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(71) Applicant: **HAMAMATSU PHOTONICS K.K.**
Hamamatsu-shi, Shizuoka-ken 435-8558 (JP)

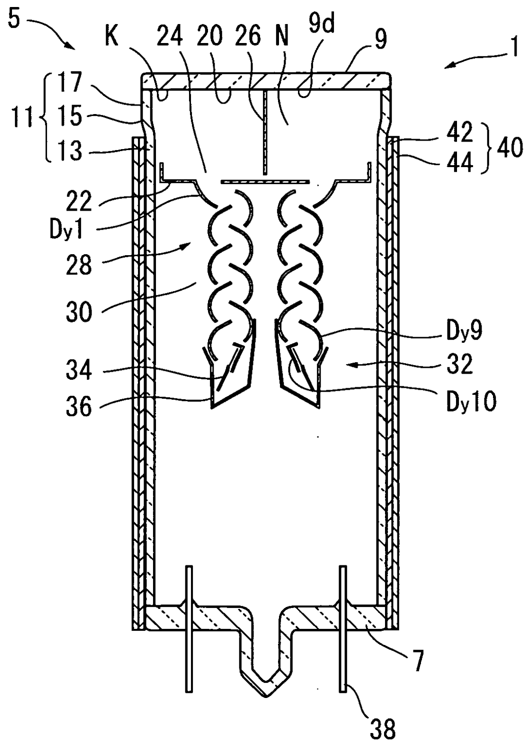
(72) Inventors:
- **YAMAGUCHI, Teruhiko**
Hamamatsu-shi, Shizuoka 435-8558 (JP)
- **KIMURA, Suenori**
Hamamatsu-shi, Shizuoka 435-8558 (JP)
- **SUZUKI, Minoru**
Hamamatsu-shi, Shizuoka 435-8558 (JP)
- **NAKAMURA, Yoshitaka**
Hamamatsu-shi, Shizuoka 435-8558 (JP)

(74) Representative: **Smith, Samuel Leonard**
J.A. Kemp & Co.,
14 South Square,
Gray's Inn
London WC1R 5JJ (GB)

(54) MULTI ANODE-TYPE PHOTOELECTRON INTENSIFIER TUBE AND RADIATION DETECTOR

(57) A side tube includes a tube head, a funnel-shaped connection neck, and a tube main body integrally along a tube axis. The size of the cross section of the tube head perpendicular to the tube axis is larger than the size of the cross section of the tube main body perpendicular to the tube axis. The radius of curvature at curved corners of the tube head is smaller than the radius of curvature at curved corners of the tube main body. The length of the tube head along the tube axis is shorter than the length of the tube main body along the tube axis. A photocathode is formed in a region inside the tube head on one surface of the faceplate that is connected to the tube head. The multi-anode type photomultiper tube having the above-described structure can guide light effectively onto the photocathode, and has a high strength.

FIG.3



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Description

TECHNICAL FIELD

[0001] The present invention relates to a multi-anode type photomultiplier tube and a radiation detector using the multi-anode type photomultiplier tube.

BACKGROUND ART

[0002] Japanese unexamined patent application publication 05-93781 (hereinafter referred to as "Patent Document 1") discloses a radiation detector 200 shown in FIG. 1. This radiation detector 200 includes a scintillator matrix 201 and a multi-anode type photomultiplier tube 203.

[0003] The scintillator matrix 201 includes a plurality of scintillators 202 arranged in a two-dimensional matrix manner, and generates and emits scintillation light in accordance with incident radiation. The multi-anode type photomultiplier tube 203 detects the scintillation light emitted from the scintillator matrix. By calculating the center of mass of output signals issued from a plurality of anode electrodes in the multi-anode type photomultiplier tube 203, it is possible to identify which scintillator has emitted the scintillation light.

[0004] Japanese unexamined patent application publication 11-250853 (hereinafter referred to as "Patent Document 2") discloses a multi-anode type photomultiplier tube that is used for a radiation detector and that includes a quadrangular prismatic hollow side tube made of glass.

[0005] Such a multi-anode type photomultiplier tube includes a faceplate made of glass and the quadrangular prismatic hollow side tube made of glass. The side tube is connected to one surface of the faceplate, and extends along a tube axis that is substantially perpendicular to the faceplate. A photocathode is formed in a region inside the side tube on the one surface of the faceplate that is connected to the side tube. The photocathode is for emitting photoelectrons according to light incident on the faceplate. A plurality of electron multiplying sections and a plurality of anode electrodes are provided inside the side tube in association with a plurality of regions in the photocathode.

[0006] Japanese unexamined patent application publication 03-173056 (hereinafter referred to as "Patent Document 3") discloses a division-type photomultiplier tube. The photomultiplier tube has a side tube, which includes a quadrangular prismatic hollow tube head having a large cross-sectional diameter and a quadrangular-prismatic hollow tube main body having a small cross-sectional diameter. The tube head is connected to one surface of a faceplate. A single anode electrode is located inside the tube main body.

DISCLOSURE OF THE INVENTION

[0007] It is conceivable to modify the quadrangular-prism-shaped glass side tube described in Patent Document 2 into a structure including a quadrangular-prism-shaped tube head having a large cross-sectional diameter and the quadrangular-prism-shaped tube main body having a small cross-sectional diameter, similar to the side tube described in Patent Document 3. Because the cross-sectional diameter of the tube head is large, it is possible to increase the size of the photocathode that is provided on the faceplate at its area inside the side tube.

[0008] If the length of the tube head in the tube axial direction is formed longer than the length of the tube main body in the tube axial direction such as the side tube in Patent Document 3, the overall strength of the side tube will become insufficient.

[0009] When the quadrangular-prism-shaped hollow side tube is made of glass, four corners of the side tube will have a curved shape. Therefore, the area on the faceplate inside the corners of the side tube will become small.

[0010] In a radiation detector, it is important to guide scintillation light from all the scintillators of the scintillator matrix substantially uniformly onto the photocathode for the conversion to photoelectrons. If the corners of the side tube are greatly curved, the incident efficiency from some scintillators on the corners of the side tube will become lower than the incident efficiency from other scintillators among the plurality of scintillators in the scintillator matrix. Consequently, it is nearly impossible to guide the scintillation light from all the scintillators uniformly onto the photocathode.

[0011] The present invention is aimed at solving the problems described above to provide a multi-anode type photomultiplier tube that guides light effectively onto a photocathode for conversion into photoelectrons and that has high strength, and a radiation detector that includes the multi-anode type photomultiplier tube to detect scintillation light from all the scintillators substantially uniformly.

[0012] In order to solve the above problem, a multi-anode type photomultiplier tube of the present invention has a multi-anode type photomultiplier tube including: a faceplate made from glass; and a hollow side tube made from glass and connected to one surface of the faceplate, the side tube extending along a tube axis that is substantially perpendicular to the faceplate, a photocathode for emitting photoelectrons according to light incident on the faceplate being provided on the one surface of the faceplate in a region inside the side tube, a plurality of electron multiplying sections and a plurality of anode electrodes being provided inside the side tube in correspondence with a plurality of regions on the photocathode, wherein the side tube includes a tube head, a funnel-shaped connection neck, and a tube main body which are arranged integrally along the tube axis, the tube main body has a substantially quadrangular prismatic hollow shape with four first curved corners, the tube main body extends along the tube axis by a first length, the tube main body has a first size of cross section substantially perpendicular to the tube axis, each of the four first curved corners is curved with a first radius of curvature, the tube head has a substantially quadrangular prismatic hollow shape with four second curved corners, the tube head extends along the tube axis by a second length, the tube head has a second size of cross section substantially perpendicular to the tube axis, each of the four second curved corners is curved with a second radius of curvature, the second length is shorter than the first length, the second size is larger than the first size, the second radius of curvature is smaller than the first radius of curvature, the funnel-shaped connection neck connects the tube head to the tube main body coaxially, the tube head is connected to the one surface of the faceplate, the photocathode is provided on the one surface of the faceplate in a region inside the tube head, and the plurality of electron multiplying sections and the plurality of anode electrodes are provided inside the tube main body.

[0013] In the multi-anode type photomultiplier tube according to the present invention, the size of the cross section of the tube head is larger than the size of the cross section of the tube main body. This construction increases an area of a part of the surface of the faceplate that is connected to the tube head and that is inside the tube head. Accordingly, it is possible to increase the size of the photocathode and to effectively guide a larger amount of light onto the photocathode for the conversion into photoelectrons.

[0014] Furthermore, the radius of curvature at the curved corners of the tube head is smaller than the radius of curvature at the curved corners of the tube main body. This construction increases the area of a part of the faceplate that is in the vicinity of the curved corners of the tube head and that is inside the curved corners. Therefore, it is possible to increase the area of a part of the photocathode that is in the vicinity of the curved corners and to effectively guide light incident in the vicinity of the curved corners of the tube head onto the photocathode for conversion into photoelectrons.

[0015] The length of the tube main body in the tube axis direction is longer than that of the tube head, so that the overall mechanical strength of the vacuum vessel is enhanced.

[0016] By setting the size of the cross section of the tube head and the radius of curvature at the curved corners of the tube head to desired values and adjusting the length of the tube main body, the length of the tube head, the size of the cross section of the tube main body, and the radius of curvature at the curved corners of the tube main body in correspondence with the size of the cross section of the tube head and the radius of curvature at the curved corners of the tube head, it is possible to set the area of the photocathode at a desired size and to guide light falling in the vicinity of the curved corners of the tube head effectively onto the photocathode while maintaining a sufficiently high strength of the entire side tube.

[0017] Preferably, the tube head includes an outer peripheral surface and an inner peripheral surface, the outer peripheral surface connects each two adjacent second curved corners with a substantially straight line, the inner peripheral surface connects each two adjacent second curved corners with a curved line, and the inner peripheral surface gradually approaches the outer peripheral surface from a substantially central position between the two adjacent second curved corners towards each of the two adjacent second curved corners. The area of a part of the faceplate that is in the vicinity of the curved corners of the tube head and that is inside the curved corners can be increased. Therefore, it is possible to increase the area of a part of the photocathode that is in the vicinity of the curved corners. Accordingly, a larger amount of light incident in the vicinity of the curved corners of the tube head can be guided onto the photocathode for conversion into photoelectrons.

[0018] Preferably, the multi-anode type photomultiplier tube of the present invention further has: a converging electrode plate converging the photoelectrons emitted from the photocathode; and a partition plate dividing an electron converging space defined between the photocathode and the converging electrode plate into a plurality of segment-spaces corresponding to the plurality of regions on the photocathode, wherein each electron multiplying section receives the photoelectrons converged by the converging electrode plate in the corresponding one of the plurality of segment-spaces, the partition plate extends from the tube head into the tube main body through the funnel-shaped connection neck in the side tube, the converging electrode plate, the plurality of electron multiplying sections, and the plurality of anode electrodes are located in the tube main body, and a magnetic shield is provided on an outer periphery of the tube main body. By arranging the converging electrode plate, the plurality of electron multiplying sections, and the plurality of anode electrodes in the tube main body and providing the magnetic shield on the outer periphery of the tube main body, it is possible to precisely perform operations for converging and multiplying photoelectrons without being affected by an external magnetic field.

[0019] From another aspect of the invention, a radiation detector of the present invention includes: a scintillator matrix that includes a plurality of scintillators arranged in a two-dimensional matrix manner, each scintillator having an output surface, and each scintillator generating scintillation light in accordance with radiation incident on the scintillator and emitting the scintillation light from the output surface; and a multi-anode type photomultiplier tube for detecting the scintillation light emitted from each scintillator of the scintillator matrix, wherein the multi-anode type photomultiplier tube includes: a faceplate made from glass; and a hollow side tube made from glass and connected to one surface of the faceplate, the side tube extending along a tube axis that is substantially perpendicular to the faceplate, another surface of the faceplate opposite to the one surface facing all of the output surfaces of the plurality of scintillators in the scintillator matrix, a photocathode for emitting photoelectrons according to scintillation light incident on the faceplate being provided on the one surface of the faceplate in a region inside the side tube, and a plurality of electron multiplying sections and a plurality of anode electrodes being provided inside the side tube in correspondence with a plurality of regions on the photocathode, wherein the side tube includes a tube head, a funnel-shaped connection neck, and a tube main body which are arranged integrally along the tube axis, the tube main body has a substantially quadrangular prismatic hollow shape with four first curved corners, the tube main body extends along the tube axis by a first length, the tube main body has a first size of cross section substantially perpendicular to the tube axis, each of the four first curved corners is curved with a first radius of curvature, the tube head has a substantially quadrangular prismatic hollow shape with four second curved corners, the tube head extends along the tube axis by a second length, the tube head has a second size of cross section substantially perpendicular to the tube axis, each of the four second curved corners is curved with a second radius of curvature, the second length is shorter than the first length, the second size is larger than the first size, the second radius of curvature is smaller than the first radius of curvature, the funnel-shaped connection neck connects the tube head to the tube main body coaxially, the tube head is connected to the one surface of the faceplate, the photocathode is provided on the one surface of the faceplate in a region inside the tube head, and the plurality of electron multiplying sections and the plurality of anode electrodes are provided inside the tube main body.

