of the second radiation detector are not parallel.

12. The method of claim 10, wherein the first axis is near or on the planar surface of the first radiation detector.

13. The method of claim 9, wherein a relative position of the first radiation detector with respect to the second radiation detector remains the same.

14. The method of claim 9, wherein the first radiation detector and the second radiation detector are configured to move relative to the radiation source by translating along a first direction relative to the radiation source.

15. The method of claim 14, wherein the first direction is parallel to the planar surface of the first radiation detector but not parallel to the planar surface of the second radiation detector.

16. The method of claim 14, wherein the first radiation detector and the second radiation detector are configured to move relative to the radiation source by translating along a second direction relative to the radiation source; wherein the second direction is different from the first direction.

17. The method of claim 9, wherein the first radiation detector and the second radiation detector are configured to move relative to the radiation source by rotating about a second axis, wherein the radiation source is on the second axis.

18. The method of claim 17, wherein the first radiation detector and the second radiation detector are configured to move relative to the radiation source by rotating about a third axis; wherein the third axis is different from the second axis.

19. The method of claim 9, wherein the first radiation detector and the second radiation detector each comprise an array of pixels.

20. The method of claim 9, wherein the first radiation detector is rectangular in shape.

21. The method of claim 9, wherein the first radiation detector is hexagonal in shape.

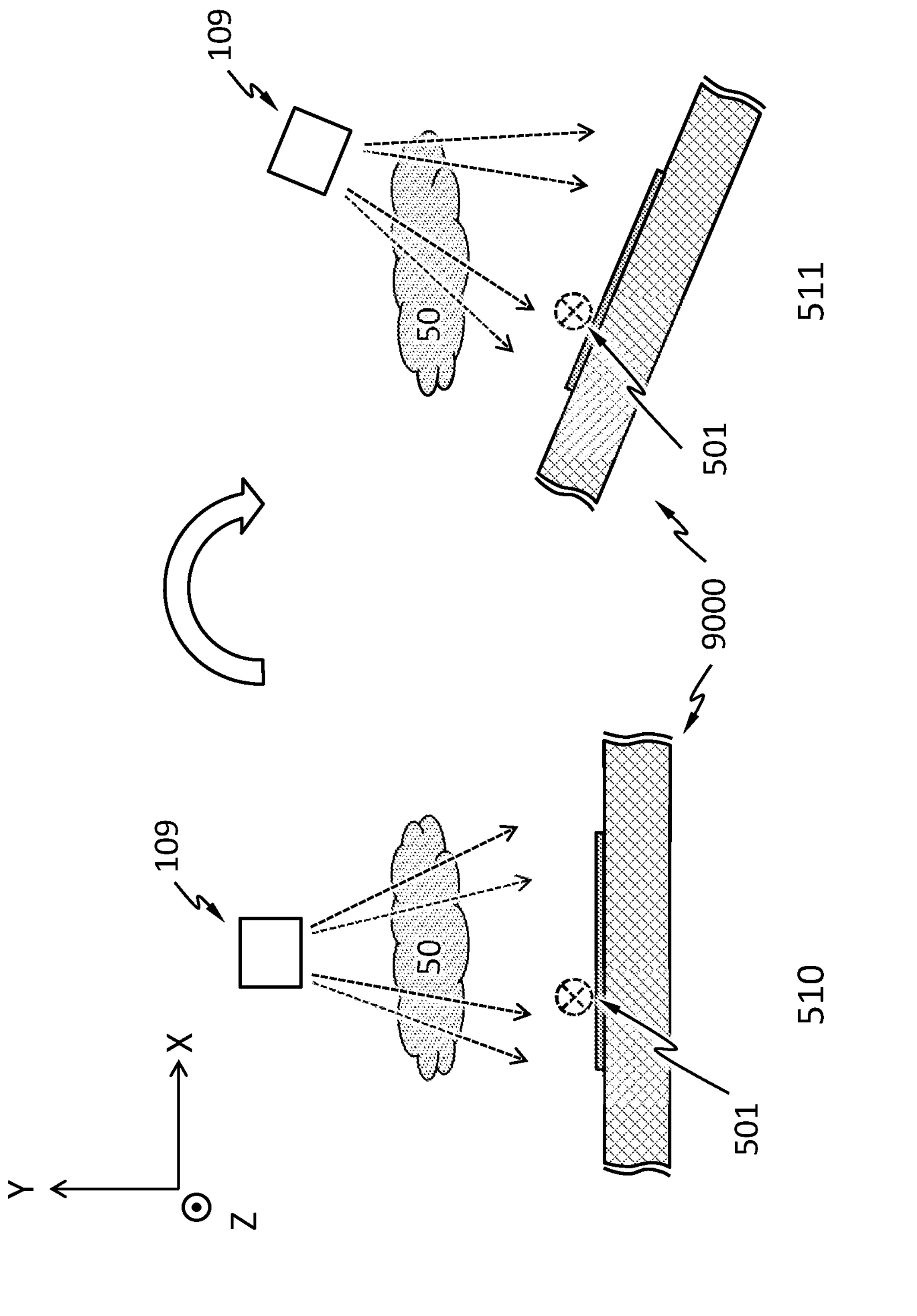


Fig. 1B

Fig. 1A

