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(54) **PIXEL TYPE TWO-DIMENSIONAL IMAGE DETECTOR**

DETEKTOR FÜR ZWEIDIMENSIONALE GEPIXELTE BILDER

DÉTECTEUR D'IMAGE BIDIMENSIONNELLE DU TYPE À PIXELS

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- **None**

EP 2 533 072 B1

Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to a pixel-type two-dimensional image detector capable of detecting heavy particle beams such as, for example, alpha particle (particle beam having the mass heavier than the mass of proton) and neutron beam by using fluorescent materials in order to create two-dimensional images with much greater accuracy in associate with the incident beam intensity of heavy particle beam and neutron. The technologies for two-dimensional image detectors are useful for the space technology field as well as the nuclear technology field and the medical technology field.

[0002] Conventionally, as for the two-dimensional neutron image detector for heavy particle beams, more specifically, alpha particles, what have been used include a particle beam detector formed by combining a fluorescent material-based particle beam detecting sheet and a wavelength shifting fiber. As for the two-dimensional neutron image detector used for neutron scattering experiments using neutron sources generated by a nuclear reactor or an accelerator, what have been used include such a detector as being formed by combining a neutron-sensitive scintillator or a fluorescent neutron detecting sheet formed together with a fluorescent material and a neutron converter with a wavelength shifting fiber (refer to Patent Literatures 1 and 2, and Non-Patent Literature 1).

[0003] Such two-dimensional image detector is so configured that the position information may be obtained by using a cross-fiber reading method. What have been used include a cross-fiber reading method, including proven methods such as a method for determining the incident position by using a coincidence counting method using such a sheet configuration that a couple of wavelength shifting fiber bundles are arranged diagonally on the upper surface and the bottom surface of the fluorescent material sheet or the scintillator plate, a method for determining the incident position by using a coincidence counting method using such a sheet configuration that couple of wavelength shifting fiber bundles are arranged diagonally on the back surface of the scintillator by improving the cross-fiber reading method, and a method using such a sheet configuration that a couple of wavelength shifting fiber bundles are arranged diagonally and that scintillators are arranged on its upper surface and bottom surface (for example, refer to Patent Literatures 1 and 2, and Non-Patent Literature 1).

[0004]

[Patent Literature 1] JP 2000-187007 A
[Patent Literature 2] JP 2002-71816 A

[0005] [Non-Patent Literature 1] Nucl. Instr. And Meth. , A430 (1999) PP. 311-320

BRIEF SUMMARY OF THE INVENTION

[PROBLEMS TO BE SOLVED BY THE INVENTION]

[0006] In the above described methods, in which the wavelength shifting fibers are arranged on a plane, there are such disadvantages that the construction of the two-dimensional image detector having a large detection area may require a complicated work, and that the fluorescent light may be diffused over the surrounding pixels other than the pixel at the incident position as there is no boundary between the pixels and thus the fluorescent light emitted from the fluorescent material sheet resultantly enter a plurality of wavelength shifting fibers.

[0007] An object of the present invention is to provide a pixel-type two-dimensional image detector capable of creating two-dimensional images with much greater accuracy in associate with the incident beam intensity of heavy particle beam and neutron by reducing the leakage of the fluorescent light, which is generated by heavy particle beam and neutron, into the pixels other than the incident pixel.

[0008] In the present invention, what is used as the detecting member for measuring the heavy particle beam is a fluorescent material-based heavy particle beam detecting sheet formed by applying the fluorescent material in the form of polycrystalline fine particle along with the binder onto the transparent substrate such as glass-based plate. In addition, as for the detecting member for measuring the neutron beam, what is used as the detecting member for measuring the neutron beam is a fluorescent material-based neutron detecting sheet formed by mixing the fluorescent material in the form of polycrystalline fine particle and the material including any one or both of ^{6}Li element and ^{10}B element, both acting as a neutron converter, and by applying this mixture along with the binder or sintering the mixture onto the metallic substrate such as aluminum plate. The detecting sheet is translucent so that the leakage into the pixels other than the incident pixel may be reduced as much as possible. In addition, it will be appreciated that the detecting accuracy can be increased also by adjusting the thickness of the detecting sheet to be 0.7mm or less in order to make the leakage area smaller.

[MEANS FOR SOLVING THE PROBLEMS]

[0009] In the pixel-type two-dimensional image detector having the most simplified structure among the two-dimensional image detectors formed according to the present invention, a lattice-like fluorescent light detecting member is used as means for determining the incident position of the heavy particle beam or neutron by detecting the fluorescent light emitted from such detecting sheet as described above, in the lattice-like pixel structure in which a series of reflecting plates that reflect the fluorescent light from the fluorescent material-based heavy particle detecting sheet emitting the fluorescent light in response to the incident of the heavy particle beam are arranged along a vertical axis at regular intervals, and a series of reflecting plates that reflect the fluorescent light are also arranged along the horizontal axis at regular intervals and at a right angle with respect to a series of fluorescent light reflecting plates arranged along the vertical axis so as to configure resultantly a couple of series of fluorescent plates, which has such a structure that has any groove being formed so as to put a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light at the upper half position of the reflecting plates arranged along the vertical axis and at the center position in the vertical axis intervals, and that any groove being formed so as to put a single wavelength shifting fiber for horizontal axis detection for detecting the fluorescent light at the lower half position of the reflecting plates arranged along the horizontal axis and at the center position in the horizontal axis intervals, said fluorescent material-based heavy particle beam detecting sheet for emitting the fluorescent light in response to an incident heavy particle beam is translucent and arranged only at a front surface or at both of a front surface and a back surface of the lattice-like fluorescent light detecting member, wherein a fluorescent light with its wavelength converted by and emitted from the wavelength shifting fiber for vertical axis detection and the wavelength shifting fiber for horizontal axis detection may be detected by respectively vertical and horizontal photodetectors to obtain a vertical axis pulse signal and a horizontal axis pulse signal; and an incident position of the heavy particle beam may be determined by applying a coincidence count measurement to the vertical axis pulse signal and the horizontal axis pulse signal.

[0010] Note that, though a single wavelength shifting fiber for vertical axis detection and a single wavelength shifting fiber for horizontal axis detection are provided for the individual pixel, respectively, in the most simplified structure described above, two or more wavelength shifting fibers may be provided for the individual pixels if required in case of expecting higher detection sensitivity.

[EFFECTS OF THE INVENTION]

[0011] According to the present invention, it will be appreciated that the leakage of the fluorescent light to the pixels other than the incident pixel may be reduced significantly because the above described translucent and thin detecting sheets are arranged at the front surface or at both of the front surface and the back surface of the lattice-like fluorescent light detecting member that is comprised in the matrix-like pixels as described above so that the image detection for the heavy ion beam or neutron beam may be enabled.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0012]

FIG. 1 illustrates a structure of the pixel-type two-dimensional image detector using heavy particle beam detecting medium according to one embodiment of the present invention.

FIG. 2 illustrates a structure of the pixel-type two-dimensional image detector using neutron detecting medium according to one embodiment of the present invention.

FIG. 3 illustrates a structure of the pixel-type two-dimensional image detector using heavy particle beam detecting medium not according to the present invention.

FIG. 4 illustrates a structure of the pixel-type two-dimensional image detector using neutron detecting medium not according to the present invention.

FIG. 5 illustrates a structure of the pixel-type two-dimensional image detector using heavy particle beam detecting medium not according to the present invention.

FIG. 6 illustrates a structure of the pixel-type two-dimensional image detector using neutron detecting medium according to another embodiment of the present invention.

FIG. 7 illustrates a structure of the pixel-type two-dimensional image detector using heavy particle beam detecting medium not according to the present invention.

FIG. 8 illustrates a structure of the pixel-type two-dimensional image detector using neutron detecting medium according to another embodiment of the present invention.

FIG. 9 illustrates a structure of the pixel-type two-dimensional image detector using heavy particle beam detecting medium not according to the present invention.

FIG. 10 illustrates a structure of the pixel-type two-dimensional image detector using heavy particle beam detecting medium not according to the present invention.

FIG. 11 illustrates a structure of the pixel-type two-dimensional image detector using neutron detecting medium not according to present invention.

FIG. 12 illustrates a structure of the pixel-type two-dimensional image detector using neutron detecting medium not according to the present invention.

FIG. 13(A) and FIG. 13(B) illustrates an influence of the fluorescent light over the surrounding pixels in the two-dimensional neutron image detector.

FIG. 14 illustrates the three-dimensional view of the influence of the fluorescent light over the surrounding pixels in the two-dimensional neutron image detector.

FIG. 15 shows the detection efficiency for thermal neutrons in case that the detecting sheets are arranged at the front surface or at both of the front surface and the back surface of the lattice-like fluorescent light detecting member.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0013] The pixel-type two-dimensional image detector according to the present invention is set out in the appended claim 1.

[0014] By referring to FIG. 1 through FIG. 15, the actual exemplary implementation of the above described principal structure will be described below. The following embodiments 3, 4, 5, 7, and 9 to 12 are not in accordance with the present invention and are present for illustration purposes only.

[Embodiment]

(Embodiment 1)

[0015] As Embodiment 1, the structure of the pixel-type two-dimensional image detector using heavy particle beam detecting medium according to the present invention is shown in FIG. 1.

[0016] In this embodiment, a translucent and thin fluorescent material-based heavy particle beam detecting sheet is used as the heavy particle beam detecting medium, which may be formed by using ZnS:Ag as a fluorescent material, and applying the ZnS:Ag-based fluorescent material with the coating density of 30mg/cm^2 onto the glass-based plate having the thickness of 0.1mm by using the binder. A mirror-finished aluminum plate is used as the material for the fluorescent light reflecting bottom plate disposed at the bottom part.

[0017] Next, the lattice-like fluorescent light detecting member will be described below. As shown in FIG. 1, the reflecting plates each of which reflects the fluorescent light emitted from the fluorescent material-based heavy particle beam detecting sheet that emits the fluorescent light in response to the incident of the heavy particle beam are arranged along the vertical axis at regular intervals. The interval between the adjacent reflecting plates may be defined to be 5mm. In addition, the other reflecting plates each of which reflects the fluorescent light are arranged along the horizontal axis at regular intervals and at a right angle with respect to a series of fluorescent light reflecting plates arranged along the vertical axis. The interval between the adjacent reflecting plates in the horizontal direction may be defined to be 5mm. A mirror-finished aluminum plate is used as the material for the reflecting plates, and its dimension may be defined to be the height of 2mm, the length of 325mm, and the thickness of 0.15mm.

[0018] As for the method for manufacturing the lattice-like structure, a groove having the width being 100μm wider than the thickness of the reflecting plate and the length being half of the depth width of the reflecting plate is formed on the reflecting plates arranged in the vertical axis direction and at the same interval as the interval of the reflecting plates arranged in the horizontal axis direction, and a groove having the width being 100μm wider than the thickness of the reflecting plate and the length being half of the depth width of the vertical axis reflecting plate is formed on the reflecting plates arranged in the horizontal axis direction and at the same interval as the interval of the reflecting plates arranged in the vertical axis direction, and finally the vertical axis reflecting plate and the horizontal axis reflecting plate are made cross each other by using the grooves so formed as described above. In the subsequent embodiments, the lattice-like structure may be formed by the same method as described above.

[0019] In the lattice-like structure in which a series of vertical axis reflecting plates and a series of horizontal axis reflecting plates are formed in the way as described above, the structure is so provided that an individual groove is formed at the upper half positions on the reflecting plate arranged in the vertical axis direction and at the center position on the vertical axis interval, that is, at the position corresponding to 2.5 mm in this embodiment, so as to accommodate a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light. As shown in FIG. 1, the groove may be shaped in combination of a semicircular part and a square part so as to prevent the fluorescent light from leaking out to the neighboring pixels. The diameter of the semicircular part may be 1.1mm and the edge length of the square part may be 1.1mm. As for the wavelength shifting fiber, BCF-92MC commercially available from Saint-Gobain K.K. is used, that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm. The wavelength shifting fiber may be shaped in a circular form with 1mm diameter.

[0020] Similarly, the structure is so provided that an individual groove is formed at the upper half positions on the reflecting plate arranged in the horizontal axis direction and at the center position on the horizontal axis interval so as to accommodate a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light. As shown in FIG. 1, the groove may be shaped in combination of a semicircular part and a square part so as to prevent the fluorescent light from leaking out to the neighboring pixels. The diameter of the semicircular part may be 1.1mm and the edge length of the square part may be 1.1mm.

[0021] As the wavelength of the fluorescent light emitted from ZnS:Ag-based fluorescent material has a distribution with its center at 450nm, the emitted fluorescent light have a wavelength range from 360nm to 540nm and the life-time of the short life-time component of the emitted fluorescent light is 300ns, BCF-92MC commercially available from Saint-Gobain K.K., that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm, is used as the wavelength shirting fiber. The wavelength shifting fiber may be shaped in a circular form with 1mm diameter.

[0022] Now that the lattice-like fluorescent light detecting member is so formed as described above, ZnS:Ag may be used as the fluorescent material to be applied, and ZnS:Ag-based fluorescent material may be coated with the coating density of 30mg/cm^2 onto the glass-based plate having the thickness of 0.1mm by using the binder, and finally the fluorescent material-based heavy particle beam detecting sheet may be disposed only onto the front surface of the lattice-like fluorescent light detecting member.

[0023] As for the optical detector for detecting the emitted fluorescent light experienced with wavelength shifting by the wavelength shifting fibers BCF-92MC, H7546 commercially available from HAMAMATSU PHOTONICS K.K. may be used, that is a 64-channel photomultiplier tube, each channel having an effective sensitive area of 2mm×2mm. The individual photoelectric signals output from a couple of photomultiplier tubes for vertical axis and horizontal axis, respectively, are amplified by the amplifiers, and then the individual amplified signals are converted into the digital pulse signals by the pulse height discriminators, respectively, and finally X-axis pulse signal and Y-axis pulse signal are obtained. The two-dimensional incident position of the heavy particle beam is determined by applying the coincidence count measurement to both of the X-axis pulse signal and the Y-axis pulse signal. As for the coincidence count time (coincidence time), the coincidence count time (coincidence time) is defined to be 1μs corresponding to about three times of the life time of the short life-time component of the fluorescent light from ZnS:Ag fluorescent material.

[0024] Using 65 reflecting plates and 64 wavelength shifting fibers for the vertical axis, and using 65 reflecting plates and 64 wavelength shifting fibers for the horizontal axis, a two-dimensional heavy particle beam image detector with 64 channels for the vertical axis and 64 channels for the horizontal axis, and with a large sensitive area with 320mm×320mm dimension for the heavy particle beam may be obtained.

(Embodiment 2)

[0025] As Embodiment 2, referring to FIG. 2, the pixel-type two-dimensional image detector using neutron detecting medium according to the present invention is described below. The structure of the two-dimensional image detector in Embodiment 2 is similar to the structure in Embodiment 1 except the structure of the detecting sheet.

[0026] In this embodiment, a neutron detecting sheet commercially available from AST in England (containing ZnS:Ag and ^{6}LiF with a mixing ratio of 4:1) is used, which was manufactured by using ZnS:Ag as the neutron detecting medium, which may be formed by ZnS:Ag as a fluorescent material, and mixing them with binder material. This detecting sheet is translucent and its thickness is 0.45mm.

[0027] Next, the lattice-like fluorescent light detecting member will be described below. As shown in FIG. 1, the reflecting plates each of which reflects the fluorescent light emitted from the fluorescent material-based neutron detecting sheet that emits the fluorescent light in response to the incident of the neutron are arranged along the vertical axis at regular intervals. The interval between the adjacent reflecting plates may be defined to be 5mm. In addition, the other reflecting plates each of which reflects the fluorescent light are arranged along the horizontal axis at regular intervals and at a right angle with respect to a series of fluorescent light reflecting plates arranged along the vertical axis. The interval between the adjacent reflecting plates in the horizontal direction may be defined to be 5mm. A mirror-finished aluminum plate is used as the material for the reflecting plates, and its dimension may be defined to be the height of 2mm, the length of 325mm, and the thickness of 0.15mm.

[0028] In the lattice-like structure in which a series of vertical axis reflecting plates and a series of horizontal axis reflecting plates are formed in the way as described above, the structure is so provided that an individual groove is formed at the upper half positions on the reflecting plate arranged in the vertical axis direction and at the center position on the vertical axis interval, that is, at the position corresponding to 2.5 mm in this embodiment, so as to accommodate a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light. As shown in FIG. 1, the groove may be shaped in combination of a semicircular part and a square part so as to prevent the fluorescent light from leaking out to the neighboring pixels. The diameter of the semicircular part may be 1.1mm and the edge length of the square part may be 1.1mm. As for the wavelength shifting fiber, BCF-92MC commercially available from Saint-Gobain K.K. is used, that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm. The wavelength shifting fiber may be shaped in a circular form with 1mm diameter.

[0029] Similarly, the structure is so provided that an individual groove is formed at the upper half positions on the reflecting plate arranged in the horizontal axis direction and at the center position on the horizontal axis interval so as to accommodate a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light. As shown in FIG. 1, the groove may be shaped in combination of a semicircular part and a square part so as to prevent the fluorescent light from leaking out to the neighboring pixels. The diameter of the semicircular part may be 1.1mm and the edge length of the square part may be 1.1mm.

[0030] As the wavelength of the fluorescent light emitted from ZnS:Ag-based fluorescent material has a distribution with its center at 450nm, the emitted fluorescent light have a wavelength range from 360nm to 540nm and the life-time of the short life-time component of the emitted fluorescent light is 300ns, BCF-92MC commercially available from Saint-Gobain K.K., that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm, is used as the wavelength shirting fiber. The wavelength shifting fiber may be shaped in a circular form with 1mm diameter.

[0031] Now that the lattice-like fluorescent light detecting member is so formed as described above, the neutron detecting sheet having the thickness of 0.45mm commercially available from AST may be disposed only onto the front surface of the lattice-like fluorescent light detecting member.

[0032] A couple of wavelength shifting fibers, BCF-92MC, may be combined and connected to the optical detector. As for the optical detector for detecting the emitted fluorescent light experienced with wavelength shifting by the combined wavelength shifting fibers, H7546 commercially available from HAMAMATSU PHOTONICS K.K. may be used, that is a 64-channel photomultiplier tube, each channel having an effective sensitive area of 2mm x 2mm. The individual photoelectric signals output from a couple of photomultiplier tubes for the vertical axis and the horizontal axis, respectively, are amplified by the amplifiers, and then the individual amplified signals are formed as X-axis pulse signal and Y-axis pulse signal. The two-dimensional neutron incident position is determined by coincident count measurement of X-axis pulse signal and Y-axis pulse signal. The coincidence count time (coincidence time) is defined to be 1μs corresponding to about three times of the short life-time component of the fluorescent light from ZnS:Ag fluorescent material.

[0033] Using 65 reflecting plates and 64 wavelength shifting fibers for the vertical axis, and using 65 reflecting plates and 64 wavelength shifting fibers for the horizontal axis, a two-dimensional neutron image detector with 64 channels for the vertical axis and 64 channels for the horizontal axis, and with a large sensitive area with 320mm×320mm dimension for the neutron may be obtained.

[0034] In order to estimate the effect of the fluorescent light over the surrounding pixels in the neutron image detector, neutron scattering experiments with YAG crystal were performed by using pulsed neutrons. Scattering from the single crystal was measured by using YAG crystal with a 3mm×3mm×3mm dimension and a neutron image detector of this embodiment arranged at the position 50cm apart from YGA crystal in the right angle to the direction of the neutron beam. As shown in FIG. 13(A) and FIG. 13(B), it is proved by the experimental result that a single peak can be observed at the single pixel due to the neutron scattering. For the better understanding of this result, FIG. 14 is provided for showing the cross-sectional distribution in the X-axis direction and the Y-axis direction, respectively. Most point values show background counts excluding one exceptional point. It is confirmed that there is almost no effect over the surrounding pixels in the X-axis and Y-axis.