[0020] In the radiation detector according to the present invention, the size of the cross section of the tube head is larger than the size of the cross section of the tube main body. The curved corners of the tube head are curved with a radius of curvature that is smaller than that of the curved corners of the tube main body. Therefore, it is possible to make most parts of the output surfaces of the scintillators that are located at the outer peripheral portion of the scintillator matrix or at the corners of the scintillator matrix properly face the part of the faceplate that is inside the tube head. Accordingly, the photocathode can receive scintillation light from all the scintillators at a substantially uniform ratio. The radiation detector can detect radiation with substantially uniform sensitivity.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021]

FIG. 1 is a perspective view of a conventional radiation detector;

FIG. 2 is a plan view of a multi-anode type photomultiplier tube according to a first embodiment of the present invention;

FIG. 3 is a sectional view of the multi-anode type photomultiplier tube taken along the line III-III of FIG. 2;

FIG. 4 is a perspective view of a glass vessel provided in the multi-anode type photomultiplier tube of the first embodiment of the present invention;

FIG. 5 is a sectional view of the glass vessel shown in FIG. 4;

FIG. 6 is a cross-sectional view of the glass vessel taken along the line VI-VI of FIG. 5;

FIG. 7 is a cross-sectional view of the glass vessel taken along the line VII-VII of FIG. 5;

FIG. 8 is a top view of the glass vessel shown in FIG. 5;

FIG. 9 is a schematic plan view showing how a plurality of radiation detectors of the first embodiment are arranged;

FIG. 10 is a sectional view taken along the line X-X of FIG. 9;

FIG. 11 is an enlarged view of an essential portion E shown in FIG. 10;

FIG. 12 is a cross-sectional view of a tube head of a glass vessel provided in a multi-anode type photomultiplier tube according to a second embodiment of the present invention;

FIG. 13 is a plan view of a multi-anode type photomultiplier tube according to a comparative example;

FIG. 14 is a sectional view of the multi-anode type photomultiplier tube taken along the line XIV-XIV of FIG. 13;

FIG. 15 is a schematic plan view showing how a plurality of radiation detectors of the comparative example are arranged;

FIG. 16 is a sectional view taken along the line XVI-XVI of FIG. 15;

FIG. 17 is an enlarged view of an essential portion H shown in FIG. 16;

FIG. 18 is an explanatory diagram showing that effective photoelectric regions of the multi-anode type photomultiplier tubes according to the first and second embodiments are larger than that of the multi-anode type photomultiplier tube according to the comparative example, because the diameters of the tube heads of the first and second embodiments are larger than the diameter of the tube of the comparative example and the radiuses of curvature at the curved corners of the tube head are smaller than the radius of curvature at the curved corners of the tube of the comparative example;

FIG. 19 is an explanatory diagram showing that scintillator effective area ratios at four scintillators in the vicinity of one corner of a scintillator matrix in the radiation detector according to each of the first and second embodiments are greater than scintillator effective area ratios at four scintillators in the vicinity of one corner of a scintillator matrix in the radiation detector of the comparative example, because the diameters of the tube heads of the first and second embodiments are larger than the diameter of the tube of the comparative example and the radiuses of curvature at the curved corners of the tube head are smaller than the radiuses of curvature at the curved corners of the tube in the comparative example;

FIG. 20 is an explanatory diagram showing that the effective photoelectric regions of the multi-anode type photomultiplier tubes according to the first and second embodiments are still larger than the effective photoelectric region of the multi-anode type photomultiplier tube according to the comparative example, even when the diameters of the tube heads of the first and second embodiments are equal to the diameter of the tube of the comparative example and the radiuses of curvature at the curved corners of the tube head are smaller than the radius of curvature at the curved corners of the tube of the comparative example; and

FIG. 21 is an explanatory diagram showing that scintillator effective area ratios at four scintillators in the vicinity of one corner of a scintillator matrix in the radiation detector according to each of the first and second embodiments are still greater than scintillator effective area ratios at four scintillators in the vicinity of one corner of a scintillator matrix in the radiation detector of the comparative example, even when the diameters of the tube heads of the first and second embodiments are equal to the diameter of the tube of the comparative example and the radiuses of curvature at the curved corners of the tube head are smaller than the radiuses of curvature at the curved corners of the tube in the comparative example.

BEST MODE FOR CARRYING OUT THE INVENTION

[0022] A multi-anode type photomultiplier tube and a radiation detector according to embodiments of the present invention will be described with reference to the accompanying drawings.

[0023] A multi-anode type photomultiplier tube and a radiation detector according to a first embodiment of the present invention will be described with reference to FIGS. 2 to 11.

[0024] First, the multi-anode type photomultiplier tube of this embodiment will be described.

[0025] FIG. 2 is a plan view of the multi-anode type photomultiplier tube 1 of this embodiment.

[0026] FIG. 3 is a sectional view of the multi-anode type photomultiplier tube 1 taken along the line III-III of FIG. 2.

[0027] The multi-anode type photomultiplier tube 1 is of a two by two multi-anode type.

[0028] As shown in FIGS. 2 and 3, the multi-anode type photomultiplier tube 1 includes a glass vessel 5 made from transparent glass.

[0029] As shown in FIG. 3, the glass vessel 5 includes a hollow side tube 11 made from transparent glass and a faceplate 9 made from transparent glass.

[0030] The side tube 11 extends along a tube axis that is substantially perpendicular to the faceplate 9. The side tube 11 includes a tube head 17, a funnel-shaped connection neck 15, and a tube main body 13 that are integrally arranged along the tube axis. The upper end of the tube head 17 of the side tube 11 is connected to a lower surface 9d of the faceplate 9. A part of the lower surface 9d of the faceplate 9 that is inside the tube head 17 is hereinafter referred to as an "effective photoelectric region K".

[0031] A stem 7 made from transparent glass is connected to the lower end of the tube main body 13, thereby hermetically sealing the inside of the glass vessel 5.

[0032] A photocathode 20, a converging electrode plate 22, partition plates 26, an electron multiplying section 28, and an anode section 32 are provided in the glass vessel 5. Input/output pins 38 are provided to pass through the stem 7.

[0033] The photocathode 20 is formed on the effective photoelectric region K of the faceplate 9.

[0034] The converging electrode plate 22 has a disk-shape. As shown in FIG. 2, the converging electrode plate 22 is formed with four openings 24.

[0035] The electron multiplying section 28 includes four dynode arrays 30. FIG. 3 illustrates only two dynode arrays 30. Each dynode array 30 includes ten dynodes Dy1 to Dy10.

[0036] The anode section 32 includes four anode electrodes 34. In FIG. 3, only two anode electrodes 34 are illustrated.

[0037] In the anode section 32, four shielding electrodes 36 are further provided. FIG. 3 illustrates only two shielding electrodes 36.

[0038] A magnetic shield 40 is provided to surround the outer periphery of the tube main body 13. The magnetic shield 40 includes a high magnetic permeability material 42 and a resin coating 44.

[0039] In this embodiment, the glass vessel 5 of the multi-anode type photomultiplier tube 1 is formed to have a shape described below. Therefore, a large amount of light can be effectively guided onto the photocathode 20, and the vessel 5 can be maintained under a high vacuum.

[0040] The shape of the glass vessel 5 will be described with reference to FIGS. 4 to 8.

[0041] First, the shape of the glass vessel 5 will be described in brief with reference to FIG. 4.

[0042] FIG. 4 is a perspective view of the glass vessel 5.

[0043] The tube main body 13 has a substantially quadrangular prismatic hollow shape extending along the tube axis, and includes four planar sides 13a and four curved corners 13b. The tube main body 13 has a substantially square cross section perpendicular to the tube axis.

[0044] The tube head 17 also has a substantially quadrangular prismatic hollow shape extending along the tube axis, and includes four planar sides 17a and four curved corners 17b. The tube head 17 has a substantially square cross section perpendicular to the tube axis.

[0045] The funnel-shaped connection neck 15 connects the tube main body 13 to the tube head 17 coaxially.

[0046] The faceplate 9 is made of a substantially square glass plate. The faceplate 9 includes an upper surface 9u, a lower surface 9d, four side surfaces 9a, and four curved corners 9b. Both the upper surface 9u and the lower surface 9d are substantially square.

[0047] The four side surfaces 9a of the faceplate 9 are continuously connected to the four planar sides 17a of the tube head 17, respectively. The four curved corners 9b of the faceplate 9 are continuously connected to the four curved corners 17b of the tube head 17, respectively.

[0048] Next, the shape of the glass vessel 5 will be described in more detail with reference to FIGS. 5 to 8.

[0049] FIG. 5 is a sectional view of the glass vessel 5.

[0050] The tube head 17 includes an outer peripheral surface 17o and an inner peripheral surface 17i. The funnel-shaped connection neck 15 includes an outer peripheral surface 15o and an inner peripheral surface 15i. The tube main body 13 includes an outer peripheral surface 13o and an inner peripheral surface 13i. The outer peripheral surface 17o of the tube head 17 is connected to the outer peripheral surface 13o of the tube main body 13 through the outer peripheral surface 15o of the funnel-shaped connection neck 15. The inner peripheral surface 17i of the tube head 17 is connected to the inner peripheral surface 13i of the tube main body 13 through the inner peripheral surface 15i of the funnel-shaped connection neck 15.

[0051] The length L1 of the tube main body 13 in the tube axial direction is longer than the length L2 of the tube head 17 in the tube axial direction.

[0052] The outside diameter W2 of the tube head 17 is larger than the outside diameter W1 of the tube main body 13. The inside diameter W2' of the tube head 17 is larger than the inside diameter W1' of the tube main body 13.

[0053] The outside diameter of the faceplate 9 is equal to the outside diameter W2 of the tube head 17.

[0054] FIG. 6 is a cross-sectional view of the glass vessel 5 taken along the line VI-VI of FIG. 5, that is, a cross-sectional view of the tube main body 13.

[0055] The outer peripheral surface 13o of the tube main body 13 connects each pair of two adjacent curved corners 13b among the four curved corners 13b at a length W1 (outside diameter of the tube main body 13) in a substantially straight line. The outer peripheral surface 13o is curved with a radius of curvature (outside radius of curvature) R1 at the curved corners 13b.

[0056] The inner peripheral surface 13i of the tube main body 13 extends along the outer peripheral surface 13o, while maintaining a substantially fixed distance from the outer peripheral surface 13o (thickness T1 of the tube main body 13). That is, the inner peripheral surface 13i connects each pair of two adjacent curved corners 13b at a length W1' (=W1-2xT1; inside diameter of the tube main body 13) in a substantially straight line. The inner peripheral surface 13i is curved with a radius of curvature (inside radius of curvature) R1' at the curved corners 13b. The inside radius of curvature R1' is substantially equal to the outside radius of curvature R1.

[0057] FIG. 7 is a cross-sectional view of the glass vessel 5 taken along the line VII-VII of FIG. 5, that is, a cross-sectional view of the tube head 17.

[0058] The outer peripheral surface 17o of the tube head 17 connects each two adjacent curved corners 17b at a length W2 (outside diameter of the tube head 17) in a substantially straight line. The outer peripheral surface 17o is curved with a radius of curvature (outside radius of curvature) R2 at the curved corners 17b. The outside radius of curvature R2 is smaller than the outside radius of curvature R1 in the tube main body 13.

[0059] The inner peripheral surface 17i of the tube head 17 extends along the outer peripheral surface 17o while maintaining a substantially fixed distance from the outer peripheral surface 17o (thickness T2 of the tube head 17). That is, the inner peripheral surface 17i connects each pair of two adjacent curved corners 17b at a length W2' (W2'=W2-2xT2: inside diameter of the tube head 17) in a substantially straight line. The thickness T2 of the tube head 17 is substantially equal to the thickness T1 of the tube main body 13. The inner peripheral surface 17i is curved with a radius of curvature (inside radius of curvature) R2' at the curved corners 17b. The inside radius of curvature R2' is substantially equal to the outside radius of curvature R2. Accordingly, the inside radius of curvature R2' is also smaller than the inside radius of curvature R1' in the tube main body 13.

[0060] FIG. 8 is a top view of the glass vessel 5 shown in FIG. 5.

[0061] The faceplate 9 has the same external shape and size as those of the external shape of the tube head 17. That is, the radius of curvature at the curved corners 9b of the faceplate 9 is equal to the outside radius of curvature R2 at the curved corners 17b of the tube head 17. Each side surface 9a of the faceplate 9 connects two curved corners 9b on the both sides of the side surface 9a at a length W2 (outside diameter of the faceplate) in a straight line. The length W2 is equal to the outside diameter W2 of the tube head 17. A part of the lower surface 9d of the faceplate 9 that is inside the inner peripheral surface 17i of the tube head 17 is the effective photoelectric region K.

