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(71) Applicant: EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH [-/CH]; CH-1211 Genève 23 (CH).

(72) Inventor: SAULI, Fabio; 12, avenue de Champel, CH-1206 Genève (CH).

(74) Agents: FRECHEDE, Michel et al.; Cabinet Plasseraud, 84, rue d'Amsterdam, F-75440 Paris Cedex 09 (FR).

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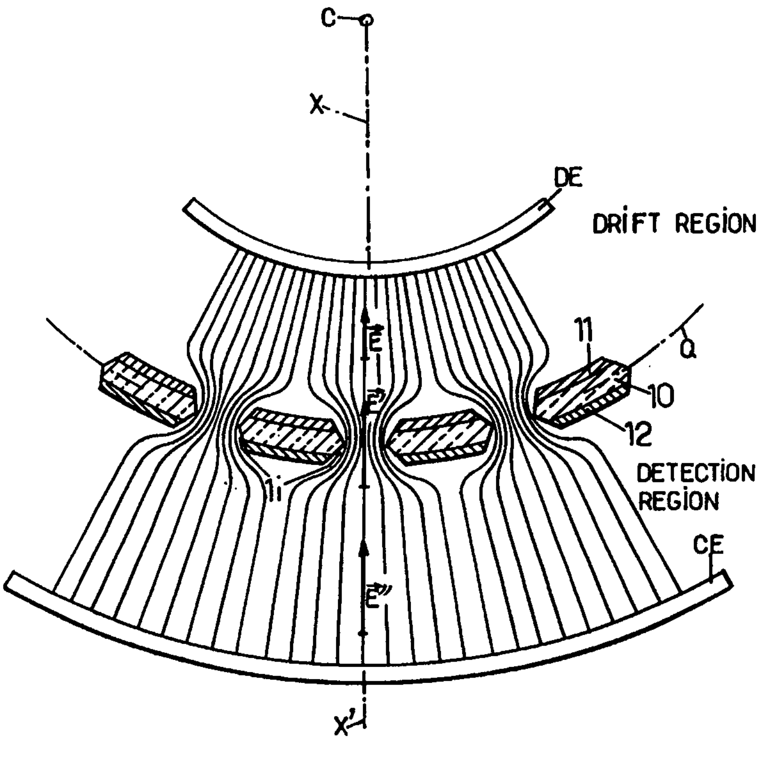
(54) Title: RADIATION DETECTOR OF VERY HIGH PERFORMANCE AND PLANISPHERICAL PARALLAX-FREE X-RAY IMAGER COMPRISING SUCH A RADIATION DETECTOR

(57) Abstract

A radiation detector in which primary electrons are released into a gas by ionizing radiations and drifted through an electric field (E) to a collecting electrode (CE) for detection. It further includes a gas electron multiplier (10, 11, 12) formed by one or several matrices of electric field condensing areas (1i) which are distributed within a solid surface perpendicular to the electric field. Each electric field condensing area consists of a tiny hole passing through the solid surface that forms a dipole adapted to produce a local electric field amplitude enhancement proper to generate an electron avalanche from one primary electron. The gas electron multiplier operates thus as an amplifier or a preamplifier within a host radiation detector.



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Radiation detector of very high performance and planispherical parallax-free X-ray imager comprising such a radiation detector

The present invention relates to an improved technique for embodying a radiation detector of very high performance that can be used for detecting in position ionizing radiations such as charged particles, photons, X-rays and neutrons.

Radiation detectors exploiting the process of ionization and charge multiplication in gases have been in use with continued improvements since hundred years.
Methods for obtaining large "stable" proportional gains in gaseous detectors are a continuing subject of investigation in the detectors community.

Several years ago, G.CHARPAK and F.SAULI introduced the multistep chamber, thereafter designated as MSC, as a way to overcome on limitations of gain in parallel plate and multiwire proportional chambers, thereafter designated as MWPC.

In MSC chambers, two parallel grid electrodes mounted in the drift region of a conventional gas detector and operated as parallel plate multipliers allow to preamplify drifting electrons and transfer them into the main detection element. Operated with a photosensitive gas mixture, the MSC chamber allows to reach gains large enough for single photodetection in ring-imaging CHERENKOV detectors, thereafter designated as RICH. For more details with respect to MSC chambers and RICH chambers, we refer to the following publications:

- G.CHARPAK and F.SAULI, Physics Letters, vol.78B, 1978, p.523, and
- M.ADAMS and al., Nuclear Instrumentation Methods, 217, 1983, 237.

More recently, G.CHARPAK and Y.GIOMATARIS have developed an improved radiation detector device thereafter designated as MICROMEGAS which is a high gain gas detector using as multiplying element a narrow gap parallel plate avalanche chamber.

In a general point of view, such a detector consists of a gap in the range 50 to 100 μm which is realized by stretching a thin metal micromesh electrode parallel to a read-out plane. G.CHARPAK and Y.GIOMATARIS have demonstrated very high gain and rate capabilities which are understood to result from the special properties of electrode avalanches in very high electric fields. For more details concerning the MICROMEGAS detector, we refer to the publication edited by Y.GIOMATARIS, P.REBOUGEARD, J.P.ROBERT and G.CHARPAK in Nuclear Instruments Methods, A376, 1996, 29.

The major point of inconvenience of both described detectors lies in the necessity of stretching and maintaining parallel meshes with very good accuracy. The presence of strong electrostatic attraction forces adds to the problem particularly for large size of the detectors. To overcome this drawback, heavy support frames are required and in the case of the MICROMEGAS detector the introduction in the gap of closely spaced insulating lines or pins with the ensuing complication of assembly and loss of efficiency is necessary.

Another radiation detector device was recently developed and proposed by F.BARTOL and al. Journal of Physics III 6 (1996), 337.

This detector device, thereafter designated as CAT, for *Compteur à trous*, substantially consists of a matrix of holes which are drilled through a cathode foil. The insertion of an insulating sheet between cathode and buried anodes allows thus to guaranty a good gap uniformity and to obtain high gains.

Radiation detectors more particularly directed to planispherical X-ray imaging devices have been up to now also investigated. Most important work concerning that particular subject matter was developed by Georges CHARPAK at the EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH in Geneva (Switzerland).

A first development concerned the properties of proportional chambers with spherical drift spaces.

A proportional wire chamber equipped with a resistive divider adapted to generate appropriate spherical equipotential surfaces within the drift space of the wire chamber has been first disclosed by G.CHARPAK, Z.HAJDUK, A.JEAVONS, R.STUBBS - CERN, Geneva, Switzerland, and R.KAHN, Centre Multidisciplinaire Paris XII, av. Général de Gaulle, Créteil, France, and edited by NUCLEAR INSTRUMENTS AND METHODS 307 (1974) - Geneva, 29 July 1974.

A proportional wire chamber embodied as a large aperture X-ray imaging chamber equipped with a spherical drift space has been also disclosed by G.CHARPAK, C.DEMIERRE, R.KAHN, J-C.STANDIARD and F.SAULI at the CERN in Geneva. See NUCLEAR INSTRUMENTS AND METHODS 141 (1977) 449-455, North-Holland Publishing Co.

A spherical drift space is disclosed as to embodying entrance and exit electrodes of spherical shape with an angular acceptance for X-rays to 90°. Coupling of spherical drift space and readout proportional chamber is disclosed to consist of a transfer space T, the lateral wall of which comprises a resistive divider adapted to generate spherical equipotential surfaces of increasing radius up to the first cathode electrode of the readout proportional chamber.

A general survey on various methods of correction for parallax errors on gaseous detectors for X-rays and UV has been published by G.CHARPAK, CERN, Geneva, Switzerland. See NUCLEAR INSTRUMENTS AND METHODS 201 (1982) 181-192, North Holland Publishing Company.

More recently, P.REHAK, G.C.SMITH and B.YU, Brookhaven National Laboratory, Uptown N.Y. 11973 presented a method for reduction of parallax broadening in gas-based position sensitive detectors at the 1996 IEEE Nuclear Science Symposium, Anaheim, CA, November 2-9, 1996 and published as IEEE Transactions on Nuclear Science, vol.44, No. 3, 1997, 651-655.
Although the drift space for photons is confined within an entrance electrode and the cathode wire plane of the readout chamber are plane and parallel, entrance window of the readout chamber is further provided with a particular conductive pattern adapted to introduce progressive bending of the equipotential surfaces, electric field lines crossing thus this equipotential surfaces at right angle, whichever the impinging direction of X-rays emanating from the focal point, so as to correct and reduce any parallax error.

In a general point of view, the above mentioned X-ray imagers may prove satisfactory to the extent that the parallax error is now reduced to a few percent. Embodying the entrance window of the readout chamber with conductive pattern adapted to provide full correction of parallax error is quite difficult to implement, since actual pattern and corresponding voltage which is to be applied to these conductive patterns are such that the electric field is approximately radial only close to the ring patterned entrance window, while it becomes substantially parallel in approaching the equipotential second electrode which defines the conversion volume. As a consequence, parallax error is thus increasing with penetration of the converting X-rays.

An object of the present invention is therefore to provide a radiation detector of very high performance that overcomes the above-mentioned drawbacks of the radiation detectors of the prior art.

Another object of the present invention is furthermore to provide a radiation detector of very high performance that appears to hold both the simplicity of the MSC chamber and the high field advantages of the MICROMEGAS and CAT radiation detectors however mechanically much simpler to implement and more versatile in use.

Another object of the present invention is therefore to provide a radiation detector of very high performance in which a very high degree of accuracy and resolution is obtained thanks to an electric charges transfer coefficient which substantially equals unity.

Another object of the present invention is therefore to provide a radiation detector with substantially constant amplifying factor for counting rates up to 10^5 Hz/mm^2.

Another object of the present invention is therefore to provide for a radiation detector more particularly directed to a planispherical parallax-free X-ray imager in which any image distorsion is suppressed thanks to its full symmetrical structure with respect to a symmetry axis orthogonal to an entrance window of the imager.

Another object of the invention is further to provide for a radiation detector more particularly directed to a planispherical parallax-free X-ray imager of very high performance embodying a specific gas electron multiplier structure overcoming the drawbacks of corresponding X-ray imagers of the prior art which however is mechanically very simple to implement.

More particularly, in accordance with the present invention, there is provided a radiation detector in which primary electrons are released into a gas by ionizing radiations and drift to a collecting electrode by means of an electric field. The radiation detector of the invention includes a gas electron multiplier comprising at least one matrix of electric field condensing areas with these electric field condensing areas being distributed within a solid surface which is substantially perpendicular to the electric field. Each of the electric field condensing areas is adapted to produce a local electric field amplitude enhancement proper to generate in the gas an electron avalanche from each one of the primary electrons. The gas electron multiplier operates thus as an amplifier of given gain for the primary electrons.

The objects, advantages and other particular features of the present invention will become more apparent upon reading of the following non-restrictive description of preferred embodiments thereof which are given by way of example only with reference to the accompanying drawings.