[0035] As for the neutron detecting medium in this embodiment, a couple of ZnS:Ag/$^{10}B_2O_3$ neutron detecting sheets (containing ZnS:Ag and $H_3{}^{10}BO_3$ with a mixing ratio of 3:2), each having a thickness of 0.25mm manufactured by sintering process using ZnS:Ag as a fluorescent material and using $^{10}B_2O_3$ as a neutron converter may be used and disposed at both of the front face and the rear face of the lattice-like fluorescent light detecting member, respectively, and then, its detection efficiency for the thermal neutrons was measured. FIG. 15 shows the measurement result of the detection efficiency for the coincidence count time varying from 0.1μs to 3μs. It is confirmed from the experimental result for the coincident count time of 1μs that the detection efficiency was 30% in case that the neutron detecting sheet is disposed only at the front face and that the detection efficiency was 48% in case that the neutron detecting sheets are disposed at both of the front face and the rear face, that is, increased by 1.6 times.

(Embodiment 3)

[0036] As Embodiment 3, referring to FIG. 3, another pixel-type two-dimensional image detector using a heavy particle beam detecting sheet is described below.

[0037] In case that the intervals between reflecting plates in the vertical axis and the horizontal axis, respectively, are made wider in order to obtain a pixel size larger than that in Embodiments 1 and 2, it may be difficult to collect sufficiently the fluorescent light emitted from the fluorescent material-based heavy particle beam detecting sheet with a single wavelength shifting fiber for X-axis and a single wavelength shifting fiber for Y-axis, respectively. In order to solve this problem, it is required to increase the number of wavelength shifting fibers for X-axis and Y-axis, respectively.

[0038] In addition, in case that the diameter of the wavelength shifting fiber in the reflecting plate is made 1mm or larger for the fiber with its cross-section shaped in a circular form, and that the edge of the wavelength shifting fiber in the reflecting plate is made 1mm or larger for the fiber with its cross-section shaped in a square form, the fluorescent light may be absorbed only by the wavelength shifting fiber disposed at the upper part and hence the fluorescent light to be collected by the wavelength shifting fiber disposed at the lower part may be reduced, which resultantly leads to some increased count loss in the coincidence count measurement. As the wavelength shifting fiber is sensitive to gamma rays to be considered as the background for the heavy particle beam measurement, in case that the diameter of the wavelength shifting fiber is made 1mm or larger for the fiber with its cross-section shaped in a circular form, and that the edge of the wavelength shifting fiber is made 1mm or larger for the fiber with its cross-section shaped in a square form, the count loss may increase due to the dimension of the diameter or edge of the wavelength shifting fiber. Owing to those factors, in comparison to the intervals between adjacent reflecting plates in the vertical axis and the horizontal axis, respectively, in case that the diameter of the wavelength shifting fiber with its cross-section shaped in a circular form is small or in case that the edge of the wavelength shifting fiber with its cross-section shaped in a square form is short, it is difficult to collect sufficiently the fluorescent light emitted from the fluorescent material-based heavy particle beam detecting sheet. In order to solve this problem, it is required to increase the number of wavelength shifting fibers for X-axis and Y-axis, respectively.

[0039] This embodiment, in order to increase the pixel size, will be described for the case that the intervals between adjacent reflecting plates in the vertical axis and the horizontal axis is 9mm. A mirror-finished aluminum plate is used as the material for the reflecting plates, and its dimension may be defined to be the height of 2mm, the length of 585mm, and the thickness of 0.15mm.

[0040] In this embodiment, a fluorescent material-based heavy particle beam detecting sheet is used as the heavy particle beam detecting medium, which may be formed by using ZnS:Ag as a fluorescent material, and applying the ZnS:Ag-based fluorescent material with the coating density of 30mg/cm^2 onto the glass-based plate having the thickness of 0.1mm by using the binder. A mirror-finished aluminum plate is used as the material for the fluorescent light reflecting bottom plate disposed at the bottom part.

[0041] Next, the lattice-like fluorescent light detecting member will be described below. As shown in FIG. 3, the reflecting plates each of which reflects the fluorescent light emitted from the fluorescent material-based heavy particle beam detecting sheet that emits the fluorescent light in response to the incident of the heavy particle beam is arranged along the vertical axis at regular intervals. The interval between the adjacent reflecting plates may be defined to be 9mm. In addition, the other reflecting plates each of which reflects the fluorescent light are arranged along the horizontal axis at regular intervals and at a right angle with respect to a series of fluorescent light reflecting plates arranged along the vertical axis. The interval between the adjacent reflecting plates in the horizontal direction may be defined to be 9mm. A mirror-finished aluminum plate is used as the material for the reflecting plates, and its dimension may be defined to be the height of 2mm, the length of 585mm, and the thickness of 0.15mm.

[0042] In the lattice-like structure in which a series of vertical axis reflecting plates and a series of horizontal axis reflecting plates are formed in the way as described above, the structure is so provided that individual grooves are formed at the upper half positions on the reflecting plate arranged in the vertical axis direction and at the center position on the vertical axis interval, that is, at the positions corresponding to 3mm and 6mm in this embodiment, so as to accommodate a couple of wavelength shifting fibers for vertical axis detection for detecting the fluorescent light. As shown in FIG. 3, the grooves may be shaped in combination of a semicircular part and a square part so as to prevent the fluorescent light from leaking out to the neighboring pixels. The diameter of the semicircular part may be 0.9mm and the edge length of the square part may be 0.9mm. As for the wavelength shifting fiber, BCF-92MC commercially available from Saint-Gobain K.K. is used, that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm. The wavelength shifting fiber may be shaped in a circular form with 0.8mm diameter.

[0043] Similarly, the structure is so provided that an individual groove is formed at the upper half positions on the reflecting plate arranged in the horizontal axis direction and at the center position on the horizontal axis interval so as to accommodate a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light. As shown in FIG. 1, the groove may be shaped in combination of a semicircular part and a square part so as to prevent the fluorescent light from leaking out to the neighboring pixels. The diameter of the semicircular part may be 0.9mm and the edge length of the square part may be 0.9mm.

[0044] As the wavelength of the fluorescent light emitted from ZnS:Ag-based fluorescent material has a distribution with its center at 450nm, the emitted fluorescent light have a wavelength range from 360nm to 540nm and the life-time of the short life-time component of the emitted fluorescent light is 300ns, BCF-92MC commercially available from Saint-Gobain K.K., that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm, is used as the wavelength shirting fiber. The wavelength shifting fiber may be shaped in a circular form with 0.8mm diameter.

[0045] Now that the lattice-like fluorescent light detecting member is so formed as described above, ZnS:Ag may be used as the fluorescent material to be applied, and ZnS:Ag-based fluorescent material may be coated with the coating density of 30mg/cm^2 onto the glass-based plate having the thickness of 0.1mm by using the binder, and finally the fluorescent material-based heavy particle beam detecting sheet may be disposed only onto the front surface of the lattice-like fluorescent light detecting member. As for the optical detector for detecting the emitted fluorescent light experienced with wavelength shifting by the wavelength shifting fibers BCF-92MC, H7546 commercially available from HAMAMATSU PHOTONICS K.K. may be used, that is a 64-channel photomultiplier tube, each channel having an effective sensitive area of 2mm×2mm. The individual photoelectric signals output from a couple of photomultiplier tubes for vertical axis and horizontal axis, respectively, are amplified by the amplifiers, and then the individual amplified signals are converted into the digital pulse signals by the pulse height discriminators, respectively, and finally X-axis pulse signal and Y-axis pulse signal are obtained. The two-dimensional incident position of the heavy particle beam is determined by applying the coincidence count measurement to both of the X-axis pulse signal and the Y-axis pulse signal. As for the coincidence count time (coincidence time), the coincidence count time (coincidence time) is defined to be 1μs corresponding to about three times of the life time of the short life-time component of the fluorescent light from ZnS:Ag fluorescent material.

[0046] Using 65 reflecting plates and 64 wavelength shifting fibers for the vertical axis, and using 65 reflecting plates and 64 wavelength shifting fibers for the horizontal axis, a two-dimensional heavy particle beam image detector with 64 channels for the vertical axis and 64 channels for the horizontal axis, and with a large sensitive area with 576mm×576mm dimension for the heavy particle beam may be obtained.

(Embodiment 4)

[0047] As Embodiment 4, referring to FIG. 4, the pixel-type two-dimensional image detector according to the present invention using the neutron detecting medium according to the present invention is described below.

[0048] In case that the intervals between reflecting plates in the vertical axis and the horizontal axis, respectively, are made wider in order to obtain a pixel size larger than that in Embodiments 1 and 2, it may be difficult to collect sufficiently the fluorescent light emitted from the fluorescent material-based neutron detecting sheet with a single wavelength shifting fiber for X-axis and a single wavelength shifting fiber for Y-axis, respectively. In order to solve this problem, it is required to increase the number of wavelength shifting fibers for X-axis and Y-axis, respectively.

[0049] In addition, in case that the diameter of the wavelength shifting fiber in the reflecting plate is made 1mm or larger for the fiber with its cross-section shaped in a circular form, and that the edge of the wavelength shifting fiber in the reflecting plate is made 1mm or larger for the fiber with its cross-section shaped in a square form, the fluorescent light may be absorbed by the wavelength shifting fiber disposed at the upper part and hence the fluorescent light to be collected by the wavelength shifting fiber disposed at the lower part may be reduced, which resultantly leads to some increased count loss in the coincidence count measurement. As the wavelength shifting fiber is sensitive to gamma rays to be considered as the background for the neutron measurement, in case that the diameter of the wavelength shifting fiber is made 1mm or larger for the fiber with its cross-section shaped in a circular form, and that the edge of the wavelength shifting fiber is made 1mm or larger for the fiber with its cross-section shaped in a square form, the count loss may increase due to the dimension of the diameter or edge of the wavelength shifting fiber. Owing to those factors, in comparison to the intervals between adjacent reflecting plates in the vertical axis and the horizontal axis, respectively, in case that the diameter of the wavelength shifting fiber with its cross-section shaped in a circular form is small or in case that the edge of the wavelength shifting fiber with its cross-section shaped in a square form is short, it is difficult to collect sufficiently the fluorescent light emitted from the fluorescent material-based neutron detecting sheet. In order to solve this problem, it is required to increase the number of wavelength shifting fibers for X-axis and Y-axis, respectively.

[0050] This embodiment, in order to increase the pixel size, will be described for the case that the intervals between adjacent reflecting plates in the vertical axis and the horizontal axis is 9mm.

[0051] In this embodiment, a neutron detecting sheet commercially available from AST in England (containing ZnS:Ag and ^{6}LiF with a mixing ratio of 4:1) is used, which was manufactured by using ZnS:Ag as the neutron detecting medium, which may be formed by ZnS:Ag as a fluorescent material, and mixing them with binder material. The thickness of the detecting sheet is 0.45mm. In this embodiment, a couple of neutron detection sheets are used.

[0052] Next, the lattice-like fluorescent light detecting member will be described below. As shown in FIG. 3, the reflecting plates each of which reflects the fluorescent light emitted from the fluorescent material-based heavy particle beam detecting sheet that emits the fluorescent light in response to the incident of the heavy particle beam are arranged along the vertical axis at regular intervals. The interval between the adjacent reflecting plates may be defined to be 9mm. In addition, the other reflecting plates each of which reflects the fluorescent light are arranged along the horizontal axis at regular intervals and at a right angle with respect to a series of fluorescent light reflecting plates arranged along the vertical axis. The interval between the adjacent reflecting plates in the horizontal direction may be defined to be 9mm. A mirror-finished aluminum plate is used as the material for the reflecting plates, and its dimension may be defined to be the height of 2mm, the length of 585mm, and the thickness of 0.15mm.

[0053] In the lattice-like structure in which a series of vertical axis reflecting plates and a series of horizontal axis reflecting plates are formed in the way as described above, the structure is so provided that individual grooves are formed at the upper half positions on the reflecting plate arranged in the vertical axis direction and at the center position on the vertical axis interval, that is, at the positions corresponding to 3mm and 6mm in this embodiment, so as to accommodate a couple of wavelength shifting fibers for vertical axis detection for detecting the fluorescent light. As shown in FIG. 3, the grooves may be shaped in combination of a semicircular part and a square part so as to prevent the fluorescent light from leaking out to the neighboring pixels. The diameter of the semicircular part may be 0.9mm and the edge length of the square part may be 0.9mm. As for the wavelength shifting fiber, BCF-92MC commercially available from Saint-Gobain K.K. is used, that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm. The wavelength shifting fiber may be shaped in a circular form with 0.8mm diameter.

[0054] Similarly, the structure is so provided that an individual groove is formed at the upper half positions on the reflecting plate arranged in the horizontal axis direction and at the center position on the horizontal axis interval so as to accommodate a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light. As shown in FIG. 1, the groove may be shaped in combination of a semicircular part and a square part so as to prevent the fluorescent light from leaking out to the neighboring pixels. The diameter of the semicircular part may be 0.9mm and the edge length of the square part may be 0.9mm.

[0055] As the wavelength of the fluorescent light emitted from ZnS:Ag-based fluorescent material has a distribution with its center at 450nm, the emitted fluorescent light have a wavelength range from 360nm to 540nm and the life-time of the short life-time component of the emitted fluorescent light is 300ns, BCF-92MC commercially available from Saint-Gobain K.K., that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm, is used as the wavelength shirting fiber. The wavelength shifting fiber may be shaped in a circular form with 0.8mm diameter.

[0056] Now that the lattice-like fluorescent light detecting member is so formed as described above, a couple of neutron detecting sheets, each having the thickness of 0.45mm, commercially available from AST may be disposed onto both of the front surface and the back surface of the lattice-like fluorescent light detecting member.

[0057] As for the optical detector for detecting the emitted fluorescent light experienced with wavelength shifting by the wavelength shifting fibers BCF-92MC, H7546 commercially available from HAMAMATSU PHOTONICS K.K. may be used, that is a 64-channel photomultiplier tube, each channel having an effective sensitive area of 2mm×2mm. The individual photoelectric signals output from a couple of photomultiplier tubes for vertical axis and horizontal axis, respectively, are amplified by the amplifiers, and then the individual amplified signals are converted into the digital pulse signals by the pulse height discriminators, respectively, and finally X-axis pulse signal and Y-axis pulse signal are obtained. The two-dimensional incident position of the heavy particle beam is determined by applying the coincidence count measurement to both of the X-axis pulse signal and the Y-axis pulse signal. As for the coincidence count time (coincidence time), the coincidence count time (coincidence time) is defined to be 1μs corresponding to about three times of the life time of the short life-time component of the fluorescent light from ZnS:Ag fluorescent material.

[0058] Using 65 reflecting plates and 64 wavelength shifting fibers for the vertical axis, and using 65 reflecting plates and 64 wavelength shifting fibers for the horizontal axis, a two-dimensional neutron image detector with 64 channels for the vertical axis and 64 channels for the horizontal axis, and with a large sensitive area with 576mm×576mm dimension for the neutron may be obtained.

(Embodiment 5)

[0059] As Embodiment 5, referring to FIG. 5, the pixel-type two-dimensional image detector according to the present invention using ZnS:Ag fluorescent material as the heavy particle beam detecting medium is described below.

[0060] In case of using ZnS as the fluorescent material, the life-time of the short life-time component of the fluorescent light is extremely as short as 300ns, though the fluorescent light having the longer life-time component is also generated upon the light emission. The life-time of the longer life-time component of the fluorescent light is about as long as 70μs, which may be defined as after-glow.

[0061] In this embodiment, a method for reducing the effect by after-glow in ZnS:Ag fluorescent material will be described. In Embodiment 1 as described above, the incident position of the heavy particle beam may be determined by applying coincidence counting process to a couple of fluorescent lights emitted from the single wavelength shifting fiber for the vertical axis and the single wavelength shifting fiber for the horizontal axis, respectively. Upon incidence of the heavy particle beam into the detector with a higher counting rate, the fluorescent light due to after-glow may not completely disappear, and hence the fluorescent light signals from the wavelength shifting fibers in the vertical axis and the horizontal axis in which the higher intensity of after-glow arises other than the incident position of the heavy particle beam may be measured as the coincidence count randomly, and identified as the positions corresponding to the background count. Specifically, in case of using the wavelength shifting fibers for detecting the fluorescent light, as the detection efficiency for the fluorescent light may be significantly as low as about 3%, and thus it is often required to use such a method that the detection of the fluorescent light by the photodetector may be performed by counting individual photons separately (photo-counting), the number of background counts measured randomly may increase.

[0062] In this embodiment, a fluorescent material-based heavy particle beam detecting sheet is used as the heavy particle beam detecting medium, which may be formed by using ZnS:Ag as a fluorescent material, and applying the ZnS:Ag-based fluorescent material with the coating density of 30mg/cm^2 onto the glass-based plate having the thickness of 0.1mm by using the binder. A mirror-finished aluminum plate is used as the material for the fluorescent light reflecting bottom plate disposed at the bottom part.

[0063] Next, the lattice-like fluorescent light detecting member will be described below. As shown in FIG. 1, the reflecting plates each of which reflects the fluorescent light emitted from the fluorescent material-based heavy particle beam detecting sheet that emits the fluorescent light in response to the incident of the heavy particle beam are arranged along the vertical axis at regular intervals. The interval between the adjacent reflecting plates may be defined to be 6mm. In addition, the other reflecting plates each of which reflects the fluorescent light are arranged along the horizontal axis at regular intervals and at a right angle with respect to a series of fluorescent light reflecting plates arranged along the vertical axis. The interval between the adjacent reflecting plates in the horizontal direction may be defined to be 6mm. A mirror-finished aluminum plate is used as the material for the reflecting plates, and its dimension may be defined to be the height of 2mm, the length of 390mm, and the thickness of 0.15mm.

[0064] In the lattice-like structure in which a series of vertical axis reflecting plates and a series of horizontal axis reflecting plates are formed in the way as described above, the structure is so provided that individual grooves are formed at the upper half positions on the reflecting plate arranged in the vertical axis direction and at the center position on the vertical axis interval, that is, at the positions corresponding to 2mm and 4mm in this embodiment, so as to accommodate a couple of wavelength shifting fibers for vertical axis detection for detecting the fluorescent light. As shown in FIG. 3, the grooves may be shaped in combination of a semicircular part and a square part so as to prevent the fluorescent light from leaking out to the neighboring pixels. The diameter of the semicircular part may be 1.1mm and the edge length of the square part may be 1.1mm. As for the wavelength shifting fiber, BCF-92MC commercially available from Saint-Gobain K.K. is used, that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm. The wavelength shifting fiber may be shaped in a circular form with 1mm diameter.

[0065] Similarly, the structure is so provided that an individual groove is formed at the upper half positions on the reflecting plate arranged in the horizontal axis direction and at the center position on the horizontal axis interval so as to accommodate a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light. As shown in FIG. 1, the groove may be shaped in combination of a semicircular part and a square part so as to prevent the fluorescent light from leaking out to the neighboring pixels. The diameter of the semicircular part may be 1.1mm and the edge length of the square part may be 1.1mm.

[0066] As the wavelength of the fluorescent light emitted from ZnS:Ag-based fluorescent material has a distribution with its center at 450nm, the emitted fluorescent light have a wavelength range from 360nm to 540nm and the life-time of the short life-time component of the emitted fluorescent light is 300ns, BCF-92MC commercially available from Saint-Gobain K.K., that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm, is used as the wavelength shirting fiber. The wavelength shifting fiber may be shaped in a circular form with 1mm diameter.

[0067] Now that the lattice-like fluorescent light detecting member is so formed as described above, ZnS:Ag may be used as the fluorescent material to be applied, and ZnS:Ag-based fluorescent material may be coated with the coating density of 30mg/cm^2 onto the glass-based plate having the thickness of 0.1mm by using the binder, and finally the fluorescent material-based heavy particle beam detecting sheet may be disposed only onto the front surface of the lattice-like fluorescent light detecting member.