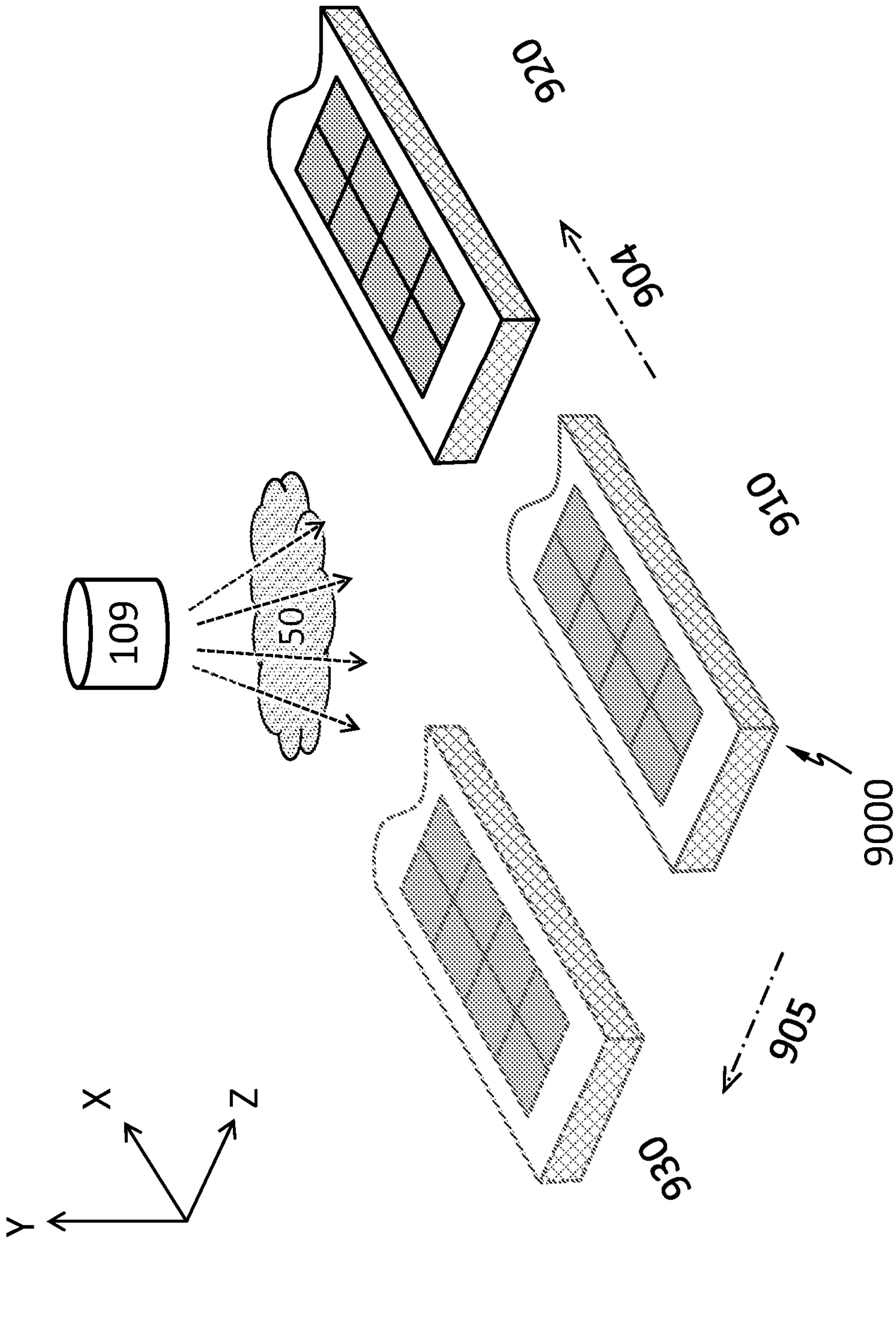


Fig. 1C

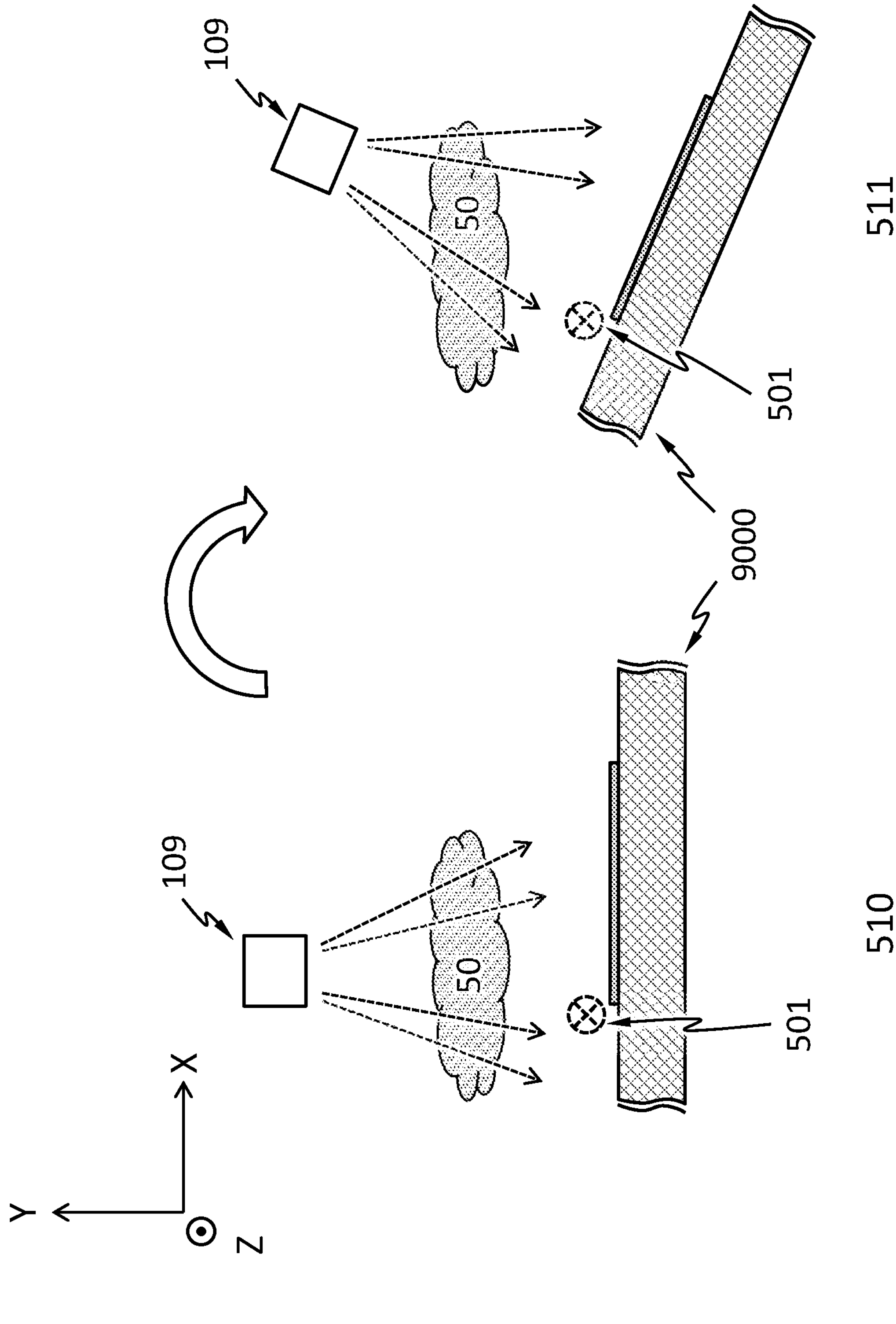


Fig. 1E

Fig. 1D

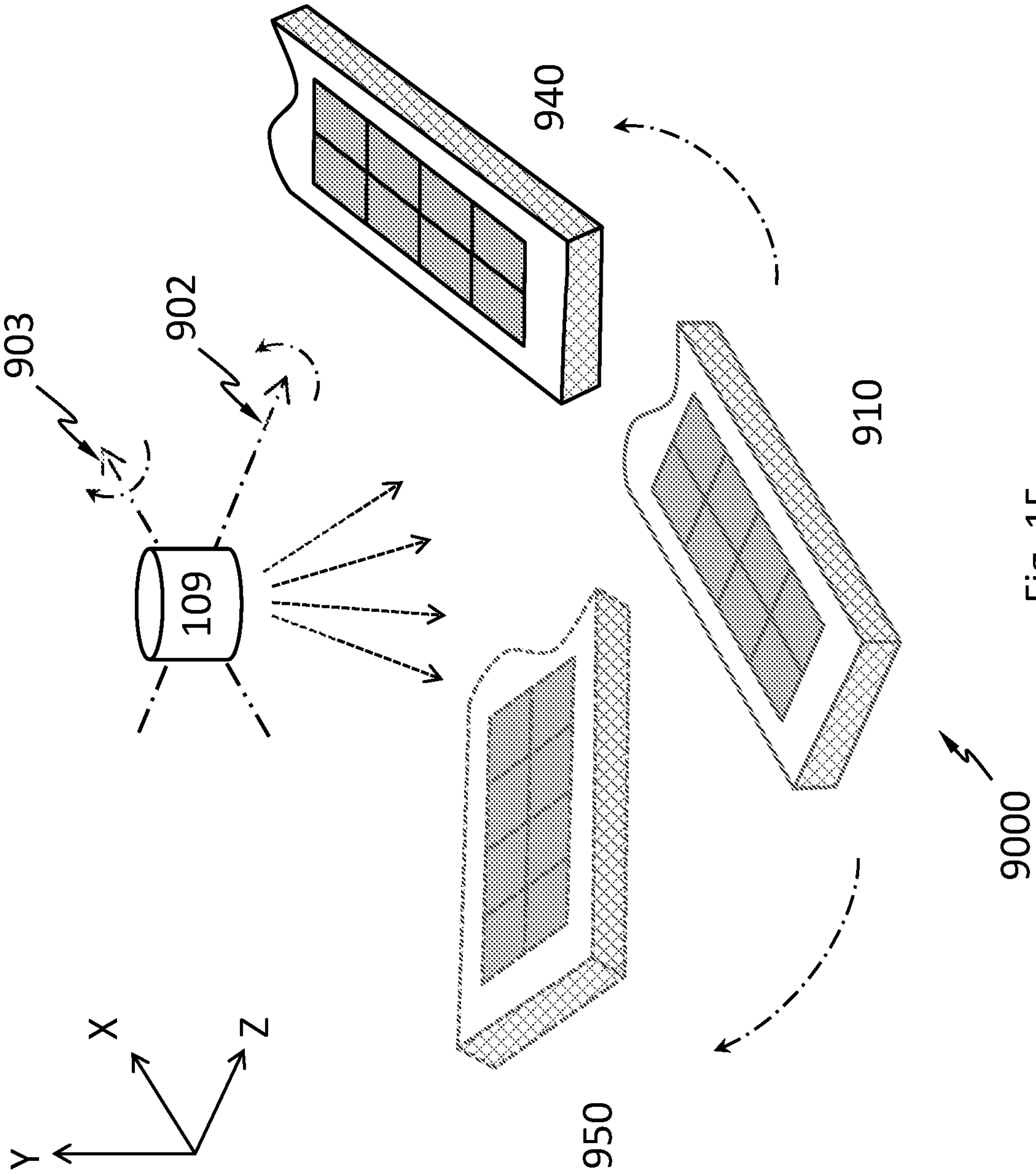


Fig. 1F

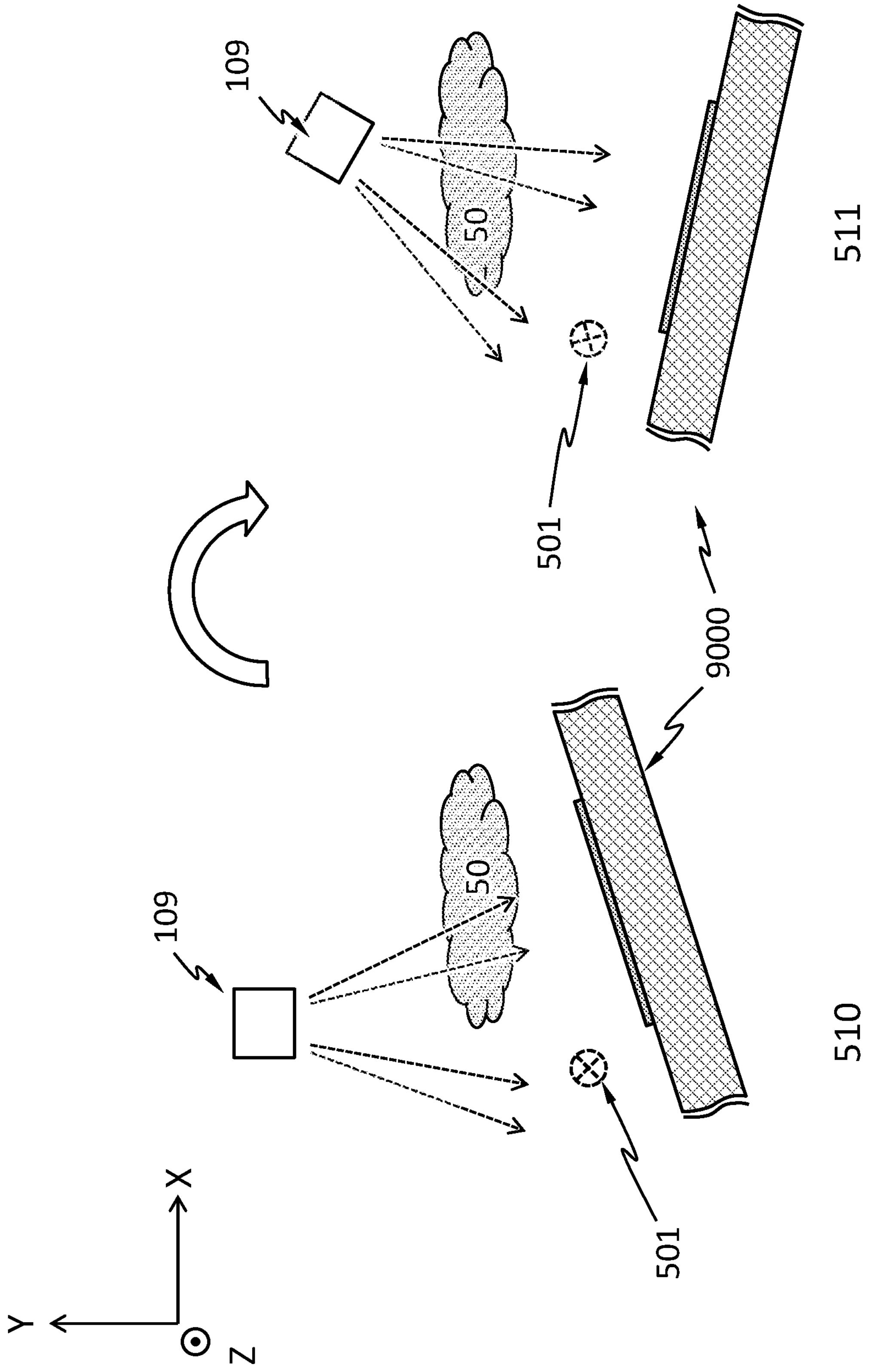


Fig. 1H

Fig. 1G

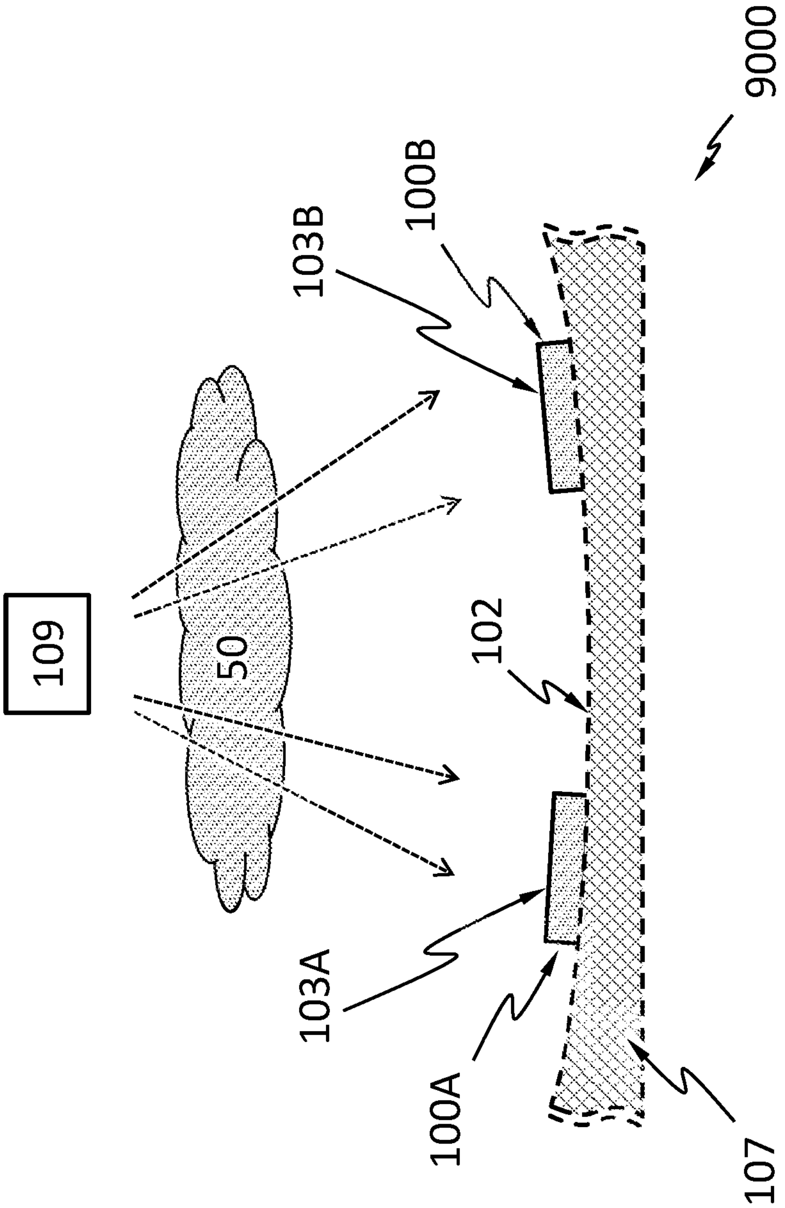


Fig. 2A

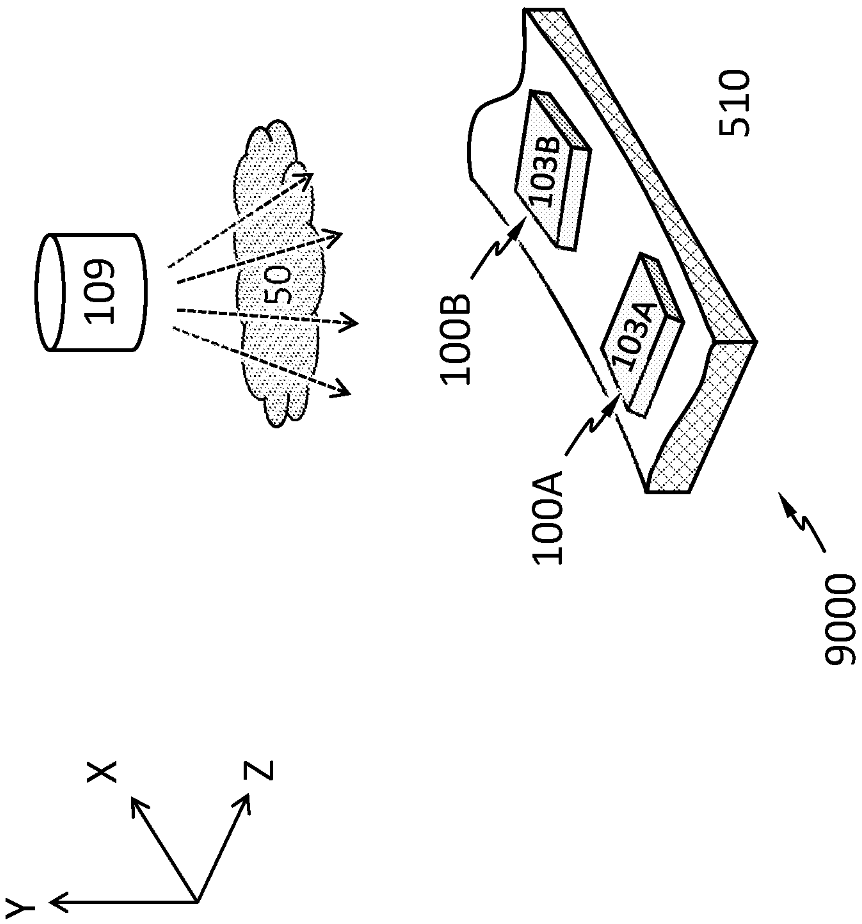


Fig. 2B

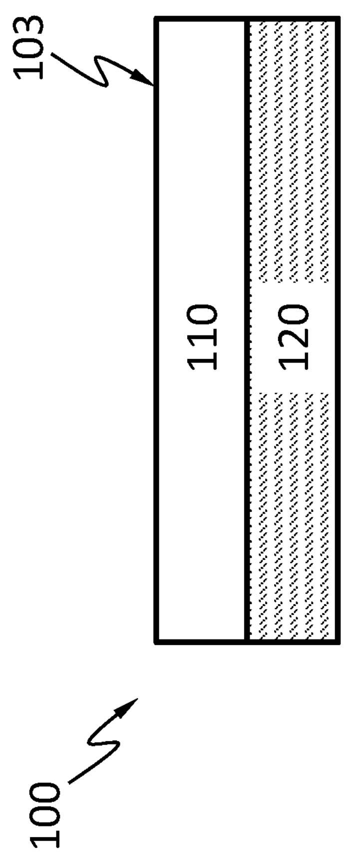


Fig. 3A

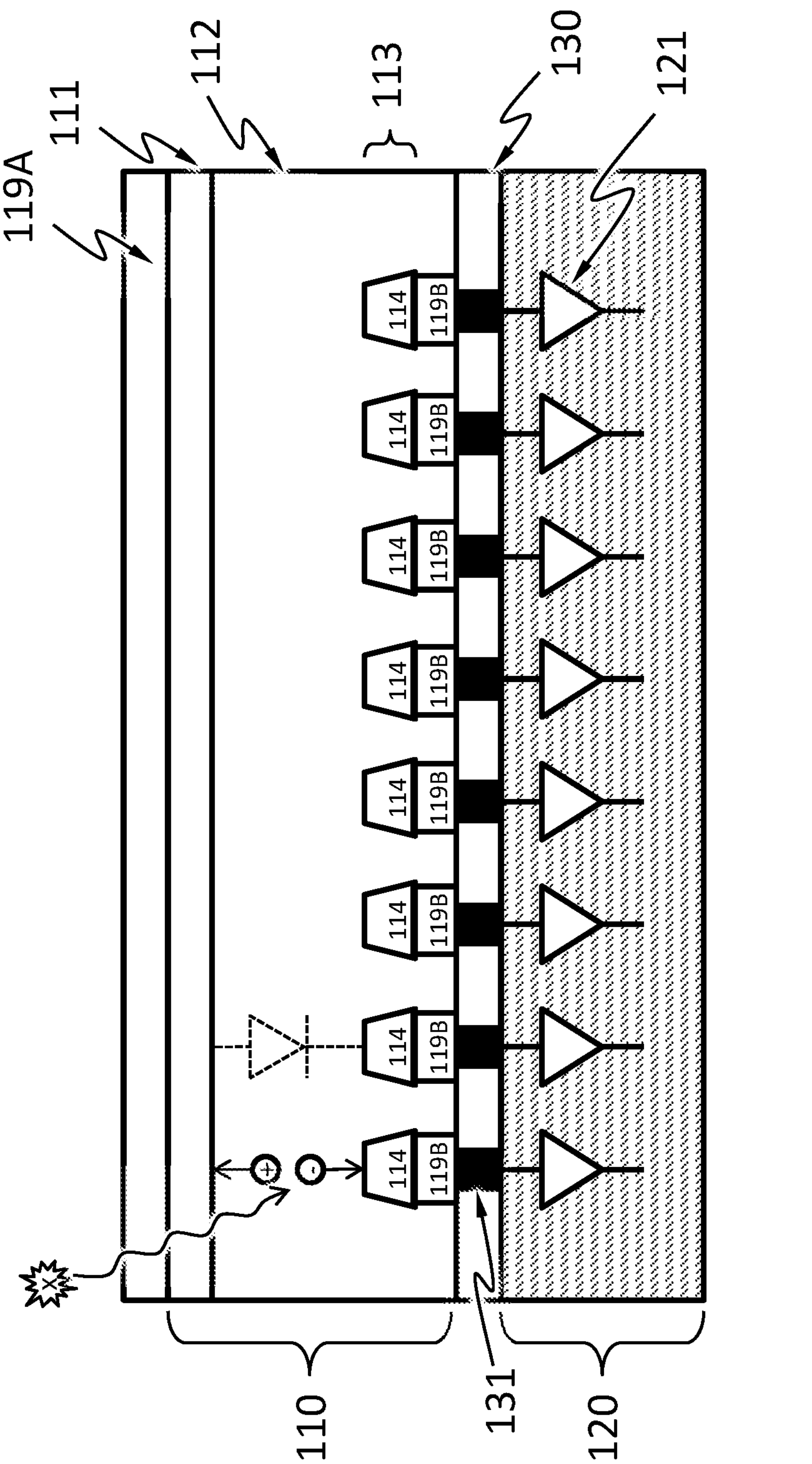
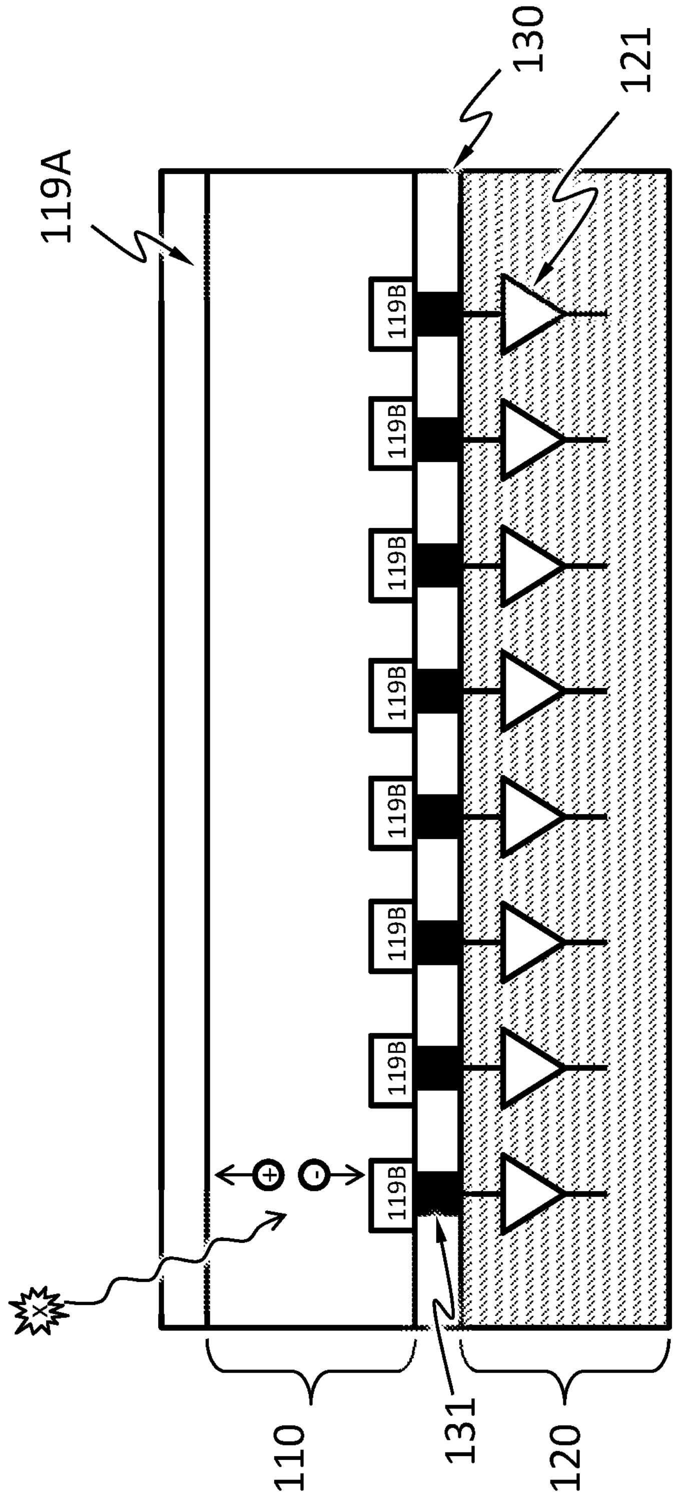


Fig. 3B


119A
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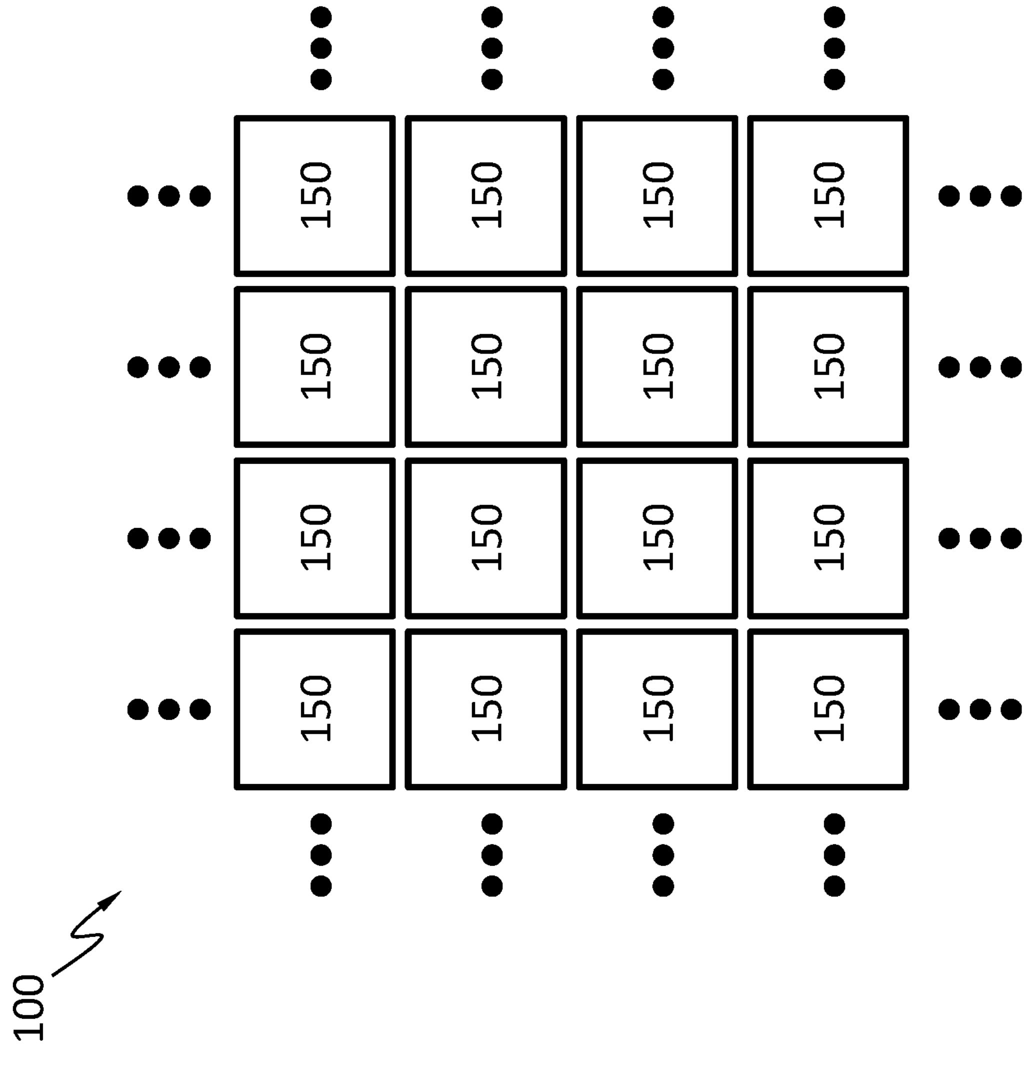
121
119B
119B
119B
119B
119B
119B
119B
119B
110
131
120