In the appended drawings:

- Figure 1a is a perspective view of a preferred embodiment of a radiation detector in accordance with the present invention which is cylindrical in shape;
- Figure 1b is a perspective view of a particular embodiment of a radiation detector in accordance with the present invention which is planar in shape;
- Figure 1c is a perspective view of a particular embodiment of a radiation detector in accordance with the present invention which is spherical in shape;
- Figure 2a is a cross-section view along a section plane designated as plane P which is represented in phantom line for figures 1a and 1b;
- Figure 2b is a cross-section view along a section plane designated as plane P which is represented in phantom line at figure 1c;
- Figure 3a is a diagram representing the electric field lines for figure 2a;
- Figure 3b is a diagram representing the electric field lines for figure 2b;
- Figure 4a is a front view representing a detail

of figure 1b, such a detail consisting of a gas electron multiplier comprising one matrix of electric field condensing areas;

- Figure 4b is a front view of a detail of figure 4a in which the matrix of electric field condensing areas is shown in a non-limitative way to consist of circular bored- through holes;
- Figures 4c, 4d, 4e and 4f show particular embodiments of matrices provided with bored-through holes of different shapes and pitch;
- Figure 5a is a perspective view of a detail of figure 4b in which the mode of operation of the gas electron multiplier in a radiation detector in accordance with the invention operates to generate an electron avalanche from a primary electron;
- Figure 5b is a cross-section view along a section plane designating as plane R represented in phantom line at figure 5a, in which the electric field lines and electric potential lines are represented at the level of a local electric field condensing area with the potential lines being represented in solid lines and the electric field line being represented in phantom lines;
- Figure 5c is a diagram representing the electric field distribution within the local condensing area shown at figure 5b, the electric field being plotted with reference to a symmetry axis X'X shown at figure 5b;
- Figures 6a and 6b are each a schematic view of a radiation detector in accordance with the invention in which more than one matrix of electric field condensing areas are used so as to embody such a radiation detector;
- Figure 7a is a schematic view of a gas electron multiplier in accordance with the present invention which is inserted into a particular radiation detector, the gas electron multiplier of the invention operating thus as a preamplifier for primary electrons;

- Figure 7b is a schematic view representing successive gas electron multiplier in accordance with the present invention which are integrated within a particular host radiation detector, the successive gas electron multipliers operating thus as separate preamplifiers for the primary electrons;

- Figure 8a is a diagram representing the amplification factor which is obtained for several gas mixtures filling a radiation detector in accordance with the invention, with this amplification factor being plotted with respect to the voltage potential which is applied to a matrix of local electric field condensing areas;

- Figure 8b is a diagram representing the relative pulse height obtained from a radiation detector in accordance with the invention which is formed from a MSGC chamber in which a gas electron multiplier is inserted as shown at figure 7a with the relative pulse height being plotted with respect to the count-rate expressed in Hz/mm^2;

- Figure 8c is a diagram of comparative measures of the preamplifying or amplifying factor of a gas electron multiplier in accordance with the invention in case dry mixture of argon and carbon dioxide and a wet mixture of the latter is used as a gas filling the radiation detector in accordance with the invention, with the amplifying or preamplifying factor being plotted with respect to time expressed in minutes;

- Figure 8d is a preferred embodiment for one local electric field condensing area in which enhancement of the electric field along the central axis of symmetry of this local electric field condensing area is furthermore increased thanks to permanent electric charges which are implanted into particular zones of this local electric field condensing area;

- Figure 9a is a front view of a radiation detector in accordance with the present invention which is particularly adapted to be used for crystallography experiments;

- Figures 9b and 9c are front views representing a preferred embodiment of a radiation detector in accordance with the present invention which is more particularly adapted for the detection of ionizing radiations which are generated by colliding particles accelerated within the colliding ring path of an accelerator of the synchrotron-type, this accelerated particles having thus very high energy levels;

- Figure 10 is a cross-section view like figure 3a, of a non limitative embodiment of the radiation detector of the invention which is more particularly directed to photons detection.

- Figure 11a is a section view of a preferred embodiment of a parallax-free X-ray imager in accordance with the present invention;

- Figure 11b is a section view of a gas electron multiplier structure integrated within the parallax-free X-ray imager of the invention particularly adapted to operate as an amplifier of given gain for primary electrons generated within the spherical conversion volume chamber, amplification of these primary electrons taking place through an avalanche phenomenon;

- Figure 11c is a partial perspective view of Fig.1a in which the mechanical structure of the entrance window and the gas electron multiplier structure and their relative position adapted to embodying the parallax-free X-ray imager in accordance with the present invention is represented;

- Figure 11d is a voltage potential distribution representation of the voltage potentials which are successively applied to the electrodes forming the entrance window and the gas electron multiplier structure embodying the parallax-free X-ray imager in accordance of the present invention;

- Figure 12a is a partial section view of the spherical conversion volume chamber, the gas electron multiplier structure and transfer and induction volume embodying the parallax-free X-ray imager of the invention in which relative voltage potential values applied to corresponding electrodes and corresponding electrical equipotential surfaces are shown;
- Figure 12b is a detail of Fig.2a in which local deformations of the electrical equipotential surfaces and corresponding electric field lines in the vicinity of the electric field condensing areas forming the gas electron multiplier structure are shown for better comprehension;
- Figure 12c is a section view of a gas electron multiplier structure integrated within the parallax-free X-ray imager of the invention more particularly adapted to allow a proper electrical voltage potential feeding of the successive conductive rings in the absence of substantial degradation of the image through masking of the feeding connecting lines.

The radiation detector according to the invention is now disclosed as a non-limitative example in the present specification. Particularly, it should be kept in mind that the radiation detector in accordance with the invention can be used with the same advantages in many types of applications such as radiography, imaging medicine, and in a more general sense any kind of radiation which comes to effect to release primary electrons in a gas.

The radiation detector in accordance with the invention is thus disclosed with reference to figures 1a, 1b and 1c.

In the accompanying drawings, the same references designate the same elements while relative dimensions of these elements are not represented for the sake of better comprehension of the whole.

As shown at figure 1a, the radiation detector in accordance to the invention is a detector of the type in which primary electrons are released into a gas by ionizing radiations with these primary electrons being drifted to a collecting electrode by means of an electric field. In the above-mentioned figures, vector $\bar{E}$ designates the electric field, CE designates the collecting electrode.

Generally, the radiation detector of the invention may comprise a vessel referred to as V containing the gas in which the primary electrons are released by an incident ionizing radiation. In figures 1a, 1b and 1c, the ionizing radiation is designated as X-rays or gamma-rays which are generated from a source referred to as S. The X-rays or gamma-rays generated by the source S enter thus the radiation detector of the invention through an inlet window referred to as IW and generate primary electrons which are released into the gas contained within the vessel V. The inlet window IW has a metal clad inner surface generally consisting of a thin metal film which, in operation, is put at a drift potential thereafter designated as VD. As shown at figure 1a for example, the collecting electrode CE, and the inlet window IW and drift electrode DE may well form the vessel V so as to contain the gas in which the primary electrons are thus released on inpingement of the ionizing radiation. Light frames referred to as F_1, F_2 may be used to build up the vessel V.

As further shown at figures 1a, 1b or 1c, the vessel V is further provided with a gas inlet thereafter designated as GI, and a gas outlet designated as GO, both consisting of a threaded tiny tube allowing the filling of the vessel V with a particular gas mixture or dedicated gas as it will be disclosed in more details later in the description. Gas inlet GI and gas outlet GO may well be located onto opposite sides of the vessel V so as to insure proper gas filling and circulation.

As clearly shown at figures 1a, 1b and 1c, the radiation detector in accordance with the invention further includes a gas electron multiplier, thereafter designated as GEM and bearing reference sign 1, this gas electron multiplier 1 comprising at least one matrix of electric field condensing areas with these electric field condensing areas being each designated as 1_i.

In the above-mentioned figures, the electric field condensing areas are distributed within a solid surface which is substantially perpendicular to the electric field vector $\vec{E}$. Each of the electric field condensing areas 1_i is adapted to produce a local electric field amplitude enhancement which is proper to generate in the gas an electron avalanche from each one of the primary electrons. The gas electron multiplier 1 operates thus as an amplifier of given gain for these primary electrons while the collecting electrode CE allows a detection of the electron avalanche to be performed, as it is disclosed later in the specification. As shown at figures 1a, 1b and 1c, the solid surface forming the matrix of electric field condensing areas may well have different shapes with the shape of the vessel V containing the gas being adapted accordingly as shown in the above-mentioned figures. Thus, at figure 1a, the solid surface embodying the gas electron multiplier is cylindrical in shape with both the inlet window IW and associated drift electrode DE together with collecting electrode CE being of same cylindrical shape so as to develop a radial electric field vector $\vec{E}$ which is substantially perpendicular to this cylindrical solid surface forming the gas electron multiplier 1.

At figure 1b, to the contrary to figure 1a, the gas electron multiplier is formed by a solid surface which is planar in shape with the inlet window IW and its associated drift electrode DE together with collecting electrode CE being parallel to one another so as to form a planar structure. As a consequence, the electric field vector,

vector $\vec{E}$, which is developed between collecting electrode CE and inlet window and drift electrode DE, is substantially perpendicular to the planar solid surface embodying the gas electron multiplier 1.

At figure 1c, the solid surface embodying the gas electron multiplier 1 is spherical in shape with this solid surface being delimited by planar intersections of this solid surface. In the same way as to figures 1a and 1b, collecting electrode CE and inlet window IW and its associated drift electrode DE are spherical in shape so as to develop an electric field vector $\vec{E}$ which is substantially perpendicular to corresponding spherical solid surface embodying the gas electron multiplier 1.

As shown at figures 1a, 1b and 1c, each electric field condensing area 1_i is represented for better comprehension as to consist of a hole in which the local electric field amplitude enhancement generated thereto is substantially symmetrical in relation to an axis of symmetry of this condensing local area. This local electric field amplitude enhancement is thus substantially at a maximum at the center of symmetry of each condensing local area 1_i. In accordance with one particular aspect of the radiation detector of the invention, the electric field condensing areas 1_i are substantially identical in shape and regularly distributed within the solid surface whichever its shape as shown at figure 1a to 1c so as to form the gas electron multiplier 1.

More details relative to the structure and the mode of operation of the gas electron multiplier 1 embodying the radiation detector of the invention will be given now with reference to figures 2a, 2b and 3a, 3b.

Figure 2a represents a cross-section view of the radiation detector in accordance with the invention as shown at figure 1a or figure 1b with this cross-section view being taken along intersecting plane P which is shown in phantom line at figures 1a and 1b while figure 2b is a cross-section view along corresponding intersecting plane P shown in phantom line at figure 1c.

Figures 2a and 2b differ only in the extent that the same elements of figure 2b are bent owing to the spherical shape of the solid surface embodying the gas electron multiplier 1 and the collecting electrode CE, the inlet window IW and its associated drift electrode DE. In any case, collecting electrode CE is deemed to consist as an example of metal pads or strips which are laid onto a printed circuit board so as to allow detection of the electrode avalanches as previously mentioned in the specification.

As shown at figures 2a and 2b in a preferred embodiment of the gas electron multiplier forming the radiation detector of the invention, the matrix of electric field condensing areas 1_i may comprise a foil metal clad insulator, referred to as 10, on each of its faces so as to form a first and second metal-cladding, referred to as 11 and 12 respectively, with these metal-cladding sandwiching the insulator foil 10 to form a regular sandwich structure. The matrix of electric field condensing areas further comprises a plurality of bored-through holes, referred to as 1_i, traversing the regular sandwich structure as shown at figures 2a and 2b so as to form these electric field condensing areas.

In addition, biasing means are adapted to develop a bias voltage potential which is applied to the first and second metal cladding 11, 12, so as to generate at the level of each of the bored-through holes one electric field condensing area 1_i. At figures 2a and 2b, the biasing means are referred 2 and adapted to develop a difference potential denoted VGEM.

The mode of operation of the radiation detector in accordance with the invention and more particularly the mode of operation of the gas multiplier 1 which is shown at figures 2a and 2b is now disclosed with reference to figure 3a and figure 3b.

Generally speaking, with the regular sandwich structure being put in operation substantially perpendicular to the electric field vector $\vec{E}$, the first metal-cladding 11 forms thus an input face for the drift electrons while the second metal-cladding 12 forms an output face for any electron avalanche which is generated at the level of each bored-through hole forming one of the electric field condensing areas 1_i.

With reference to figure 3a, the electric field lines bearing the electric field vector $\vec{E}$ are represented between drift electrode DE and the gas electron multiplier 1, respectively the latter and collecting electrode CE while the electric field lines bearing the electric field vector $\vec{E}''$ are represented between the gas electron multiplier 1 and the collecting electrode CE. With the first 11 and second 12 metal-cladding being put at a convenient voltage potential, i.e. a continuous voltage potential difference value, each of the local electric field condensing area 1_i, i.e. each bored-through hole, behaves as a dipole which in fact super-imposes a further electric field vector $\vec{E}'$ with this further electric field being substantially directed along a symmetry axis of each bored-through hole. It should be borne in mind that the electric field lines are thus distorted as shown at figure 3a or 3b at the level of each of the local electric field condensing areas 1_i.