[0068] As for the optical detector for detecting the emitted fluorescent light experienced with wavelength shifting by the wavelength shifting fibers BCF-92MC, H7546 commercially available from HAMAMATSU PHOTONICS K.K. may be used, that is a 64-channel photomultiplier tube, each channel having an effective sensitive area of 2mm×2mm. The individual photoelectric signals output from a couple of photomultiplier tubes for the vertical axis are amplified by the amplifiers, and then the individual amplified signals are converted into the digital pulse signals by the pulse height discriminators, respectively, and finally a couple of Y-axis position determining pulse signals are obtained. Applying the coincidence count measurement to a couple of Y-axis position determining pulse signals (for example, Y1-1 and Y1-2 for the first pixel), if the coincidence of those signals is detected, the incidence position in Y-axis is determined and then Y-axis pulse signal is provided. Similarly, the individual photoelectric signals output from a couple of photomultiplier tubes for the horizontal axis are amplified by the amplifiers, and then the individual amplified signals are converted into the digital pulse signals by the pulse height discriminators, respectively, and finally a couple of X-axis position determining pulse signals are obtained. Applying the coincidence count measurement to a couple of X-axis position determining pulse signals (for example, X1-1 and X1-2 for the first pixel), if the coincidence of those signals is detected, the incidence position in Y-axis may be determined and then Y-axis pulse signal is provided. Finally, in case that the coincidence of Y-axis pulse and X-axis pulse is detected, the two-dimensional incident position of the heavy particle beam may be determined. As for the coincidence count time (coincidence time), the coincidence count time (coincidence time) is defined to be 1μs corresponding to about three times of the life time of the short life-time component of the fluorescent light from ZnS:Ag fluorescent material.

[0069] By repeating the coincidence count measurement three times, it will be appreciated that the event probability for the background counts occurring randomly due to after-glow in ZnS:Ag may be reduced.

[0070] Using 65 reflecting plates and 64 wavelength shifting fibers for the vertical axis, and using 65 reflecting plates and 64 wavelength shifting fibers for the horizontal axis, a two-dimensional heavy particle beam image detector with 64 channels for the vertical axis and 64 channels for the horizontal axis, and with a large sensitive area with 384mm×384mm dimension for the heavy particle beam may be obtained.

(Embodiment 6)

[0071] As Embodiment 6, referring to FIG. 6, the pixel-type two-dimensional image detector according to the present invention using ZnS:Ag fluorescent material as the neutron detecting medium according to the present invention is described below.

[0072] In case of using ZnS as the fluorescent material, the life-time of the short life-time component of the fluorescent light is extremely as short as 300ns, though the fluorescent light having the longer live-time component is also generated upon the light emission. The life-time of the longer life-time component of the fluorescent light is about as long as 70μs, which may be defined as after-glow.

[0073] In this embodiment, a method for reducing the effect by after-glow in ZnS:Ag fluorescent material will be described. In Embodiment 1 as described above, the incident position of the neutron may be determined by applying coincidence counting process to a couple of fluorescent lights emitted from the single wavelength shifting fiber for the vertical axis and the single wavelength shifting fiber for the horizontal axis, respectively. Upon incidence of neutron into the detector with a higher counting rate, the fluorescent light due to after-glow may not completely disappear, and hence the fluorescent light signals from the wavelength shifting fibers in the vertical axis and the horizontal axis in which the higher intensity of after-glow arises other than the incident position of the heavy particle beam may be measured as the coincidence count randomly, and identified as the positions corresponding to the background count. Specifically, in case of using the wavelength shifting fibers for detecting the fluorescent light, as the detection efficiency for the fluorescent light may be significantly as low as about 3%, and thus it is often required to use such a method that the detection of the fluorescent light by the photodetector may be performed by counting individual photons separately (photo-counting), the number of background counts measured randomly may increase.

[0074] In this embodiment, a neutron detecting sheet commercially available from AST in England (containing ZnS:Ag and ^{6}LiF with a mixing ratio of 4:1) is used, which was manufactured by using ZnS:Ag as the neutron detecting medium, which may be formed by ZnS:Ag as a fluorescent material, and mixing them with binder material. This detecting sheet is translucent and its thickness is 0.45mm. In this embodiment, a couple of neutron detection sheets are used and disposed at both of the front face and the rear face of the lattice-like fluorescent light material.

[0075] Next, the lattice-like fluorescent light detecting member will be described below. As shown in FIG. 3, the reflecting plates each of which reflects the fluorescent light emitted from the fluorescent material-based neutron detecting sheet that emits the fluorescent light in response to the incident of the neutron are arranged along the vertical axis at regular intervals. The interval between the adjacent reflecting plates may be defined to be 6mm. In addition, the other reflecting plates each of which reflects the fluorescent light are arranged along the horizontal axis at regular intervals and at a right angle with respect to a series of fluorescent light reflecting plates arranged along the vertical axis. The interval between the adjacent reflecting plates in the horizontal direction may be defined to be 6mm. A mirror-finished aluminum plate is used as the material for the reflecting plates, and its dimension may be defined to be the height of 2mm, the length of 390mm, and the thickness of 0.15mm.

[0076] In the lattice-like structure in which a series of vertical axis reflecting plates and a series of horizontal axis reflecting plates are formed in the way as described above, the structure is so provided that individual grooves are formed at the upper half positions on the reflecting plate arranged in the vertical axis direction and at the center position on the vertical axis interval, that is, at the positions corresponding to 2mm and 4mm in this embodiment, so as to accommodate a couple of wavelength shifting fibers for vertical axis detection for detecting the fluorescent light. As shown in FIG. 3, the grooves may be shaped in combination of a semicircular part and a square part so as to prevent the fluorescent light from leaking out to the neighboring pixels. The diameter of the semicircular part may be 1.1mm and the edge length of the square part may be 1.1mm. As for the wavelength shifting fiber, BCF-92MC commercially available from Saint-Gobain K.K. is used, that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm. The wavelength shifting fiber may be shaped in a circular form with 1mm diameter.

[0077] Similarly, the structure is so provided that an individual groove is formed at the upper half positions on the reflecting plate arranged in the horizontal axis direction and at the center position on the horizontal axis interval so as to accommodate a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light. As shown in FIG. 1, the groove may be shaped in combination of a semicircular part and a square part so as to prevent the fluorescent light from leaking out to the neighboring pixels. The diameter of the semicircular part may be 1.1mm and the edge length of the square part may be 1.1mm.

[0078] As the wavelength of the fluorescent light emitted from ZnS:Ag-based fluorescent material has a distribution with its center at 450nm, the emitted fluorescent light have a wavelength range from 360nm to 540nm and the life-time of the short life-time component of the emitted fluorescent light is 300ns, BCF-92MC commercially available from Saint-Gobain K.K., that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm, is used as the wavelength shirting fiber. The wavelength shifting fiber may be shaped in a circular form with 1mm diameter.

[0079] As for the optical detector for detecting the emitted fluorescent light experienced with wavelength shifting by the wavelength shifting fibers BCF-92MC, H7546 commercially available from HAMAMATSU PHOTONICS K.K. may be used, that is a 64-channel photomultiplier tube, each channel having an effective sensitive area of 2mm×2mm. The individual photoelectric signals output from a couple of photomultiplier tubes for the vertical axis are amplified by the amplifiers, and then the individual amplified signals are converted into the digital pulse signals by the pulse height discriminators, respectively, and finally a couple of Y-axis position determining pulse signals are obtained. Applying the coincidence count measurement to a couple of Y-axis position determining pulse signals (for example, Y1-1 and Y1-2 for the first pixel), if the coincidence of those signals is detected, the incidence position in Y-axis is determined and then Y-axis pulse signal is provided. Similarly, the individual photoelectric signals output from a couple of photomultiplier tubes for the horizontal axis are amplified by the amplifiers, and then the individual amplified signals are converted into the digital pulse signals by the pulse height discriminators, respectively, and finally a couple of X-axis position determining pulse signals are obtained.

[0080] Applying the coincidence count measurement to a couple of X-axis position determining pulse signals (for example, X1-1 and X1-2 for the first pixel), if the coincidence of those signals is detected, the incidence position in Y-axis may be determined and then Y-axis pulse signal is provided. Finally, the coincidence of Y-axis pulse and X-axis pulse is detected, the two-dimensional incident position of the heavy particle beam may be determined. As for the coincidence count time (coincidence time), the coincidence count time (coincidence time) is defined to be 1μs corresponding to about three times of the life time of the short life-time component of the fluorescent light from ZnS:Ag fluorescent material.

[0081] By repeating the coincidence count measurement three times, it will be appreciated that the event probability for the background counts occurring randomly due to after-glow in ZnS:Ag may be reduced.

[0082] Using 65 reflecting plates and 64 wavelength shifting fibers for the vertical axis, and using 65 reflecting plates and 64 wavelength shifting fibers for the horizontal axis, a two-dimensional neutron image detector with 64 channels for the vertical axis and 64 channels for the horizontal axis, and with a large sensitive area with 384mm×384mm dimension for neutron may be obtained.

(Embodiment 7)

[0083] As Embodiment 7, referring to FIG. 7, the pixel-type two-dimensional image detector according to the present invention using ZnS:Ag fluorescent material as the heavy particle beam detecting medium according to the present invention is described below.

[0084] In case of using ZnS as the fluorescent material, the life-time of the short life-time component of the fluorescent light is extremely as short as 300ns, though the fluorescent light having the longer live-time component is also generated upon the light emission. The life-time of the longer life-time component of the fluorescent light is about as long as 70μs, which may be defined as after-glow.

[0085] In this embodiment, a method for reducing the effect by after-glow in ZnS:Ag fluorescent material will be described. In Embodiment 1 as described above, the incident position of the heavy particle beam may be determined by applying coincidence counting process to a couple of fluorescent lights emitted from one end face of the single wavelength shifting fiber for the vertical axis and one end face of the single wavelength shifting fiber for the horizontal axis, respectively. Upon incidence of the heavy particle beam into the detector with a higher counting rate, the fluorescent light due to after-glow may not completely disappear, and hence the fluorescent light signals from the wavelength shifting fibers in the vertical axis and the horizontal axis in which the higher intensity of after-glow arises other than the incident position of the heavy particle beam may be measured as the coincidence count randomly, and identified as the positions corresponding to the background count. Specifically, in case of using the wavelength shifting fibers for detecting the fluorescent light, as the detection efficiency for the fluorescent light may be significantly as low as about 3%, and thus it is often required to use such a method that the detection of the fluorescent light by the photodetector may be performed by counting individual photons separately (photo-counting), the number of background counts measured randomly may increase.

[0086] In this embodiment, a fluorescent material-based heavy particle beam detecting sheet is used as the heavy particle beam detecting medium, which may be formed by using ZnS:Ag as a fluorescent material, and applying the ZnS:Ag-based fluorescent material with the coating density of 30mg/cm^2 onto the glass-based plate having the thickness of 0.1mm by using the binder. Owing to this configuration, after-glow affects the detection of the heavy particle beam. A mirror-finished aluminum plate is used as the material for the fluorescent light reflecting bottom plate disposed at the bottom part.

[0087] In order to solve the above problem, the fluorescent light emitted from the other end face of the wavelength shifting fiber may be also used in addition to the fluorescent light emitted from one end face of the individual wavelength shifting fiber for the vertical axis and the horizontal axis, respectively, in Embodiment 1.

[0088] The lattice-like fluorescent light detecting member will be described below. As shown in FIG. 3, the reflecting plates each of which reflects the fluorescent light emitted from the fluorescent material-based heavy particle beam detecting sheet that emits the fluorescent light in response to the incident of the heavy particle beam are arranged along the vertical axis at regular intervals. The interval between the adjacent reflecting plates may be defined to be 5mm. In addition, the other reflecting plates each of which reflects the fluorescent light are arranged along the horizontal axis at regular intervals and at a right angle with respect to a series of fluorescent light reflecting plates arranged along the vertical axis. The interval between the adjacent reflecting plates in the horizontal direction may be defined to be 5mm. A mirror-finished aluminum plate is used as the material for the reflecting plates, and its dimension may be defined to be the height of 2mm, the length of 325mm, and the thickness of 0.15mm.

[0089] In the lattice-like structure in which a series of vertical axis reflecting plates and a series of horizontal axis reflecting plates are formed in the way as described above, the structure is so provided that an individual groove is formed at the upper half positions on the reflecting plate arranged in the vertical axis direction and at the center position on the vertical axis interval, that is, at the position corresponding to 2.5 mm in this embodiment, so as to accommodate a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light. As shown in FIG. 1, the groove may be shaped in combination of a semicircular part and a square part so as to prevent the fluorescent light from leaking out to the neighboring pixels. The diameter of the semicircular part may be 1.1mm and the edge length of the square part may be 1.1mm. As for the wavelength shifting fiber, BCF-92MC commercially available from Saint-Gobain K.K. is used, that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm. The wavelength shifting fiber may be shaped in a circular form with 1mm diameter.

[0090] Similarly, the structure is so provided that an individual groove is formed at the upper half positions on the reflecting plate arranged in the horizontal axis direction and at the center position on the horizontal axis interval so as to accommodate a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light. As shown in FIG. 1, the groove may be shaped in combination of a semicircular part and a square part so as to prevent the fluorescent light from leaking out to the neighboring pixels. The diameter of the semicircular part may be 1.1mm and the edge length of the square part may be 1.1mm.

[0091] As the wavelength of the fluorescent light emitted from ZnS:Ag-based fluorescent material has a distribution with its center at 450nm, the emitted fluorescent light have a wavelength range from 360nm to 540nm and the life-time of the short life-time component of the emitted fluorescent light is 300ns, BCF-92MC commercially available from Saint-Gobain K.K., that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm, is used as the wavelength shirting fiber. The wavelength shifting fiber may be shaped in a circular form with 1mm diameter.

[0092] Now that the lattice-like fluorescent light detecting member is so formed as described above, ZnS:Ag may be used as the fluorescent material to be applied, and ZnS:Ag-based fluorescent material may be coated with the coating density of 30mg/cm^2 onto the glass-based plate having the thickness of 0.1mm by using the binder, and finally the fluorescent material-based heavy particle beam detecting sheet may be disposed only onto the front surface of the lattice-like fluorescent light detecting member.

[0093] As for the optical detector for detecting the emitted fluorescent light experienced with wavelength shifting by the wavelength shifting fibers BCF-92MC, H7546 commercially available from HAMAMATSU PHOTONICS K.K. may be used, that is a 64-channel photomultiplier tube, each channel having an effective sensitive area of 2mm×2mm. Both one end face and the other end face of the photomultiplier tube for vertical axis are connected to a couple of photomultiplier tubes, respectively, and fluorescent light electric signals are provided. The individual photoelectric signals provided as described above are amplified by the amplifiers, and then the individual amplified signals are converted into the digital pulse signals by the pulse height discriminators, respectively, and finally a couple of Y-axis pulse signals are obtained. Applying the coincidence count measurement to a couple of Y-axis position determining pulse signals (for example, Y1-1 and Y1-2 for the first pixel), if the coincidence of those signals is detected, the incidence position in Y-axis is determined and then Y-axis pulse signal is provided. Similarly, both one end face and the other end face of the photomultiplier tube for horizontal axis are connected to a couple of photomultiplier tubes, respectively, and fluorescent light electric signals are provided. The individual photoelectric signals provided are amplified by the amplifiers, and then the individual amplified signals are converted into the digital pulse signals by the pulse height discriminators, respectively, and finally a couple of X-axis pulse signals are obtained. Applying the coincidence count measurement to a couple of X-axis position determining pulse signals (for example, X1-1 and X1-2 for the first pixel), if the coincidence of those signals is detected, the incidence position in X-axis is determined and then X-axis pulse signal is provided.

[0094] In case that the coincidence of Y-axis pulse and X-axis pulse is detected, the two-dimensional incident position of the heavy particle beam may be determined. As for the coincidence count time (coincidence time), the coincidence count time (coincidence time) is defined to be 1μs corresponding to about three times of the life time of the short life-time component of the fluorescent light from ZnS:Ag fluorescent material.

[0095] By repeating the coincidence count measurement three times, it will be appreciated that the event probability for the background counts occurring randomly due to after-glow in ZnS:Ag may be reduced .

[0096] Using 65 reflecting plates and 64 wavelength shifting fibers for the vertical axis, and using 65 reflecting plates and 64 wavelength shifting fibers for the horizontal axis, a two-dimensional heavy particle beam image detector with 64 channels for the vertical axis and 64 channels for the horizontal axis, and with a large sensitive area with 320mm×320mm dimension for the heavy particle beam may be obtained.

(Embodiment 8)

[0097] As Embodiment 7, referring to FIG. 8, the pixel-type two-dimensional image detector according to the present invention using ZnS:Ag fluorescent material as the neutron detecting medium according to the present invention is described below.

[0098] In case of using ZnS as the fluorescent material, as shown in the figure, the life-time of the short life-time component of the fluorescent light is extremely as short as 300ns, though the fluorescent light having the longer live-time component is also generated upon the light emission. The life-time of the longer life-time component of the fluorescent light is about as long as 70μs, which may be defined as after-glow.

[0099] In this embodiment, a method for reducing the effect by after-glow in ZnS:Ag fluorescent material will be described. In Embodiment 1 as described above, the incident position of the heavy particle beam may be determined by applying coincidence counting process to a couple of fluorescent lights emitted from one end face of the single wavelength shifting fiber for the vertical axis and one end face of the single wavelength shifting fiber for the horizontal axis, respectively. Upon incidence of neutron into the detector with a higher counting rate, the fluorescent light due to after-glow may not completely disappear, and hence the fluorescent light signals from the wavelength shifting fibers in the vertical axis and the horizontal axis in which the higher intensity of after-glow arises other than the neutron incident position may be measured as the coincidence count randomly, and identified as the positions corresponding to the background count. Specifically, in case of using the wavelength shifting fibers for detecting the fluorescent light, as the detection efficiency for the fluorescent light may be significantly as low as about 3%, and thus it is often required to use such a method that the detection of the fluorescent light by the photodetector may be performed by counting individual photons separately (photo-counting), the number of background counts measured randomly may increase.

[0100] In this embodiment, a neutron detecting sheet commercially available from AST in England (containing ZnS:Ag and ^{6}LiF with a mixing ratio of 4:1) is used, which was manufactured by using ZnS:Ag as the neutron detecting medium, which may be formed by ZnS:Ag as a fluorescent material, and mixing them with binder material. This detecting sheet is translucent and its thickness is 0.45mm. In this embodiment, a couple of neutron detection sheets are used and disposed at both of the front face and the rear face of the lattice-like fluorescent light material.

[0101] In order to solve the above problem, the fluorescent light emitted from the other end face of the wavelength shifting fiber may be also advantageously used in addition to the fluorescent light emitted from one end face of the individual wavelength shifting fiber for the vertical axis and the horizontal axis, respectively, in Embodiment 1.

[0102] The lattice-like fluorescent light detecting member will be described below. As shown in FIG. 3, the reflecting plates each of which reflects the fluorescent light emitted from the fluorescent material-based neutron detecting sheet that emits the fluorescent light in response to the incident of neutron are arranged along the vertical axis at regular intervals. The interval between the adjacent reflecting plates may be defined to be 5mm. In addition, the other reflecting plates each of which reflects the fluorescent light at are arranged along the horizontal axis at regular intervals and at a right angle with respect to a series of fluorescent light reflecting plates arranged along the vertical axis. The interval between the adjacent reflecting plates in the horizontal direction may be defined to be 5mm. A mirror-finished aluminum plate is used as the material for the reflecting plates, and its dimension may be defined to be the height of 2mm, the length of 325mm, and the thickness of 0.15mm.

[0103] In the lattice-like structure in which a series of vertical axis reflecting plates and a series of horizontal axis reflecting plates are formed in the way as described above, the structure is so provided that an individual groove is formed at the upper half positions on the reflecting plate arranged in the vertical axis direction and at the center position on the vertical axis interval, that is, at the position corresponding to 2.5 mm in this embodiment, so as to accommodate a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light. As shown in FIG. 1, the groove may be shaped in combination of a semicircular part and a square part so as to prevent the fluorescent light from leaking out to the neighboring pixels. The diameter of the semicircular part may be 1.1mm and the edge length of the square part may be 1.1mm. As for the wavelength shifting fiber, BCF-92MC commercially available from Saint-Gobain K.K. is used, that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm. The wavelength shifting fiber may be shaped in a circular form with 1mm diameter.

[0104] Similarly, the structure is so provided that an individual groove is formed at the upper half positions on the reflecting plate arranged in the horizontal axis direction and at the center position on the horizontal axis interval so as to accommodate a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light. As shown in FIG. 1, the groove may be shaped in combination of a semicircular part and a square part so as to prevent the fluorescent light from leaking out to the neighboring pixels. The diameter of the semicircular part may be 1.1mm and the edge length of the square part may be 1.1mm.