[0062] It is possible to produce the glass vessel 5 having the above shape by using a method described below. First, an internal mold to produce the side tube 11 is prepared. The shape of the outer peripheral surface of the internal mold is identical to the shape of the inner peripheral surface of the side tube 11. Then, transparent glass is supplied to around the internal mold so as to have a desired thickness, thereby producing the side tube 11. The side tube 11 may be formed by using soft glass or hard glass. Next, the lower surface 9d of the faceplate 9 is fused to the upper end of the tube head 17 of the side tube 11. As a result, the glass vessel 5 is produced.

[0063] Next, an internal construction of the multi-anode type photomultiplier tube of this embodiment will be described referring to FIGS. 2 and 3 again.

[0064] As described above, the photocathode 20 is formed on the effective photoelectric region K of the faceplate 9.

[0065] The converging electrode plate 22 faces the photocathode 20, and converges photoelectrons emitted from the photocathode 20 to guide the photoelectrons into the electron multiplying section 28. The four openings 24 are arranged two-dimensionally in a two by two matrix manner.

[0066] The partition plates 26 divide an electron converging space defined between the photocathode 20 and the converging electrode plate 22 into two by two segment spaces N corresponding to the two by two openings 24. The photocathode 20 has two by two regions corresponding to the two by two segment spaces N. The photoelectrons emitted from one region of the photocathode 20 are converged by the converging electrode plate 22 while traveling in a corresponding segment space N. The photoelectrons then pass through the corresponding opening 24 of the converging electrode plate 22 to reach the electron multiplying section 28.

[0067] In the electron multiplying section 28, the four dynode arrays 30 are arranged so as to face the four openings 24 in a one-to-one correspondence. Each dynode array 30 multiplies incident photoelectrons having passed through a corresponding opening 24. The dynodes Dy1 to Dy10 are arranged in the tube axis direction in a linear-focus manner.

[0068] In the anode section 32, the four anode electrodes 34 are arranged so as to be associated with the four dynode arrays 30 in a one-to-one manner. Each anode electrode 34 is located between the 9th stage dynode Dy9 and the 10th stage dynode Dy10 of a corresponding dynode array 30 so as to face each of the 9ty and 10th dynodes. Each anode electrode 34 receives photoelectrons multiplied by a corresponding dynode array 30 to generate an output signal indicating the amount of photoelectrons.

[0069] The four shielding electrodes 36 are provided to isolate each of the four anode electrodes 34 from the other.

[0070] The input/output pins 38 are connected to the photocathode 20, the converging electrode plate 22, the electron multiplying section 28, and the anode section 32 with wiring (not shown). The pins 28 are fixed through the stem 7.

[0071] As described above, in this embodiment, the two by two dynode arrays 30 and the two by two anode electrodes 34 are provided so as to correspond to the two by two segment spaces N, respectively. Each dynode array 30 receives photoelectrons emitted from a corresponding region in the photocathode 20 to multiply the received photoelectrons. Then, the corresponding anode electrode 34 receives the photoelectrons and generates an output signal indicating the amount of the received photoelectrons to the outside through the input/output pins 38.

[0072] The partition plates 26 extend across the tube head 17 and the funnel-shaped connection neck 15 into the tube main body 13 of the side tube 11. The converging electrode plate 22, the electron multiplying section 28, and the anode section 32 are provided in the tube main body 13.

[0073] The magnetic shield 40 shields the converging electrode plate 22, the electron multiplying section 28, and the anode section 32 in the tube main body 13 from an external magnetic field. The high magnetic permeability material 42 is made of permalloy, for instance, and directly covers the outer periphery of the tube main body 13. The resin coating 44 covers the outer periphery of the high magnetic permeability material 42. The resin coating 44 fixes the high magnetic permeability material 42 to the photomultiplier tube 1.

[0074] The multi-anode type photomultiplier tube 1 of this embodiment having the above structure operates as follows.

[0075] Predetermined voltages are applied to the photocathode 20, the converging electrode plate 22, the anode section 32, and the electron multiplying section 28 through the input/output pins 38. When light is incident on a region of the faceplate 9 that corresponds to one segment space N, photoelectrons, whose amount corresponds to the amount of the incident light, are emitted from the corresponding region of the photocathode 20. These photoelectrons are converged by the converging electrode plate 22 while traveling in the segment space N, and then guided onto the corresponding dynode array 30 through the corresponding opening 24. The photoelectrons are multiplied at each stage of the dynode array 30, and then collected by the corresponding anode electrode 34 to be outputted as an output signal through the input/output pins 38. This output signal indicates what amount of light has impinged on a region of the faceplate 9 and which segment space N faces that region.

[0076] In this embodiment, the converging electrode plate 22, the electron multiplying section 28, and the anode section 32 are placed in the tube main body 13. The magnetic shield 40 is provided on the outer periphery of the tube main body 13. Therefore, the convergence and multiplication of photoelectrons are performed precisely without being affected by the external magnetic field.

[0077] In the multi-anode type photomultiplier tube 1 of this embodiment, the outside diameters W2 of the tube head 17 and the faceplate 9 are larger than the outside diameter W1 of the tube main body 13. The inside diameter W2' of the tube head 17 is also larger than the inside diameter W1' of the tube main body 13. Accordingly, the effective photoelectric region K on the lower surface 9d of the faceplate 9 can be increased, so that a large amount of light can be guided onto the photocathode 20 for the photoelectrical conversion.

[0078] In this embodiment, the outside radius of curvature R2 at the curved corners 17b of the tube head 17 is smaller than the outside radius of curvature R1 at the curved corners 13b of the tube main body 13. Additionally, the inside radius of curvature R2' at the curved corners 17b of the tube head 17 is smaller than the inside radius of curvature R1' at the curved corners 13b of the tube main body 13. Therefore, the effective photoelectric region K inside the curved corners 17b in the vicinity of the curved corners 17b can be increased. As a result, the area of a part of the photocathode 20 that is in the vicinity of the curved corners 17b can be increased, so that light reaching the vicinity of the curved corners 17b can be effectively guided onto the photocathode 20.

[0079] The tube head 17 has large outside and inside diameters and small radius of curvature at the curved corners 17b, so that the mechanical strength of the tube head 17 is low. However, the tube main body 13 having small outside and inside diameters and large radius of curvature at the curved corners 13b supports the tube head 17. This structure enhances the overall strength of the side tube 11. In addition, the length L1 of the tube main body 13 in the tube axial direction is longer than the length L2 of the tube head 17 in the tube axial direction, so that the overall strength of the side tube 11 is further enhanced.

[0080] As described above, in this embodiment, the size of the cross section of the tube head 17 perpendicular to the tube axis is larger than the size of the cross section of the tube main body 13 perpendicular to the tube axis. The radiuses of curvature at the four curved corners 17b of the tube head 17 are smaller than the radiuses of curvature at the four curved corners 13b of the tube main body 13. The length of the tube head 17 along the tube axis is shorter than the length of the tube main body 13 along the tube axis. Therefore, by setting the size of the tube head 17 and the radiuses of curvature at the curved corners 17b to desired values according to application and adjusting the length of the tube main body 13, the length of the tube head 17, the size of the tube main body 13, and the radiuses of curvature at the curved corners 13b as a function of the size of the tube head 17 and the radiuses of curvature at the curved corners 17b, the overall mechanical strength of the side tube 11 can be maintained at a sufficiently high level.

[0081] Next, a radiation detector 50 of the first embodiment will be described with reference to FIGS. 9 to 11.

[0082] FIG. 9 is a schematic plan view showing an arrangement in which a plurality of radiation detectors 50 (three radiation detectors in FIG. 9) of this embodiment are arranged adjacent to one another. FIG. 10 is a sectional view of the plural radiation detectors 50 taken along the line X-X in FIG. 9. FIG. 11 is an enlarged view of an essential portion E shown in FIG. 10.

[0083] As shown in FIG. 10, a radiation detector 50 includes the multi-anode type photomultiplier tube 1 and a scintillator matrix 52. The multi-anode type photomultiplier tube 1 has the construction described with reference to FIGS. 2 and 3. In FIG. 10, the illustration of the internal construction of the multi-anode type photomultiplier tube 1 is omitted for clarification purposes.

[0084] The scintillator matrix 52 generates scintillation light in accordance with the radiation incident thereon. As shown in FIGS. 9 and 10, the scintillator matrix 52 is formed by two-dimensionally arranging a plurality of scintillators 54 (36 scintillators in this embodiment) in a six by six matrix manner. Each scintillator 54 has a rectangular prismatic shape having a substantially square cross section. The scintillator 54 has a substantially square output surface (lower surface) 54d. When receiving incident radiation, the scintillator 54 generates scintillation light corresponding to the amount of the radiation and emits the scintillation light from the output surface 54d as scattered light.

[0085] The upper surface 9u of the faceplate 9 of the multi-anode type photomultiplier tube 1 faces all the output surfaces 54d of the scintillators 54 in the scintillator matrix 52, and is bonded to all the output surfaces 54d.

[0086] FIG. 9 schematically shows a positional relationship between the effective photoelectric region K of the faceplate 9 and 36 output surfaces 54d of the scintillators 54 constituting the scintillator matrix 52. As seen from FIG. 9, some scintillators 54 are positioned at the outer periphery of the scintillator matrix 52 among the 36 scintillators 54 of the scintillator matrix 52, and face the outer periphery of the tube head 17 through the outer periphery of the faceplate 9. In particular, the scintillators 54 at four corners of the scintillator matrix 52 face the four curved corners 17b of the tube head 17 through the four curved corners 9b of the faceplate 9, respectively.

[0087] When a plurality of radiation detectors 50 are arranged, it is necessary that the adjacent tube heads 17 be spaced away from one another by a minimum distance S without contacting one another directly. This is because the adjacent tube heads 17 should be prevented from colliding to each other to be damaged.

[0088] In this embodiment, the outside diameter W1 of the tube main body 13, the outside diameters W2 of the faceplate 9 and the tube head 17, and the inside diameter W2' of the tube head 17 of the multi-anode type photomultiplier tube 1 have the following relationship with reference to the outside diameter W of the scintillator matrix 52. The thickness of the magnetic shield 40 is set as "M". The thickness M of the magnetic shield is larger than the distance S.

[0089] The outside diameter W1 of the tube main body 13 is equal to the outside diameter W of the scintillator matrix 52. The outside diameters W2 of the faceplate 9 and the tube head 17 are larger than the outside diameter W1 of the tube main body 13 or the outside diameter W of the scintillator matrix 52 by a difference (M-S) between the thickness M of the magnetic shield 40 and the minimum distance S. The inside diameter W2' of the tube head 17 is smaller than the outside diameter W2 by twice of the thickness T2. In this example, "2xT2" is slightly larger than (M-S), and therefore the inside diameter W2' of the tube head 17 is slightly smaller than the outside diameter W of the scintillator matrix 52.

[0090] By arranging the radiation detectors 50 having the above sizes so that adjacent magnetic shields 40 contact one another, adjacent tube heads 17 can be spaced from one another by the minimum distance S, as shown in FIG. 11. Accordingly, the adjacent scintillator matrixes 52 are also spaced from one another by a certain distance equal to the thickness M of the magnetic shield 40.

[0091] The outside diameters W2 of the faceplate 9 and the tube head 17 are larger than the outside diameter W of the scintillator matrix 52. The inside diameter W2' of the tube head 17 is slightly smaller than the outside diameter W of the scintillator matrix 52. Accordingly, most portions of the output surfaces 54d of those scintillators 54 that are located at the outer periphery of the scintillator matrix 52 properly face the effective photoelectric region K inside the tube head 17 as shown in FIG 9.

[0092] Additionally, in this embodiment, the radiuses of curvature R2 and R2' at the curved corners 17b have desired small values. Accordingly, most portions of the output surfaces 54d of those scintillators 54 that are located at the four corners of the scintillator matrix 52 properly face the effective photoelectric region K inside the curved corners 17b.

[0093] According to this embodiment, when the area of the photocathode 20 is intended to increase, such as when the number of the scintillators 54 in the scintillator matrix 52 is intended to increase, it is sufficient to increase the cross-sectional areas W2 and W2' of the tube head 17 and to set the radiuses of curvature R2 and R2' at the curved corners 17b to desired values. In order to maintain the overall strength of the side tube 11, the length L1 of the tube main body 13, the length L2 of the tube head 17, the cross-sectional areas W1 and W1' of the tube main body 13, and the radiuses of curvature R1 and R1' at the curved corners 13b are adjusted in correspondence with the cross-sectional areas W2 and W2' of the tube head 17 and the radiuses of curvature R2 and R2' at the curved corners 17b. Accordingly, the side tube 11 can enhance the overall strength, while increasing the area of the photocathode 20 and guiding light in the vicinity of the curved corners 17b onto the photocathode 20 effectively.

[0094] The radiation detector 50 of this embodiment having the above construction operates as follows.

[0095] When radiation (for example, gamma rays) is incident on one scintillator 54 in one radiation detector 50, the scintillator 54 generates scintillation light. This scintillation light outputs from the output surface 54d of the scintillator 54 and impinges on the faceplate 9 of the photomultiplier tube as scattered light, and is then converted into photoelectrons by the photocathode 20. The photoelectrons are multiplied by the electron multiplying section 28, and then outputted as four output signals from the anode section 32. A not-shown operating apparatus (computer) receives these four output signals and calculates ratios among the four output signals, thereby obtaining the center of mass in these output signals. Referring to the result of the calculation, the scintillator 54 having received the radiation is identified. Distribution of incident positions of radiation can be detected over a wide area because a plurality of radiation detectors 50 are arranged adjacent to one another at regular intervals.