For the sake of clarity and better comprehension, figures 3a and 3b are shown in the absence of electric charges within the drift region and the detection region that in such a case fully corresponds to the absence of ionizing radiations. For instance, any virtual solid surface thereafter designated as FT which is delimited by the outermost electric field lines reaching one given local electric field condensing area, as shown at figure 3a for example, delineates an electric field tube FT in which the electric field flux presents a preservative character. As a consequence, it is clear to any person of ordinary skill in the corresponding art that the enhancement of the electric field at the level of each local electric field condensing area 1_i is thus given accordingly with any surface being passed through by the condensed electric field vector $\vec{E}'$ being in direct relation to the enhancement of the resulting electric field which is thus equal to the sum of original electric field vector $\vec{E}$ and superimposed electric field vector $\vec{E}'$.

Owing to the symmetrical character of the sandwich structure with respect to the symmetry plane referred to as plane Q at figure 3a, any virtual solid surface formed by the outermost electric field lines reaching a corresponding local electric field condensing area 1_i is substantially transferred as a symmetrical virtual solid surface formed by the electric field line leaving the same local electric field condensing area in the detection region, as shown at figure 3a with respect to the same electric field tube FT. As a consequence, provided given relations between voltage difference potential which is applied to the first 11 and the second 12 metal-cladding sandwiching the insulator foil 10 which will be explained later in the specification are fulfilled, it is thus clear that the distorted solid surface of electric field lines of the drift region is fully restored within the detection region as shown at figure 3a. It is furthermore emphasized that while the electric field $\vec{E}$ within the drift region and the electric field $\vec{E}''$ within the detection region are substantially parallel, they may well have amplitude of different value.

As an example, the detection region electric field amplitude $|\vec{E}''|$ may be set up at a larger value than the drift region electric field amplitude $|\vec{E}|$ so as to increase the transfer velocity to the collecting electrode to get thus faster signals. The same situation occurs at figure 3b with the general form of the electric field lines being modified only by the spherical shape of the sandwich structure and more particularly its circular shape as represented at figure 3b.

A preferred embodiment of the gas electron mutiplier embodying a radiation detector in accordance with the present invention is now disclosed with reference to figures 4a, 4b and more generally figures 4c to 4f. As shown for example at figure 4a, the gas electron multiplier 1 may consist of a thin insulator foil referred to as 10 which is metal clad on each of its faces, the metal cladding being thus referred to as 11 and 12 with reference to figures 2a and 2b, the sandwich structure thus formed being further traversed by a regular matrix of tiny holes referred to as 1_i. Typical values are 25 to 500 μm of thickness for the foil with the centre of the tiny holes being separated at a distance comprised between 50 and 300 μm. The tiny holes may well have a diameter which is comprised between 20 and 100 μm. The matrix of tiny holes 1_i is generally formed in the central area of an insulator foil of regular shape as shown at figure 4a. The insulator foil 10 is thus provided with electrodes on each of its faces which are referred to as 120 and 110, these electrodes being thus adapted so as to apply a potential difference between the two metal sides of the mesh embodying the matrix of tiny holes. The composite mesh can thus be manufactured with conventional technologies which will be described later in the description, is simple to install rugged and resistant to accidental discharges.

The mesh as shown at figure 4a can be realized by conventional printed circuit technology. As an example, two identical films or masks are imprinted with the desired pattern of holes and overlaid on each side of the metal clad insulator foil 10 which is previously coated with a light sensitive resin. The insulator foil 10 may consist of a polymer such as KAPTON or the like, KAPTON being a registered trade-mark to DUPONT DE NEMOURS. Exposure to ultra-violet light and development of the resin exposes thus the metal to acid etching only in the regions to be removed, i.e. the tiny holes. The foils are then immersed into an adequate solvent for the polymer used and holes dig within the foils from the two sides by chemical etching. The whole processing uses common and well-known industrial procedures as though a precise control of the etching parameter are essential to obtain a reproducible mesh. The above-mentioned method is proper to allow the manufacturing of mesh from an insulator foil of thickness comprised between 20 to 100 μm for example. For insulator foils of greater thickness, i.e. of a thickness comprised between about 100 to 500 μm, alternative standard methods of manufacturing like plasma etching or laser drilling can also be used and provide similar results. One method of particular interest appears to be laser drilling since the process of drilling holes can be computed and controlled accordingly so as to obtain matrices of tiny holes of adapted shape with respect to corresponding application.

A detail of the mesh thus obtained is represented at figure 4b. Although the tiny holes shown at figure 4b are circular in shape, they may well be of different shape as it will be thus disclosed with reference to figures 4c, 4d and 4e.

These figures consist of a front view of the mesh together with a cross-section view of this front view along a plane containing the center of symmetry of two successive tiny holes forming the matrix of tiny holes in the corresponding front view. With reference to figures 4b, 4c, 4d and 4e, each tiny hole is deemed to be included within an opening aperture diameter which is comprised between 20 and 100 μm. While the tiny holes as shown at figure 4b are circular in shape with the outermost dimension of the holes fully corresponding to its aperture diameter, to the contrary, the tiny holes which are shown at figures 4c and 4d fully correspond to square holes with rounded angles with the rounded angles corresponding to the opening aperture diameter of the hole.

The rounded angles allow to reduce the erratic electric discharges phenomenon.

At figure 4e, the tiny holes are represented so as to fully correspond to the tiny holes which are shown at figure 4b. In figures 4c, 4d and 4e, parameters P, D, d, T and S designate:

P the distance separating two successive tiny holes centers;

D the outermost dimension of any square tiny hole;

d the innermost dimension of any square tiny hole;

T the thickness of the insulator foil 10,

S the thickness of the first 11 and second 12 metal cladding embodying the sandwich structure.

Corresponding values of the above-mentioned parameters P, D, d, T and S are thus given for figures 4c and 4d with these dimensions being expressed in micrometers.

As shown as an example at figures 4c and 4d, each bored-through hole 1_i consists of a bored-through hole which is formed by a first and a second frusto-conical bored hole. The first frusto-conical bored hole extends from the first metal-cladding 11 to an intermediate surface of the regular sandwich structure which is referred to as plane Q at figure 3a, 3b and 4c, 4e. The second frusto-conical bored hole extends from the second metal-cladding 12 to the same intermediate surface referred to as plane Q, both frusto-conical bored-holes having a first circular opening of a diameter of a given value as previously mentioned in the description at the level of the corresponding metal-cladding 11 or 12. Both of the frusto-conical bored holes join together at the level of the intermediate surface Q of the regular sandwich structure forming thus the corresponding bored-through hole 1_i as shown at figures 4c and 4e. With the same pitch P of given value as previously mentioned in the description, the bored-through holes 1_i which are identical in shape and regularly distributed over all the metal clad faces of the insulator foil 10 form thus the matrix of tiny holes embodying the matrix of local electric field condensing areas in operation.

At figure 4d, a further particular embodiment of the matrix of tiny holes of the invention is shown in which each of the bored-through holes 1_i has a cross-section along a longitudinal plane of symmetry of this bored-through hole which is conical in shape.

Corresponding parameters are given now with respect to figures 4c to 4e in which:

P, T and S fully designate the same parameters as per figures 4c and 4e, and

D_1 designates the outermost dimension of one tiny hole formed at the level of first cladding 11, for example;

D_2 designates the outermost dimension for a square tiny hole which is formed at the level of the second cladding 12;

d_1 designates the outermost dimension for the bored-through hole within the insulator foil 10 at the level of first cladding 11;

d_2 designates the outermost dimension for the square bored-through hole through the insulator foil and at the level of second metal cladding 12.

These dimensions are given in micro-meters. These parameters values are given thereafter as sizes example only with reference to tables I, II and III which are related to Fig. 4c, Fig. 4d and Fig. 4e, 4f respectively.

Table I

P	D	D	T	s
140	110	60	50	15
200	130	70	50	18

Table II

P	D_1	D_2	d_1	d_2	T	s
200	160	120	75	60	50	5

Table III

P	D	D	T	d
200	130	100	50	18

Each of the bored-through holes 1_i as shown at figure 4d comprises thus a first and a second circular opening or substantially circular opening for given values which are different from each other and thus form a first and a second opening aperture diameter of different value at the level of the first 11 and the second cladding 12.

Figure 4f refers to another particular embodiment in which each of the bored-through holes is fully circular in shape, all the way through. The dimensions given at figure 4f may thus well correspond to those given at table

III, with d being thus equal to D. Such a matrix as shown at figure 4f can be obtained by laser drilling.

A more detailed mode of operation of the gas electron multiplier 1 embodying the radiation detector of the invention is now disclosed with reference to figures 5a, 5b and 5c.

In operation, when a potential difference is applied between the first and the second metal cladding 11 and 12 of the mesh, very high localized electric fields as vector $\vec{E}'$ previously mentioned in the description are created within the open channel in the tiny holes, as shown at figures 3a, 3b and 5a, 5b, 5c.

The electric field enhancement as shown at figures 3a or 5a, 5b is large enough to induce an avalanche multiplication from any primary electron entering one of the field tube FT of the drift region as shown at figures 3a, 3b or 5a.

Figure 5b represents the distribution of the electric field lines and the potential lines at the level of one electric field condensing area of the gas electron multiplier 1 embodying a radiation detector in accordance with the object of the invention, with the electric field lines being represented in solid lines and the potential lines in phantom lines. It is particularly emphasized that provided a given potential difference VGEM is applied to the first 11 and second 12 metal-cladding of the gas electron multiplier 1 embodying a radiation detector in accordance with the present invention, no electric field lines do reach either the first and second metal-cladding 11 and 12 or the insulator foil 10 as it is clearly shown at figure 5b.

It is also emphasized with reference to figure 5c that the electric field distribution along an axis of symmetry designated as X'X at figure 5b or 3a, 3b is substantially symmetrical with respect to the intermediate surface Q which is the plane of symmetry with respect to figure 5b as shown at figure 5c. It should be borne in mind that since no field line from the drift region except for the mathematical boundary between cells or field tube FT terminates on the upper electrode, any local electric field condensing area 1_i provides thus a full transmission of any drift electron as an electron avalanche, the gas electron multiplier 1 embodying the radiation detection of the invention providing thus a full electrical charges transmission and, as a consequence, an electrical transparency that substantially equals 1. This electrical transparency should be distinguished over the optical transparency of the mesh embodying the gas electron multiplier 1 since this electrical transparency substantially equal to 1 is obtained for an optical transparency of the mesh which is defined as the ratio between the total surface of all the tiny holes embodying the local electric field condensing areas over the total surface of the metal clad insulator foil and thus is comprised between 10% and 50%. It is further emphasized that the high density of channels, i.e. of tiny holes, reduces thus the image distorsions to values which are comparable to the intrinsic spread due to diffusion.

A particular embodiment of the radiation detector of the invention is now disclosed with reference to figure 6a.

The gain or the amplifying factor of the radiation is in a direct relationship to the amplifying factor yield by the gas electron multiplier as disclosed in the description. This amplifying factor is in a direct relationship to the electric field enhancement and more particularly to the electric field amplitude value along the symmetrical axis of symmetry X'X of each tiny hole embodying one electric field condensing area together with the path length of the electron avalanche within one of the local electric field condensing area, and as a consequence, the thickness of the metal clad insulator foil 10. Insofar as the thickness is open to reach 100 μm with the tiny holes being drilled thanks to a laser processing as previously mentioned in the description, the amplifying factor which is defined as a ratio of the number of electrons of the electron avalanche entering the detection region to one primary electron yields those values to above 1000. With such a gain, or amplifying factor, the collecting electrode CE is adapted to operate at unity gain in ionization mode for example. In such a case, this electrode may consist of a plurality of elementary anodes as shown for example at figures 1a to 1c, each elementary anode consisting for example of one strip or one pad of conductive material which allows an electronic detection of each electron avalanche. Each elementary anode as shown for example at figures 2a and 2b is put at a reference potential such as a ground potential and is connected thanks to a capacitor CA to an amplifier A adapted to deliver a detection signal to a detection device which is not shown in the above-mentioned figures. The detection device is not disclosed for it is well-known *per se* to any person of ordinary skill in the corresponding art.