[0105] As the wavelength of the fluorescent light emitted from ZnS:Ag-based fluorescent material has a distribution with its center at 450nm, the emitted fluorescent light have a wavelength range from 360nm to 540nm and the life-time of the short life-time component of the emitted fluorescent light is 300ns, BCF-92MC commercially available from Saint-Gobain K.K., that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm, is used as the wavelength shirting fiber. The wavelength shifting fiber may be shaped in a circular form with 1mm diameter.

[0106] As for the optical detector for detecting the emitted fluorescent light experienced with wavelength shifting by the wavelength shifting fibers BCF-92MC, H7546 commercially available from HAMAMATSU PHOTONICS K.K. may be used, that is a 64-channel photomultiplier tube, each channel having an effective sensitive area of 2mm×2mm. Both one end face and the other end face of the photomultiplier tube for vertical axis are connected to a couple of photomultiplier tubes, respectively, and fluorescent light electric signals are provided. The individual photoelectric signals provided as described above are amplified by the amplifiers, and then the individual amplified signals are converted into the digital pulse signals by the pulse height discriminators, respectively, and finally a couple of Y-axis pulse signals are obtained. Applying the coincidence count measurement to a couple of Y-axis position determining pulse signals (for example, Y1-1 and Y1-2 for the first pixel), if the coincidence of those signals is detected, the incidence position in Y-axis is determined and then Y-axis pulse signal is provided. Similarly, both one end face and the other end face of the photomultiplier tube for horizontal axis are connected to a couple of photomultiplier tubes, respectively, and fluorescent light electric signals are provided.

[0107] The individual photoelectric signals provided are amplified by the amplifiers, and then the individual amplified signals are converted into the digital pulse signals by the pulse height discriminators, respectively, and finally a couple of X-axis pulse signals are obtained. Applying the coincidence count measurement to a couple of X-axis position determining pulse signals (for example, X1-1 and X1-2 for the first pixel), if the coincidence of those signals is detected, the incidence position in X-axis is determined and then X-axis pulse signal is provided.

[0108] In case that the coincidence of Y-axis pulse and X-axis pulse is detected, the two-dimensional neutron incident position may be determined. As for the coincidence count time (coincidence time), the coincidence count time (coincidence time) is defined to be 1μs corresponding to about three times of the life time of the short life-time component of the fluorescent light from ZnS:Ag fluorescent material.

[0109] By repeating the coincidence count measurement three times, it will be appreciated that the event probability for the background counts occurring randomly due to after-glow in ZnS:Ag may be reduced .

[0110] Using 65 reflecting plates and 64 wavelength shifting fibers for the vertical axis, and using 65 reflecting plates and 64 wavelength shifting fibers for the horizontal axis, a two-dimensional heavy particle beam image detector with 64 channels for the vertical axis and 64 channels for the horizontal axis, and with a large sensitive area with 320mm×320mm dimension for neutron may be obtained.

(Embodiment 9)

[0111] As Embodiment 9, referring to FIG. 9, the pixel-type two-dimensional image detector according to the present invention using the heavy particle beam detecting medium is described below.

[0112] In this embodiment, a translucent and thin fluorescent material-based heavy particle beam detecting sheet is used as the heavy particle beam detecting medium, which may be formed by using ZnS:Ag as a fluorescent material, and applying the ZnS:Ag-based fluorescent material with the coating density of 30mg/cm^2 onto the glass-based plate having the thickness of 0.1mm by using the binder. A mirror-finished aluminum plate is used as the material for the fluorescent light reflecting bottom plate disposed at the bottom part.

[0113] In case that the wavelength shifting fiber for vertical axis in the lattice-like fluorescent light detecting member, which will be described later, disposed behind the fluorescent material-based heavy particle beam detecting sheet is configured to contact firmly to this detecting sheet, the fluorescent light emitted from the detecting sheet close to this firmly contact portion may be absorbed by the wavelength shifting fiber for vertical axis and the fraction of the fluorescent light directly detected by the wavelength shifting fiber for horizontal axis disposed below may become significantly low. In order to remedy this defect, it is required to keep a distance between the fluorescent material-based heavy particle beam detecting sheet and the wavelength shifting fiber for vertical axis. In case of attempting to realize this structure in Embodiment 1, the fluorescent light may leak out to the neighboring pixels because a clearance gap resulted from the distance kept as described above is formed at the reflecting plate.

[0114] BCF-92MC commercially available from Saint-Gobain K.K., that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm, is used as the wavelength shirting fiber. The wavelength shifting fiber may be shaped in a circular form with 1mm diameter.

[0115] In order to remedy the above described defect, in this embodiment, in the lattice-like structure in which a series of vertical axis reflecting plates and a series of horizontal axis reflecting plates are formed, the structure is so provided that an individual hole may be formed at the upper half positions on the reflecting plate arranged in the vertical axis direction and at the center position on the vertical axis interval, that is, at the position corresponding to 2.5 mm in this embodiment, so as to accommodate a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light. As shown in FIG. 9, the hole may be shaped in a circular form with 1.1mm diameter and with a center position being shifted 1mm from the upper part of the reflecting part so as to prevent the fluorescent light from leaking out to the neighboring pixels. Owing to such structure, it will be appreciated that an interval of 0.5mm may be provided between the fluorescent material-based heavy particle beam detecting sheet and the surface of the wavelength shifting fiber for vertical axis, which can remedy the above described defect.

[0116] Similarly, the structure is so provided that an individual hole may be formed at the upper half positions on the reflecting plate arranged in the vertical axis direction and at the center position on the vertical axis interval, that is, at the position corresponding to 2.5 mm in this embodiment, so as to accommodate a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light. As shown in FIG. 9, the hole may be shaped in a circular form with 1.1mm diameter and with a center position being shifted 1mm from the upper part of the reflecting part so as to prevent the fluorescent light from leaking out to the neighboring pixels. Owing to such structure, it will be appreciated that an interval of 0.5mm may be provided between the fluorescent light reflecting bottom plate disposed at the bottom part and the surface of the wavelength shifting fiber for horizontal axis, which can prevent the light condensing ratio from decreasing by means of firm contact between the fluorescent light reflecting bottom plate and the surface of the wavelength shifting fiber for horizontal axis.

[0117] The usage method and related descriptions of the lattice-like fluorescent light detecting member so formed as described above are the same as Embodiment 1, which will not be repeated herein.

[0118] Using 65 reflecting plates and 64 wavelength shifting fibers for the vertical axis, and using 65 reflecting plates and 64 wavelength shifting fibers for the horizontal axis, a two-dimensional heavy particle beam image detector with 64 channels for the vertical axis and 64 channels for the horizontal axis, and with a large sensitive area with 320mm×320mm dimension for the heavy particle beam may be obtained.

(Embodiment 10)

[0119] As Embodiment 10, referring to FIG. 10, the pixel-type two-dimensional image detector according to the present invention using the heavy particle beam detecting medium is described below.

[0120] In this embodiment, a translucent and thin fluorescent material-based heavy particle beam detecting sheet is used as the heavy particle beam detecting medium, which may be formed by using ZnS:Ag as a fluorescent material, and applying the ZnS:Ag-based fluorescent material with the coating density of 30mg/cm^2 onto the glass-based plate having the thickness of 0.1mm by using the binder. A mirror-finished aluminum plate is used as the material for the fluorescent light reflecting bottom plate disposed at the bottom part.

[0121] In case that the wavelength shifting fiber for vertical axis in the lattice-like fluorescent light detecting member, which will be described later, disposed behind the fluorescent material-based heavy particle beam detecting sheet is configured to contact firmly to this detecting sheet, the fluorescent light emitted from the detecting sheet close to this firmly contact portion may be absorbed by the wavelength shifting fiber for vertical axis and the fraction of the fluorescent light directly detected by the wavelength shifting fiber for horizontal axis disposed below may become significantly low. In order to remedy this defect, it is required to keep a distance between the fluorescent material-based heavy particle beam detecting sheet and the wavelength shifting fiber for vertical axis. In case of attempting to realize this structure in Embodiment 1, the fluorescent light may leak out to the neighboring pixels because a clearance gap resulted from the distance kept as described above is formed at the reflecting plate.

[0122] BCF-92MC commercially available from Saint-Gobain K.K., that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm, is used as the wavelength shirting fiber. The wavelength shifting fiber may be shaped in a square form with 1mm edge.

[0123] In order to remedy the above described defect, in this embodiment, in the lattice-like structure in which a series of vertical axis reflecting plates and a series of horizontal axis reflecting plates are formed, the structure is so provided that an individual hole may be formed at the upper half positions on the reflecting plate arranged in the vertical axis direction and at the center position on the vertical axis interval, that is, at the position corresponding to 2.5 mm in this embodiment, so as to accommodate a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light. As shown in FIG. 10, the hole may be shaped in a square form with 1.1mm edge and with a center position being shifted 1mm from the upper part of the reflecting plate so as to prevent the fluorescent light from leaking out to the neighboring pixels. Owing to such structure, it will be appreciated that an interval of 0.5mm may be provided between the fluorescent material-based heavy particle beam detecting sheet and the surface of the wavelength shifting fiber for vertical axis, which can remedy the above described defect.

[0124] Similarly, the structure is so provided that an individual hole may be formed at the upper half positions on the reflecting plate arranged in the vertical axis direction and at the center position on the vertical axis interval, that is, at the position corresponding to 2.5 mm in this embodiment, so as to accommodate a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light. As shown in FIG. 10, the hole may be shaped in a square form with 1.1mm edge and with a center position being shifted 1mm from the upper part of the reflecting plate so as to prevent the fluorescent light from leaking out to the neighboring pixels. Owing to such structure, it will be appreciated that an interval of 0.5mm may be provided between the fluorescent light reflecting bottom plate disposed at the bottom part and the surface of the wavelength shifting fiber for horizontal axis, which can prevent the light condensing ratio from decreasing by means of firm contact between the fluorescent light reflecting bottom plate and the surface of the wavelength shifting fiber for horizontal axis.

[0125] The usage method and related descriptions of the lattice-like fluorescent light detecting member so formed as described above are the same as Embodiment 1, which will not be repeated herein.

[0126] Using 65 reflecting plates and 64 wavelength shifting fibers for the vertical axis, and using 65 reflecting plates and 64 wavelength shifting fibers for the horizontal axis, a two-dimensional heavy particle beam image detector with 64 channels for the vertical axis and 64 channels for the horizontal axis, and with a large sensitive area with 320mm×320mm dimension for the heavy particle beam may be obtained.

(Embodiment 11)

[0127] As Embodiment 11, referring to the embodiment 2 of the structure of the pixel-type two-dimensional image detector according to the present invention using the neutron detecting medium, the two-dimensional neutron image detector according to the present invention is described below by referring to FIG. 11.

[0128] In this embodiment, a neutron detecting sheet commercially available from AST in England (containing ZnS:Ag and ^{6}LiF with a mixing ratio of 4:1) is used, which was manufactured by using ZnS:Ag as the neutron detecting medium, which may be formed by ZnS:Ag as a fluorescent material, and mixing them with binder material. The thickness of the detecting sheet is 0.45mm. In this embodiment, a couple of neutron detection sheets are used at both of the front face and the rear face of the lattice-like fluorescent light material.

[0129] In case that the wavelength shifting fiber for vertical axis in the lattice-like fluorescent light detecting member, which will be described later, disposed behind the fluorescent material-based neutron detecting sheet is configured to contact firmly to this detecting sheet, the fluorescent light emitted from the detecting sheet close to this firmly contact portion may be absorbed by the wavelength shifting fiber for vertical axis and the fraction of the fluorescent light directly detected by the wavelength shifting fiber for horizontal axis disposed below may become significantly low. In order to remedy this defect, it is required to keep a distance between the fluorescent material-based neutron detecting sheet and the wavelength shifting fiber for vertical axis. In case of attempting to realize this structure in Embodiment 1, the fluorescent light may leak out to the neighboring pixels because a clearance gap resulted from the distance kept as described above is formed at the reflecting plate.

[0130] BCF-92MC commercially available from Saint-Gobain K.K., that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm, is used as the wavelength shirting fiber. The wavelength shifting fiber may be shaped in a circular form with 1mm diameter.

[0131] In order to remedy the above described defect, in this embodiment, in the lattice-like structure in which a series of vertical axis reflecting plates and a series of horizontal axis reflecting plates are formed, the structure is so provided that an individual hole may be formed at the upper half positions on the reflecting plate arranged in the vertical axis direction and at the center position on the vertical axis interval, that is, at the position corresponding to 2.5 mm in this embodiment, so as to accommodate a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light. As shown in FIG. 11, the hole may be shaped in a circular form with 1.1mm diameter and with a center position being shifted 1mm from the upper part of the reflecting part so as to prevent the fluorescent light from leaking out to the neighboring pixels. Owing to such structure, it will be appreciated that an interval of 0.5mm may be provided between the fluorescent material-based heavy particle beam detecting sheet and the surface of the wavelength shifting fiber for vertical axis, which can remedy the above described defect.

[0132] Similarly, the structure is so provided that an individual hole may be formed at the upper half positions on the reflecting plate arranged in the vertical axis direction and at the center position on the vertical axis interval, that is, at the position corresponding to 2.5 mm in this embodiment, so as to accommodate a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light. As shown in FIG. 11, the hole may be shaped in a circular form with 1.1mm diameter and with a center position being shifted 1mm from the upper part of the reflecting part so as to prevent the fluorescent light from leaking out to the neighboring pixels. Owing to such structure, it will be appreciated that an interval of 0.5mm may be provided between the neutron detecting sheet disposed at the bottom part and the surface of the wavelength shifting fiber for horizontal axis, which can prevent the light condensing ratio from decreasing by means of firm contact between the neutron detecting sheet and the surface of the wavelength shifting fiber for horizontal axis.

[0133] The usage method and related descriptions of the lattice-like fluorescent light detecting member so formed as described above are the same as Embodiment 2, which will not be repeated herein.

[0134] Using 65 reflecting plates and 64 wavelength shifting fibers for the vertical axis, and using 65 reflecting plates and 64 wavelength shifting fibers for the horizontal axis, a two-dimensional neutron image detector with 64 channels for the vertical axis and 64 channels for the horizontal axis, and with a large sensitive area with 320mm×320mm dimension for neutron may be obtained.

(Embodiment 12)

[0135] As Embodiment 12, referring to FIG. 12, the pixel-type two-dimensional image detector using neutron detecting medium according to the present invention is described below.

[0136] In this embodiment, a neutron detecting sheet commercially available from AST in England (containing ZnS:Ag and ^{6}LiF with a mixing ratio of 4:1) is used, which was manufactured by using ZnS:Ag as the neutron detecting medium, which may be formed by ZnS:Ag as a fluorescent material, and mixing them with binder material. The thickness of the detecting sheet is 0.45mm. In this embodiment, a couple of neutron detection sheets are used at both of the front face and the rear face of the lattice-like fluorescent light material.

[0137] In case that the wavelength shifting fiber for vertical axis in the lattice-like fluorescent light detecting member, which will be described later, disposed behind the fluorescent material-based neutron detecting sheet is configured to contact firmly to this detecting sheet, the fluorescent light emitted from the detecting sheet close to this firmly contact portion may be absorbed by the wavelength shifting fiber for vertical axis and the fraction of the fluorescent light directly detected by the wavelength shifting fiber for horizontal axis disposed below may become significantly low. In order to remedy this defect, it is required to keep a distance between the fluorescent material-based neutron detecting sheet and the wavelength shifting fiber for vertical axis. In case of attempting to realize this structure in Embodiment 1, the fluorescent light may leak out to the neighboring pixels because a clearance gap resulted from the distance kept as described above is formed at the reflecting plate.

[0138] BCF-92MC commercially available from Saint-Gobain K.K., that is sensitive to the fluorescent light having the wavelength from 350nm to 440nm and transforms the wavelength of the fluorescent light into 490nm, is used as the wavelength shirting fiber. The wavelength shifting fiber may be shaped in a square form with 1mm edge.

[0139] In order to improve the above described defect, in this embodiment, in the lattice-like structure in which a series of vertical axis reflecting plates and a series of horizontal axis reflecting plates are formed, the structure is so provided that an individual hole may be formed at the upper half positions on the reflecting plate arranged in the vertical axis direction and at the center position on the vertical axis interval, that is, at the position corresponding to 2.5 mm in this embodiment, so as to accommodate a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light. As shown in FIG. 11, the hole may be shaped in a square form with 1.1mm edge and with a center position being shifted 1mm from the upper part of the reflecting part so as to prevent the fluorescent light from leaking out to the neighboring pixels. Owing to such structure, it will be appreciated that an interval of 0.5mm may be provided between the fluorescent material-based neutron detecting sheet and the surface of the wavelength shifting fiber for vertical axis, which can remedy the above described defect.

[0140] Similarly, the structure is so provided that an individual hole may be formed at the upper half positions on the reflecting plate arranged in the horizontal axis direction and at the center position on the horizontal axis interval, that is, at the position corresponding to 2.5 mm in this embodiment, so as to accommodate a single wavelength shifting fiber for horizontal axis detection for detecting the fluorescent light. As shown in FIG. 12, the hole may be shaped in a square form with 1.1mm edge and with a center position being shifted 1mm from the upper part of the reflecting plate so as to prevent the fluorescent light from leaking out to the neighboring pixels. Owing to such structure, it will be appreciated that an interval of 0.5mm may be provided between the fluorescent light reflecting bottom plate disposed at the bottom part and the surface of the wavelength shifting fiber for horizontal axis, which can prevent the light condensing ratio from decreasing by means of firm contact between the neutron detecting sheet and the surface of the wavelength shifting fiber for horizontal axis.

[0141] The usage method and related descriptions of the lattice-like fluorescent light detecting member so formed as described above are the same as Embodiment 1, which will not be repeated herein.

[0142] Using 65 reflecting plates and 64 wavelength shifting fibers for the vertical axis, and using 65 reflecting plates and 64 wavelength shifting fibers for the horizontal axis, a two-dimensional neutron image detector with 64 channels for the vertical axis and 64 channels for the horizontal axis, and with a large sensitive area with 320mm×320mm dimension for neutron may be obtained.

[0143] In the above embodiments, two-dimensional image detectors with a relatively simplified structure having a small number of wavelength shifting fibers have been described in order to provide a better understanding of the present invention, though it will be appreciated that the detection sensitivity may be increased by making larger the number of wavelength shifting fibers to be displaced per pixel in comparison with the number disclosed in the above embodiments.

[0144] Though the above embodiments refer to the structure in which a couple of wavelength shifting fibers are disposed per one pixel in the above embodiments, it will be appreciated that further large-area two-dimensional image detector can be realized also with additional overall cost reduction in the two-dimensional image detector by means that three or more wavelength shifting fibers are disposed per one pixel and a photomultiplier tube is connected. For example, in case of using three wavelength shifting fibers, the first and third wavelength shifting fibers may be connected the photomultiplier tube 1, and the second wavelength shifting fiber may be connected the photomultiplier tube 2. Alternately, for example, in case of using four wavelength shifting fibers, the first and third wavelength shifting fibers may be connected to the photomultiplier tube 1, and the second and forth wavelength shifting fibers may be connected to the photomultiplier tube 2. In case of using 5 or more wavelength shifting fibers, the similar configuration may be available.

[0145] In the above embodiments, two-dimensional image detectors with a relatively simplified structure having a small number of wavelength shifting fibers have been described in order to provide a better understanding of the present invention, though it will be appreciated that the detection sensitivity may be increased by making larger the number of wavelength shifting fibers to be displaced per pixel in comparison with the number disclosed in the above embodiments.

[0146] Though the above embodiments refer to the structure in which a couple of wavelength shifting fibers are disposed per one pixel in the above embodiments, it will be appreciated that further large-area two-dimensional image detector can be realized also with additional overall cost reduction in the two-dimensional image detector by means that three or more wavelength shifting fibers are disposed per one pixel and a photomultiplier tube is connected. For example, in case of using three wavelength shifting fibers, the first and third wavelength shifting fibers may be connected the photomultiplier tube 1, and the second wavelength shifting fiber may be connected the photomultiplier tube 2. Alternately, for example, in case of using four wavelength shifting fibers, the first and third wavelength shifting fibers may be connected to the photomultiplier tube 1, and the second and forth wavelength shifting fibers may be connected to the photomultiplier tube 2. In case of using 5 or more wavelength shifting fibers, the similar configuration may be available.