[0096] In this embodiment, because the outside diameter W2 and the inside diameter W2' of the tube head 17 are large, most parts of the output surfaces 54d of those scintillators 54 that are located at the outer periphery of the scintillator matrix 52 properly face the effective photoelectric region K inside the tube head 17, that is, the photocathode 20.

[0097] Additionally, most parts of the output surfaces 54d of the scintillators 54 that are located at the corners of the scintillator matrix 52 properly face the photocathode 20 inside the curved corners 17b of the tube head 17, because the radiuses of curvature (outside radius of curvature R2 and inside radius of curvature R2') at the curved corners 17b of the tube head 17 are small.

[0098] Accordingly, it is possible to guide, onto the photocathode 20, almost the whole part of the light that is outputted from peripheral scintillators 54 that are located at the outer periphery of the scintillator matrix 52 as well as the whole part of the light that is outputted from central scintillators 54 that are located in the central portion of the scintillator matrix 52. Thus, the photocathode 20 can receive scintillation light from all the scintillators 54 substantially uniformly, and can detect radiation with a uniform sensitivity.

[0099] In this embodiment, the magnetic shield 40 is provided on the outer periphery of the tube main body 13 having a smaller outside diameter of the side tube 11. Therefore, the outside diameter W2 of the tube head 17 can increase up to a sum of the outside diameter W1 of the tube main body 13 and the thickness M of the magnetic shield 40. Accordingly, the size of the photocathode 20 can be increased. Additionally, the entire side tube 11 including the magnetic shield 40 can have a substantially flat lateral side, so that the side tube 11 is easy for handling.

[0100] Next, a multi-anode type photomultiplier tube 1 and a radiation detector 50 according to a second embodiment will be described.

[0101] First, the multi-anode type photomultiplier tube 1 according to this embodiment will be described with reference to FIGS. 2 to 6 and 8.

[0102] The multi-anode type photomultiplier tube 1 according to this embodiment is the same as the multi-anode type photomultiplier tube 1 of the first embodiment except for the cross-sectional shape of the tube head 17.

[0103] The multi-anode type photomultiplier tube 1 of this embodiment has a construction shown in FIGS. 2 and 3. The glass vessel 5 in the multi-anode type photomultiplier tube 1 of this embodiment has an external shape shown in FIG. 4, a section shown in FIG. 5, and a top profile shown in FIG. 8. A cross-section of the tube main body 13 (the cross-section taken along the line VI-VI of FIG. 5) has a shape shown in FIG. 6. However, a cross-section of the tube head 17 (the cross-section taken along the line VII-VII of FIG. 5) has a shape shown in FIG. 12 instead of a shape shown in FIG. 7.

[0104] The cross-sectional shape of the tube head 17 in this embodiment will be described below with reference to FIG. 12.

[0105] In this embodiment, the external shape of the tube head 17 is the same as that of the tube head 17 of the first embodiment (see FIG. 7). That is, the outer peripheral surface 17o connects each two adjacent curved corners 17b at a length W2 (outside diameter of the tube head 17) in a substantially straight line. The curved corners 17b are each curved with the radius of curvature (outside radius of curvature) R2. The outside radius of curvature R2 is smaller than the outside radius of curvature R1 at the curved corners 13b of the tube main body 13. The outside diameter W2 is larger than the outside diameter W1 of the tube main body 13.

[0106] The inner peripheral surface 17i of the tube head 17 has a shape that attains a pin-cushion shape that is thinning toward the curved corners 17b. That is, the inner peripheral surface 17i of the tube head 17 connects two adjacent curved corners 17b in a curved manner. The inner peripheral surface 17i is spaced the farthest from the outer peripheral surface 17o at a midpoint between the two adjacent curved corners 17b. The inner peripheral surface 17i gradually approaches the outer peripheral surface 17o as approaches toward the corresponding curved corners 17b. Therefore, the thickness T2 of the tube head 17 (distance between the outer peripheral surface 17o and the inner peripheral surface 17i) has the maximum value T2max at the midpoint between the two adjacent curved corners 17b. The thickness T2 of the tube head 17 gradually reduces as approaching to the curved corners 17b. Accordingly, the inside radius of curvature R2' at the curved corners 17b of the inner peripheral surface 17i is smaller than the outside radius of curvature R2, thereby being smaller than the inside radius of curvature R1' of the tube main body 13. The maximum value T2max of the thickness is substantially equal to the thickness T1 of the tube main body 13. In this embodiment, the maximum value T2max of the thickness is substantially equal to the thickness T2 in the first embodiment. In this embodiment, the inside diameter W2' is defined as "W2'=W2-2xT2max." The inside diameter W2' is larger than the inside diameter W1' of the tube main body 13.

[0107] The side tube 11 having the above shape is produced by a method described below. First, an external mold is prepared. The shape of the inner peripheral surface of the external mold is identical to the shape of the outer periphery of the side tube 11. Then, glass is injected into the external mold so as to have a desired thickness, so that the side tube 11 of this embodiment is formed. The side tube 11 of this embodiment can be formed of any one of soft glass and hard glass.

[0108] According to this embodiment, the inner peripheral surface 17i of the tube head 17 attains a shape that is thinning toward the curved corners 17b. Therefore, the area of a part of the effective photoelectric region K that is in the vicinity of the curved corners 17b can be increased compared with that of the first embodiment. Therefore, light reaching the vicinity of the curved corners 17b can be effectively guided onto the photocathode 20 for the conversion into photoelectrons.

[0109] Next, a radiation detector 50 according to this embodiment will be described.

[0110] The radiation detector 50 according to this embodiment is the same as the radiation detector 50 of the first embodiment of FIGS. 9 to 11 except for the usage of the multi-anode type photomultiplier tube 1 according to this embodiment.

[0111] In the radiation detector 50 according to this embodiment, the tube head 17 has a cross-section shown in FIG. 12. Accordingly, most parts of the output surfaces 54d of the scintillators 54 that are located at the corners of the scintillator matrix 52 properly face the photocathode 20 inside the curved corners 17b of the tube head 17. As a result, photoelectric conversion of scintillation light from all the scintillators 54 can be performed uniformly, so that radiation can be detected with uniform sensitivity.

[0112] Advantages provided by the multi-anode type photomultiplier tube 1 and the radiation detector 50 of the first and second embodiments will be described below in detail in comparison with a multi-anode type photomultiplier tube and a radiation detector of a comparative example.

[0113] First, a multi-anode type photomultiplier tube 101 of the comparative example will be described with reference to FIGS. 13 and 14.

[0114] FIG. 13 is a plan view of the multi-anode type photomultiplier tube 101 of the comparative example.

[0115] FIG. 14 is a sectional view taken along the line XIV-XIV of FIG. 13.

[0116] As shown in FIGS. 13 and 14, the multi-anode type photomultiplier tube 101 of the comparative example is the same as the multi-anode type photomultiplier tube 1 of the first embodiment except for the shapes of a side tube 111 and a faceplate 109. The side tube 111 is formed only of a single tube 112. The tube 112 is connected to a lower surface 109d of the faceplate 109. The tube 112 has a quadrangular prismatic hollow shape similar to the tube main body 13 of the first and second embodiments.

[0117] As shown in FIG. 13, the cross section of the tube 112 perpendicular to the tube axis is substantially square. The tube 112 includes four planar sides 112a and four curved corners 112b. The tube 112 has a substantially uniform thickness. The outside diameter of the tube 112 is referred to as "Wc," the thickness of the tube 112 is referred to as "Tc," and the inside diameter of the tube 112 is referred to as "Wc '" (Wc'=Wc-2xTc). The outside radius of curvature and the inside radius of curvature at the curved corners 112b are referred to as "Rc" and "Rc"', respectively. The outside radius of curvature Rc is substantially equal to the inside radius of curvature Rc'. Further, the outside diameter Wc is smaller than the outside diameter R2 of the tube head 13 of the first and second embodiments. The inside diameter Wc' is smaller than the inside diameter R2' of the tube head 17 of the first and second embodiments. The outside radius of curvature Rc and the inside radius of curvature Rc' are larger than the outside radius of curvature R2 and the inside radius of curvature R2' of the first and second embodiments, respectively.

[0118] The faceplate 109 has the same shape and size as those of the external shape of the tube 112. That is, the faceplate 109 is a plate having a substantially square. The faceplate 109 includes: four curved corners 109b having the radius of curvature Rc; and four side surfaces 109a connecting two adjacent curved corners 109b at a length equal to the outside diameter Wc. A photocathode 120 is formed on the effective photoelectric region K that is defined on the lower surface 109d of the faceplate 109 and inside the tube 112.

[0119] Further, a magnetic shield 40 covers the outer periphery of the lower portion of the tube 112. The magnetic shield 40 includes a high magnetic permeability material 42 and a resin coating 44 similarly to that of the first and second embodiments.

[0120] Next, a radiation detector 150 of the comparative example that includes the multi-anode type photomultiplier tube 101 of the comparative example will be described with reference to FIGS. 15 to 17.

[0121] FIG. 15 is a schematic plan view showing an arrangement in which a plurality of radiation detectors 150 of the comparative example are arranged one-dimensionally adjacent to one another. FIG. 16 is a sectional view taken along the line XVI-XVI of FIG. 15. FIG. 17 is an enlarged view of an essential portion H shown in FIG. 16.

[0122] In the radiation detector 150 of the comparative example, a scintillator matrix 52 is bonded to the faceplate 109 of the multi-anode type photomultiplier tube 101 of the comparative example. The multi-anode type photomultiplier tube 101 has the construction described with reference to FIGS. 13 and 14. FIG. 16 omits an internal construction of the multi-anode type photomultiplier tube 101.

[0123] FIG. 15 is a view similar to FIG. 9, and schematically shows a positional relationship between the output surfaces 54d of 36 scintillators 54 constituting the scintillator matrix 52 and the effective photoelectric region K of the faceplate 109. As seen from FIG. 15, in the radiation detector 150 of the comparative example, the scintillators 54 at the outer periphery of the scintillator matrix 52 face the outer periphery of the tube 112 through the outer periphery of the faceplate 109 of the multi-anode type photomultiplier tube 101, similarly to those of the first and second embodiments. In particular, the scintillators 54 at four corners of the scintillator matrix 52 face the four curved corners 112b of the tube 112 through the four curved corners 109b of the faceplate 109 in the multi-anode type photomultiplier tube 101.

[0124] Here, in the comparative example, the outside diameters Wc of the faceplate 109 and the tube 112 and the inside diameter Wc' of the tube 112 have the following relationship with respect to the outside diameter W (39 mm, for instance) of the scintillator matrix 52 and the thickness M of the magnetic shield 40.

[0125] The outside diameters Wc of the faceplate 109 and the tube 112 are equal to the outside diameter W of the scintillator matrix 52. The inside diameter Wc' of the tube 112 is smaller than the outside diameter Wc by twice as large as the thickness Tc. Therefore, the inside diameter Wc' is smaller than the outside diameter W of the scintillator matrix 52 by "2xTc".

[0126] When the radiation detectors 150 of the comparative example having the above sizes are arranged so that the adjacent magnetic shields 40 contact with one another, adjacent tubes 112 are spaced away by the distance equal to the thickness M of the magnetic shield 40, as shown in FIG. 17. It is sufficient that the adjacent tubes 112 be spaced away by the minimum distance S, and therefore a dead space corresponding to (M-S) is generated. Additionally, the outside diameters Wc of the faceplate 109 and the tube 112 are equal to the outside diameter W of the scintillator matrix 52. The inside diameter Wc' of the tube 112 is considerably smaller than the outside diameter W of the scintillator matrix 52. Therefore, as shown in FIG. 15, large portions of the output surfaces 54d of those scintillators 54 that are located at the outer periphery of the scintillator matrix 52 do not face the effective photoelectric region K inside the tube 112. The radiuses of curvature Rc and Rc' of the curved corners 112b are large. Accordingly, large portions of the output surfaces 54d of those scintillators 54 that are located at the four corners of the scintillator matrix 52 do not face the effective photoelectric region K inside the curved corners 112b.

[0127] As described above, in the comparative example, the outside diameter Wc of the tube 112 is equal to the outside diameter W of the scintillator matrix 52. In contrast, in the first and second embodiments, the outside diameter W1 of the tube main body 13 is equal to the outside diameter W of the scintillator matrix 52, and the outside diameter W2 of the tube head 17 is larger than the outside diameter W of the scintillator matrix 52. Accordingly, the outside diameter W2 of the tube head 17 in the first and second embodiments is larger than the outside diameter Wc of the tube 112 of the comparative example. Additionally, the inside diameter W2' of the tube head 17 in the first and second embodiments is larger than the inside diameter Wc' of the tube 112 of the comparative example. Furthermore, the radiuses of curvature R2 and R2' at the curved corners 17b of the tube head 17 in the first and second embodiments are smaller than the radiuses of curvature Rc and Rc' at the curved corners 112b of the comparative example.