Thanks to its above mentioned electrical transparency that substantially equals one, the radiation detector of the invention may well be adapted to perform either monodimensional or bidimensional position detection. For such a purpose, as shown as a non-limitative example at figure 2a, the collecting electrode CE may be provided with elementary anodes ST_i which are laid onto the face of an insulator foil or printed circuit board facing the gas electron multiplier 1, in case of monodimensional detection, with these elementary anodes each consisting of one electric conductive strip, these strips being thus parallel and extending along a first direction.

In case of bidimensional detection however further elementary anodes ST_j may be provided on the other side of the insulator foil, and separated from the first ones, so as to form parallel electric conductive strips extending along a second direction transverse to the first one. The conductive strips ST_i facing the gas electron multiplier 1 are preferably regularly spaced apart from each other so as to cover 50% only of the total surface of the collecting electrode CE, so as to allow any electron avalanche generated in front of any elementary anode ST_i facing the gas electron multiplier 1 to also induce a corresponding detection signal onto corresponding elementary anodes ST_j which are partially masked by the latters. The gain of detection amplifiers A embodying each detection circuit with capacitor CA and resistor RA may well be set up to different adapted values for each set of elementary electrodes, so as to introduce a good balance of the induced detection signal onto each set of elementary electrodes.

In order to improve the gain yield from the gas electron multiplier embodying a radiation detector in accordance with the invention as shown at figure 6a, a plurality of successive matrices of electric field condensing areas can be used, these matrices being in a cascade relationship over the primary electron stream, two matrices referred to as GEM_1 and GEM_2 being shown only for the sake of better comprehension at figure 6a. These successive matrices are put parallel to one another, i.e. in the absence of intersection, to define homothetic matrices over a common centre C forming the radiation detector as shown at figure 6a. As shown at this figure, two successive matrices are spaced apart from each other at a given separating distance value in a direction which is parallel to the corresponding electric field. As a consequence, the drift electrode DE, the first matrix or gas electron multiplier GEM_1, the second matrix or second gas electron multiplier GEM_2 and successive matrices together with the collecting electrode CE define therebetween successive electric fields which are referred to as vector $\vec{E}_{1D}$, vector $\vec{E}_{21}$, vector $\vec{E}_{02}$ and the like, each successive electric field allowing any primary electron or electron of one electron avalanche to drift as a primary electron along the separating distance thanks to its corresponding electric field.

The gas electron multiplier formed by successive matrices as shown at figures 6a and 6b cooperates thus as an amplifier, the gain of which is the product of the gain yield for each successive matrix. Figure 6b actually represents a planar embodiment of the radiation detector shown at figure 6a. It is further recalled that for planar embodiments as shown at figure 6b, the common center C actually lies at an infinite distance.

The radiation detector of the invention as it has been disclosed up to now with reference to figures 1a to 6b fully operates as an amplifier, the collecting electrode CE of which operates at unity gain and can thus be made of a simple and very cheap stripped printed circuit for which the total gain or amplifying factor is obtained from the gas electron multiplier only, either single or multiple gas electron multiplier as shown at figures 6a and 6b.

Another way to embodying the radiation detector of the invention is now disclosed in which the gas electron multiplier 1 is inserted into a host detector which has its proper gain with reference to figures 7a and 7b. The host detector, in a general way, may consist as a non-limitative example, as a well-known micro-strip gas chamber, thereafter designated as MSGC, or a multiwire proportional chamber. As shown at figure 7a in case of a MSGC, the collecting electrode CE consists now of successive anode electrodes designated as AN and cathode electrodes, referred to as CO, which are interleaved and distributed over a dielectric support so as to form the collecting electrode CE. Each of the anode electrodes AN is connected to the reference potential referred to as the ground potential through resistor RA and to an amplifier A so as to allow detection while each of the cathode electrodes CO is connected to a bias potential generator VC, the MSGC chamber having thus its own gain depending on the gain which is yield through amplification between each of the cathode electrodes and anode electrodes. As further shown at figure 7a, one gas electron multiplier 1 is further inserted between the drift electrode DE and the collecting electrode CE so as to define a first drift region, drift$_1$, and a second drift region, drift$_2$, which are separated from each other by the gas electron multiplier 1.

While proportional counters, multiwire chambers, and microstrip gas chambers, all exploit the basic amplification process of electron avalanche multiplication but differ only in their geometry and their performances, the maximum amplification factor that can be safely reached depends on many parameters and is limited by the probability of a catastrophic hazardous discharge in case too large gains, i.e. too large voltages, are used.

As an example, the microstrip gas chamber which is made with its thin and fragile metal strips appears particularly exposed to discharge damages. The sophisticated electronic circuits connected to the strips such as amplifier A as shown at figure 7a, can also be irreversibly damaged by these discharges.

Inserting a gas electron multiplier 1 as shown at figure 7a within for example a microstrip gas chamber with the gas electron multiplier being inserted on the path of electrons drifting in the gas under the effect of a moderate electric field comes to effect to pull the primary electrons which are generated in the first drift region, $drift_1$, into the tiny holes forming the local electric field condensing areas and multiply them in an avalanche in the high local electric field and thus push them out from the other side, i.e. in the second drift region, $drift_2$, with the primary electrons being multiplied by a factor of many hundreds.

The gas electron multiplier 1 of the invention operates thus as a preamplifier of given gain for the primary electrons upstream the collecting electrode CE of the radiation detector.

Provided the bias potentials which are put to the drift electrode DE and the collecting electrode CE, particularly to the cathode electrode CO and the first and second metal-cladding 11 and 12 of the gas electron multiplier 1 as shown at figure 7a are independent, such a configuration allows independent operation of the gas electron multiplier 1 and the microstrip gas chamber or multiwire proportional chamber as well as a controlled injection of ionization electrons into the preamplifying gas electron multiplier 1.

Such mode of operation is called preamplification mode and can be used to largely increase the electric charges to be detected. Combined with a multiwire or a microstrip gas chamber, it makes much easier and safer to detect small amounts of electric charges. While the combination of a gas electron multiplier 1 adapted to a multiwire proportional chamber or a microstrip gas chamber of corresponding shape can be performed with these shapes corresponding to spherical or cylindrical ones, the preamplification mode of operation of the gas electron module 1 of the invention appears of highest interest in case of multiwire proportional chamber or microstrip gas chamber of planar structure, the gas electron multiplier 1 in such a case corresponding also to a planar structure as shown at figure 7a.

As per figures 6a or 6b to which the gas electron multiplier operates in amplification mode, combining several successive gas electron multipliers as shown at figure 7b appears of outmost interest so far these gas electron multipliers are adapted to operate independently since it is thus possible to achieve increasing large gains in a succession of elements with each of the elements being individually set at moderate amplification factor and therefore intrinsically safer to operate. As shown at figure 7b, two successive gas electron multipliers, referred to as GEM_1 and GEM_2, are shown to embody a resulting gas electron multiplier with each gas electron multiplier GEM_1, GEM_2 being set to yield a gain or amplifying factor to 100. The resulting amplifying factor is thus the product of each gain, then, as a consequence, has a value that equals 10 000.

Irrespective to its mode of operation, in order to operate the radiation detector of the invention which is shown at figures 6a, 6b or 7a, 7b, the voltage potentials can be set up at the following values:

- conducting strips of the collecting electrode CE of figures 6a or 6b at the reference potential referred to as the ground potential;
- anode AN of the collecting electrode CE of figures 7a or 7b at the reference potential.

All the other voltage potentials set up with respect to the reference or ground potential. The following potential values are given as a non-limitative example for a given $A\text{-}CO_2$ (argon-carbon dioxide) gas mixture, as shown at figure 8a, given gas electron multiplier geometry embodying an insulator foil 10 of thickness 50 μm and tiny holes of diameter 100 μm, this gas electron multiplier being operated with this gas mixture being at atmospheric pressure. Change of any parameter would imply correlative changes in the ranges of voltage potential values.

- cathode potential VC to each cathode electrode CO at figure 7a or 7b, Vc = -500 V;
- V_4 set up between -100 V and -1000 V;
- V_3 set up between -600 V and -1500 V with V_{GEM} = -500 V;
- V_2 set up between -1600 V and -2300 V;
- V_1 set up between -2100 V and -2800 V with V_{GEM} = -500 V.

The distances separating the gas electron multiplier from the drift electrode, or the successive electrode CE were set up to 3 mm.

A multistage detector in accordance with the invention operating in either amplification or preamplification mode is thus functionnaly equivalent to a multidynode photomultiplier except it operates in a gaseous environment while each matrix element of local electric field condensing areas has a much larger gain.

As compared to similar gas devices realized with stretched parallel metal meshes, the so-called parallel plate and multistep chambers, the gas electron multiplier which is the object of the invention is fully self-supporting since the multiplying gap and therefore the gain are kept substantially constant by the fixed thickness of the insulating foil regardless of the precise location of the gas electron multiplier within the detector or the host detector. Furthermore, heavy support frames are not necessary, this greatly simplifying construction and increasing reliability while reducing costs.

Extensive experimental measurements were realized with several types and models of gas electron multipliers, meshes as self-standing one's operating in amplification mode or in combination with host detectors and have been described in papers which are listed thereafter :

· *Nuclear Instrum. Methods, Methods in Phys.Res.* A386(1997)531; F.SAULI;

· *IEEE Trans.Nucl.Sci.* NS-(1997); R.BOUCLIER,

M.CAPEANS, W.DOMINIK, M.HOCH, J-C.LABBE, G.MILLION, L.ROPELEWSKI, F.SAULI and A.SHARMA;

- *CERN-PPE/97-32*; R.BOUCLIER, W.DOMINIK, M.HOCH, J-C.LABBE, G.MILLION, L.ROPELEWSKI, F.SAULI, A.SHARMA and G.MANZIN;
- *Progress with the Gas Electron Multiplier,* CERN-PPE/97-73; C.BUETTNER, M.CAPEANS, W.DOMINIK, M.HOCH, J-C.LABBE, G.MANZIN, G.MILLION, L.ROPELEWSKI, F.SAULI, A.SHARMA.

During those experimental measurements, preamplification factors above 100 have been observed in many gases and gas mixtures of noble gases such as helium, argon, xenon or the like with organic or inorganic quenchers like carbon dioxide, methane and dimethylether. Figure 8a gives some examples of the gas electron multiplier amplification factor which is plotted in relation to the potential difference which is applied to the first and second metal-cladding 11 and 12 embodying one gas electron multiplier 1 in accordance with the invention. Experimental results as shown in figure 8a are given for a first mixture of:

Argon and dimethylether, thereafter designated as A_DME with 90% argon and 10% DME;

Argon and carbon-dioxide thereafter designated as A_CO_2 with a ratio of 90% argon and 10% CO_2;

Helium and methane, thereafter designated as He_CH_4 with a ration of 70% helium and 30% methane;

Argon and dimethylether, thereafter designated as A_DME with a ratio to 50% argon and 50% DME.

Preceding ratios are given as volume ratios.

The voltage difference which was applied to the first 11 and second metal-cladding 12 was comprised between 200 and about 600 volts, thereafter designated as V_{GEM}.

Most measurements have been realized at atmospheric pressure convenient for the manufacture and operation of light and safe detectors but correct performance at pressure between few millibars and 10 bars revealed satisfactory.

A fundamental property of the gas electron multiplier embodying one radiation detector in accordance with the invention appears to be the wide range of electric fields strengths that can be applied above the mesh forming the matrix of local electric field condensing areas without affecting the gain actually yield. Such a property appears of highest importance because it makes the gas electron multiplier of the invention almost insensitive to large mechanical variations in the surrounding electrodes. As a consequence, such a property allows the choice of the drift field for optimal physical requirements as the value of the electrons drift velocity, diffusion and collection time.