Claims

1. A pixel-type two-dimensional image detector comprising:

   a fluorescent material-based heavy particle beam detecting sheet; a lattice-like pixel structure in which a series of reflecting plates that reflect a fluorescent light from the fluorescent material-based heavy particle beam detecting sheet emitting a fluorescent light in response to an incident heavy particle beam are arranged along a vertical axis at a regular interval, and a series of reflecting plates that reflect a fluorescent light are arranged along a horizontal axis at a regular interval and at a right angle with respect to the fluorescent light reflecting plates arranged along the vertical axis,

   a lattice-like fluorescent light detecting member comprising wavelength shifting fibers formed by providing a groove formed at a front, upper half position or a back, lower half position of the reflecting plates which are arranged in a vertical axis direction, and at a center position in a vertical axis interval for accommodating a single wavelength shifting fiber for vertical axis detection for detecting the fluorescent light, and providing a groove formed at a front, upper half position or a back, lower half position of the reflecting plates which are arranged in a horizontal axis direction, and at a center position in a horizontal axis interval for accommodating a single wavelength shifting fiber for horizontal axis detection for detecting the fluorescent light;

   vertical and horizontal photodetectors for respective wavelength shifting fibers for vertical axis detection and the wavelength shifting fibers for horizontal axis detection;

   wherein said fluorescent material-based heavy particle beam detecting sheet for emitting the fluorescent light in response to an incident heavy particle beam is translucent and arranged only at a front surface or at both of a front surface and a back surface of the lattice-like pixel structure of reflecting plates,

   wherein a fluorescent light with its wavelength converted by and emitted from the wavelength shifting fiber for vertical axis detection and the wavelength shifting fiber for horizontal axis detection may be detected by said respective vertical and horizontal photodetectors to obtain a vertical axis pulse signal and a horizontal axis pulse signal; and an incident position of the heavy particle beam may be determined by applying a coincidence count measurement to the vertical axis pulse signal and the horizontal axis pulse signal.

2. A pixel-type two-dimensional image detector according to claim 1 wherein the heavy particle beam is a neutron beam, and the fluorescent material-based heavy particle beam detecting sheet is a fluorescent material-based neutron detecting sheet formed by mixing a material including any one or both of ^{6}Li element and ^{10}B element as a neutron converter with a fluorescent material.

Patentansprüche

1. Zweidimensionaler Pixelbilddetektor, der Folgendes umfasst:

einen auf fluoreszierendem Material basierenden Schirm zur Detektion eines Strahls aus schweren Teilchen;
eine gitterartige Pixelstruktur, in der eine Reihe von reflektierenden Platten, die ein fluoreszierendes Licht von dem auf fluoreszierendem Material basierenden Schirm zur Detektion eines Strahls aus schweren Teilchen, der ein fluoreszierendes Licht als Reaktion auf einen einfallenden Strahl aus schweren Teilchen emittiert, reflektieren, entlang einer vertikalen Achse in einem gleichmäßigen Abstand angeordnet sind und eine Reihe von reflektierenden Platten, die ein fluoreszierendes Licht reflektieren, entlang einer horizontalen Achse in einem gleichmäßigen Abstand und im rechten Winkel in Bezug auf die das fluoreszierende Licht reflektierenden Platten, die entlang der vertikalen Achse angeordnet sind, angeordnet sind,
ein gitterartiges Element zur Detektion von fluoreszierendem Licht, das Wellenlängenverschiebungsfasern umfasst, das durch das Bereitstellen einer Vertiefung, die an einer vorderen Position in der oberen Hälfte oder einer hinteren Position in der unteren Hälfte der reflektierenden Platten, die in Richtung einer vertikalen Achse angeordnet sind, und an einer mittleren Position in einem Abstand auf einer vertikalen Achse ausgebildet ist, um eine einzelne Wellenlängenverschiebungsfaser zur Detektion auf der vertikalen Achse zum Detektieren des fluoreszierenden Lichts aufzunehmen, und durch das Bereitstellen einer Vertiefung ausgebildet ist, die an einer vorderen Position in der oberen Hälfte oder einer hinteren Position in der unteren Hälfte der reflektierenden Platten, die in Richtung einer horizontalen Achse angeordnet sind, und an einer mittleren Position in einem Abstand auf einer horizontalen Achse ausgebildet ist, um eine einzelne Wellenlängenverschiebungsfaser zur Detektion auf der horizontalen Achse zum Detektieren des fluoreszierenden Lichts aufzunehmen;
vertikale und horizontale Photodetektoren für entsprechende Wellenlängenverschiebungsfasern zur Detektion auf der vertikalen Achse und die Wellenlängenverschiebungsfasern zur Detektion auf der horizontalen Achse;
wobei der auf fluoreszierendem Material basierende Schirm zur Detektion eines Strahls aus schweren Teilchen, der ein fluoreszierendes Licht als Reaktion auf einen einfallenden Strahl aus schweren Teilchen emittiert, lichtdurchlässig und nur an einer vorderen Seite oder sowohl an einer vorderen Seite als auch einer hinteren Seite der gitterartigen Pixelstruktur von reflektierenden Platten angeordnet ist,
wobei ein fluoreszierendes Licht, dessen Wellenlänge von der Wellenlängenverschiebungsfaser zur Detektion auf der vertikalen Achse und der Wellenlängenverschiebungsfaser zur Detektion auf der horizontalen Achse umgewandelt und von diesen emittiert wird, von den entsprechenden vertikalen und horizontalen Photodetektoren detektiert werden kann, um ein Impulssignal auf der vertikalen Achse und ein Impulssignal auf der horizontalen Achse zu erhalten;
und eine Einfallsposition des Strahls aus schweren Teilchen durch das Anwenden einer Koinzidenzzählwertmessung auf das Impulssignal auf der vertikalen Achse und das Impulssignal auf der horizontalen Achse bestimmt werden kann.

2. Zweidimensionaler Pixelbilddetektor nach Anspruch 1, wobei der Strahl aus schweren Teilchen ein Neutronenstrahl ist und der auf fluoreszierendem Material basierende Schirm zur Detektion eines Strahls aus schweren Teilchen ein auf fluoreszierendem Material basierender Schirm zur Detektion von Neutronen ist, der durch das Vermischen eines Materials, das eines oder beide aus einem ^{6}Li-Element und ^{10}B-Element als Neutronenkonverter umfasst, mit einem fluoreszierenden Material ausgebildet ist.

Revendications

1. Détecteur d'image bidimensionnel de type pixel comprenant :

une feuille de détection de faisceau de particules lourdes à base de matériau fluorescent ;
une structure de pixels de type réseau dans laquelle une série de plaques réfléchissantes qui réfléchissent une lumière fluorescente depuis la feuille de détection de faisceau de particules lourdes à base de matériau fluorescent émettant une lumière fluorescente en réponse à un faisceau de particules lourdes incident sont agencées le long d'un axe vertical à intervalle régulier, et une série de plaques réfléchissantes qui réfléchissent une lumière fluorescente sont agencées le long d'un axe horizontal à intervalle régulier et à un angle droit par rapport aux plaques réfléchissant la lumière fluorescente agencées le long de l'axe vertical,

un élément de détection de lumière fluorescente de type réseau comprenant des fibres de décalage de longueur d'onde formées par fourniture d'une rainure formée à une

position avant, de moitié supérieure ou une position arrière, de moitié inférieure des plaques réfléchissantes qui sont agencées dans une direction d'axe vertical,
et à une position centrale dans un intervalle d'axe vertical pour recevoir une fibre de décalage de longueur d'onde individuelle pour la détection d'axe vertical pour détecter la lumière fluorescente, et fournir une rainure formée à une position avant, de moitié supérieure ou une position arrière, de moitié inférieure des plaques réfléchissantes qui sont agencées dans une direction d'axe horizontal,

et à une position centrale dans un intervalle d'axe horizontal pour recevoir une fibre de décalage de longueur d'onde individuelle pour la détection d'axe horizontal pour détecter la lumière fluorescente ;
des photodétecteurs verticaux et horizontaux pour des fibres de décalage de longueur d'onde respectives pour la détection d'axe vertical et des fibres de décalage de longueur d'onde pour la détection d'axe horizontal ;
dans lequel

ladite feuille de détection de faisceau de particules lourdes à base de matériau fluorescent pour émettre la lumière fluorescente en réponse à un faisceau de particules lourdes incident est translucide et agencée uniquement au niveau d'une surface avant ou à la fois d'une surface avant et d'une surface arrière de la structure de pixels de type réseau de plaques réfléchissantes,
dans lequel une lumière fluorescente avec sa longueur d'onde convertie par et émise depuis la fibre de décalage de longueur d'onde pour la détection d'axe vertical et la fibre de décalage de longueur d'onde pour la détection d'axe horizontal peut être détectée par lesdits photodétecteurs verticaux et horizontaux respectifs pour obtenir un signal d'impulsion d'axe vertical et un signal d'impulsion d'axe horizontal ; et une position incidente du faisceau de particules lourdes peut être déterminée par application d'une mesure de comptage de coïncidence au signal d'impulsion d'axe vertical et au signal d'impulsion d'axe horizontal.

2. Détecteur d'image bidimensionnel de type à pixels selon la revendication 1 dans lequel le faisceau de particules lourdes est un faisceau de neutrons, et la feuille de détection de faisceau de particules lourdes à base de matériau fluorescent est une feuille de détection de neutrons à base de matériau fluorescent formée par mélange d'un matériau comprenant l'un quelconque ou les deux parmi l'élément ^{6}Li et l'élément ^{10}B en tant que convertisseur de neutrons avec un matériau fluorescent.

FIG. 1

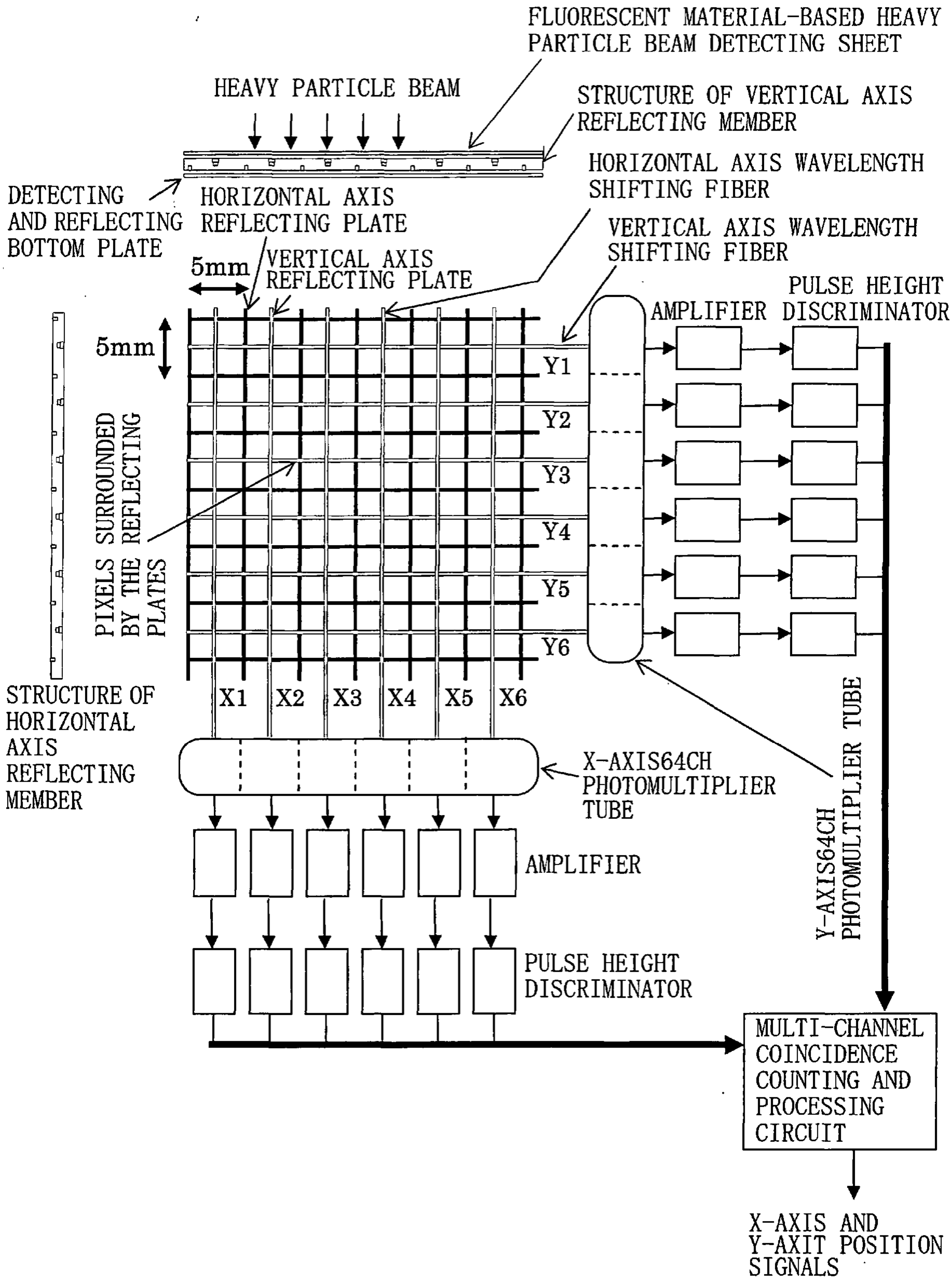

FLUORESCENT MATERIAL-BASED HEAVY PARTICLE BEAM DETECTING SHEET
HEAVY PARTICLE BEAM
STRUCTURE OF VERTICAL AXIS REFLECTING MEMBER
HORIZONTAL AXIS WAVELENGTH SHIFTING FIBER
DETECTING AND REFLECTING BOTTOM PLATE
HORIZONTAL AXIS REFLECTING PLATE
VERTICAL AXIS WAVELENGTH SHIFTING FIBER
5mm
VERTICAL AXIS REFLECTING PLATE
PULSE HEIGHT DISCRIMINATOR
AMPLIFIER
5mm
Y1
Y2
Y3
Y4
Y5
Y6
PIXELS SURROUNDED BY THE REFLECTING PLATES
STRUCTURE OF HORIZONTAL AXIS REFLECTING MEMBER
X1
X2
X3
X4
X5
X6
X-AXIS64CH PHOTOMULTIPLIER TUBE
Y-AXIS64CH PHOTOMULTIPLIER TUBE
AMPLIFIER
PULSE HEIGHT DISCRIMINATOR
MULTI-CHANNEL COINCIDENCE COUNTING AND PROCESSING CIRCUIT
X-AXIS AND Y-AXIT POSITION SIGNALS

FIG.2

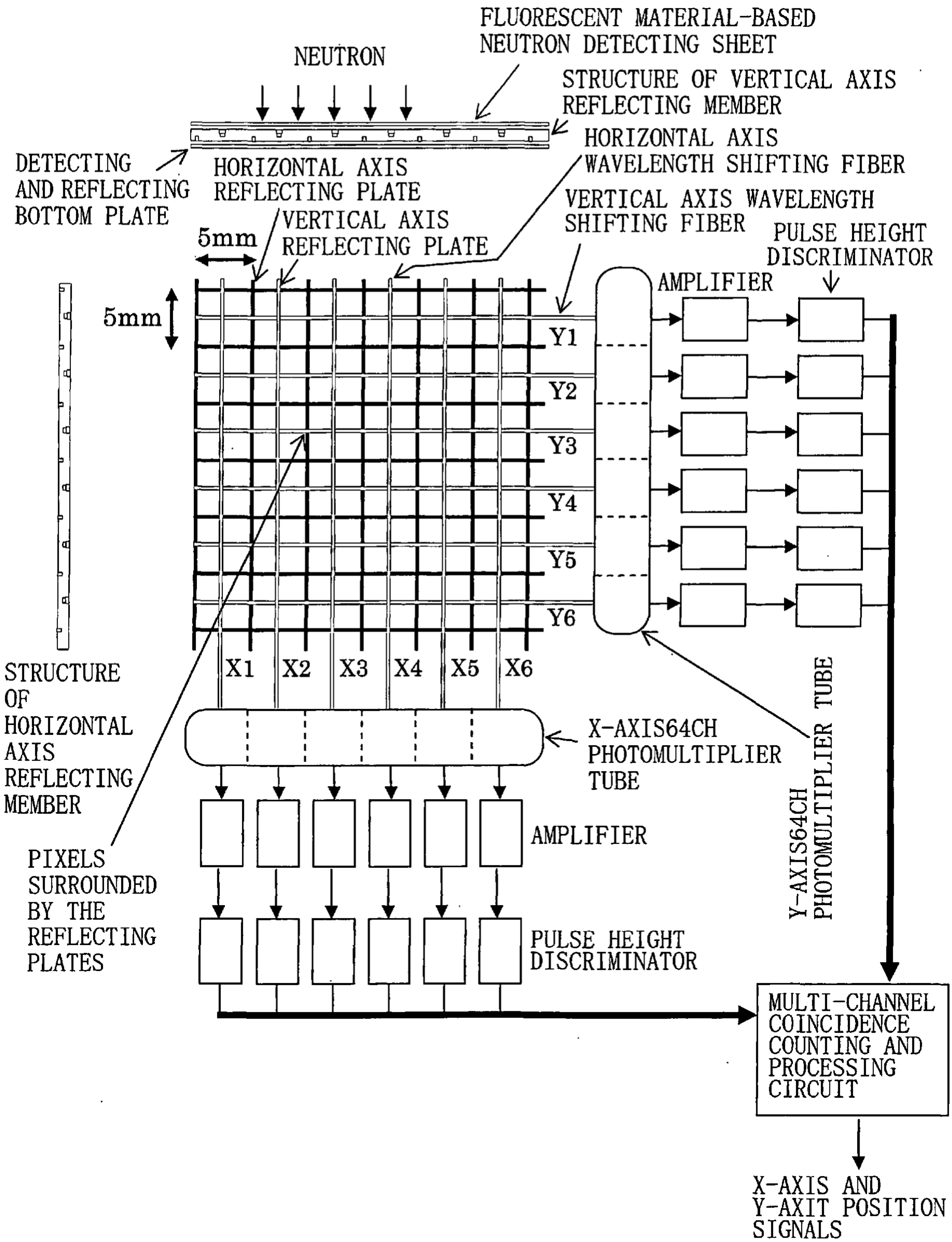

FLUORESCENT MATERIAL-BASED NEUTRON DETECTING SHEET
NEUTRON
STRUCTURE OF VERTICAL AXIS REFLECTING MEMBER
HORIZONTAL AXIS WAVELENGTH SHIFTING FIBER
DETECTING AND REFLECTING BOTTOM PLATE
HORIZONTAL AXIS REFLECTING PLATE
VERTICAL AXIS WAVELENGTH SHIFTING FIBER
VERTICAL AXIS REFLECTING PLATE
5mm
PULSE HEIGHT DISCRIMINATOR
AMPLIFIER
5mm
Y1
Y2
Y3
Y4
Y5
Y6
X1
X2
X3
X4
X5
X6
STRUCTURE OF HORIZONTAL AXIS REFLECTING MEMBER
X-AXIS64CH PHOTOMULTIPLIER TUBE
Y-AXIS64CH PHOTOMULTIPLIER TUBE
AMPLIFIER
PIXELS SURROUNDED BY THE REFLECTING PLATES
PULSE HEIGHT DISCRIMINATOR
MULTI-CHANNEL COINCIDENCE COUNTING AND PROCESSING CIRCUIT
X-AXIS AND Y-AXIT POSITION SIGNALS