[0128] Next will be described with reference to FIGS.

18 and 19 advantages of the first and second embodiments in which the outside diameter W2 of the tube head 17 is larger than the outside diameter Wc of the comparative example, the inside diameter W2' of the tube head 17 is larger than the inside diameter Wc' of the comparative example, and the radiuses of curvature R2 and R2' at the curved corners 17b of the tube head 17 are smaller than the radiuses of curvature Rc and Rc' at the curved corners 112b of the comparative example.

[0129] FIG. 18 shows the effective photoelectric region K of the multi-anode type photomultiplier tube 1 in each of the first and second embodiments, comparing with the effective photoelectric region K of the comparative example. When the effective photoelectric region K of the comparative example is assumed as "100%", the effective photoelectric region K in the first embodiment is 110%, and the effective photoelectric region K in the second embodiment is increased up to 114%.

[0130] As described above, in the multi-anode type photomultiplier tube 1 of each of the first and second embodiments, the effective photoelectric region K can be increased in comparison with that of the comparative example. In particular, in the second embodiment, the inner peripheral surface 17i of the tube head 17 attains a pin-cushion shape that is thinning toward the curved corners 17b. Accordingly, the effective photoelectric region K inside the curved corners 17b in the vicinity of the curved corners 17b can be further increased.

[0131] FIG. 19 shows a positional relationship between the output surfaces 54d of the scintillators 54 in the scintillator matrix 52 and the effective photoelectric region K in each of the first second embodiments and the comparative example shown in FIG. 18. The ratio (percentage) of the area of a part of the output surface 54d of each scintillator that faces the effective photoelectric region K relative to the area of the entire part of the output surface 54d is designated as the "scintillator effective area ratio" for the subject scintillator hereinafter. FIG. 19 shows the values of the scintillator effective area ratios for four scintillators 54 that are located in the vicinity of one corner of the scintillator matrix 52.

[0132] As seen from FIG. 19, in the comparative example, the outside diameter Wc of the tube 112 is equal to the outside diameter W of the scintillator matrix 52. Accordingly, the scintillator effective area ratio is significantly lowered at the scintillators 54 that are located at the outer periphery of the scintillator matrix 52. Furthermore, the radiuses of curvature Rc and Rc' at the curved corners 112b are large. Accordingly, the scintillator effective area ratio is further lowered in the vicinity of the curved corners 112b. Accordingly, in the comparative example, the sensitivity is significantly different between the central portion of the scintillator matrix 52 and the outer peripheral portion (corners, in particular) of the scintillator matrix 52.

[0133] In contrast, in the first embodiment, the outside diameter W2 of the tube head 17 is larger than the outside diameter W of the scintillator matrix 52. Accordingly, the scintillator effective area ratio of the scintillator 54 at the outer periphery of the scintillator matrix 52 becomes larger than that of the comparative example. In addition, the radiuses of curvature R2 and R2' of the curved corners 17b are small. Accordingly, the scintillator effective area ratio in the vicinity of the curved corners 17b becomes significantly larger than that of the comparative example. Therefore, the sensitivity is substantially uniform at all of the central portion, the outer peripheral portion, and the corners of the scintillator matrix 52. In particular, in the second embodiment, the scintillator effective area ratio in the vicinity of the curved corners 17b is further improved. Accordingly, the sensitivity becomes further uniform at all of the center portion, the outer peripheral portion, and the corners of the scintillator matrix 52.

[0134] As described above, in the first and second embodiments, each scintillator 54 has substantially a uniform large amount of ratio, of the area of a part of the output surface 54d that faces the photocathode 20, relative to the area of the entire part of the output surface 54d. Accordingly, the photocathode 20 is capable of receiving scintillation light from all the scintillators 54 at a substantially uniform ratio and is capable of detecting radiation with substantially uniform sensitivity.

[0135] Next, it is assumed that the multi-anode type photomultiplier tube 101 of the comparative example does not have the magnetic shield 40. It is also assumed that the outside diameter Wc of the tube 112 of the comparative example is equal to the outside diameter W2 of the tube head 17 in the first and second embodiments. That is, it is assumed that the outside diameter Wc is greater than the outside diameter W of the scintillator matrix 52 by (M-S). In this case, when the radiation detectors 150 of the comparative example are arranged so that adjacent scintillator matrixes 52 are spaced apart from one another by the distance M similarly to the first and second embodiments, the adjacent tubes 112 are spaced away from one another by the minimum distance S. However, by making the radiuses of curvature R2 and R2' at the curved corners 17b of the tube head 17 in each of the first and second embodiments smaller than the radiuses of curvature Rc and Rc' at the curved corners 112b of the comparative example, it is possible to make the effective photoelectric region K in each of the first and second embodiments larger than that of the comparative example and to make the scintillator effective area ratios of all the scintillators in the first and second embodiments more uniform than those of the comparative example.

[0136] In more detail, assume that the outside diameter W2 of the tube head 17 in each of the first and second embodiments is equal to the outside diameter Wc in the comparative example and that the inside diameter W2' of the tube head 17 is equal to the inside diameter Wc' in the comparative example. In this example, if the radiuses of curvature R2 and R2' at the curved corners 17b of the tube head 17 in each of the first and second embodiments are smaller than the radiuses of curvature Rc and Rc' at the curved corners 112b in the comparative example, the effective photoelectric regions K in the first and second embodiments will become 104% and 108%, respectively, in comparison with the effective photoelectric region K (100%) in the comparative example as shown in FIG 20. Further, the scintillator effective area ratios in the vicinity of the curved corners 17b in the first and second embodiments will become larger than those of the comparative example as shown in FIG. 21.

[0137] The multi-anode type photomultiplier tube and the radiation detector according to the present invention are not limited to the embodiments described above. Various modifications and changes can be made without departing from the scope of the inventions.

[0138] For instance, the shape of the faceplate and the cross-sectional shapes of the tube head and the tube main body are not limited to squares so long as these shapes are substantially quadrangular. For instance, these shapes may be substantially rectangular.

[0139] The thickness of the tube head may be thinner than the thickness of the tube main body.

[0140] In the first embodiment, the thickness T2 of the tube head 17 may be slightly reduced in the vicinity of the curved corners 17b. The inside radius of curvature R2' may be slightly smaller than the outside radius of curvature R2. Similarly, the thickness T1 of the tube main body 13 may be slightly reduced in the vicinity of the curved corners 13b. The inside radius of curvature R1' may be slightly smaller than the outside radius of curvature R1.

[0141] The multi-anode type photomultiplier tube is not limited to the two by two type, and may be of any types in which any numbers of dynode arrays and anode electrodes are arranged.

[0142] Each dynode array is not limited to the linear focus type but can be of any other type.

[0143] A plurality of radiation detectors may be arranged in a two-dimensional manner or a three-dimensional manner instead of the one-dimensional manner.

[0144] The multi-anode type photomultiplier tube may not be provided with the magnetic shield.

[0145] The multi-anode type photomultiplier tube may be used for any devices other than the radiation detector.

INDUSTRIAL APPLICABILITY

[0146] The multi-anode type photomultiplier tube and the radiation detector according to the present invention are widely used as a positron emission tomography in the medical field. In addition, the present invention can be used in various fields such as other radiation detection and photodetection.

Claims

1. A multi-anode type photomultiplier tube comprising:

    a faceplate made from glass; and
    a hollow side tube made from glass and connected to one surface of the faceplate, the side tube extending along a tube axis that is substantially perpendicular to the faceplate, a photocathode for emitting photoelectrons according to light incident on the faceplate being provided on the one surface of the faceplate in a region inside the side tube, a plurality of electron multiplying sections and a plurality of anode electrodes being provided inside the side tube in correspondence with a plurality of regions on the photocathode,
    wherein
    the side tube includes a tube head, a funnel-shaped connection neck, and a tube main body which are arranged integrally along the tube axis,
    the tube main body has a substantially quadrangular prismatic hollow shape with four first curved corners, the tube main body extends along the tube axis by a first length, the tube main body has a first size of cross section substantially perpendicular to the tube axis, each of the four first curved corners is curved with a first radius of curvature,
    the tube head has a substantially quadrangular prismatic hollow shape with four second curved corners, the tube head extends along the tube axis by a second length, the tube head has a second size of cross section substantially perpendicular to the tube axis, each of the four second curved corners is curved with a second radius of curvature, the second length is shorter than the first length, the second size is larger than the first size, the second radius of curvature is smaller than the first radius of curvature,
    the funnel-shaped connection neck connects the tube head to the tube main body coaxially,
    the tube head is connected to the one surface of the faceplate, the photocathode is provided on the one surface of the faceplate in a region inside the tube head, and
    the plurality of electron multiplying sections and the plurality of anode electrodes are provided inside the tube main body.

2. The multi-anode type photomultiplier tube according to claim 1, wherein
    the tube head includes an outer peripheral surface and an inner peripheral surface,
    the outer peripheral surface connects each two adjacent second curved corners with a substantially straight line,
    the inner peripheral surface connects each two adjacent second curved corners with a curved line, and
    the inner peripheral surface gradually approaches the outer peripheral surface from a substantially cen-

tral position between the two adjacent second curved corners towards each of the two adjacent second curved corners.

3. The multi-anode type photomultiplier tube according to claim 1, further comprising:

a converging electrode plate converging the photoelectrons emitted from the photocathode; and
a partition plate dividing an electron converging space defined between the photocathode and the converging electrode plate into a plurality of segment-spaces corresponding to the plurality of regions on the photocathode, wherein
each electron multiplying section receives the photoelectrons converged by the converging electrode plate in the corresponding one of the plurality of segment-spaces,
the partition plate extends from the tube head into the tube main body through the funnel-shaped connection neck in the side tube,
the converging electrode plate, the plurality of electron multiplying sections, and the plurality of anode electrodes are located in the tube main body, and
a magnetic shield is provided on an outer periphery of the tube main body.

4. A radiation detector comprising:

a scintillator matrix that includes a plurality of scintillators arranged in a two-dimensional matrix manner, each scintillator having an output surface, and each scintillator generating scintillation light in accordance with radiation incident on the scintillator and emitting the scintillation light from the output surface; and
a multi-anode type photomultiplier tube for detecting the scintillation light emitted from each scintillator of the scintillator matrix, wherein
the multi-anode type photomultiplier tube includes:

a faceplate made from glass; and a hollow side tube made from glass and connected to one surface of the faceplate, the side tube extending along a tube axis that is substantially perpendicular to the faceplate, another surface of the faceplate opposite to the one surface facing all of the output surfaces of the plurality of scintillators in the scintillator matrix, a photocathode for emitting photoelectrons according to scintillation light incident on the faceplate being provided on the one surface of the faceplate in a region inside the side tube, and a plurality of electron multiplying sections and a plurality of anode electrodes being provided inside the side tube in correspondence with a plurality of regions on the photocathode,
wherein
the side tube includes a tube head, a funnel-shaped connection neck, and a tube main body which are arranged integrally along the tube axis,
the tube main body has a substantially quadrangular prismatic hollow shape with four first curved corners, the tube main body extends along the tube axis by a first length, the tube main body has a first size of cross section substantially perpendicular to the tube axis, each of the four first curved corners is curved with a first radius of curvature,
the tube head has a substantially quadrangular prismatic hollow shape with four second curved corners, the tube head extends along the tube axis by a second length, the tube head has a second size of cross section substantially perpendicular to the tube axis, each of the four second curved corners is curved with a second radius of curvature,
the second length is shorter than the first length, the second size is larger than the first size, the second radius of curvature is smaller than the first radius of curvature,
the funnel-shaped connection neck connects the tube head to the tube main body coaxially,
the tube head is connected to the one surface of the faceplate, the photocathode is provided on the one surface of the faceplate in a region inside the tube head, and
the plurality of electron multiplying sections and the plurality of anode electrodes are provided inside the tube main body.