Fig. 3C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100

Fig. 4

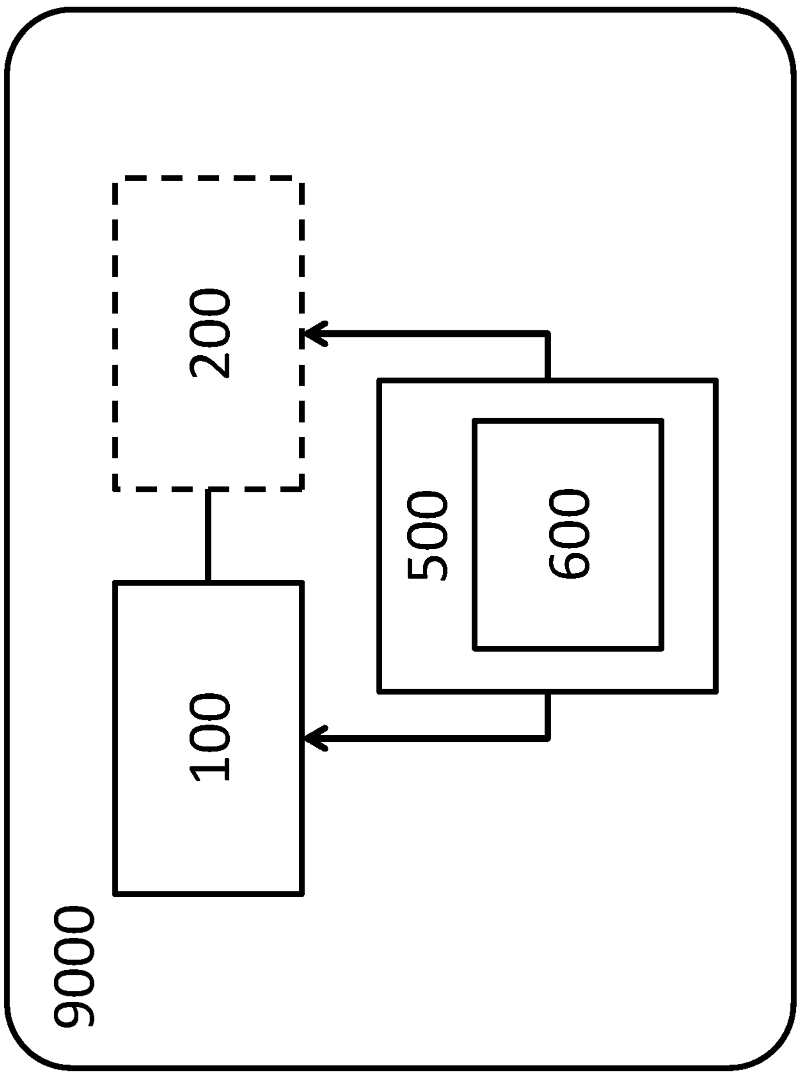


Fig. 5

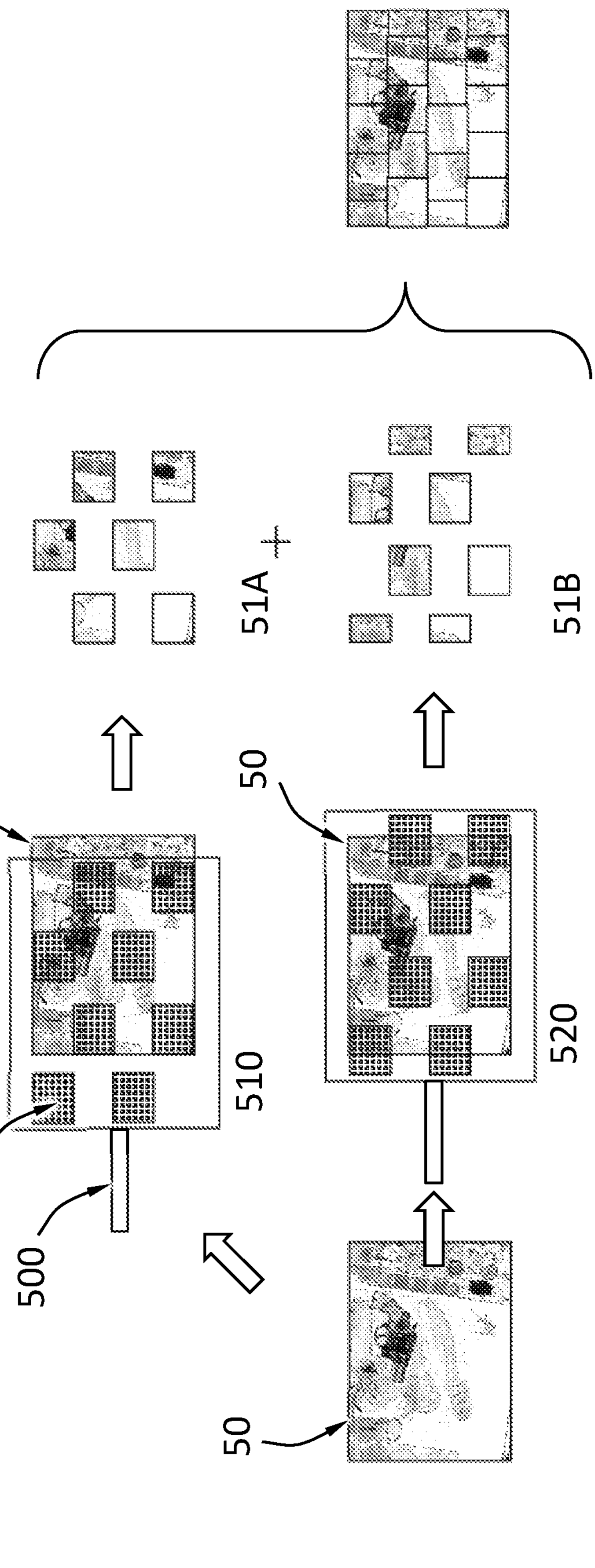


Fig. 6

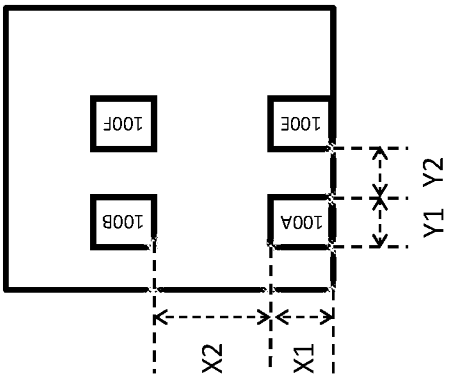


Fig. 7B

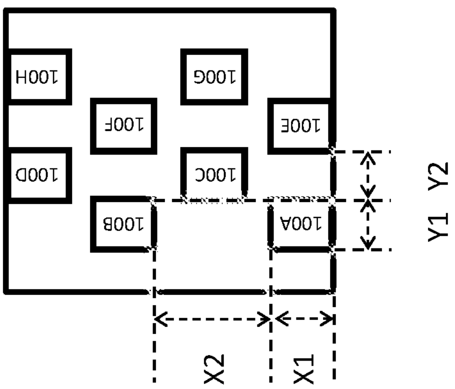
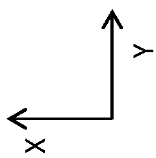