A concern of high-rate applications is the behavior of the gas electron multiplier embodying the radiation detector in accordance with the present invention under condition of large detected currents. While most of the electric charges, electrons and positive ions, smoothly drift in the open gas channel without affecting the operation, some stray charges may collect on the surface of the insulator with these stray charges distorting the field and therefore the gain thus obtained. It has been however demonstrated that a very small surface conductivity in the channel which is obtained very simply by the addition to the gas of a small amount not exceeding 1% of water vapor completely stabilizes the operation up to detected X-ray fluxes of 10^7 Hz cm^{-2} or more.

Other methods of increasing the surface conductivity to the desired value have been investigated such as ion implantation or vacuum evaporation of semiconducting layers. It has thus been observed that using a polymeric foil embodying the insulator foil 10 with an intrinsic resistivity between 10^{12} and 10^{13} Ω x cm would properly solve the charging up problem in a natural way.

As a consequence, as it is shown at figure 8d, each tiny hole or bored-through hole 1_i is provided with an internal lateral surface which is delimited by the insulator foil 10. As clearly shown at figure 8d, this lateral surface comprises preferably one local zone with intrinsic resistivity between 10^{12} and 10^{13} Ω x cm. In a non-limitative way, as shown at figure 8d, this local zone is deemed to cover the extremal portion of the frusto-conical bored-through hole in which electric charges such as positive ions have been introduced through ion implantation for example.

With reference to figure 8d, it is clear to one of ordinary skill in the corresponding art that, thanks to the presence of the positive electric charges which are implanted at the extreme part of the frusto-conical profile of the insulator foil with these electric charges being distributed substantially with the same concentration all around the periphery of the tiny hole, i.e. in the vicinity of the medium plane or symmetry plane Q which was already mentioned with reference to figure 5b, the electric field lines are made very tight at the level of the intermediate plane or symmetry plane Q shown at figure 8d with the electric field being thus accordingly increased thanks to the preservative character of its flux within the modified solid surface or field tube FT through the presence of the implanted electric charges.

To detect the amount of the electrical charges which are released into a gas by soft X-rays or fast particles, about 100 electrons, amplification factors of 10 000 or so are necessary, given the limitations of modern highly integrated electronics. This can be achieved safely by combining one gas electron multiplier mesh with an amplifying factor of 100 together with a multiwire or microstrip gas chamber safely operated also at a gain of 100. The discrete nature of the electrodes in the host detector which are wires or strips allows then to achieve the electron avalanche localization.

It is also clear to one of ordinary skill in the corresponding art that this can also be achieved thanks to a radiation detector operating as an amplifier in which the collecting electrode CE is put at unity gain so far the gas electron multiplier 1 is enough thick to yield corresponding value of amplifying factor equal to 10 000 with the thickness of the sandwich structure being thus open to reach a thickness substantially equal to 500 μm, or by a multistage gas electron multiplier as shown at figure 6a or 6b for example.

Another fundamental property of the gas electron multiplier embodying the radiation detector of the invention is its high-rate capability while the gain or the relative pulse height of the radiation detector is substantially maintained at a constant value over its full rate range.

While the gain of the gas electron multiplier in accordance with the present invention has been defined as the ratio of the electrons number in the electron avalanche leaving the output face to the number of electrons of the primary electrons or the electrons entering the input face at the level of each local condensing area of the matrix embodying the gas electron multiplier, one mode of operation to evaluate such a gain may consist as an example to measure the preamplification factor or the amplification factor which is defined as a ratio of the most probable pulse height between transferred and direct spectra for the 5.9 keV line radiated by an external ^{55}Fe source.

As shown at figure 8b, the relative pulse height PH is plotted with respect to the rate expressed in Hz/mm^2 in three modes of operation of a gas electron multiplier inserted within a host detector which consists of a micro-strip gas chamber in the following situations:

- micro-strip gas chamber only,
- gas electron multiplier only, and
- multi-strip gas chamber and gas electron multiplier joined together.

The results which are shown at figure 8b clearly confirm the high-rate capability for the charge gain remains essentially constant within few percent up to the maximum rate that could be achieved, around 10^5 Hz/mm^2, regardless of the mode of operation thus demonstrating the absence of short-term ion induced charging up or charge space effects in the local electric field condensing areas.

One should also note that the fraction of ions receding into and through the gas electron multiplier local electric field condensing areas depends on the applied voltages. In the mode of operation of unity gain of the micro-strip gas chamber with the gas electron multiplier being operative only, there are no positive ions produced in the lower gas volume and presumably no substrate charging up and ageing problems.

Another fundamental property of the radiation detector in accordance with the present invention which is embodied through a gas electron multiplier fully concerns the absence of time-dependent gain shifts.

While the presence of an insulator material close to the multiplication channels or the tiny holes is open to introduce the possibility of dynamic gain shifts due to the deposition of electric charges and the consequent modification of electric fields, this drawback can thus be fully overcome as already mentioned previously in the description, either by using a wet gas mixture in which a given proportion of water vapor is introduced or by giving particular values of electric conductivity to given zones of the internal part of each tiny hole forming a corresponding local electric field condensing area, as previously mentioned in the description.

With respect to this last solution consisting for example in implanting positive ions as it is shown at figure 8d, it is also emphasized that it comes to effect to repell the positive charges which are possibly generated by the electron avalanche towards the symmetry axis X'X as shown at figure 8d thereby allowing to reduce the charging up phenomenon of the insulator foil internal lateral surface while the electrons of the electron avalanche are quite unaffected by the presence of the implanted ions. The residual electric charges which are charged up by the internal lateral surface of the insulator foil has thus its contribution to the total electric field distorsion drastically reduced, the charging up phenomenon being thus overcome.

Figure 8c shows the variation of the pulse amplifying factor of one gas electron multiplier 1 in accordance of the object of the present invention, with this amplifying factor being plotted over the time during which the gas electron multiplier 1 is actually on, the time being expressed in minutes.

Corresponding curve I is given for a gas electron multiplier operated with a potential difference applied to the first 11 and second 12 metal-cladding of the sandwich structure which was put to 420 volts with the radiation detector being filled with a gas mixture of argon and carbon dioxide to a ratio 72% / 28%.

The charging up phenomenon comes up to effect to increase the pulse amplifying factor for an initial value that equals 40 to a value greater than or substantially equal to 52 after 20 minutes the radiation detector is on.

Corresponding curve II is given for the same radiation detector as it was used to get curve 1 except that the gas mixture is further provided with water vapor to 0.35% in addition.

Curve II clearly shows the full constant character of the pulse amplifying factor which substantially equals 40 all over the time the radiation detector of the invention is on, that is from the very beginning to the end of the experiment 50 minutes later.

It should be thus understood that after the addition of water vapor, the inter-electrode resistivity of the gas electron multiplier mesh decreases gradually by a factor of 10, from 100 to 10 GΩ, and then remains constant. Taking into account the total area of the channels and particularly of the tiny holes embodying the latters, this clearly indicates that a surface resistivity around 10^{16} Ω /square is sufficient to eliminate the charging up phenomenon as the highest rates. The original value of resistivity as well as the final one after introduction of water depend on the total area and the number of tiny holes. Preceding values refer to a 10 x 10 cm^2 gas electron multiplier 1 provided with about 5 x 10^5 tiny holes.

Particular embodiments well adapted to specific applications are now described with reference to figures 9a, 9b and 9c.

Each of the above-mentioned embodiments is well adapted to operate either on amplification or preamplification mode as previously disclosed in the description. It is furthermore emphasized that the amplification mode may well be preferred for applications in which ionizing radiations of very high energy level are to be investigated.

Accordingly, figure 9a shows the radiation detector of the invention in which the sandwich structure forming a gas electron multiplier 1 is provided which is spherical in shape. This radiation detector may well correspond to that which is shown at figure 1c with the external form of the detector being circular in shape as shown at the front view of figure 9a. This radiation detector is adapted to crystallography trials in which X rays are directed to a crystal, the radiation detector of the invention being thus adapted to allow a full detection of the diffraction pattern generated by the impingement of the X-rays onto the crystal. As clearly shown at figure 9a, the bored-through holes forming the electric field condensing areas are regularly distributed over a part only of the metal-clad faces of the insulator foil so as to form at least one blind detection zone which is referred to as BZ for the radiation detector. The blind detection zone is thus substantially spherical in shape and located at the center part of the sandwich structure with the bored-through holes being distributed all around this blind detection zone so as to allow detection of the diffraction pattern out of this blind detection zone only. Particularly in case the radiation detector of the invention as shown at figure 9a is used in amplification mode, that is in the absence of micro-strip or multiwire chamber as final amplifier, it allows to adapt the collecting electrode CE shape to the needs with this electrode for example consisting of strips, pads or rings, the rings being particularly adapted in case of crystal diffraction measurements. At figure 9a, the rings forming the collecting electrode CE are shown in phantom line for better comprehension and clarity of the drawings.

Figures 9b and 9c are concerned with radiation detectors in accordance with the present invention which are more particularly adapted and suited for colliding beams accelerators or very high energy particles colliding ring accelerators like that which is in operation at the CERN (Centre Européen de Recherche Nucléaire) in Geneva, Switzerland. At figures 9b and 9c, the colliding ring accelerator, owing to its very high curvature radius, is represented as a straight portion. As shown at figures 9b and 9c, the gas electron multiplier embodying the radiation detector in accordance with the invention consists of a solid surface made of adjacent elementary solid surfaces, each elementary solid surface forming one elementary gas electron multiplier which comprises at least one matrix of electric field condensing area so as to form elementary detectors which are referred to as RD_1 to RD_9. The elementary detectors are joined to one another so as to form a three-dimensional radiation detector which surrounds the colliding ring accelerator as shown at figures 9b and 9c.

The three-dimensional detector shown at figure 9b is spherical in shape and formed from elementary radiation detectors which are each spherical in shape and fully correspond to the radiation detector in accordance with the present invention which is shown at figure 1c with elementary detectors RD_1, RD_2, RD_3 and RD_4 being designed so as to form a skullcap while the other elementary detectors are design as a part of a corresponding volume spherical in shape. Elementary detectors RD_2 and RD_3 may well be provided with a central blind detection zone, as already shown at figure 9a, this blind detection zone being further drilled so as to allow the colliding ring accelerator to pass through. Each elementary radiation detector may be manufactured as the radiation detector shown at figure 1c by thermo-forming all its constituting parts such as the input window and drift electrode, the sandwich structure and the collecting electrode CE together with the intermediate frames which are necessary to build up any radiation detector or elementary radiation detector in accordance of the present invention. As shown at figure 1a or 1c, in order to embody one elementary radiation detector as shown at figure 9b or 9c, the gas inlet and gas outlet GI and GO may be removed and replaced by bored-through holes with the bored-through holes forming the gas inlet and gas outlet of two neighbouring adjacent elementary radiation detectors, such as RD_2 and RD_5 at figure 9b, these bored-through holes being put to face each other and to be sealed thanks to O rings. The electrodes terminals which are adapted to apply the difference potential to the input and output face formed by the first and second metal-cladding 11 and 12 as shown at figures 1a and 1c, are reduced and adapted to further allow the interconnecting of the first and second metal-cladding respectively of two successive adjacent elementary radiation detectors, the same difference potential voltage being thus applied to each gas electron multiplier embodying each elementary radiation detector which as a consequence yield the same gain.

As further shown at figure 9a, one general gas inlet GI and gas outlet GO only are provided which are preferably located close the blind zone in the vicinity of the colliding ring accelerator. The same for the electrodes 110 and 120, one of these electrodes only being thus provided to allow a same difference voltage potential VGEM to be applied to each elementary first 11 and second 12 metal-cladding.