FIG.1

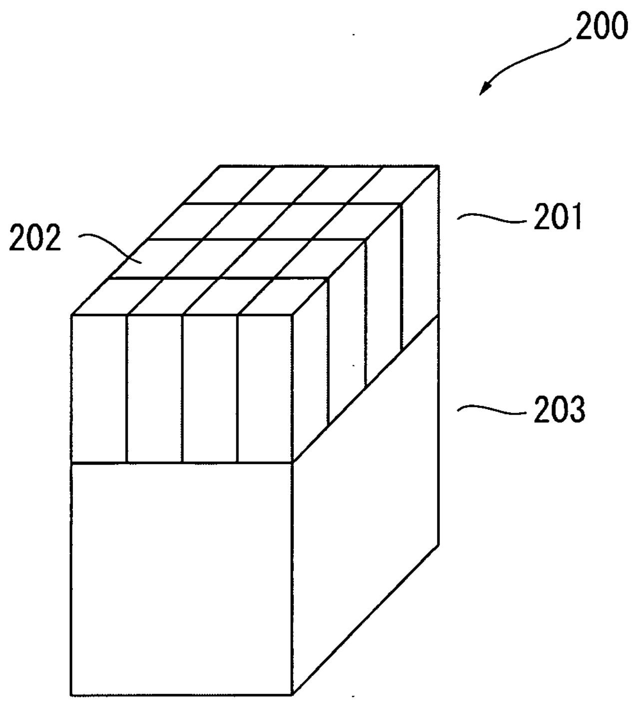


FIG.2

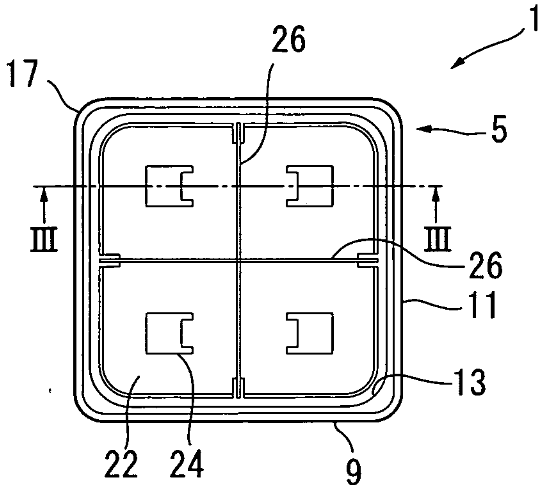

1
26
17
5
Ⅲ
Ⅲ
26
11
13
22
24
9

FIG.3

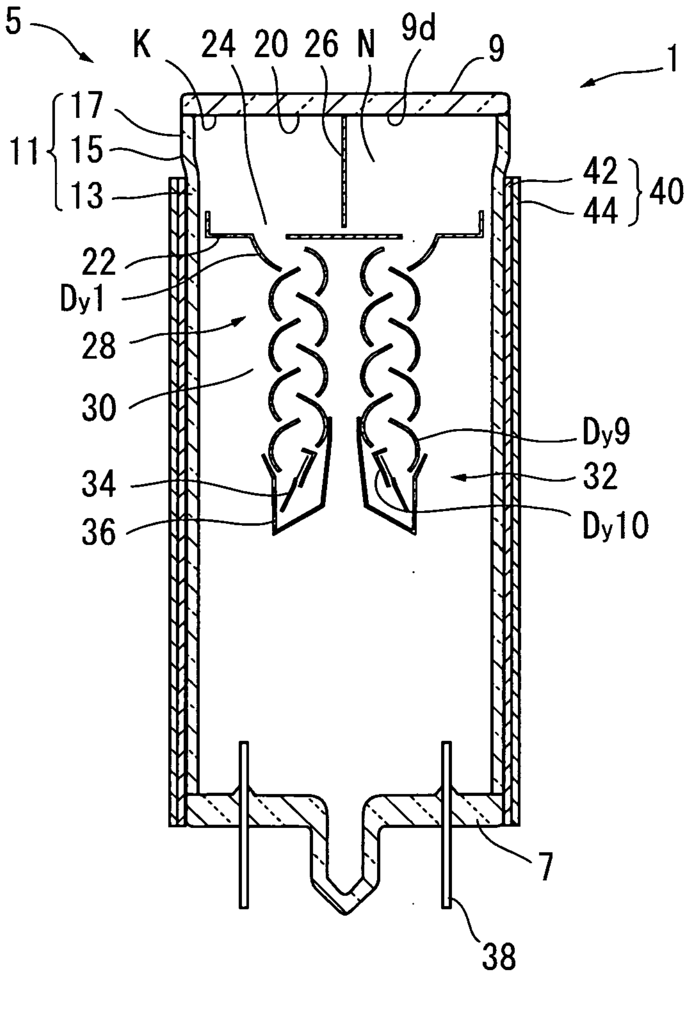

5
K
24
20
26
N
9d
9
1
17
11
15
13
42
40
44
22
Dy1
28
30
Dy9
34
32
36
Dy10
7
38

FIG.4

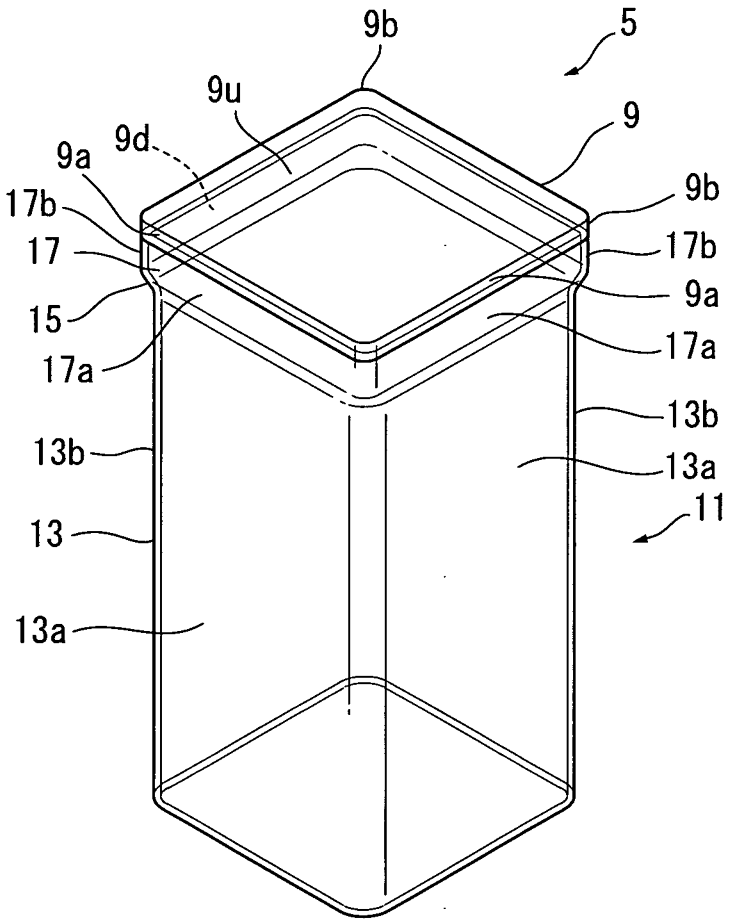


FIG.5

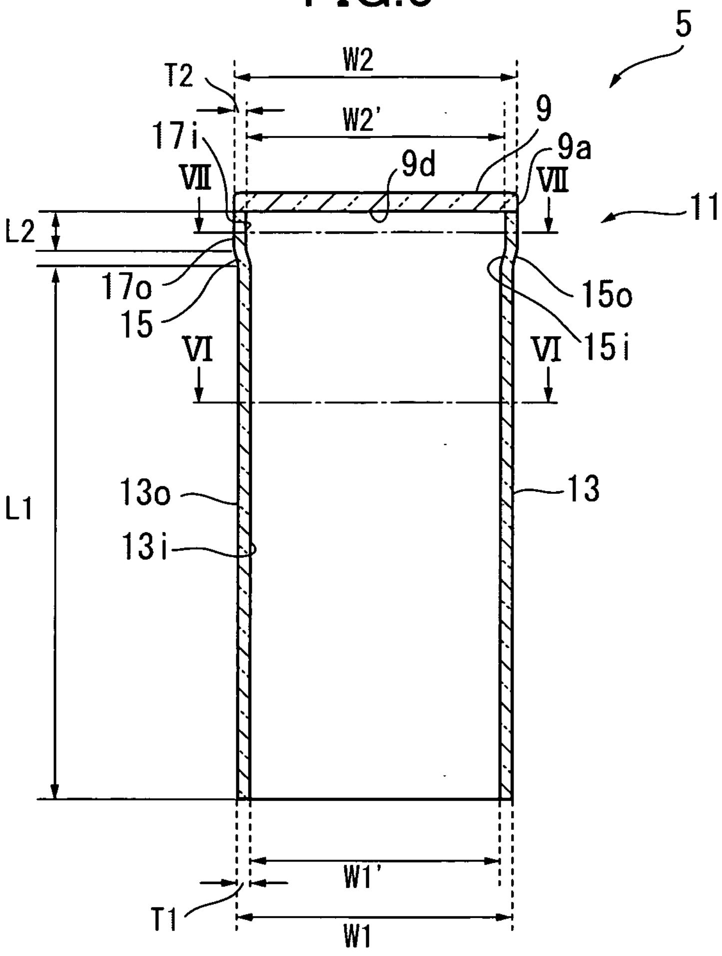

5
W2
T2
W2'
9
17i
9a
9d
VII
VII
11
L2
17o
15o
15
15i
VI
VI
L1
13o
13
13i
W1'
T1
W1

FIG.6

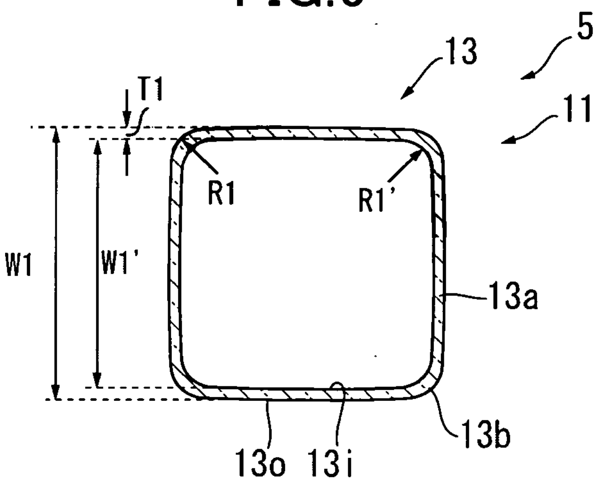

13
5
T1
11
R1
R1'
W1
W1'
13a
13b
13o
13i

FIG.7

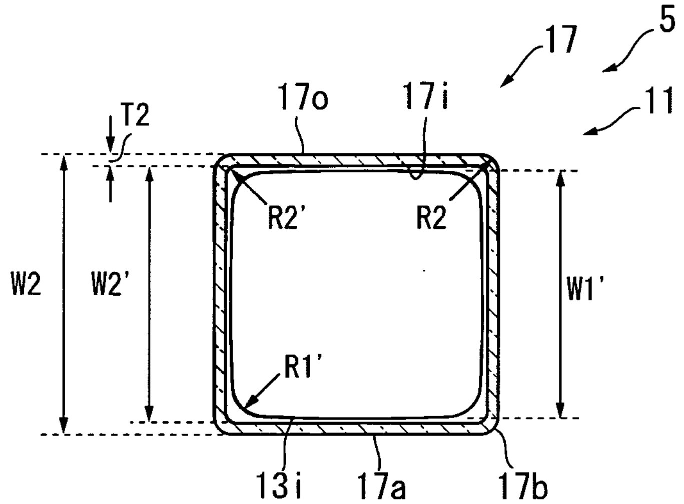

17
5
11
T2
17o
17i
R2'
R2
W2
W2'
W1'
R1'
13i
17a
17b

FIG.8

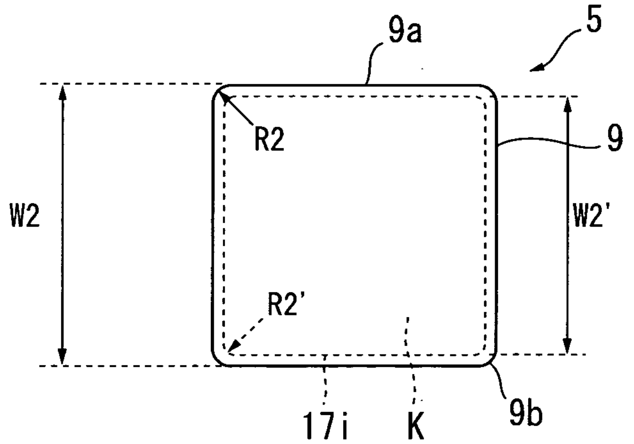

5
9a
R2
9
W2
W2'
R2'
17i
K
9b

FIG.9

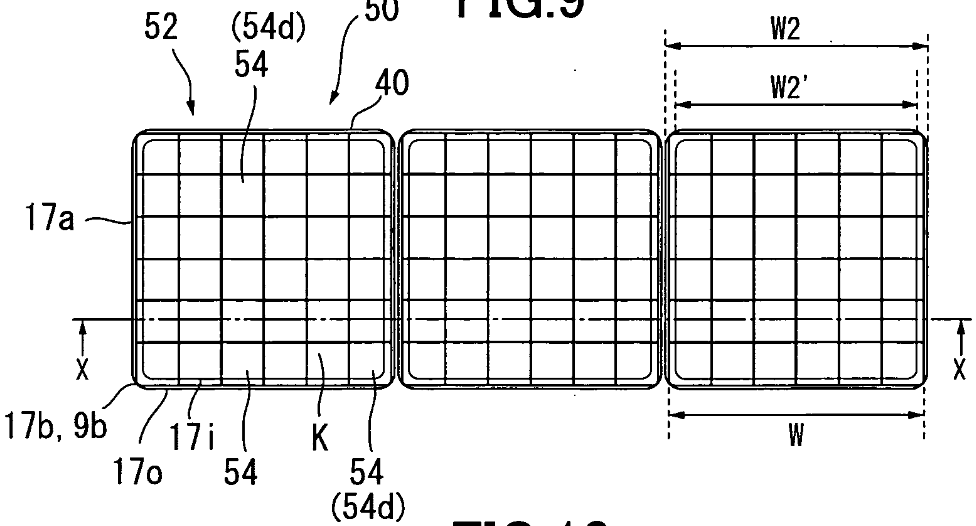


FIG.10

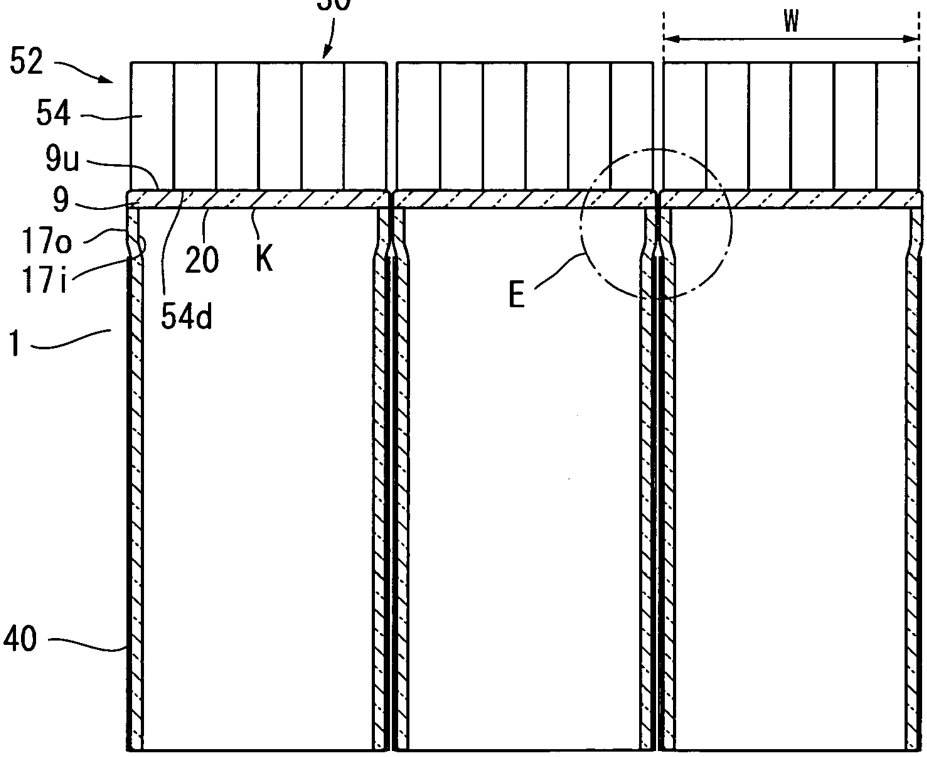


FIG.11

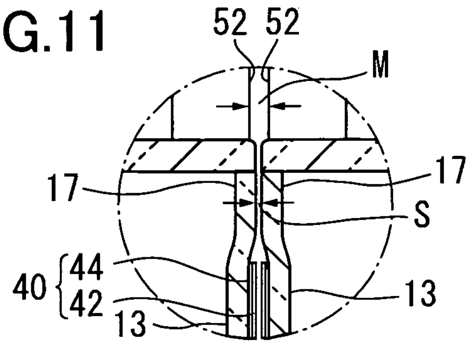


FIG.12

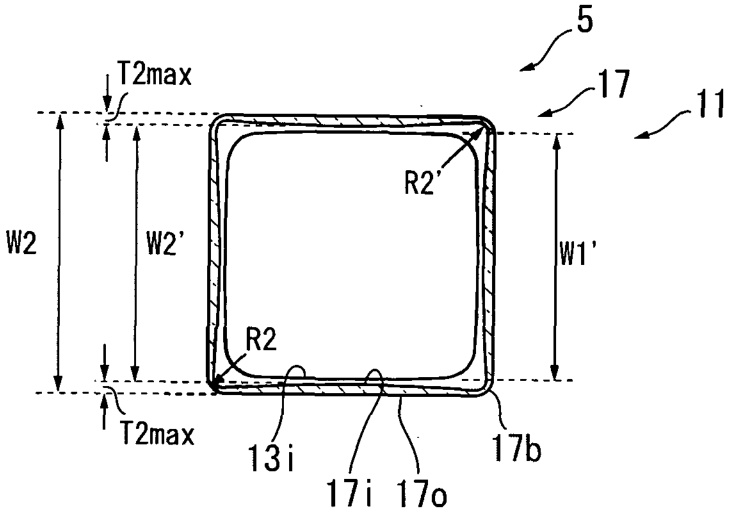


FIG.13

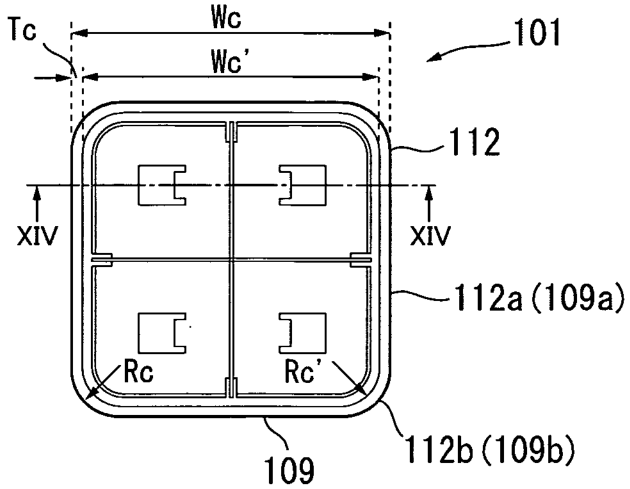

Tc
Wc
Wc'
101
112
XIV
XIV
112a (109a)
Rc
Rc'
112b (109b)
109

FIG.14

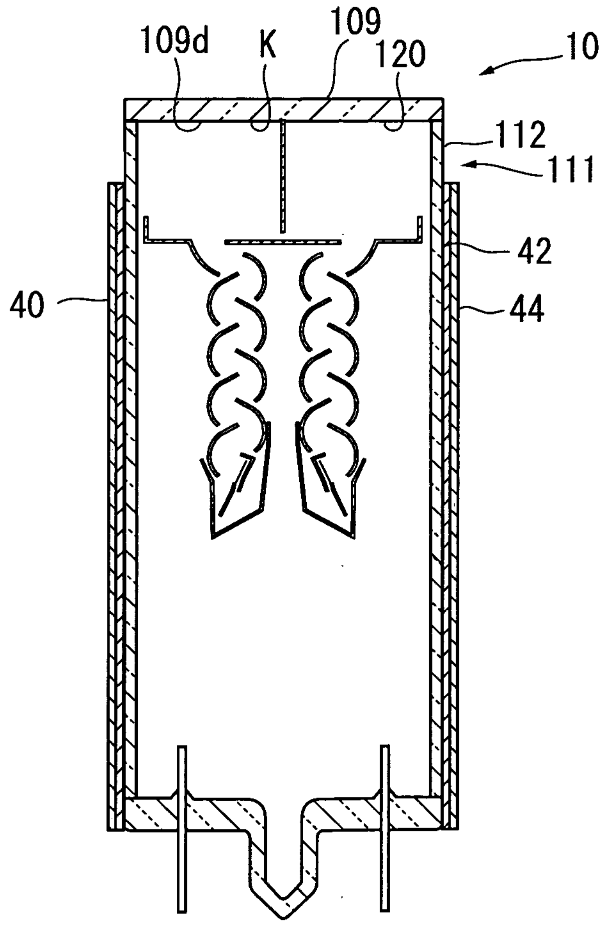

109d
K
109
120
101
112
111
42
40
44

FIG.15

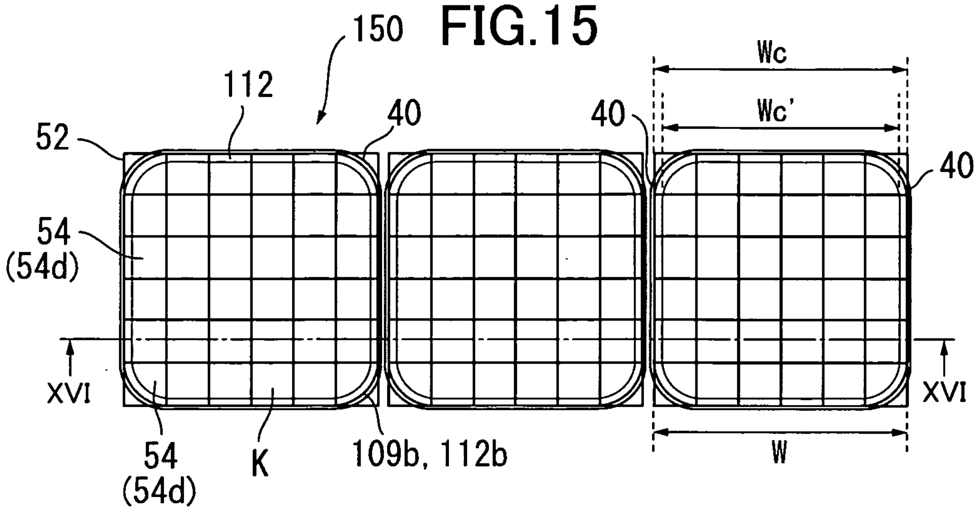


FIG.16

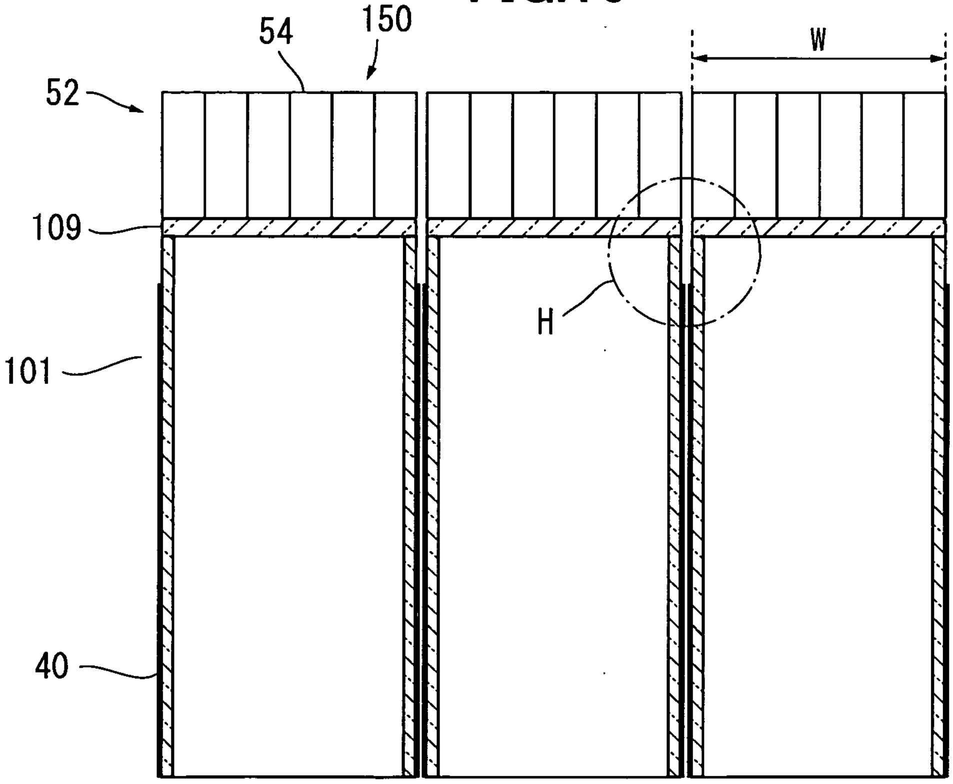


FIG.17

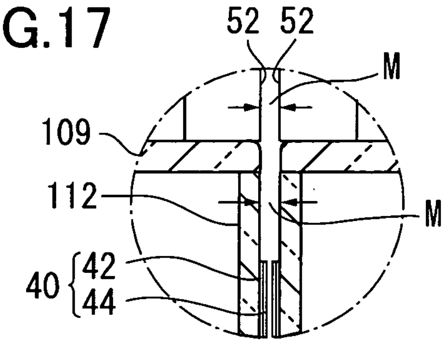


FIG.18

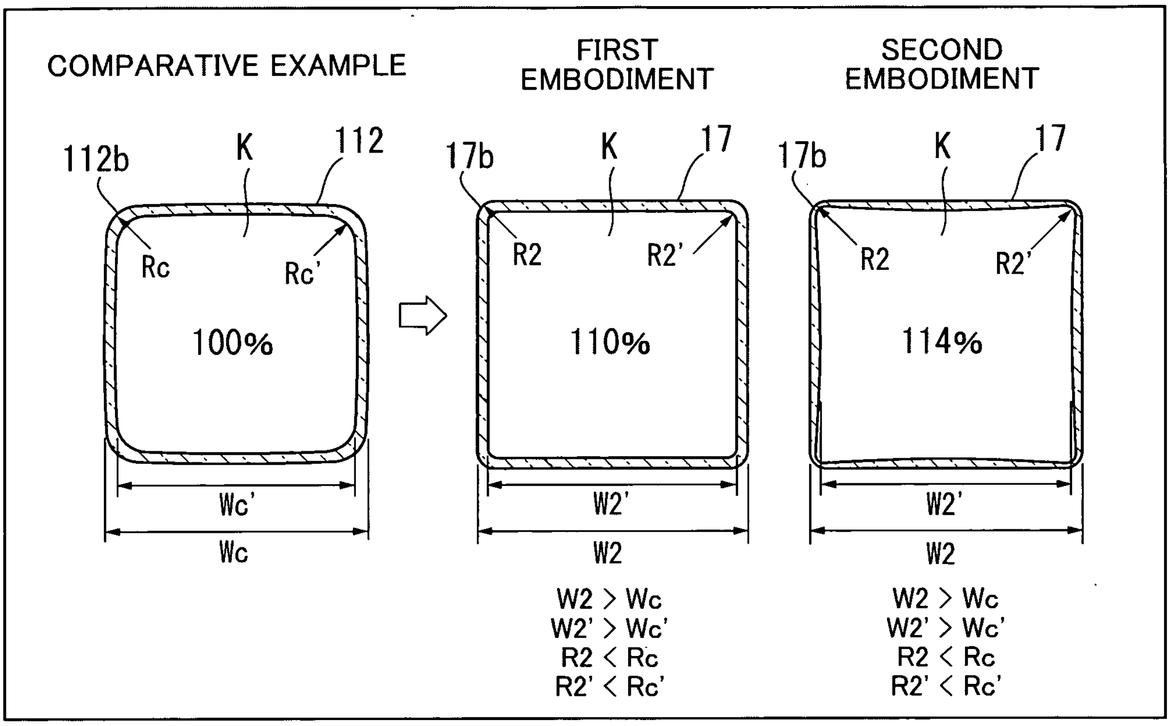

COMPARATIVE EXAMPLE
FIRST EMBODIMENT
SECOND EMBODIMENT
112b
K
112
Rc
Rc'
100%
Wc'
Wc
17b
17
R2
R2'
110%
W2'
W2
W2 > Wc
W2' > Wc'