FIG.3

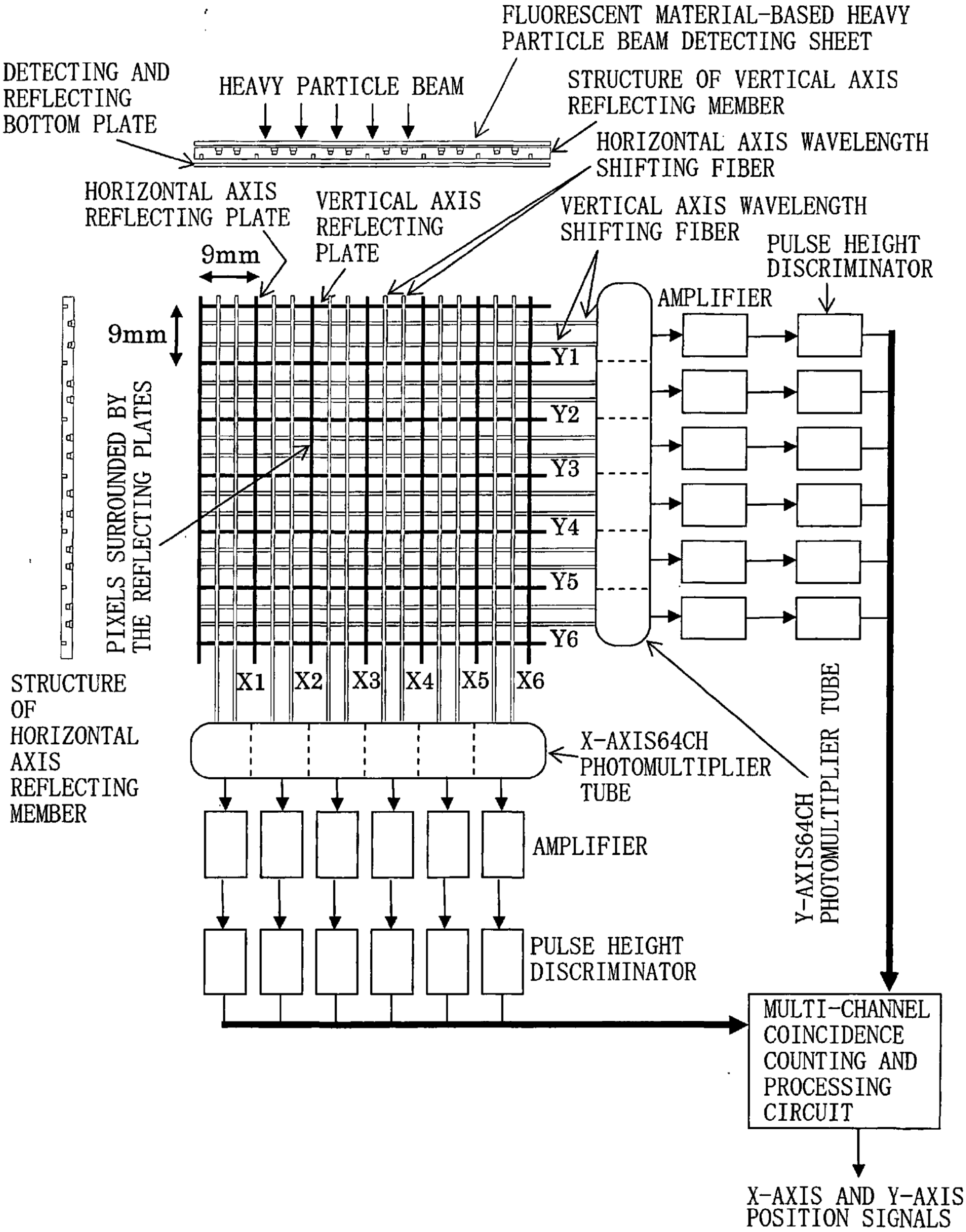

FLUORESCENT MATERIAL-BASED HEAVY PARTICLE BEAM DETECTING SHEET
DETECTING AND REFLECTING BOTTOM PLATE
HEAVY PARTICLE BEAM
STRUCTURE OF VERTICAL AXIS REFLECTING MEMBER
HORIZONTAL AXIS WAVELENGTH SHIFTING FIBER
HORIZONTAL AXIS REFLECTING PLATE
VERTICAL AXIS REFLECTING PLATE
VERTICAL AXIS WAVELENGTH SHIFTING FIBER
PULSE HEIGHT DISCRIMINATOR
9mm
AMPLIFIER
9mm
Y1
Y2
Y3
Y4
Y5
Y6
PIXELS SURROUNDED BY THE REFLECTING PLATES
STRUCTURE OF HORIZONTAL AXIS REFLECTING MEMBER
X1
X2
X3
X4
X5
X6
X-AXIS64CH PHOTOMULTIPLIER TUBE
Y-AXIS64CH PHOTOMULTIPLIER TUBE
AMPLIFIER
PULSE HEIGHT DISCRIMINATOR
MULTI-CHANNEL COINCIDENCE COUNTING AND PROCESSING CIRCUIT
X-AXIS AND Y-AXIS POSITION SIGNALS

FIG.4

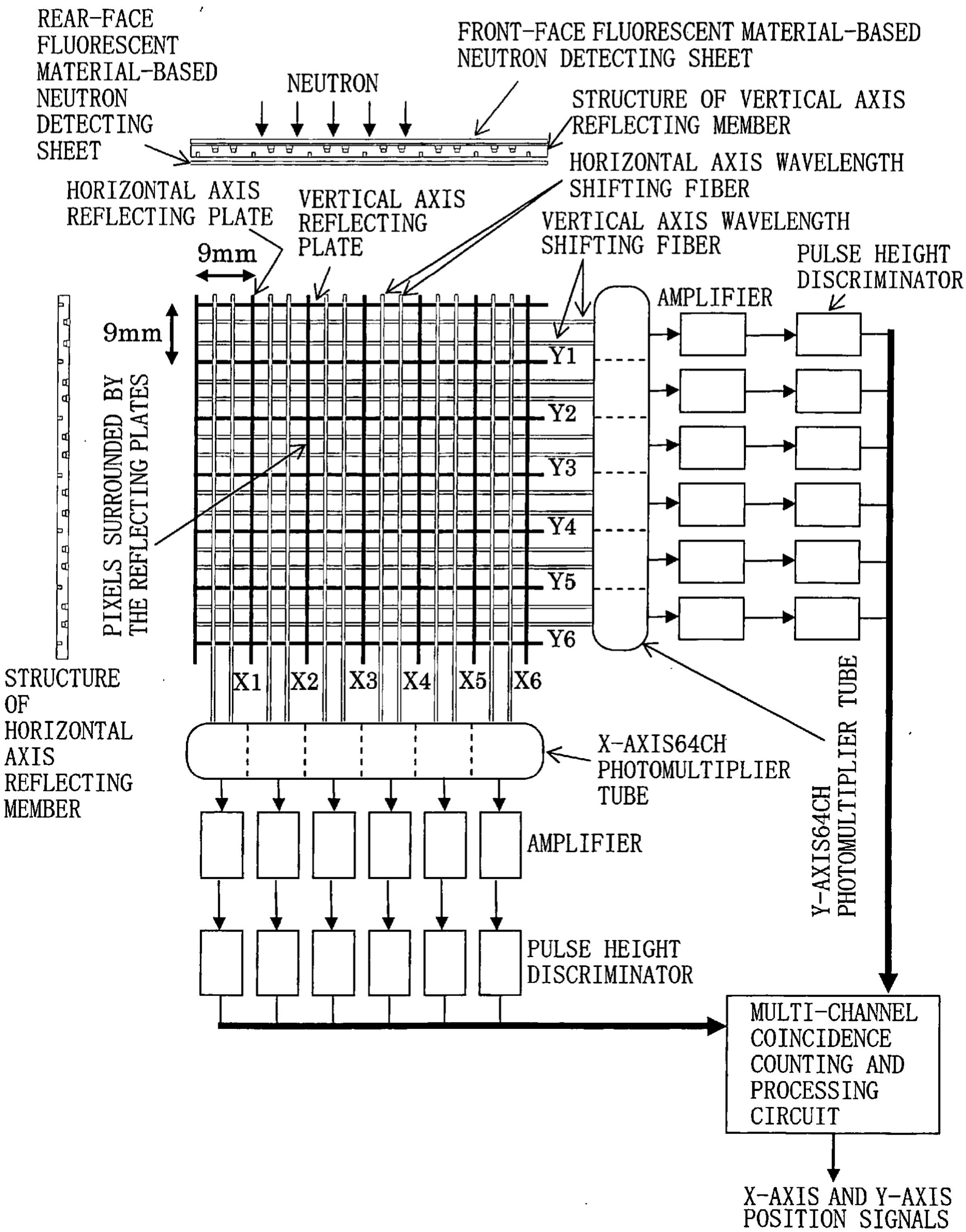

REAR-FACE FLUORESCENT MATERIAL-BASED NEUTRON DETECTING SHEET
NEUTRON
FRONT-FACE FLUORESCENT MATERIAL-BASED NEUTRON DETECTING SHEET
STRUCTURE OF VERTICAL AXIS REFLECTING MEMBER
HORIZONTAL AXIS WAVELENGTH SHIFTING FIBER
HORIZONTAL AXIS REFLECTING PLATE
VERTICAL AXIS REFLECTING PLATE
VERTICAL AXIS WAVELENGTH SHIFTING FIBER
9mm
9mm
PULSE HEIGHT DISCRIMINATOR
AMPLIFIER
PIXELS SURROUNDED BY THE REFLECTING PLATES
Y1
Y2
Y3
Y4
Y5
Y6
X1
X2
X3
X4
X5
X6
STRUCTURE OF HORIZONTAL AXIS REFLECTING MEMBER
X-AXIS64CH PHOTOMULTIPLIER TUBE
Y-AXIS64CH PHOTOMULTIPLIER TUBE
AMPLIFIER
PULSE HEIGHT DISCRIMINATOR
MULTI-CHANNEL COINCIDENCE COUNTING AND PROCESSING CIRCUIT
X-AXIS AND Y-AXIS POSITION SIGNALS

FIG.5

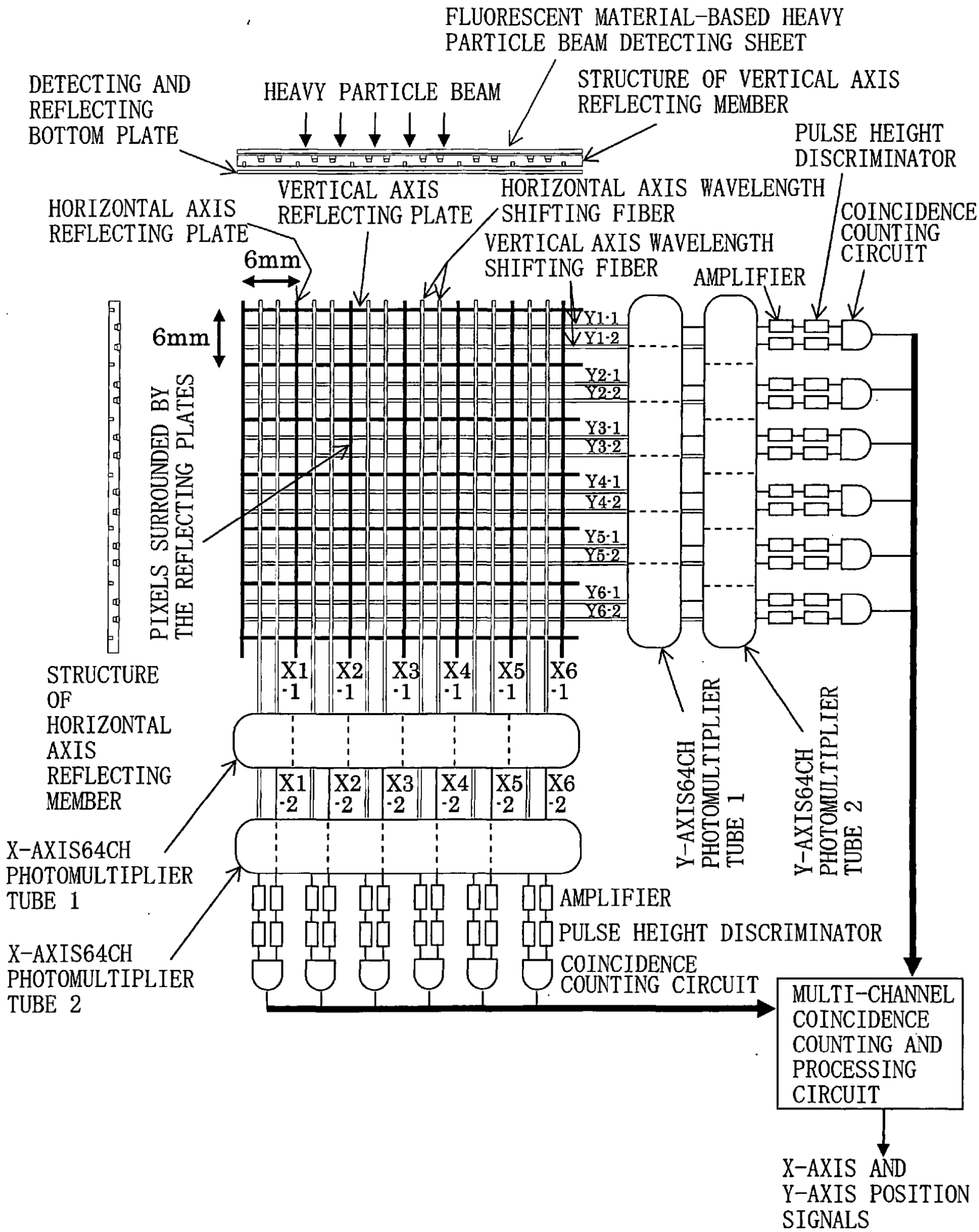

FLUORESCENT MATERIAL-BASED HEAVY PARTICLE BEAM DETECTING SHEET
DETECTING AND REFLECTING BOTTOM PLATE
HEAVY PARTICLE BEAM
STRUCTURE OF VERTICAL AXIS REFLECTING MEMBER
PULSE HEIGHT DISCRIMINATOR
VERTICAL AXIS REFLECTING PLATE
HORIZONTAL AXIS WAVELENGTH SHIFTING FIBER
HORIZONTAL AXIS REFLECTING PLATE
COINCIDENCE COUNTING CIRCUIT
VERTICAL AXIS WAVELENGTH SHIFTING FIBER
6mm
AMPLIFIER
6mm
Y1-1
Y1-2
Y2-1
Y2-2
Y3-1
Y3-2
Y4-1
Y4-2
Y5-1
Y5-2
Y6-1
Y6-2
PIXELS SURROUNDED BY THE REFLECTING PLATES
STRUCTURE OF HORIZONTAL AXIS REFLECTING MEMBER
X1 -1
X2 -1
X3 -1
X4 -1
X5 -1
X6 -1
X1 -2
X2 -2
X3 -2
X4 -2
X5 -2
X6 -2
X-AXIS64CH PHOTOMULTIPLIER TUBE 1
X-AXIS64CH PHOTOMULTIPLIER TUBE 2
Y-AXIS64CH PHOTOMULTIPLIER TUBE 1
Y-AXIS64CH PHOTOMULTIPLIER TUBE 2
AMPLIFIER
PULSE HEIGHT DISCRIMINATOR
COINCIDENCE COUNTING CIRCUIT
MULTI-CHANNEL COINCIDENCE COUNTING AND PROCESSING CIRCUIT
X-AXIS AND Y-AXIS POSITION SIGNALS

FIG.6

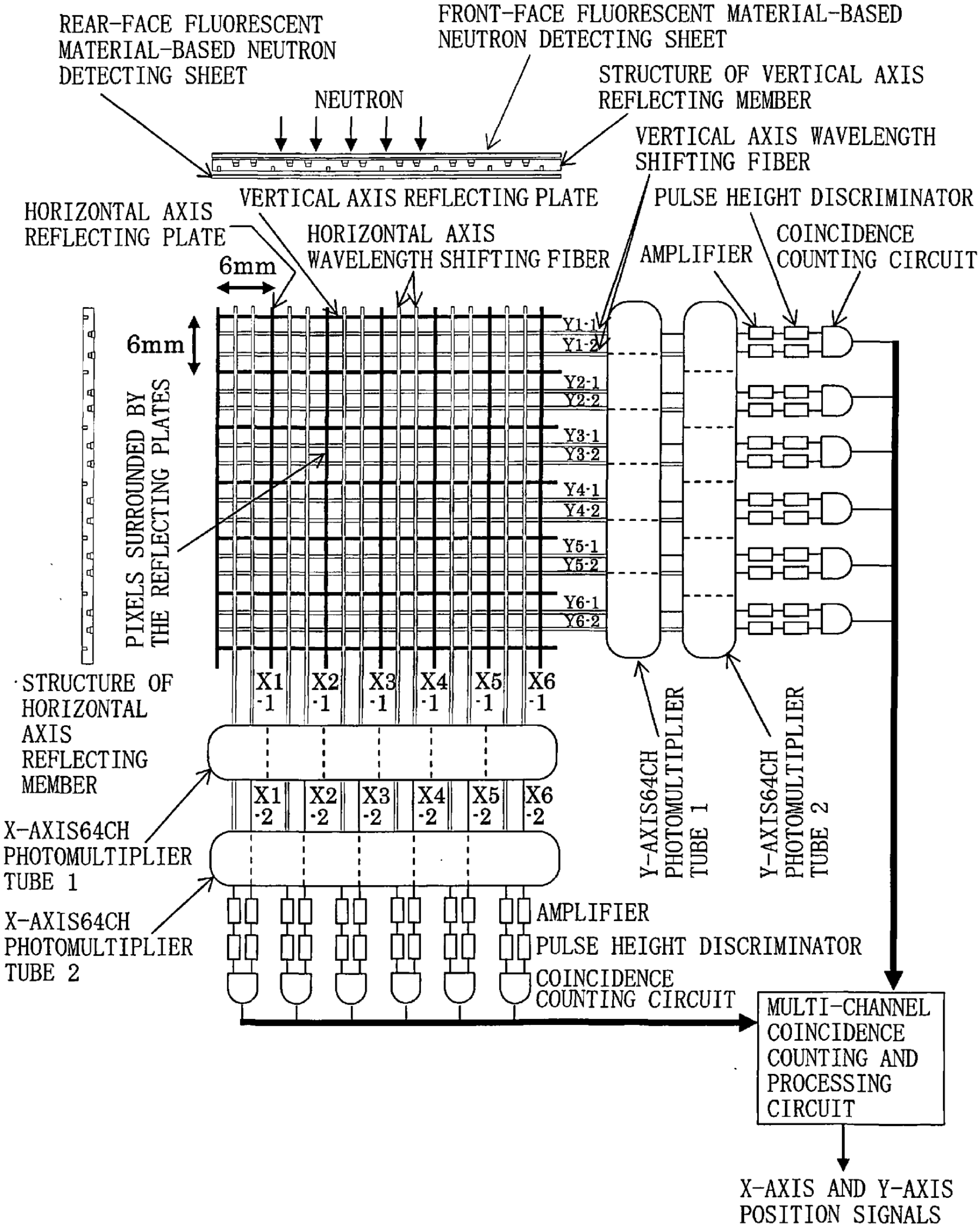

REAR-FACE FLUORESCENT MATERIAL-BASED NEUTRON DETECTING SHEET
FRONT-FACE FLUORESCENT MATERIAL-BASED NEUTRON DETECTING SHEET
STRUCTURE OF VERTICAL AXIS REFLECTING MEMBER
NEUTRON
VERTICAL AXIS WAVELENGTH SHIFTING FIBER
HORIZONTAL AXIS REFLECTING PLATE
VERTICAL AXIS REFLECTING PLATE
PULSE HEIGHT DISCRIMINATOR
HORIZONTAL AXIS WAVELENGTH SHIFTING FIBER
AMPLIFIER
COINCIDENCE COUNTING CIRCUIT
6mm
6mm
PIXELS SURROUNDED BY THE REFLECTING PLATES
Y1-1
Y1-2
Y2-1
Y2-2
Y3-1
Y3-2
Y4-1
Y4-2
Y5-1
Y5-2
Y6-1
Y6-2
STRUCTURE OF HORIZONTAL AXIS REFLECTING MEMBER
X1 -1
X2 -1
X3 -1
X4 -1
X5 -1
X6 -1
X1 -2
X2 -2
X3 -2
X4 -2
X5 -2
X6 -2
Y-AXIS64CH PHOTOMULTIPLIER TUBE 1
Y-AXIS64CH PHOTOMULTIPLIER TUBE 2
X-AXIS64CH PHOTOMULTIPLIER TUBE 1
X-AXIS64CH PHOTOMULTIPLIER TUBE 2
AMPLIFIER
PULSE HEIGHT DISCRIMINATOR
COINCIDENCE COUNTING CIRCUIT
MULTI-CHANNEL COINCIDENCE COUNTING AND PROCESSING CIRCUIT
X-AXIS AND Y-AXIS POSITION SIGNALS