Figure 9c is directed to a three-dimensional radiation detector which is substantially cylindrical in shape at the extremities of which two elementary half-spherical radiation detectors are abutted. The elementary half-spherical radiations detectors may well consist of one or several elementary radiation detectors thereafter designated as RD_1, RD_2, RD_8, RD_9 with elementary radiation detectors RD_1 and RD_9 playing the same role as the elementary detectors as RD_2 and RD_3 at figure 9b. The length of the cylindrical part as shown at figure 9c may extend along the colliding ring accelerator for several meters with this cylindrical part consisting of several adjacent elementary radiation detectors thereafter designated as RD_3 to RD_7. In order to allow three-dimensional radiation detectors of great dimensions to be operated, the inner part of these detectors as shown at figures 9b and 9c may well be filled outside the inlet window of each elementary radiation detector with a foam which is substantially transparent to the X or gamma rays of very high energy.

A radiation detector of very high efficiency, in accordance with the present invention, has thus been disclosed in which a gas electron multiplier may be used in the field of elementary particle experiments.

Generally speaking, embodying a radiation detector in accordance with the invention operating in the preamplification mode with the gas electron multiplier mounted within a micro-strip gas chamber for example, allows to operate such a sophisticated but fragile device in much safer conditions.

Several new experiments embodying a gas electron multiplier in accordance with the object of the invention were actually conducted.

One first new approved experiment, thereafter designated as *HERA-B* at DESY in Hamburg, Germany (DESY, for *Deutsche Elektron Synchrotron*) qualified and adopted the gas electron multiplier of the invention, in order to improve the reliability of the high rate host tracking detector.

One second new approved experiment, thereafter designated as *COMPASS* at CERN, came to adopt the gas electron multiplier technology in accordance with the invention for similar reasons.

Another proposed new experiment designated as FELIX and conducted at the CERN (Centre Européen de Recherche Nucléaire) in Geneva is carried out so as to improve radiation detectors operating in the amplification mode in the cylindrical geometry.

Another detector, thereafter designated as HELLAZ, is proposed for large cosmic rays experiment in the Italian

Laboratory under the GRAN SASSO with the aim of achieving large enough gains to detect single electrons.

A further particular use of the gas electron multiplier of the invention may also consist to prevent transmission of electrons and/or ions through the control of external voltages. As shown for example at figure 2a or 2b, the biasing source 2 may well consist of two detening voltage generators of opposite polarity that can be switched through a common switch K. Operating the switch K allows the difference voltage potential VGEM to be reversed so as to allow to prevent transmission of electrons and/or ions, the sandwich structure operating thus as an active gate, the enhanced electric field being thus strong enough to repell given electric charges ions or electrons.

A further embodiment of the radiation detector in accordance with the object of the present invention is now disclosed with reference to figure 10.

This embodiment is more particularly directed to a radiation detector for photons which are emitted by an external source.

The operating principle of the gas electron multiplier 1 which is the object of the present invention operating as a photon detector relies on the following specific properties of its structure:

- a controlled electrical transparency, from 0 to 1, actually depending on the voltage potentials which are applied on the various electrodes of a composite structure operating either as an amplifier or a preamplifier and including thus a gas electron multiplier as previously disclosed in the description;
- a geometry controlled optical transparency from about 10% to 50% which is obtained by appropriate patterning during manufacturing;
- a demonstrated operation with gain in pure and inert gases which actually proved harmless to photocathode

materials, and the existence of photocathode materials operating in many particular wavelengths either visible or invisible ones that have large quantum efficiency and long survivability in a gaseous environment.

The schematics of a reverse photocathode, gas electron multiplier, photon detector in accordance with the object of the present invention is shown at figure 10 together with its corresponding features and electric field lines.

As previously disclosed in the description with reference to figure 3a for example, the radiation detector for photons which is the object of the present invention consists of a vessel, which is not shown at figure 10 for the sake of better comprehension, with this vessel being filled with a gas adapted to generate an electron avalanche from a primary electron through an electric field.

An inlet window IW is further provided which is associated with a transparent electrode denoted as C, this inlet window and transparent electrode being adapted to transmit the photons within the gas contained by the vessel. The inlet window IW and transparent electrode C are made of a material which is substantially transparent to the photons wavelength. Well-known technology may be used so as to put the inlet window IW and the transparent electrode C together, the transparent electrode for this reason being represented with phantom line only at figure 10.

As further shown at the above-mentioned figure, a photocathode layer, denoted as PhC, faces the transparent electrode C with this photocathode layer being adapted to generate one photo-electron as a primary electron under impingement of each one of the photons onto this photocathode layer.

A gas electron multiplier 1 is further provided so as to include at least, as previously mentioned in the description, one matrix of electric field condensing areas which is formed from the foil metal clad insulator 10 provided with metal cladding 11 and 12 onto its faces, with metal cladding 11 facing the transparent electrode C. As clearly shown at figure 10, the photocathode layer PhC, the metal claddings 11 and 12 together with the insulator foil 10 form thus a regular sandwich structure as previously mentioned in the description. Furthermore, a plurality of bored-through holes denoted 1_i traverse thus the regular sandwich structure with each of the bored-through holes being adapted to allow a free flowing therethrough for the gas and any electrically charged particle generated within the latter. As a matter of fact, in order to embody the electron gas multiplier 1 as shown at figure 10, one may well have first a metal clad insulator provided with metal claddings 11 and 12 onto one of the faces of which a layer of photosensitive material is deposited so as to build up the photocathode layer PhC. The bored-through holes may thus be drilled according to anyone of the technologies which are actually disclosed in the description.

As shown at figure 10, inlet window IW and transparent electrode C are spaced apart to form a convey region which operates in a similar way as the drift region of figure 3a, as it will be disclosed in more details later in the description.

On the bottom side of the vessel, the detector of the invention further includes a detection unit adapted to perform a position detection of any electron avalanche generated within the detection region which is formed between the gas electron multiplier 1 and the detection unit as shown at figure 10. For the sake of better comprehension, the detection unit is represented as a collecting electrode CE as previously mentioned with reference to figures 2a or 3a. It is further emphasized, although not represented for the sake of better comprehension at figure 10, that the detection unit may well include another gas electron multiplier so as to form a multistage gas electron multiplier as previously mentioned in the description or a microstrip chamber or even a multiwire chamber for example.

To the contrary, as shown at figure 10, the top electrode of the collecting electrode CE is provided with elementary anodes, each of which is denoted ST_i, whith these elementary anodes consisting for example as parallel electric conductive strips which are laid onto an insulator foil denoted CEF. Electronic circuits consisting of resistor RA, capacitor CA and amplificator A, are further provided as previously mentioned in the description.

As further shown at figure 10, a biasing circuit referred to as B_1, is provided and adapted so as to maintain the transparent electrode C and the first metal cladding 11 substantially to the same voltage potential value with respect to the reference potential value so as to allow extraction of any photo-electron which is generated by the photocathode layer PhC under impingement onto the latter of each one of the emitted photons. Biasing circuit B_1 is represented thus as a short-circuit conductor.

A further biasing circuit, referred to as B_2, is provided so as to develop a bias voltage potential referred to as VGEM which is applied between the metal claddings 11 and 12 so as to form at the level of each of the bored-through holes one of the electric field condensing areas 1_i as previously mentioned in the description. Applying such a voltage allows thus to generate a condensed electric field denoted as vector $\vec{E}'$ within each of the electric field condensing area.

Another biasing circuit, referred to as B_3, is further provided so as to develop a bias voltage potential which is actually applied between metal-cladding 12 and collecting electrode CE and more particularly elementary anodes referred to as ST_i at figure 10 so as to allow the detection of the electron avalanche as it will be explained thereafter.

At first, it is recalled that each elementary anode ST_i forming part of the collecting electrode CE is substantially set up as a reference potential thanks to resistor RA which is a resistor of very high value connecting each corresponding elementary anode to the reference potential.

The mode of operation of the radiation detector for photons as shown at figure 10 is now explained with reference to this figure.

Maintaining the transparent electrode C and the metal-cladding 11 which faces the transparent electrode substantially to the same voltage potential value thanks to biasing means B_1 comes to effect to put the electric field vector $\vec{E}$ as shown at figure 3a to a value that substantially equals 0.

As a consequence, each condensed electric field vector $\vec{E}'$ generated within each electric field condensing area, which is thus an electric field of very high amplitude value, operates thus within the region delimited between the transparent electrode C and the metal-cladding 11 and photocathode layer PhC as to convey each of the photo-electron to one given electric field condensing area which is the closest of the impingement region of this photon within the fill tube FT which is actually generated between metal-cladding 11 and collecting electrode CE, as shown at figure 10. Cancelling the electric field vector $\vec{E}$ with its amplitude being quite set up to zero value in the vicinity of transparent electrode C as shown at figure 10 comes thus to the effect of substituting a convey region to the drift region which is represented at figure 3a. As a consequence, the field tube FT is thus folded back to the metal-cladding 11 with any photo-electron being thus conveyed to within a corresponding electric field condensing area 1_i. The condensed electric field vector $\bar{E}'$ operates thus to generate from this photo-electron regarded as a primary electron one electron avalanche within corresponding bored-through hole with this electron avalanche being thus passed through this bored-through hole to the detection region, as shown at figure 10. The electron avalanche is thus submitted to detection thanks to electric field vector $\bar{E}''$ and elementary anodes ST_i of the collecting electrode CE.

For distances separating on the one hand the transparent electrode C from the photocathode layer PhC and on the other hand metal-cladding 12 from elementary anodes ST_i defining thus the convey region and the detection region, which have quite the same values as those previously mentioned with reference to figure 3a, corresponding voltage potential values may well be set up to similar values. As a consequence, potential value VGEM may well be set up to 500 volts while potential value applied between metal-cladding 12 and elementary anodes ST_i may be set up to 1000 volts, with this values being thus given as an example.

As further shown at figure 10, position detection of any avalanche which is passed through any electric field condensing area 1_i may preferably be performed as a bidimensional detection. In such a case, while the inner face of the collecting electrode CE is provided with a first set of elementary anodes ST_i, the outer face of same collecting electrode CE is thus provided with another set of elementary anodes referred to as ST_j consisting also of parallel electric conductive strips, with each of the sets of elementary anodes ST_i and ST_j extending along distinct transverse directions so as to allow bidimensional detection in corresponding directions.

In case a further electron gas multiplier is used so as to embody a multistage radiation detector for photons, the multiplied electrons by the high field in the hole in avalanche process drift to the second element of amplification for further amplification.

A fundamental property of the radiation detector for photons either as single stage or multistage version, which cannot be obtained with any other known gas detector, is that secondary photons produced during the electron avalanche process, both primary in the bored-through holes forming each electric field condensing area of the gas electron multiplier and secondary in the second stage element, cannot heat the photocathode layer PhC thereby preventing to induce secondary emission.

The high dipole field which is created within the bored-through holes allow thus to obtain a collection efficiency, i.e. electrical transparency close to unity with an optical transparency close to zero.

The large ratio of the total area to the holes area implies also that most of the surface of the metal-cladding 11 can thus be coated by photosensitive material with a geometrical quantum efficiency close to 1. The field configuration which is obtained with a large difference of potential between metal-cladding 12 and elementary anodes ST_i is such that only a small fraction of the positive ions which are produced at the final amplification stage can thus actually reach the photocathode layer PhC reducing thus the damage effects.

The radiation detector for photons in accordance with the object of the present invention permits thus to obtain simultaneously :

- large quantum efficiency of over extended areas,
- large gains without photons feed-back and very reduced ions feed-back.

The total combined gain of the two amplification elements in case of a multistage gas electron multiplier may thus be set up to a value sufficient enough for the detection and localization of single photo-electrons opening thus the way to numerous scientific, technical or industrial applications like CHERENKOV ring imaging, image intensifiers, fluorescence analysis in the visible and near ultraviolet range, or any applications requiring detection and localization of photons over extended areas.

The rigid and simple construction of gas electron multiplier detectors in accordance with the object of the present invention, either in preamplification or amplification mode, makes them interesting for applications in many fields where low and high rate detection and localization of radiation can be exploited for industrial or medical diagnosis.