R2 < Rc
R2' < Rc'
114%

FIG.19

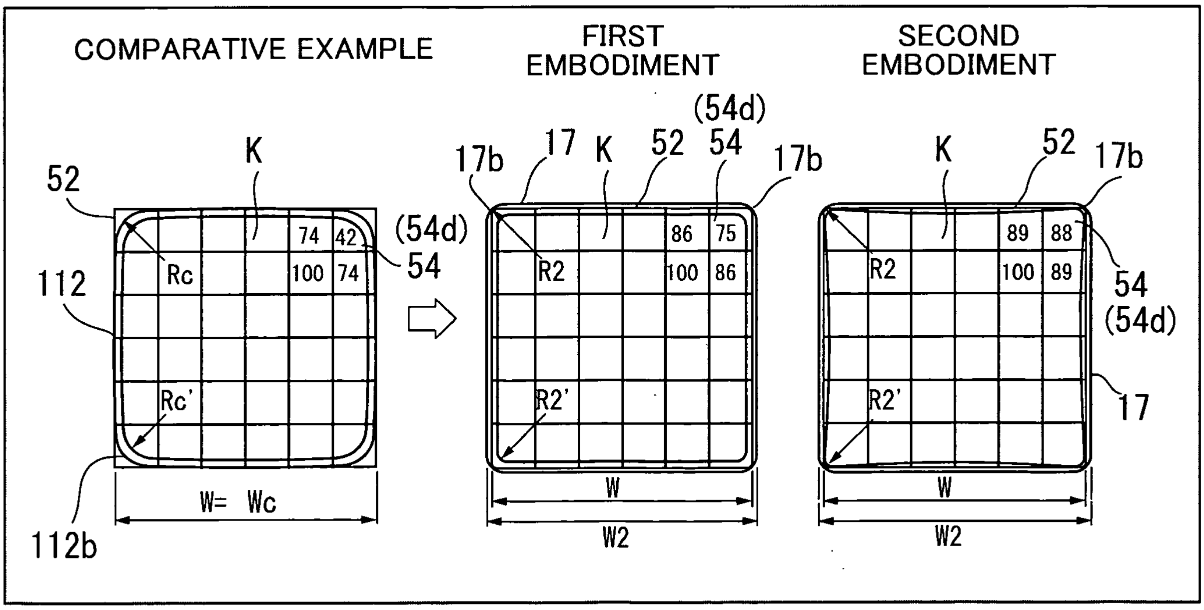
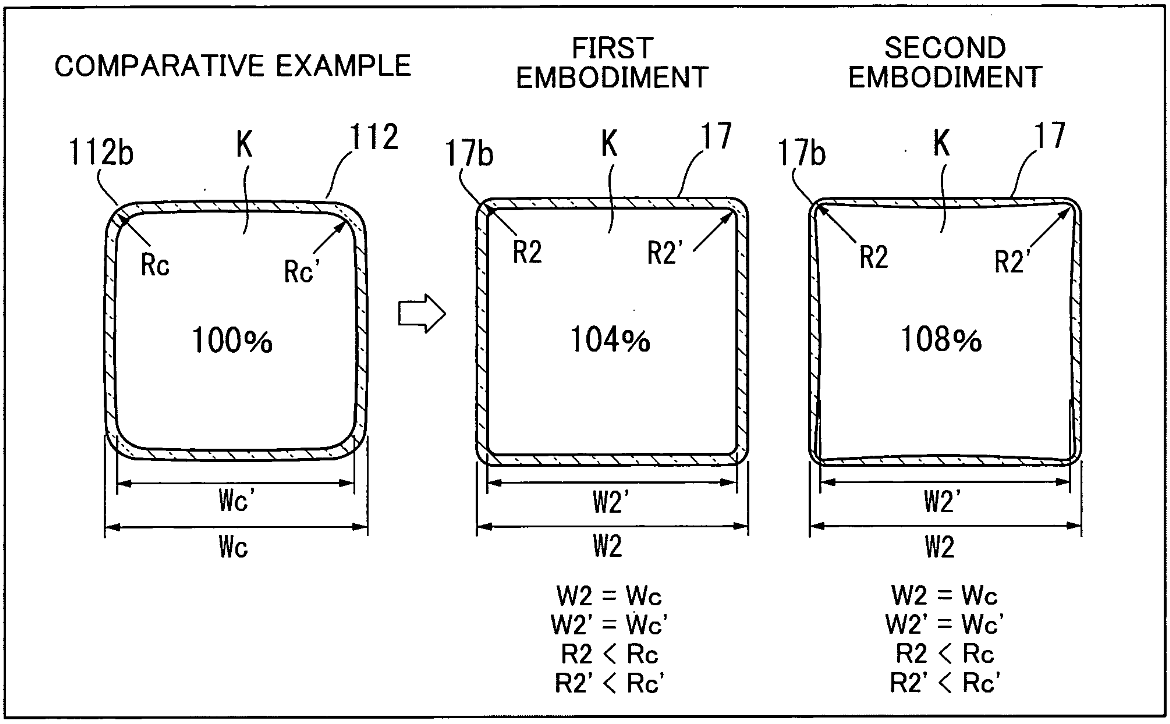
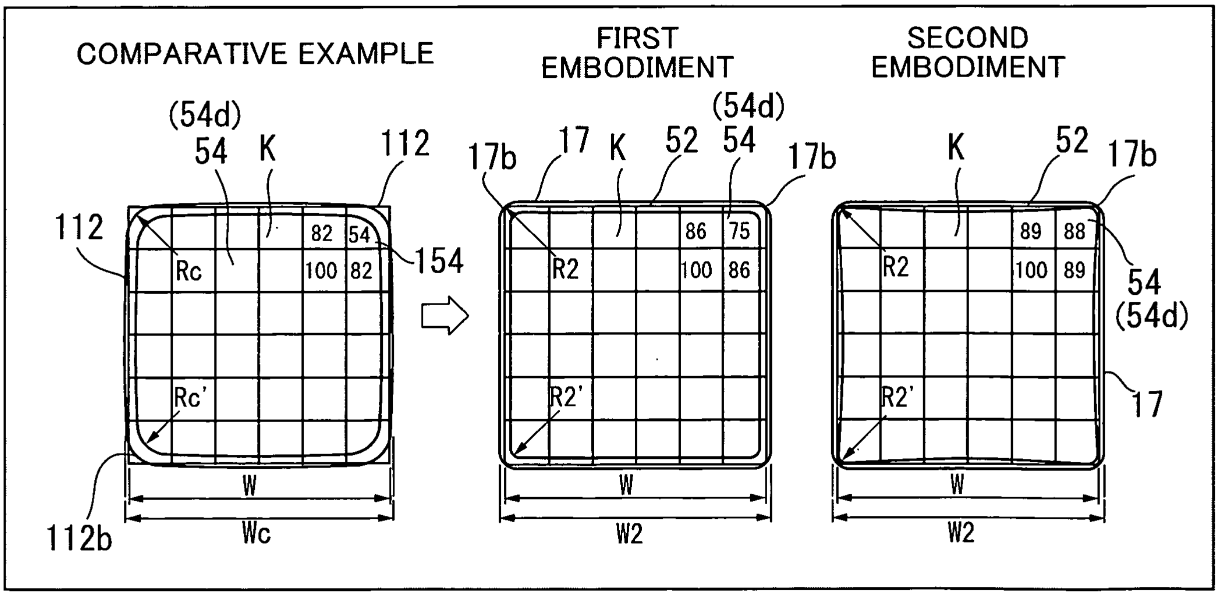

COMPARATIVE EXAMPLE
FIRST EMBODIMENT
SECOND EMBODIMENT
52
K
112
Rc
Rc'
74
42
100
74
(54d)
54
112b
W= Wc
17b
17
86
75
100
86
R2
R2'
W
W2
89
88
100
89
54
(54d)
17

FIG.20



COMPARATIVE EXAMPLE
FIRST EMBODIMENT
SECOND EMBODIMENT
112b
K
112
Rc
Rc'
100%
Wc'
Wc
17b
17
R2
R2'
104%
W2'
W2
W2 = Wc
W2' = Wc'
R2 < Rc
R2' < Rc'
108%

FIG.21



COMPARATIVE EXAMPLE
FIRST EMBODIMENT
SECOND EMBODIMENT
(54d)
54
K
112
154
112b
Rc
Rc'
82
54
100
82
W
Wc
17b
17
52
86
75
100
86
R2
R2'
W2
89
88
100
89

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP03/07420

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl[7] H01J43/28, 43/20, G01T1/20

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl[7] H01J43/00-43/30, G01T1/20

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

Jitsuyo Shinan Koho	1922-1996	Toroku Jitsuyo Shinan Koho	1994-2003
Kokai Jitsuyo Shinan Koho	1971-2003	Jitsuyo Shinan Toroku Koho	1996-2003

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 59-14244 A (Director General, Agency of Industrial Science and Technology), 25 January, 1984 (25.01.84), Full text; all drawings (Family: none)	1 3,4
Y	JP 11-250853 A (Hamamatsu Photonics Kabushiki Kaisha), 17 September, 1999 (17.09.99), Full text; all drawings (Family: none)	3

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