Fig. 7A



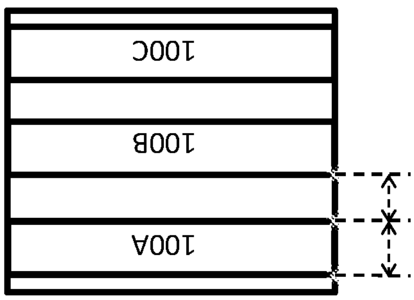


Fig. 7C

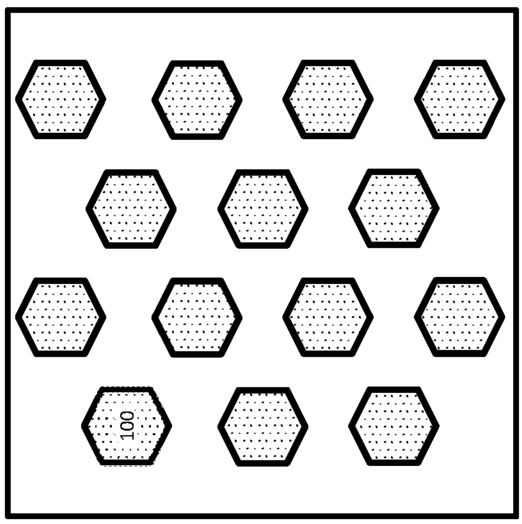


Fig. 8

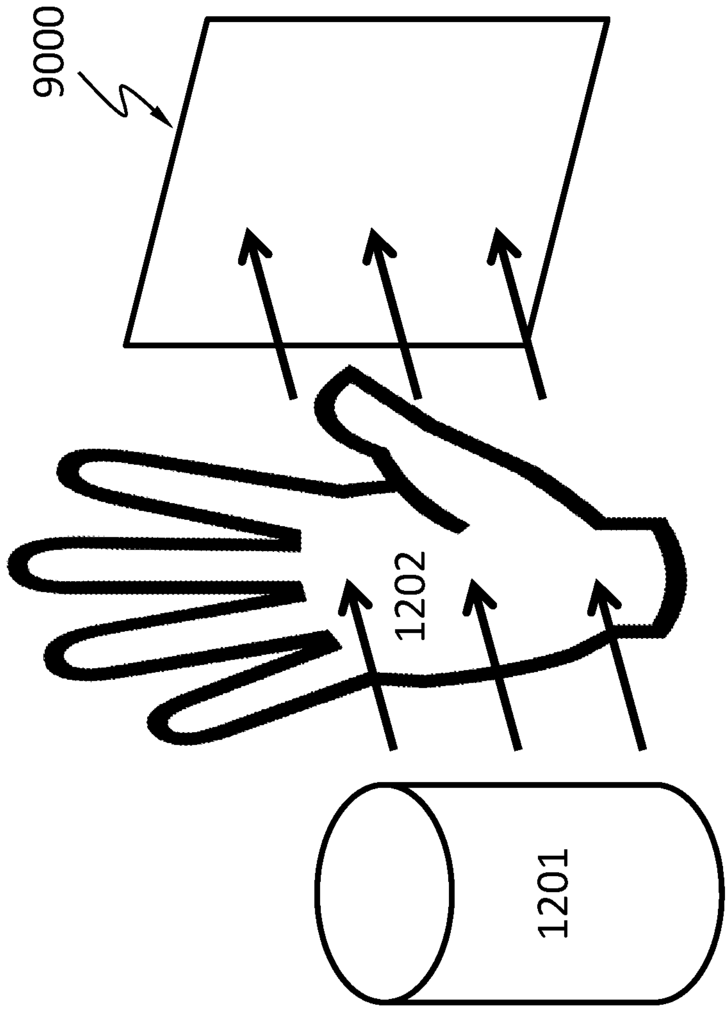


Fig. 9

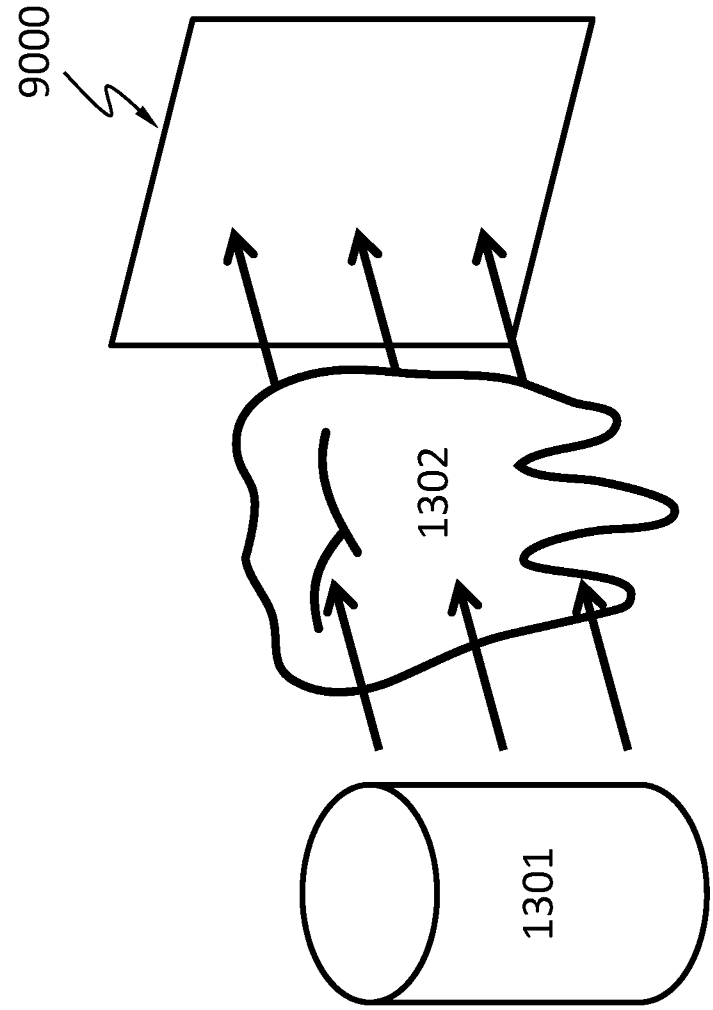


Fig. 10

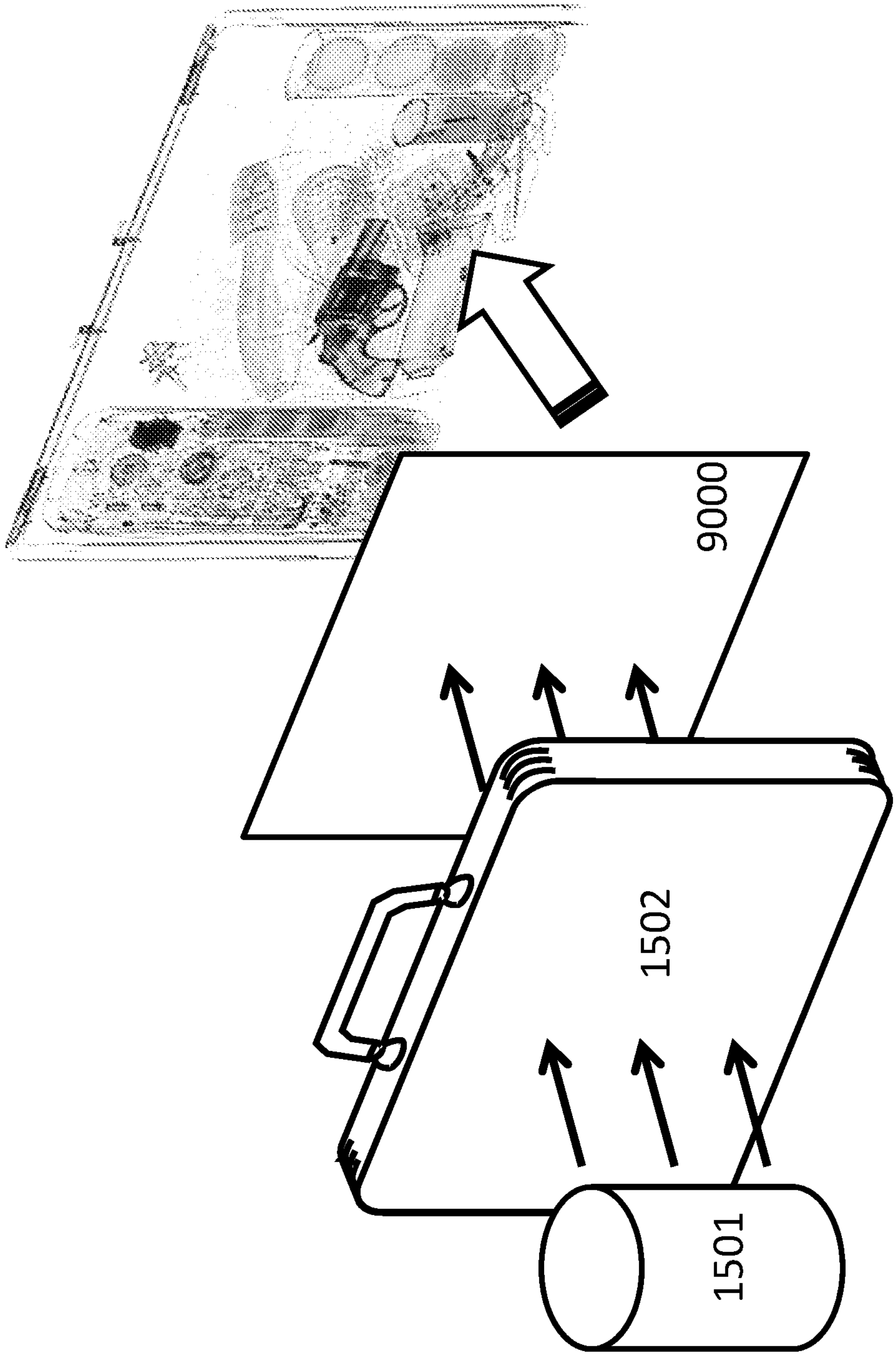


Fig. 11

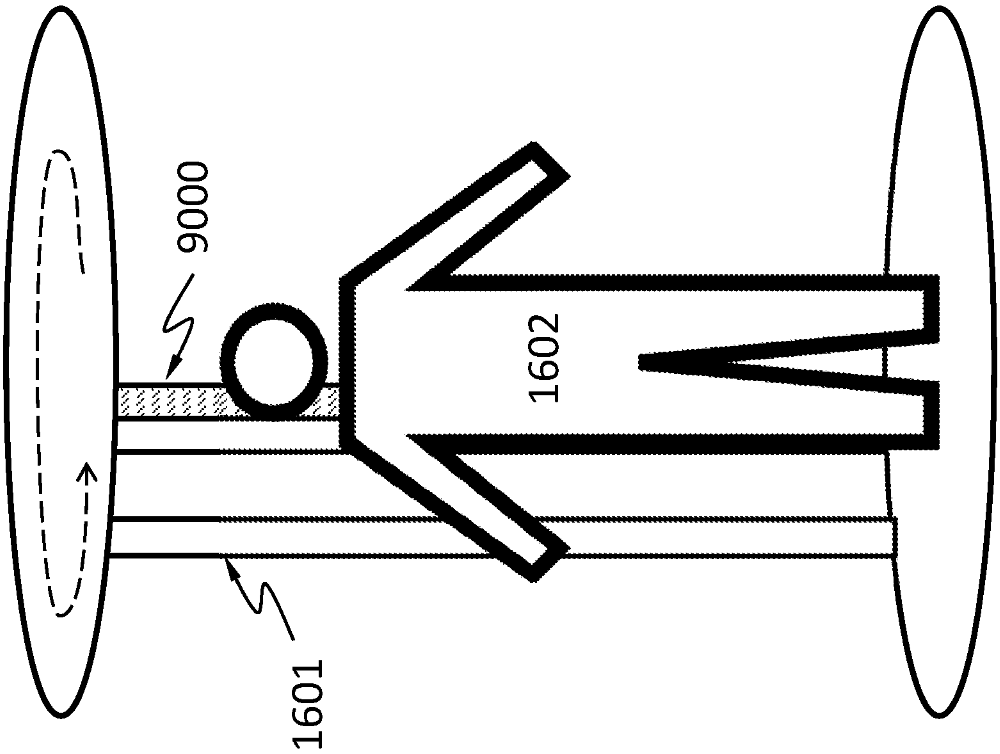


Fig. 12

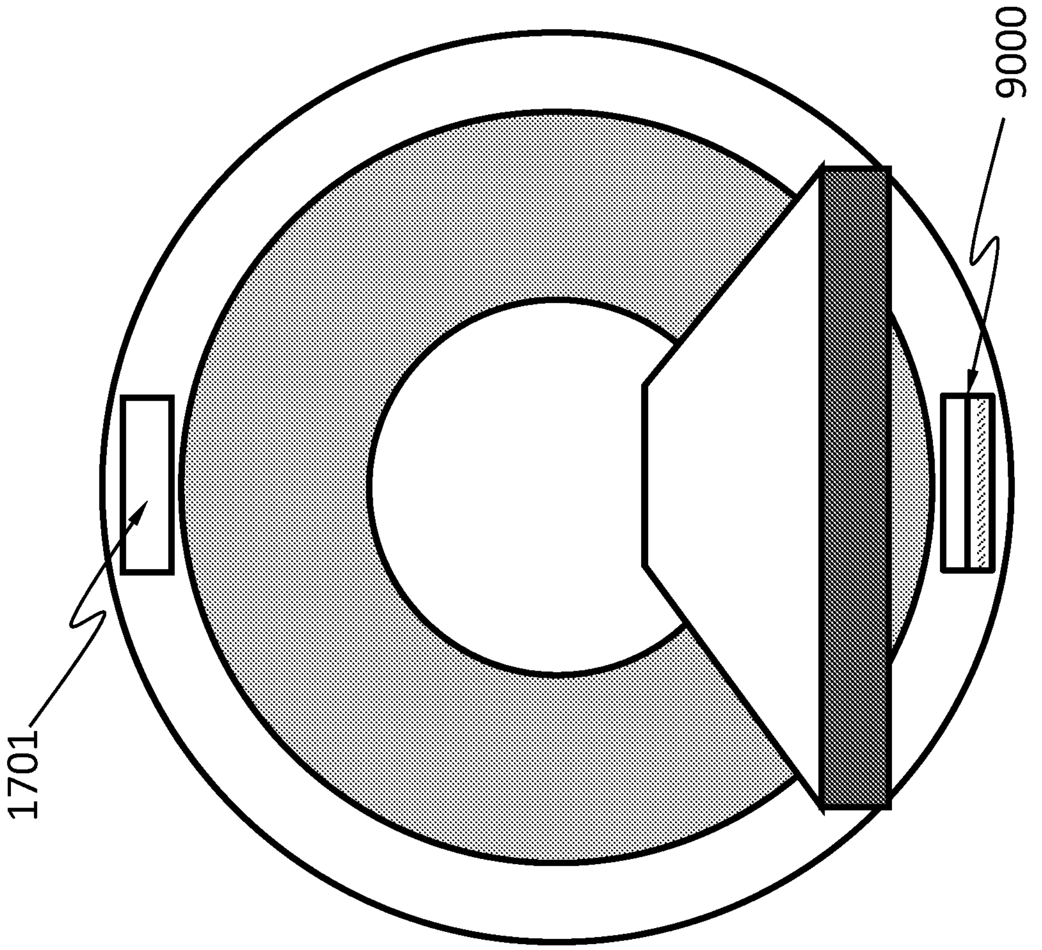


Fig. 13

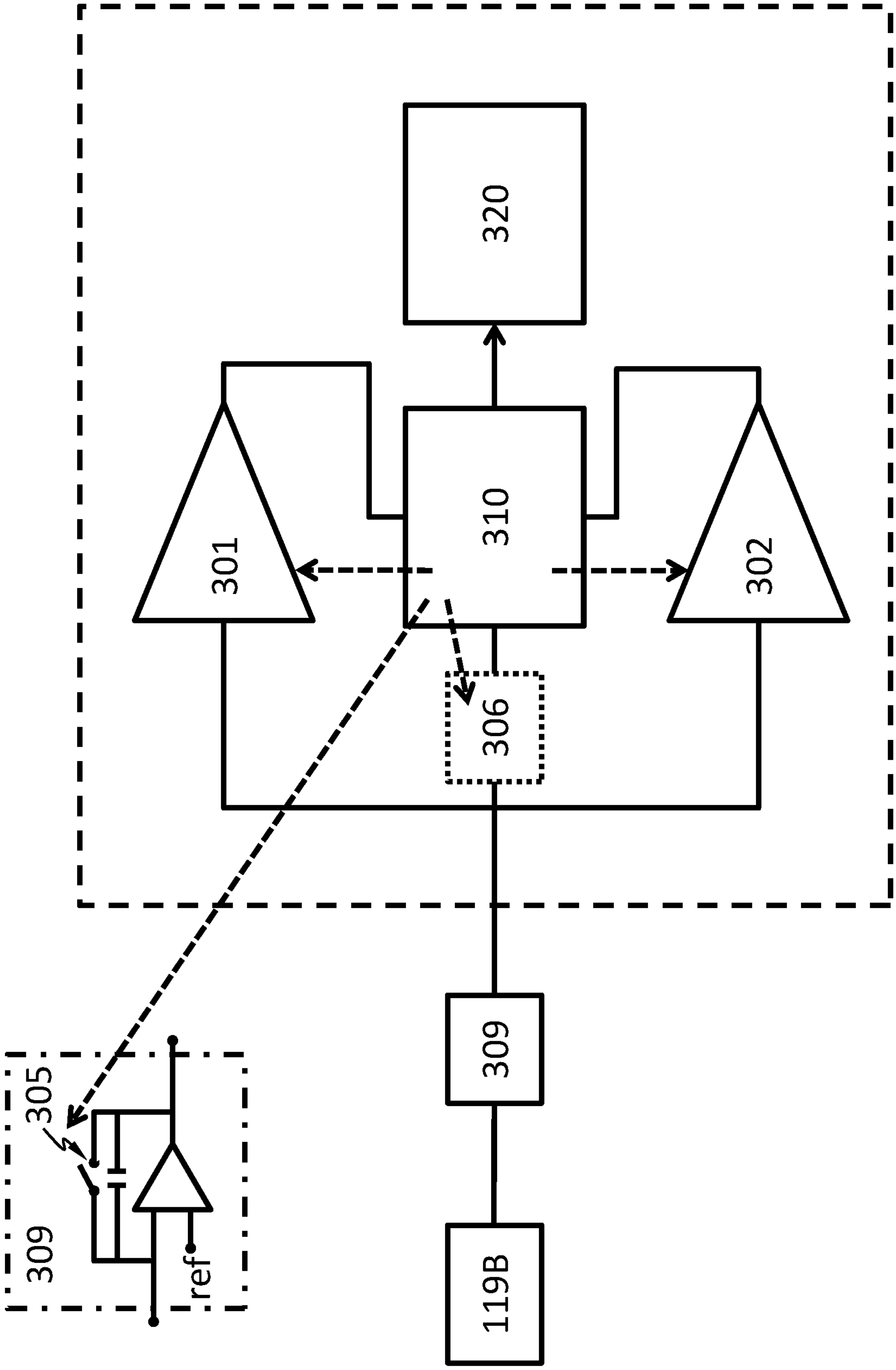


Fig. 14A

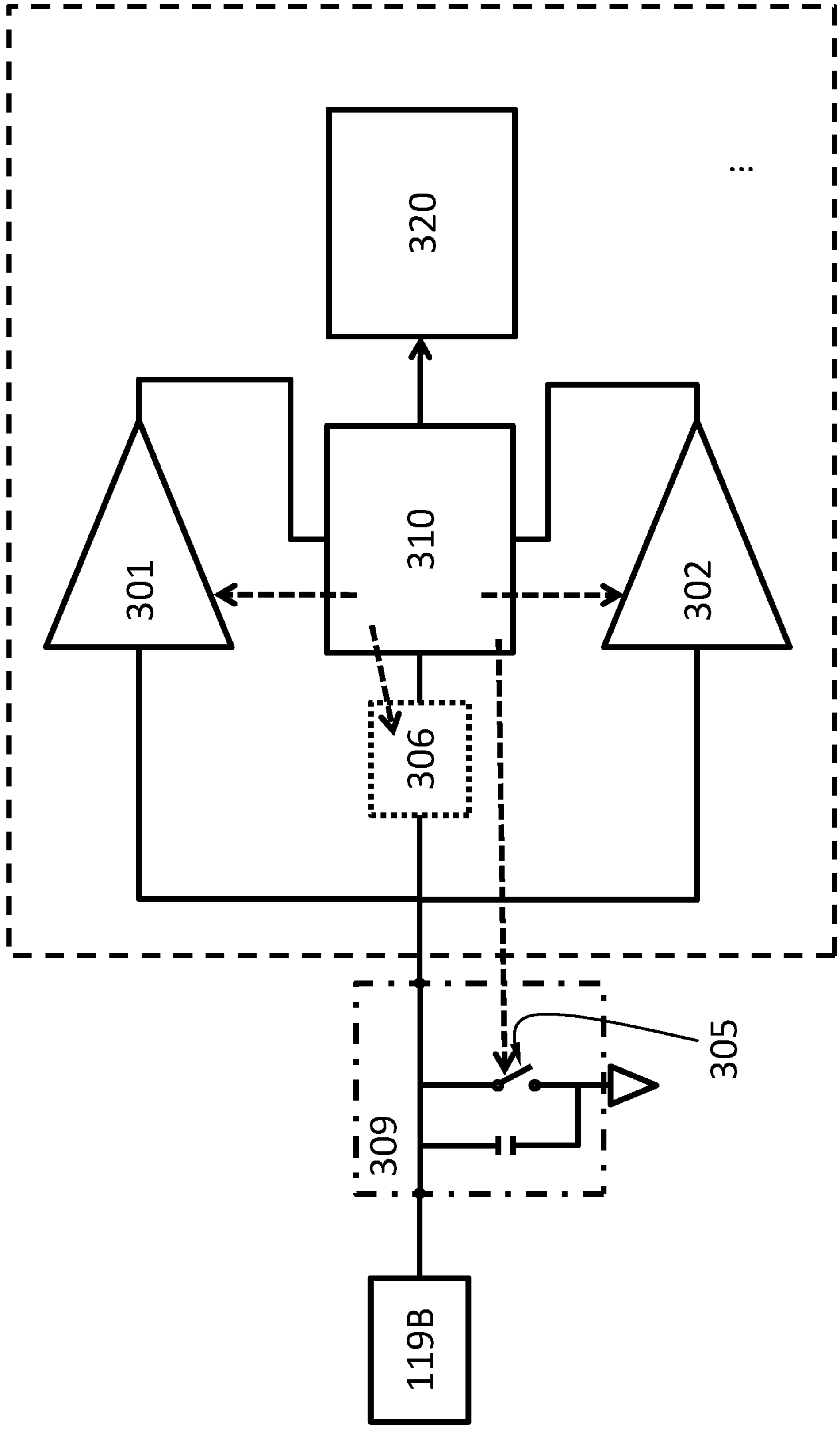


Fig. 14B

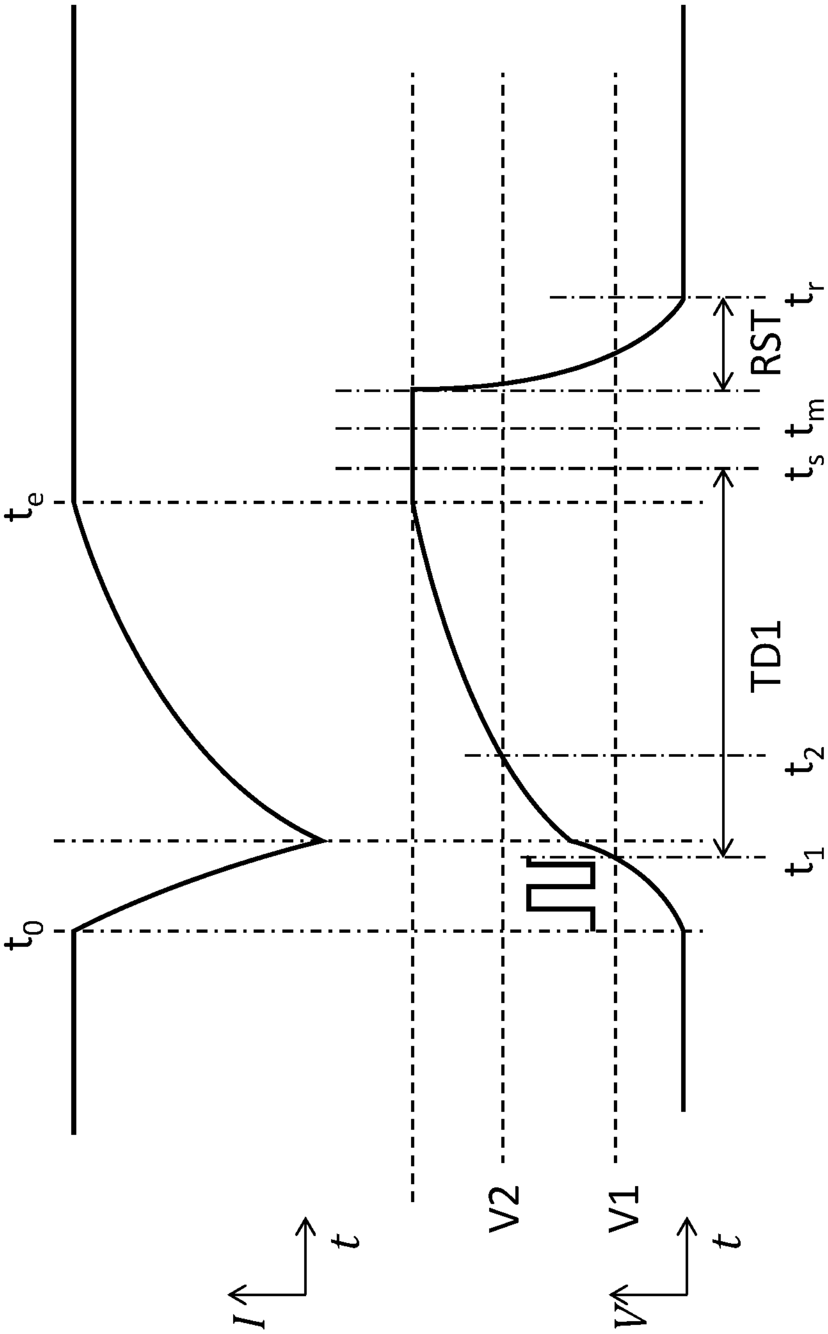


Fig. 15

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2018/106376

A. CLASSIFICATION OF SUBJECT MATTER

A61B 6/00(2006.01)i； G01T 1/16(2006.01)i； G01N 23/04(2018.01)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)

A61B; G01T; G01N

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; CNKI; WPI; EPODOC:XPECTVISION,imaging, radiation, X-ray, source, detector, image sensor, axis? , rotat+, translat+, first position, second position, moving, stitch+

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	CN 104173068 A (SIEMENS AKTIENGESELLSCHAFT) 03 December 2014 (2014-12-03) description, paragraphs[0038]-[0050], figures3-5	1-21
Y	CN 101965153 A (IMAGING SCIENCES INTERNATIONAL L.L.C.) 02 February 2011 (2011-02-02) description, paragraphs[0038], [0058]-[0060], [0062], claim 1, figures1, 7-9	1-21
A	CN 101933813 A (SHENZHEN INST ADVANCE TECHNOLOGY CHINESE) 05 January 2011 (2011-01-05) the whole document	1-21
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Date of the actual completion of the international search	Date of mailing of the international search report
08 May 2019	**27 May 2019**

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