At end, while present technologies which are used to manufacturing the gas electron multiplier embodying the radiation detectors of the invention do consist in drilling holes on metal clad by chemical etching, plasma etching or laser drilling, future developments may consist in coating with conductors an insulating mesh with narrow holes like for example micropore filters.

Medical diagnosis covers corresponding medical fields as large as:

- Radio and beta-chromatography, electrophoresis in which anatomical preparations or blot paper diffusions contain molecules labelled with electron emitting isotopes, the two-dimensional activity distribution measured on slide samples which provides information on the tissue in take off labelled molecules or on the molecular weight of substances diffusing on a support under the effect of electric field;
- Position-dependent fluorescent analysis in which the capability of simultaneous obtention of information on

the energy and the emission point of soft X-rays over extended areas can be exploited for material analysis in Archeology and Art certification;

- Protein crystallography which is realized in a spherical geometry for which gas electron multipliers detectors can map without parallax distorsions both position an intensity of the diffraction pattern of crystallized molecules. High rates are achievable at the dedicated synchrotron radiation facilities;
- Mammography in which a gas electron multiplier in accordance with the invention when coupled to a secondary electron emitted converter can effectively map the absorption profile of X-rays which are used for soft tissue radiography, with a sub-millimeter resolution;
- High flux beam diagnosis which is used for therapy in which high flux charged particle beams can be fully certified in spatial and energy loss profiles before or during exposure. In such an application, the dynamic control of the beam characteristics is thus possible.

One further possibility of the radiation detector of the invention also concerns the possibility for the gas electron multiplier to be tailored to applications or specific needs and particularly its shape with special cut outs as for approaching vacuum beam tubes in accelerators or the like.

Among the above-mentioned large medical fields, the gas electron multiplier of the invention appears of highest interest for embodying parallax-free X-ray imagers.

More particularly, in accordance with the present invention, there is provided a planispherical parallax-free X-ray imager in which a parallel X-ray beam is directed to a crystal so as to generate a conical X-ray beam for illuminating an entrance window of the X-ray imager. The X-ray imager at least comprises a vessel containing a ionizing gas through the entrance window.

The X-ray imager further comprises within the vessel, a spherical conversion volume chamber which is associated with the entrance window. The conversion volume chamber comprises a first and a second parallel electrodes adapted to generate in operation electrical equipotential surfaces of spherical shape and corresponding radial electric field lines within this spherical conversion volume chamber with these electrical equipotential surfaces of spherical shape being thus each centred at a focus common centre point substantially corresponding to the location of the crystal so as to allow any primary electron generated within the spherical conversion volume chamber to drift along the radial field lines. A third electrode substantially parallel with the second electrode is provided so as to form together a gas electron multiplier structure which comprises at least one matrix of electric field condensing areas distributed within a solid surface. Each of the electric field condensing areas is adapted to produce a local electric field amplitude enhancement proper to generate within the gas an electron avalanche from one of the primary electrons so as to allow the gas electron multiplier structure to operate as an amplifier of given gain for the primary electrons. A readout electrode is further provided with an array of elementary electrodes which is formed onto a wall of the vessel and is laid parallel to the third electrode.

The X-ray imager also comprises, outside the vessel, an electrical bias circuit which is connected to the first, second and third electrodes and thus adapted to deliver adequate voltage potentials so as to drift the primary electrons within the spherical conversion volume chamber and then multiply corresponding drifted primary electrons through an avalanche phenomenon within the gas electron multiplier structure. A detection circuit is further provided and connected to the readout electrode so as to allow a bi-dimensional readout of the position of any generated avalanche phenomenon thanks to the gas electron multiplier structure in the absence of a substantial parallax readout phenomenon.

A parallax-free X-ray imager embodying a specific gas electron multiplier in accordance with the present invention is now disclosed as a non limitative example. Particularly, it should be kept in mind that the planispherical parallax-free X-ray imager in accordance with the invention can be used with specific advantages in various types of applications such as imaging of the diffraction patterns of X-rays diffused from a crystal used for proteins structural analysis and genome characterization, low dose absorption radiography for medical diagnosis for mammography, industrial absorptive and back-scattering radiography with X-rays, and focused imaging of specific regions within a body with blurring of the photons emitted from surrounding materials.

More particularly, any kind of radiations which come to effect to release primary electrons in gas with these radiations emanating as a conical X-ray beam illuminating an entrance window can thus be detected thanks to the planispherical parallax-free X-ray imager of the invention.

The planispherical parallax-free X-ray imager in accordance with the invention is thus disclosed with reference to Figures 11a, 11b and 11c.
In the accompanying drawings, relative dimensions of corresponding elements are not represented for the sake of better comprehension of the whole.

Figure 11a shows a section view of the planispherical parallax-free X-ray imager of the invention, this section view being thus represented within a symmetry plane corresponding to the plane of Fig. 11a. The parallax-free X-ray imager of the invention is more preferably embodied as cylindrical in shape, this symmetry plane corresponding thus to a radial symmetry plane of this cylinder, as it will be disclosed in more detail later in the specification.

As shown at Fig. 11a, the planispherical parallax-free X-ray imager of the invention is used with a parallel X-ray beam which is directed to a crystal so as to generate a conical X-ray beam for illuminating an entrance window, referred to as IW, of the X-ray imager.

As further shown at Fig.1a, the X-ray imager of the invention comprises a vessel V containing a ionizing gas for generating primary electrons under impingement of the X-ray beam and particularly the conical X-ray beam, as further mentioned in the specification, within the ionizing gas through the entrance or input window IW.

As previously mentioned in the specification, the vessel V is cylindrical in shape with its entrance window IW being thus circular, plane and oriented towards the impinging conical X-ray beam.

The X-ray imager of the invention as shown at Fig. 11a further comprises within the vessel V a spherical conversion volume chamber, referred to as SPC, which is associated with the entrance window IW. This conversion volume chamber SPC comprises a first 1 and a second 2 parallel electrodes which are adapted to generate in operation electrical equipotential surfaces of spherical shape and corresponding radial electric field lines FL within this spherical conversion volume chamber SPC.

As a consequence, according to one feature of highest interest of the parallax-free X-ray imager of the invention, the conversion volume chamber SPC fully operates as a spherical conversion volume chamber, since its equipotential surfaces are spherical in shape while it has a full planar or rectangular structure only. It should thus be born in mind that while such a rectangular or planar structure is quite easy to implement a fine control of the spherical equipotential surfaces shapes can thus be performed through adequate voltage potentials applied to the electrodes embodying such rectangular or planar structure as will be explained later in the specification.

According to one essential feature of the parallax-free X-ray imager in accordance with the invention, the electrical equipotential surfaces are each centred at a focus common centred point, referred to as FP, which in operation substantially corresponds to the location of the crystal in order to allow any primary electrons generated within the spherical conversion volume chamber SPC to drift along the radial field lines.

In Fig. 11a, one radial field line only is represented with this field line being fully orthogonal to the spherical electrical equipotential surfaces which are represented in dotted lines within the conversion volume chamber SPC. The field line is referred to as FL at Fig.11a.

Further to the first 1 and second 2 electrodes, the vessel embodying the parallax-free X-ray imager in accordance with the invention further comprises a third electrode 3 which is substantially parallel with the second electrode 2 with these second 2 and third 3 electrodes forming thus a gas electron multiplier structure, referred to as GEM, which is adapted to thus operate as an amplifier of given gain for the primary electrons.

In a general sense, the gas electron multiplier structure GEM comprises one matrix of electric field condensing areas, referred to as C_i. These electrical field condensing areas C_i are thus distributed within a solid surface with this solid surface being delimited by the above mentioned second 2 and third 3 electrodes contained within the vessel V.

The structure is shown at Fig. 11b and its mode of operation substantially correspond to that of Fig. 3a. In Fig. 11b however a drift electrode DE is referred to as first electrode 1, first and second metal-cladding as second and third electrodes 2 and 3 respectively and collecting electrode CE as readout electrode 4.

As shown in more detail at Fig.11b, the above mentioned solid surface may be thus embodied through a printed circuit board and preferably may consist of a thin insulator foil which is metal clad on each of its faces, the metal cladding being thus referred to as 2 and 3 so as to embody the second 2 and third 3 electrodes contained within the vessel. The sandwich structure thus formed is further traversed by a regularly matrix of tiny holes, referred to as C_i at Fig. 11b. Typical values are 25 to 500 μm of thickness for the foil with the centre of the tiny holes being thus separated at a distance comprised between 50 and 300 μm. The tiny holes may well have a diameter which is comprised between 20 and 100 μm. The matrix of tiny holes is generally formed in all or most of the area of an insulator foil of regular shape. The insulator foil is thus provided with electrodes on each of its faces, these electrodes being thus adapted so as to form the second 2 and third 3 electrodes and to apply a potential difference between the metal sides of the mesh embodying thus the matrix of tiny holes.

The composite mesh can thus be manufactured with conventional technologies as mentioned earlier in the present specification, and appear simple to install rigid and resistant to accidental discharges.

The mesh embodying the matrix of tiny holes can be thus released by conventional printed circuit technology.

The structure of the matrix of tiny holes, dimension and shapes of the holes, type of gas or gas mixture and corresponding mode of operation of the GEM structure are disclosed earlier in the present specification.

The second 2 and third 3 electrodes are thus adapted to be set at a convenient voltage potential, i.e. a continuous voltage potential difference value so as to form at the level of each of the tiny holes forming the matrix of tiny holes within this solid surface to form a corresponding electric field condensing area C_i. It should be thus understood that each tiny hole or through hole traversing the sandwich structure behaves thus as a dipole which in fact superimposes a further electric field vector $\bar{E}'$ with this further electric field being substantially directed along a symmetry axis of each tiny hole, as disclosed earlier in the present specification.

As a consequence, each of the electric field condensing area is thus adapted to produce a local electric field amplitude enhancement, referred to $\bar{E}'$, which is proper to generate within the gas an electron avalanche from the primary electrons generated within the spherical conversion volume, referred to as SPC, under impingement of one ray of the conical X-ray beam.

For the sake of clarity and better comprehension, Fig.11b is shown in the absence of electric charges within the drift region, i.e. the spherical conversion volume SPC, and the transfer and induction volume, referred to as TIVC, which corresponds to a detection region, this case fully corresponding as an example to the absence of ionizing radiations. With reference to Fig.11b, any virtual solid surface, thereafter designated as FT, which is delimited by the outermost electric field lines reaching one local electric field condensing area as shown at Fig.11a for example, delineates thus an electric field tube FT in which the electric field flux presents a preservative character. As a consequence, it is clear to any person of ordinary skill in the corresponding art that the enhancement of the electric field at the level of each local electric field condensing area C_i is thus given accordingly with any surface being passed through by the condensing electric field vector $\vec{E}'$ being in direct relation to the enhancement for the resulting electric field which is thus equal to the sum of original electric field vector $\vec{E}$ and superimposed electric field vector $\vec{E}'$.

It is further emphasized that the sandwich structure embodying the matrix of electric field condensing areas C_i is of symmetrical character with respect to a symmetry plane, referred to as plane Q at Fig.1b. As a consequence, any virtual solid surface formed by the outermost electric field lines reaching a corresponding local electric field condensing area C_i is substantially transferred as a symmetrical virtual solid surface formed by the electric field line leaving the same local electric field condensing area C_i in the detection region, as shown at Fig.1a with respect to the same electric field tube FT.

As further shown at Fig.11a, the parallax-free X-ray imager in accordance with the present invention is further provided within the vessel V with a signal readout electrode 4 preferably formed onto a wall of the vessel V and which is parallel to the third electrode 3. The signal readout electrode 4 may for example consist of elementary electrodes, referred to as 4_{jk}, each elementary electrode consisting for example of parallel conductive strips or pads in case bidimensional readout is performed.