FIG.7

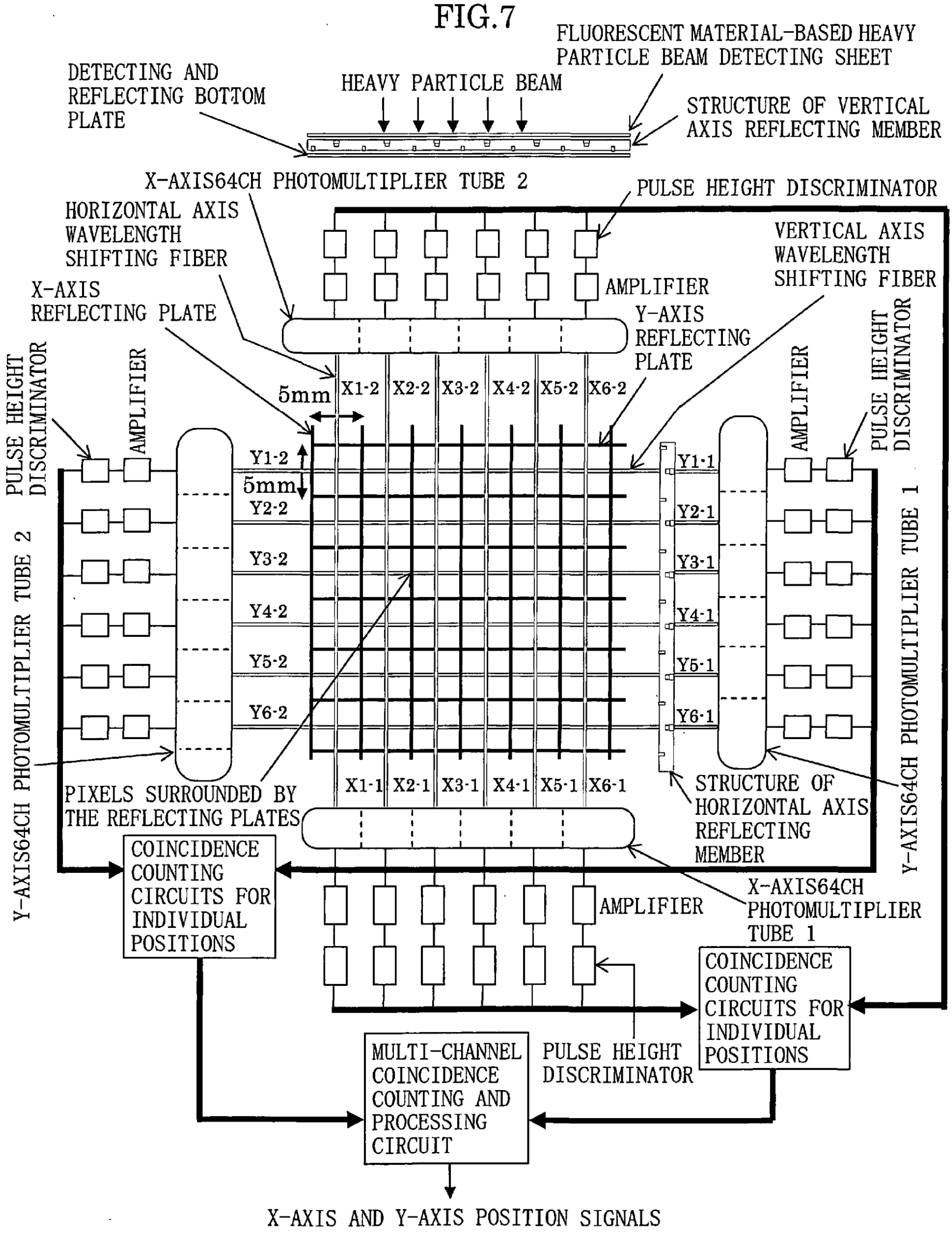

DETECTING AND REFLECTING BOTTOM PLATE
HEAVY PARTICLE BEAM
FLUORESCENT MATERIAL-BASED HEAVY PARTICLE BEAM DETECTING SHEET
STRUCTURE OF VERTICAL AXIS REFLECTING MEMBER
X-AXIS64CH PHOTOMULTIPLIER TUBE 2
PULSE HEIGHT DISCRIMINATOR
HORIZONTAL AXIS WAVELENGTH SHIFTING FIBER
VERTICAL AXIS WAVELENGTH SHIFTING FIBER
AMPLIFIER
X-AXIS REFLECTING PLATE
Y-AXIS REFLECTING PLATE
5mm
X1-2
X2-2
X3-2
X4-2
X5-2
X6-2
Y1-2
Y2-2
Y3-2
Y4-2
Y5-2
Y6-2
Y1-1
Y2-1
Y3-1
Y4-1
Y5-1
Y6-1
X1-1
X2-1
X3-1
X4-1
X5-1
X6-1
Y-AXIS64CH PHOTOMULTIPLIER TUBE 2
Y-AXIS64CH PHOTOMULTIPLIER TUBE 1
PIXELS SURROUNDED BY THE REFLECTING PLATES
STRUCTURE OF HORIZONTAL AXIS REFLECTING MEMBER
COINCIDENCE COUNTING CIRCUITS FOR INDIVIDUAL POSITIONS
X-AXIS64CH PHOTOMULTIPLIER TUBE 1
MULTI-CHANNEL COINCIDENCE COUNTING AND PROCESSING CIRCUIT
X-AXIS AND Y-AXIS POSITION SIGNALS

FIG.8

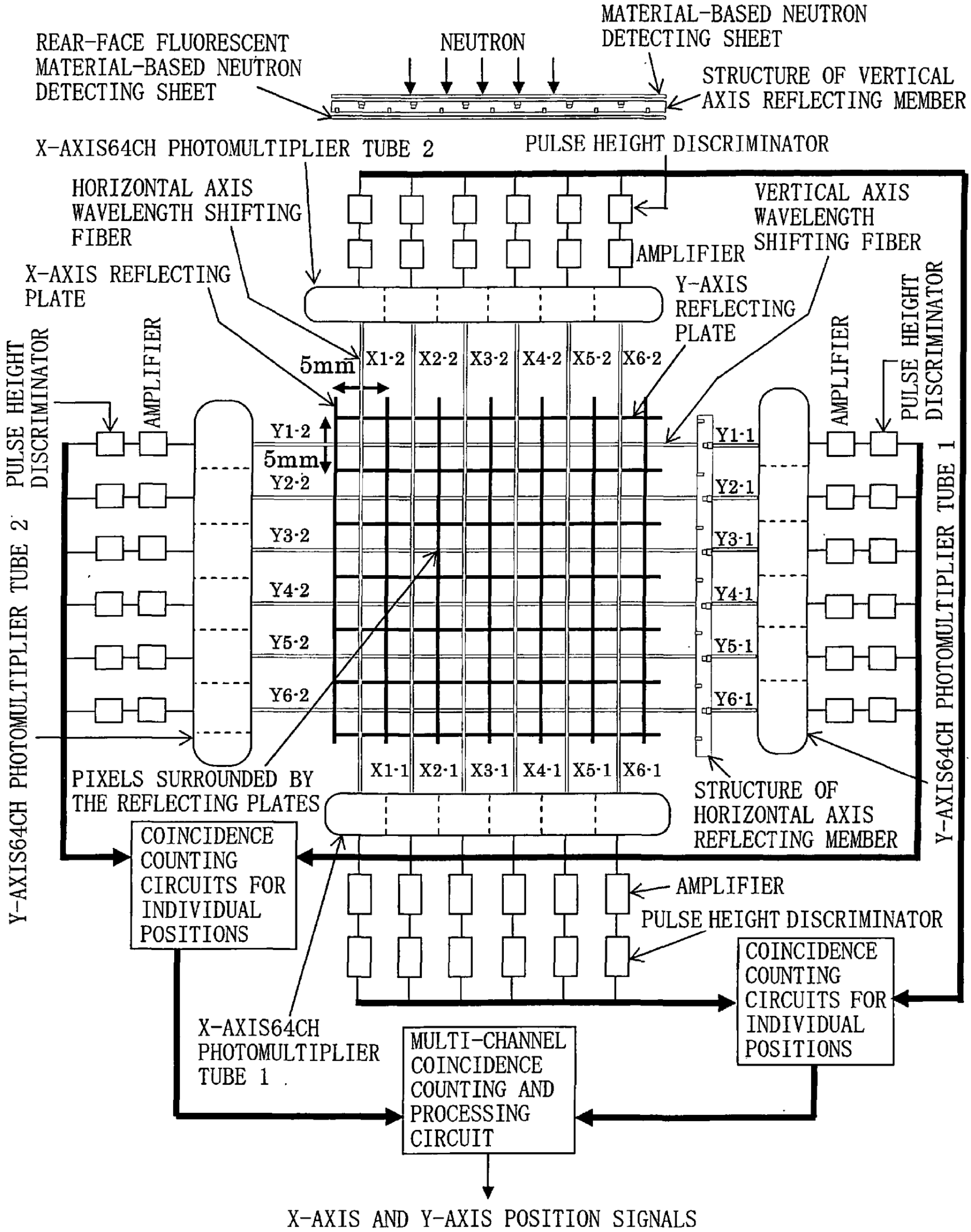

REAR-FACE FLUORESCENT MATERIAL-BASED NEUTRON DETECTING SHEET
NEUTRON
FRONT-FACE FLUORESCENT MATERIAL-BASED NEUTRON DETECTING SHEET
STRUCTURE OF VERTICAL AXIS REFLECTING MEMBER
X-AXIS64CH PHOTOMULTIPLIER TUBE 2
PULSE HEIGHT DISCRIMINATOR
HORIZONTAL AXIS WAVELENGTH SHIFTING FIBER
VERTICAL AXIS WAVELENGTH SHIFTING FIBER
AMPLIFIER
X-AXIS REFLECTING PLATE
Y-AXIS REFLECTING PLATE
PULSE HEIGHT DISCRIMINATOR
AMPLIFIER
5mm
X1·2 X2·2 X3·2 X4·2 X5·2 X6·2
Y1·2 Y2·2 Y3·2 Y4·2 Y5·2 Y6·2
Y1·1 Y2·1 Y3·1 Y4·1 Y5·1 Y6·1
X1·1 X2·1 X3·1 X4·1 X5·1 X6·1
Y-AXIS64CH PHOTOMULTIPLIER TUBE 2
Y-AXIS64CH PHOTOMULTIPLIER TUBE 1
PIXELS SURROUNDED BY THE REFLECTING PLATES
STRUCTURE OF HORIZONTAL AXIS REFLECTING MEMBER
COINCIDENCE COUNTING CIRCUITS FOR INDIVIDUAL POSITIONS
AMPLIFIER
PULSE HEIGHT DISCRIMINATOR
X-AXIS64CH PHOTOMULTIPLIER TUBE 1
MULTI-CHANNEL COINCIDENCE COUNTING AND PROCESSING CIRCUIT
X-AXIS AND Y-AXIS POSITION SIGNALS

FIG.9

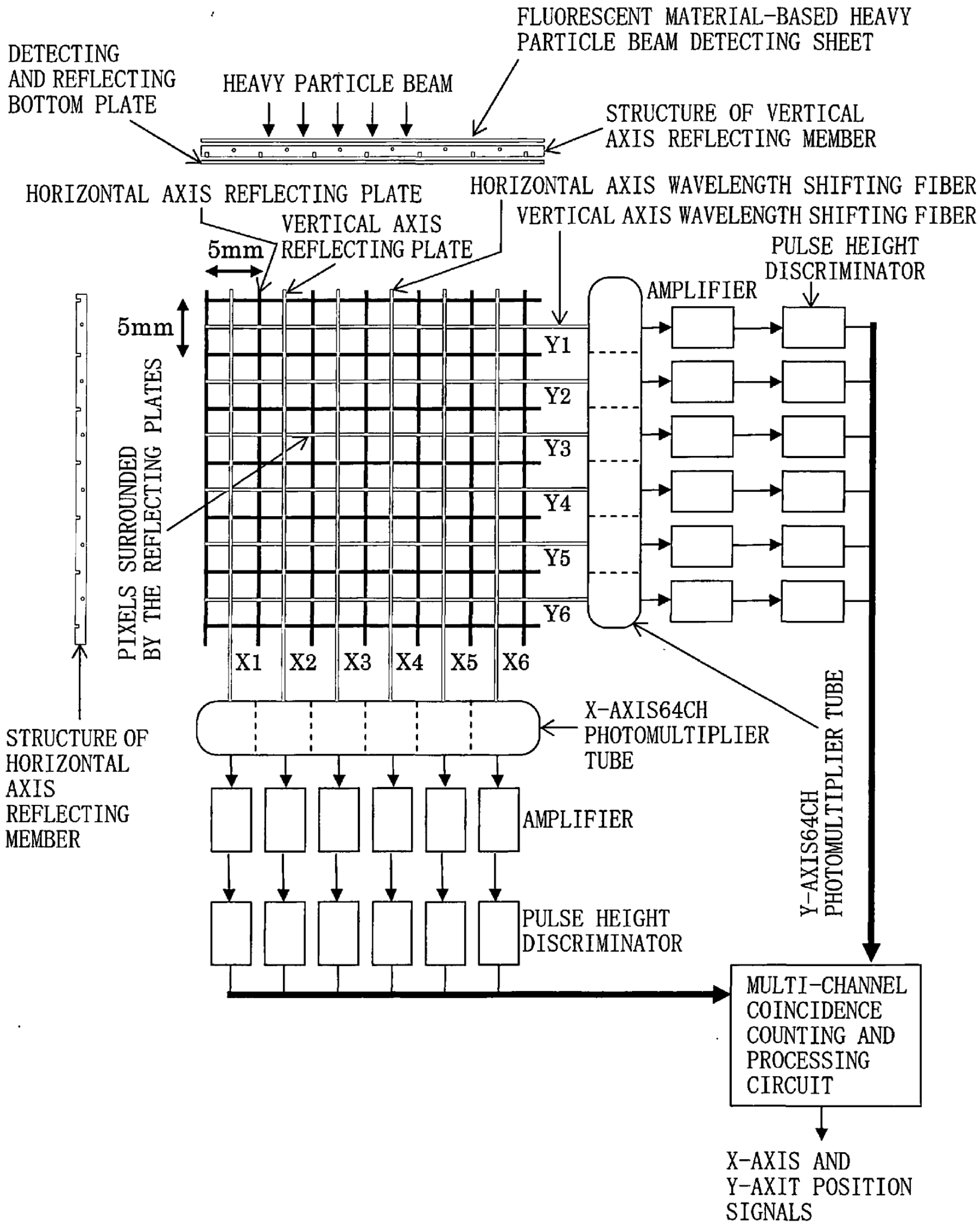

FLUORESCENT MATERIAL-BASED HEAVY PARTICLE BEAM DETECTING SHEET
DETECTING AND REFLECTING BOTTOM PLATE
HEAVY PARTICLE BEAM
STRUCTURE OF VERTICAL AXIS REFLECTING MEMBER
HORIZONTAL AXIS REFLECTING PLATE
HORIZONTAL AXIS WAVELENGTH SHIFTING FIBER
VERTICAL AXIS WAVELENGTH SHIFTING FIBER
VERTICAL AXIS REFLECTING PLATE
5mm
PULSE HEIGHT DISCRIMINATOR
AMPLIFIER
5mm
PIXELS SURROUNDED BY THE REFLECTING PLATES
Y1
Y2
Y3
Y4
Y5
Y6
X1
X2
X3
X4
X5
X6
STRUCTURE OF HORIZONTAL AXIS REFLECTING MEMBER
X-AXIS64CH PHOTOMULTIPLIER TUBE
Y-AXIS64CH PHOTOMULTIPLIER TUBE
AMPLIFIER
PULSE HEIGHT DISCRIMINATOR
MULTI-CHANNEL COINCIDENCE COUNTING AND PROCESSING CIRCUIT
X-AXIS AND Y-AXIT POSITION SIGNALS

FIG.10

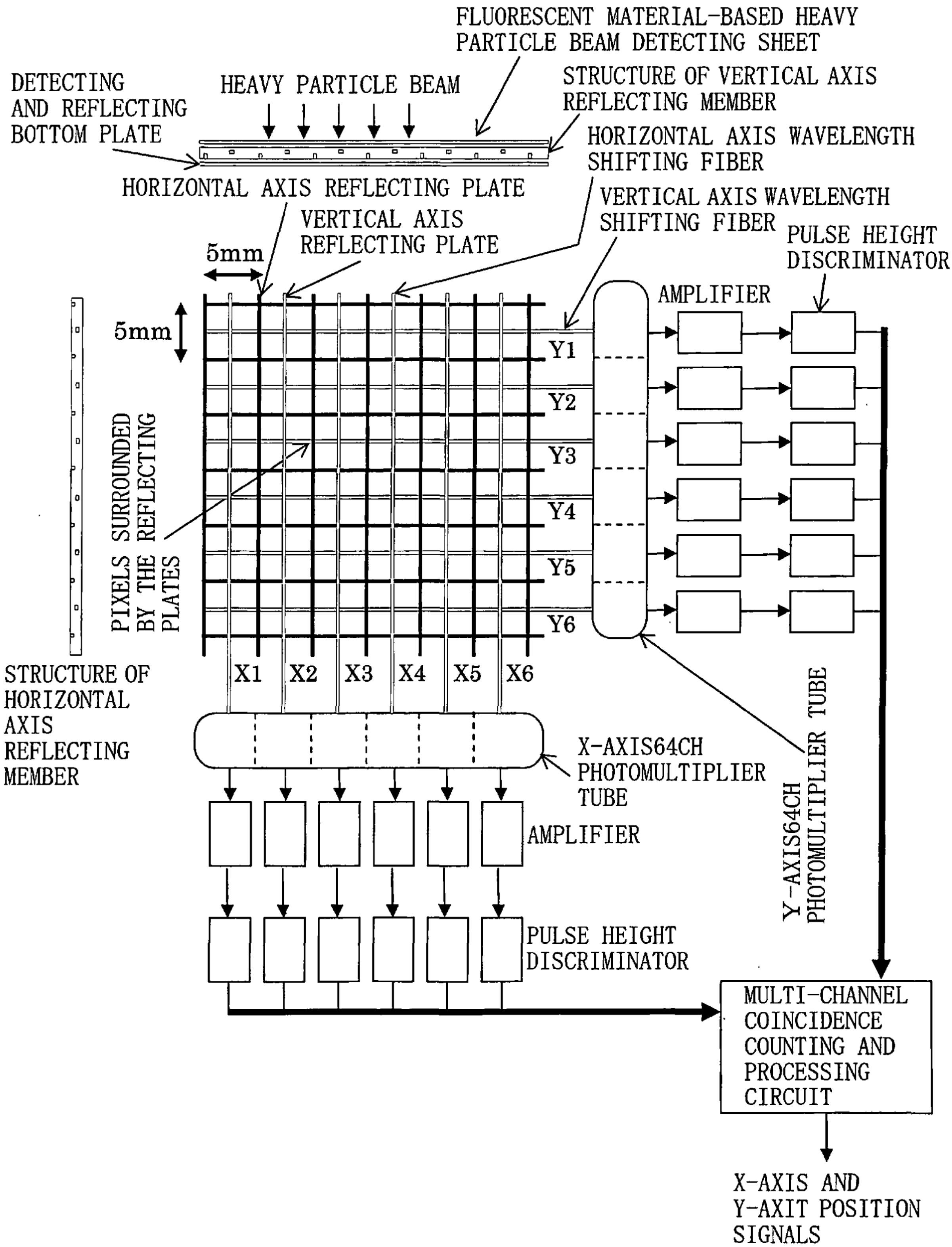

FLUORESCENT MATERIAL-BASED HEAVY PARTICLE BEAM DETECTING SHEET
DETECTING AND REFLECTING BOTTOM PLATE
HEAVY PARTICLE BEAM
STRUCTURE OF VERTICAL AXIS REFLECTING MEMBER
HORIZONTAL AXIS WAVELENGTH SHIFTING FIBER
HORIZONTAL AXIS REFLECTING PLATE
VERTICAL AXIS WAVELENGTH SHIFTING FIBER
VERTICAL AXIS REFLECTING PLATE
PULSE HEIGHT DISCRIMINATOR
5mm
AMPLIFIER
5mm
Y1
Y2
Y3
Y4
Y5
Y6
PIXELS SURROUNDED BY THE REFLECTING PLATES
STRUCTURE OF HORIZONTAL AXIS REFLECTING MEMBER
X1
X2
X3
X4
X5
X6
X-AXIS64CH PHOTOMULTIPLIER TUBE
Y-AXIS64CH PHOTOMULTIPLIER TUBE
AMPLIFIER
PULSE HEIGHT DISCRIMINATOR
MULTI-CHANNEL COINCIDENCE COUNTING AND PROCESSING CIRCUIT
X-AXIS AND Y-AXIT POSITION SIGNALS