09 September, 2003 (09.09.03)	24 September, 2003 (24.09.03)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP03/07420

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4649276 A (Capintec, Inc.), 10 April, 1987 (10.04.87), Column 4, lines 35 to 51; Fig. 1 & JP 61-262675 A Page 5, upper left column, line 6 to upper right column, line 1; Fig. 1 & EP 199434 A1 & CA 1236937 A & IL 77952 A & DK 113686 A & DE 3671540 C	3
Y	JP 5-93781 A (Hamamatsu Photonics Kabushiki Kaisha), 16 April, 1993 (16.04.93), Full text; all drawings (Family: none)	4
A	US 5126629 A (U.S. Philips Corp.), 30 June, 1992 (30.06.92), Full text; all drawings & JP 3-173056 A Full text; all drawings & EP 428215 A1 & FR 2654552 A & DE 69016932 E	1-4
A	JP 61-83585 A (Shimadzu Corp.), 28 April, 1986 (28.04.86), Full text; all drawings (Family: none)	1-4
A	JP 57-194445 A (Director General, Agency of Industrial Science and Technology), 30 November, 1982 (30.11.82), Full text; all drawings (Family: none)	1-4
A	US 5077504 A (Burle Technologies, Inc.), 31 December, 1991 (31.12.91), Full text; all drawings & JP 5-36372 A Full text; all drawings & EP 487178 A2 & DE 69112778 E	1-4
A	JP 2003-98262 A (Shimadzu Corp.), 03 April, 2003 (03.04.03), Full text; all drawings (Family: none)	1-4
A	JP 9-72963 A (Hitachi Medical Corp.), 18 March, 1997 (18.03.97), Full text; all drawings (Family: none)	1-4

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