FIG.11

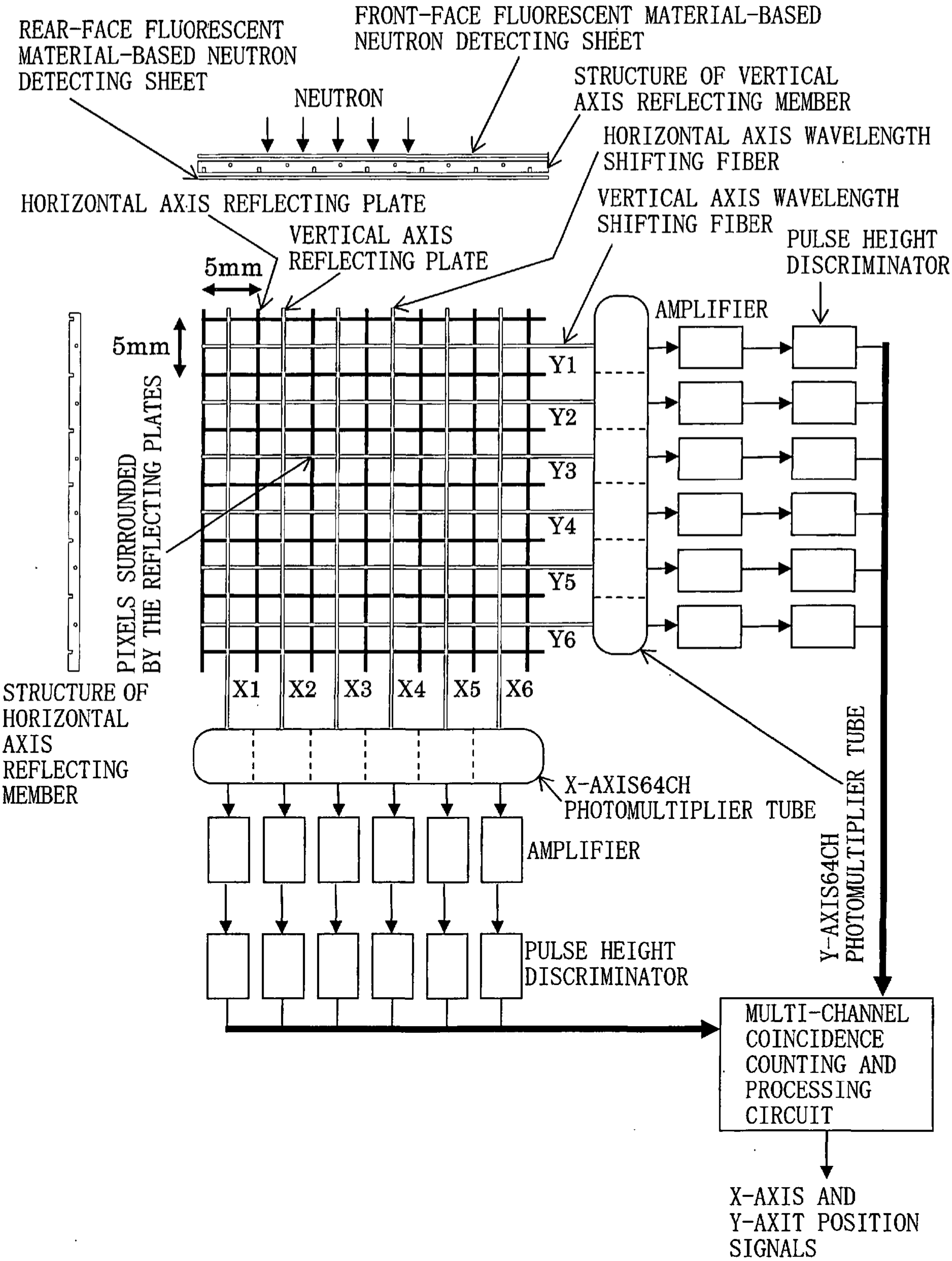

REAR-FACE FLUORESCENT MATERIAL-BASED NEUTRON DETECTING SHEET
FRONT-FACE FLUORESCENT MATERIAL-BASED NEUTRON DETECTING SHEET
NEUTRON
STRUCTURE OF VERTICAL AXIS REFLECTING MEMBER
HORIZONTAL AXIS WAVELENGTH SHIFTING FIBER
HORIZONTAL AXIS REFLECTING PLATE
VERTICAL AXIS WAVELENGTH SHIFTING FIBER
VERTICAL AXIS REFLECTING PLATE
PULSE HEIGHT DISCRIMINATOR
5mm
AMPLIFIER
5mm
Y1
Y2
Y3
Y4
Y5
Y6
PIXELS SURROUNDED BY THE REFLECTING PLATES
STRUCTURE OF HORIZONTAL AXIS REFLECTING MEMBER
X1
X2
X3
X4
X5
X6
X-AXIS64CH PHOTOMULTIPLIER TUBE
Y-AXIS64CH PHOTOMULTIPLIER TUBE
AMPLIFIER
PULSE HEIGHT DISCRIMINATOR
MULTI-CHANNEL COINCIDENCE COUNTING AND PROCESSING CIRCUIT
X-AXIS AND Y-AXIT POSITION SIGNALS

FIG.12

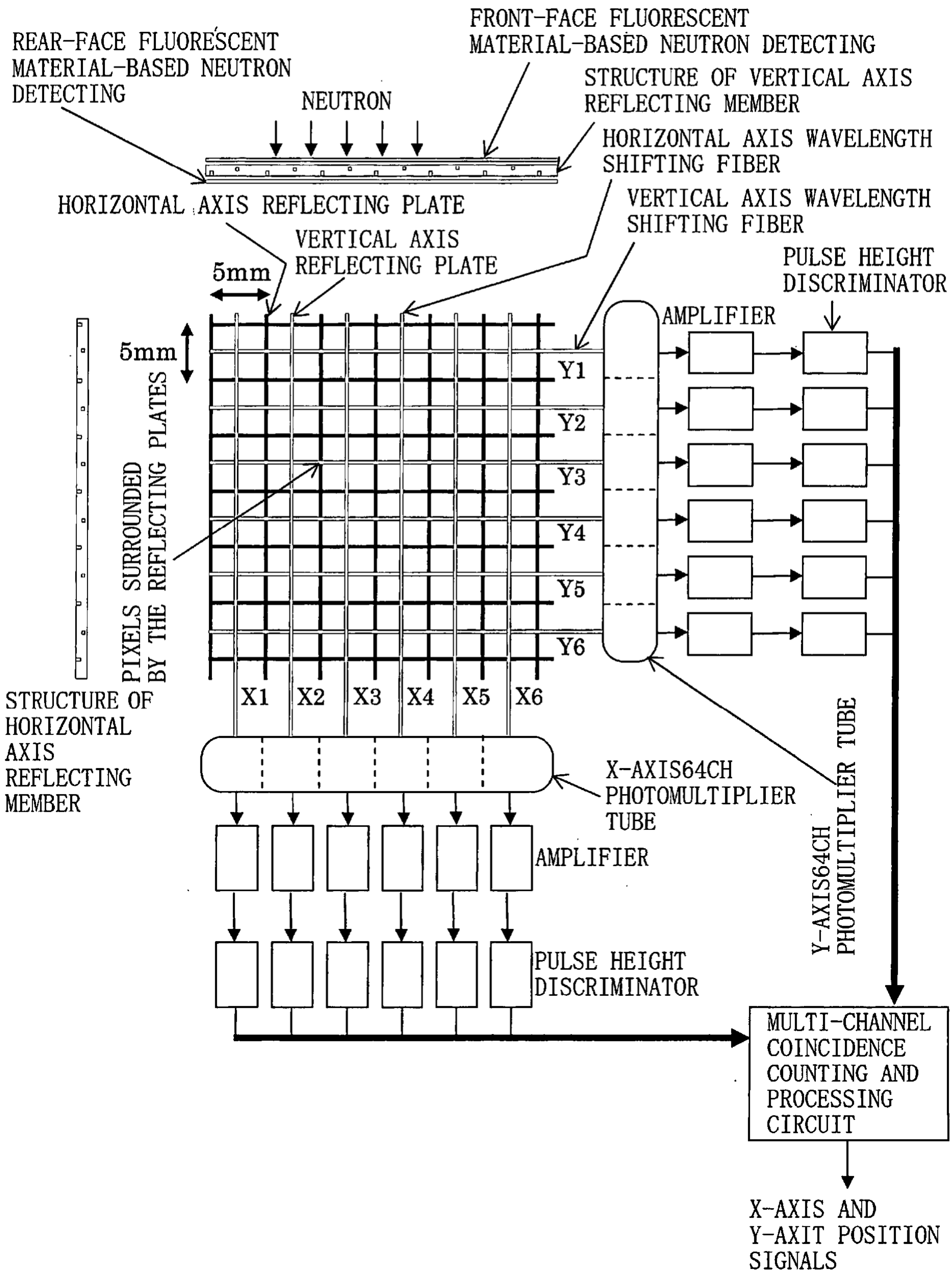
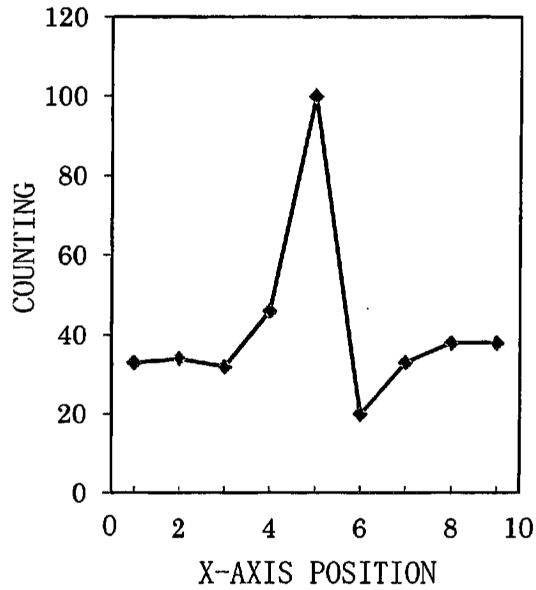

REAR-FACE FLUORESCENT MATERIAL-BASED NEUTRON DETECTING
FRONT-FACE FLUORESCENT MATERIAL-BASED NEUTRON DETECTING
NEUTRON
STRUCTURE OF VERTICAL AXIS REFLECTING MEMBER
HORIZONTAL AXIS WAVELENGTH SHIFTING FIBER
HORIZONTAL AXIS REFLECTING PLATE
VERTICAL AXIS WAVELENGTH SHIFTING FIBER
VERTICAL AXIS REFLECTING PLATE
PULSE HEIGHT DISCRIMINATOR
5mm
5mm
AMPLIFIER
PIXELS SURROUNDED BY THE REFLECTING PLATES
Y1
Y2
Y3
Y4
Y5
Y6
X1
X2
X3
X4
X5
X6
STRUCTURE OF HORIZONTAL AXIS REFLECTING MEMBER
X-AXIS64CH PHOTOMULTIPLIER TUBE
Y-AXIS64CH PHOTOMULTIPLIER TUBE
AMPLIFIER
PULSE HEIGHT DISCRIMINATOR
MULTI-CHANNEL COINCIDENCE COUNTING AND PROCESSING CIRCUIT
X-AXIS AND Y-AXIT POSITION SIGNALS

FIG.13

(A)


120
100
80
60
40
20
0
COUNTING
0
2
4
6
8
10
X-AXIS POSITION

(B)

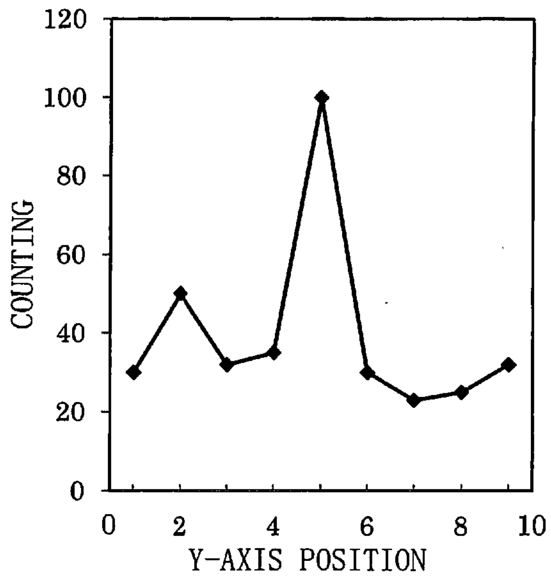

120
100
80
60
40
20
0
COUNTING
0
2
4
6
8
10
Y-AXIS POSITION

FIG.14

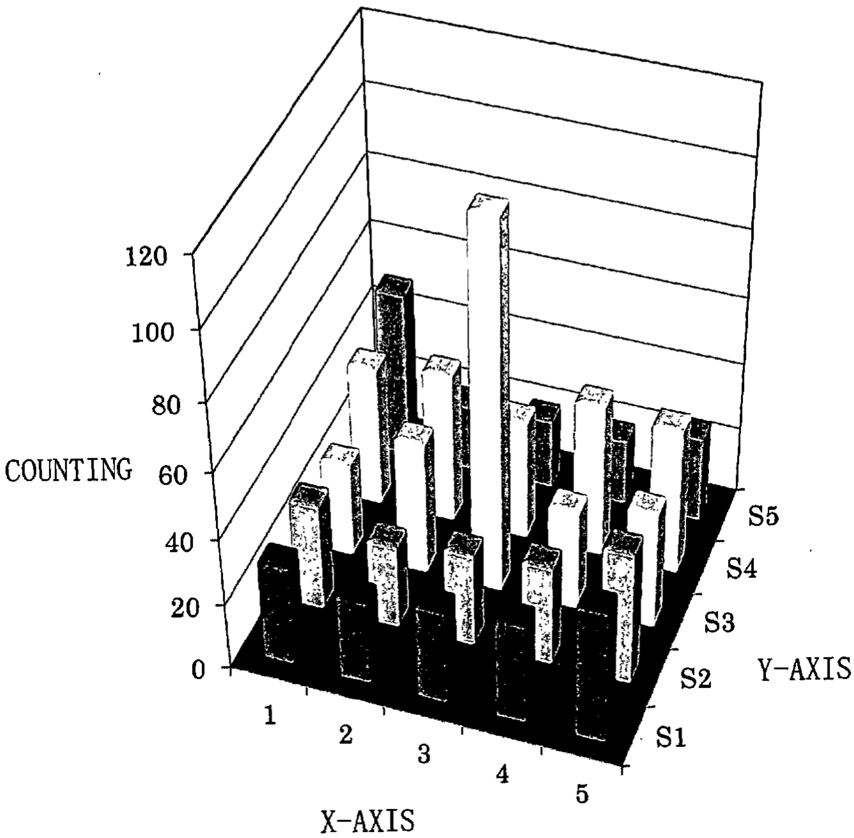
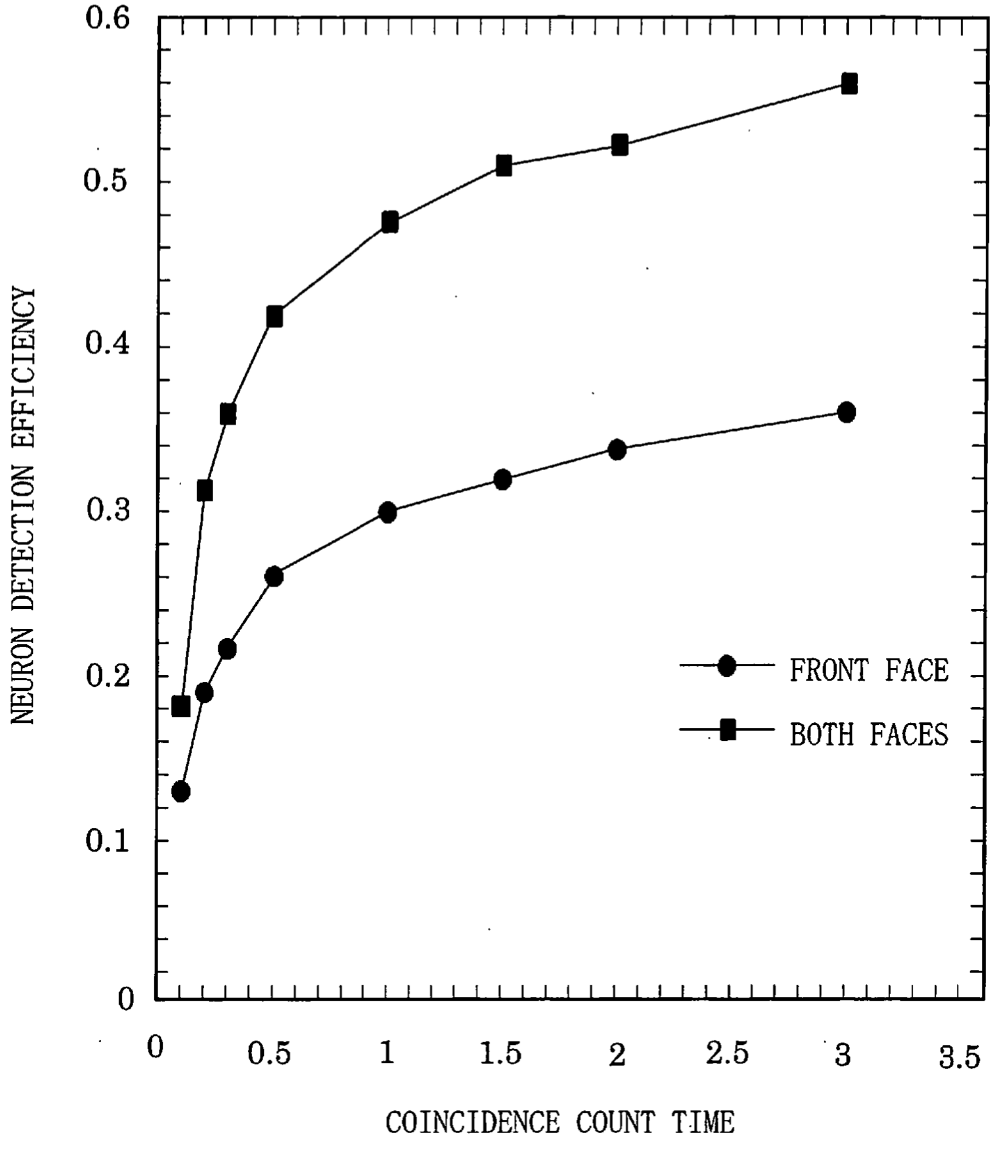


FIG.15


0.6
0.5
0.4
0.3
0.2
0.1
0
NEURON DETECTION EFFICIENCY
FRONT FACE
BOTH FACES
0
0.5
1
1.5
2
2.5
3
3.5
COINCIDENCE COUNT TIME

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2000187007 A **[0004]**
- JP 2002071816 A **[0004]**

Non-patent literature cited in the description

- *Nucl. Instr. And Meth.,* 1999, vol. A430, 311-320 **[0005]**