In a general sense, the readout electrode 4 and corresponding elementary electrodes 4_{jk} form a transfer and induction volume, referred to as TIVC, with the third electrode 3. This transfer and induction volume chamber TIVC fully corresponds to a detection region as previously mentioned with reference to Fig.11b. For this reason, the electrical equipotential surfaces of the transfer and induction volume chamber TIVC are represented parallel to the signal readout electrode 4 as shown at Fig.11a. As it will be disclosed in more details in the specification, electrical equipotential surfaces of the TIVC chamber may even be slightly bent through appropriate electrodes in order to have a full transfer of the avalanche phenomenons which are generated within each electric field condensing areas C_i in the absence of any substantial parallax error.

As further shown at Fig.11a, the planispherical parallax-free X-ray imager in accordance with the present invention is further provided, outside the vessel V, with electrical bias means 5 which are connected to the first 1, the second 2 and the third 3 electrodes and which are adapted to deliver adequate voltage potentials so as to drift the primary electrons within the spherical conversion volume chamber SPC, multiply corresponding drifted primary electrons through the above mentioned avalanche phenomenon within the gas electron multiplier structure GEM and then transfer this avalanche phenomenon within the TIVC chamber up to the signal readout electrode 4 in proper conditions. For the sake of comprehension, the electrical bias circuit 5 is represented in a conventional manner at Fig.1a as a D.C. or voltage source feeding an adequate resistor adapted to deliver necessary potentials to the first 1, the second 2 and the third 3 electrodes as known in a conventional manner. It should be born in mind that the signal readout electrode 4, or in other words the elementary electrodes 4_{jk} embodying the latter, are put at the reference potential with the difference voltage potential applied to the third, the second and the first electrodes being thus decreasing negative potentials.

Further to the electrical bias circuit 5, detection circuits 6 are provided outside the vessel V and connected to the readout electrode 4. The detection circuits 6 may consist of elementary amplifiers 6_{jk}, each connected to one of the elementary electrode embodying the signal readout electrode 4 in a well-known manner. In case the elementary electrodes associated with their own elementary operational amplifier are provided, the position of any generated avalanche phenomenon can be thus readout in a bidimensional readout thanks to the index j and k which are allotted to each elementary electrode and associated operational amplifier.

As further shown at Fig.11a, the first 1, second 2 and third 3 electrodes are each provided with electrical conductive field rings or surfaces which are engraved onto these electrodes. The electrical conductive field rings of first electrode 1 are referred to as 1_0 to 1_N, those of electrode 2 are referred to as 2_0 to 2_N and those of electrode 3 are referred to as 3_0 to 3_N. These electrical conductive field rings have a common centre, referred to as 1_0, 2_0 and 3_0 respectively and are each distributed over the external surface of their corresponding electrodes.

A general perspective view of the parallax-free X-ray imager of the invention is shown at Fig.1c for a vessel V which is cylindrical in shape. In such a case, the entrance window IW, the first 1, second 2 and third 3 and readout 4 electrodes are shaped as a disk with each of this disks being thus joined together thanks to a lateral curve surface so as to form the cylindrical vessel V. As shown in more detail in connection with Fig.1c, the common centre 1_0, 2_0 and 3_0 of first 1, second 2 and third 3 electrodes may thus consist of a single disk of conductive material while the rings of upper rank have their own common centre and are each distributed over the external surface of the corresponding electrode.

As shown in more details in connection with Fig.11a, 11c and 11d, the second 2 and third 3 electrodes are each provided with concentric electrical field rings which are spaced apart from one another on one face of its corresponding electrode by a circular grove, one grove and one electrical field ring of same rank of the second electrode 2 facing one corresponding grove and electric conductive field ring of same rank of the third electrode 3 so as to allow, on the one hand, the electrical conductive field rings of the second electrode 2, when these are set at an adequate electrical potential, to define corresponding limit electrical potential values for the electrical equipotential surfaces in a direction which is parallel to the surface of the second electrode 2 and, on the other hand, to allow the second 2 and the third 3 electrodes to perform the gas electrode multiplier function in the absence of any substantial distortion.

More particularly, it will thus be understood that the same ring pattern is realized on both sides of the gas electron multiplier structure by second etching the foils after implementation of the matrix of tiny holes for example, as described earlier in the present specification. A fine segmentation is thus performed allowing thus the local difference of potential within second electrode 2 and third electrode 3 embodying the gas electron multiplier structure to remain roughly constant and thus ensure a good gain uniformity.

As a matter of fact, the lateral curved surfaces joining the first and second electrodes or even the third and the signal readout electrode 4 are further provided with edge-shaping electrodes, referred to as ES_1 to ES_N. The first 1, second 2 and corresponding lateral curved surface and edge-shaping electrodes ES_1 to ES_N form thus the spherical conversion volume chamber SPC, with the edge-shaping electrodes ES_1 to ES_N being set at an adequate electrical potential so as to generate adapted limit electrical potential values for the electrical equipotential surfaces of spherical shape, as shown at Fig.11a. The same corresponding feature can be provided at the level of the TIVC chamber so as to give to the electrical potential surfaces or the TIVC chamber a slight bend, as it will be disclosed in more detail later in the specification.

As shown in more details at Fig.11d, the signal readout electrode 4 is set in operation at a reference potential while the central electrical conductive ring of the third, second and first electrodes, referred to as 3_0, 2_0, 1_0 respectively, are set at relative decreasing bias electrical potential with respect to the reference potential. Accordingly, each of the electrical conductive ring belonging to one of the third 3, second 2 and first 1 electrodes are further set to successive increasing bias electrical potential with respect to the corresponding bias electrical potential of its corresponding central electrical conductive ring 3_0, 2_0, 1_0 respectively, thanks to the electrical bias circuit 5.

As a consequence, the potential gradient between two electrical conductive rings facing each other onto these second 2 and three electrode 3 have substantially the same value between conjugate rings 2_0, 3_0 to 2_N, 3_N, these gradients of same value generating thus a substantially same amplifying electric field $\tilde{E}'$ within the whole gas electron multiplier structure GEM.

As further shown at Fig.11a, the electrical bias circuits 5 may be provided with adjustable bias voltage potential device, feeding resistors referred to as R_{12}, R_{23} and R_{34}, this device being adapted to deliver a bias voltage potential of adjusted value within a given voltage range value which is applied to the first and second electrodes 1, 2, so as to vary the focus location along the symmetry axis shown at Fig.11a. Operating the adjustable bias voltage potential device, or even adjusting one or several of the resistors values, allows thus to dynamically vary the focal length in a given range by adjusting externally the voltage potentials which are applied to the main nodes and then to the conductive rings.

A full representation of the electrical equipotential surfaces of spherical shape within the spherical conversion volume chamber SPC and corresponding electrical equipotential surfaces within the TIVC chamber, or in other words within the drift region and the detection region respectively, is shown at Fig.12a for given electrical potential values applied to the successive rings forming the first 1, second 2 and third 3 electrodes and corresponding edge-shaping electrodes ES_1 to ES_M of the above mentioned chambers.

At Fig.12a, half part of these chambers are shown, i.e. the left part as referred to at Fig.11a with respect to the symmetry axis Y'Y.

Potential values are indicated in kV as an example only.

In order to have the electrical equipotential surfaces of the TIVC chamber slightly bent as shown at Fig.12a, given steps of voltage potentials to 100 volts may be spread along the edge-shaping electrodes referred to as ES_1 to ES_P as shown at Fig. 12a.

The most external conductive ring, referred to as 3_N, of electrode 3, is thus preferably set at a voltage potential decreased of one voltage's step with respect to the last shaping-electrode ES_P while successive inner rings are set at voltage potentials which are decreased by the same voltage's step, i.e. 100 volts, with the central ring 3_0 being set at -1.3 kV.

Corresponding conjugate conductive rings are set with reference to Fig.11d at corresponding potentials so as to generate the same voltage gradient between conjugate rings 2_0, 3_0 to 2_N, 3_N. The most external conductive ring 2_N is thus put at a voltage potential to -1.0 kV as shown at Fig.2a. Successive edge-shaping electrodes, referred to as ES_{P+1} to ES_M which are distributed over the lateral surface of the spherical conversion volume SPC, as shown at Fig.12a, are set at successive step potentials of 100 volts with the last edge-shaping electrode referred to as ES_M being thus put to -2.6 kV.

Successive conductive rings of the first electrode 1 from the outermost conductive ring 1_N are thus set at stepped potentials decreasing from corresponding step value with respect to last potential value applied to the last edge-shaping electrode ES_M, central conductive disk 1_0 being thus put to the most negative voltage potential to -3.7 kV.

As shown at Fig.12a, it is thus emphasized that applying successive decreasing step voltages to the edge-shaping electrodes ES_1 to ES_P, then to conjugate conductive rings 3_N, 2_N to 3_0, 2_0 and then to edge-shaping electrode ES_{P+1} to ES_M and successive conductive rings of the first electrode 1_N to 1_0 allows thus to generate voltage equipotential surfaces of spherical shape within the drift region of the spherical conversion volume chamber SPC and then to transform these electrical equipotential surfaces to slightly bent equipotential surfaces which are then modified to planar electrical equipotential surfaces in the vicinity of the readout electrode 4 without introducing any substantial distortion of the image read on this readout electrode.

A representation of the electrical equipotential surface, referred to as EPS, and the field lines, referred to as FL, in the vicinity of the electrical field condensing area C_i of two conjugate conductive rings, for example conductive ring 3_2 of electrode 3 and conductive ring 2_2 of electrode 2, is now disclosed with reference to Fig. 12b.

As a matter of fact, Fig. 12b fully corresponds to

Fig.11b in which the electrical equipotential surfaces are bent in the drift region, as shown for example at Fig.12a, while corresponding electrical equipotential surfaces of the detection region are also slightly bent to correspond to those of the TIVC chamber in the detection region.

As shown at Fig.12b, the electrical equipotential surfaces EPS are slightly bent and distorted in the vicinity of each electrical field condensing area C_i only. As a consequence, any corresponding field lines FL is thus submitted to a local distortion only while each of them is maintained in orthogonal relationship to the distorted electrical equipotential surface EPS. Consequently, any field tube FT is preserved, in the same manner as in Fig.11b, as shown at Fig.12b, in the absence of any substantial distortion of the image introduced by the transfer of the electrons from the drift region to the detection region after amplification through avalanche phenomenon.

Adequate electric potential bias voltages feeding the successive conductive rings 2_0 to 2_N and 3_0 to 3_N may thus take place either by direct feeding of the appropriate voltage potentials to each conductive ring from an external resistive partition network, using insulating conductors, or thanks to surface mount resistors of appropriate values directly soldered and thus connected between adjacent rings, while feeding adequate voltage potentials to the central rings 2_0 and 3_0 through single insulated conductors.

A sectional view of the GEM structure is shown at Fig. 12c in a preferred embodiment in which a special sandwich structure has been developed to allow a proper electrical voltage potential feeding of the conductive rings in the absence of a substantial degradation of the image through masking introduced by the feeding connecting lines.

As shown at Fig. 12c, the sandwich structure consists of the second electrode 2 and its rings 2_0 to 2_N, a resistive layer 10_a covering the insulator foil 10 and a further resistive layer 10_b and the third electrode 3 and its rings 3_0 to 3_N. The whole structure is traversed by tiny holes embodying the electric field condensing areas, which are not shown at Fig. 12c. Connecting each resistive layer 10_a, 10_b through adequate resistors R_{10a1}, R_{10a2} and R_{10b1}, R_{10b2} to adapted voltage potential values $-VU_1$, $-VU_2$ and $-VD_1$, $-VD_2$ respectively allow thus to put corresponding conductive rings to adaptive voltage potential values, as shown in Fig. 12a, while smoothing the electric field transition from one ring to the adjacent one, the voltage gradient between two conjugate rings being preserved and, as a consequence, the GEM structure amplification factor or gain over the whole surface of the latter.

CLAIMS

1. A radiation detector in which primary electrons are released into a gas by ionizing radiations and drifted to a collecting electrode by means of an electric field, said radiation detector including a gas electron multiplier comprising at least one matrix of electric field condensing areas, said electric field condensing areas being distributed within a solid surface which is substantially perpendicular to said electric field, each of said condensing areas being adapted to produce a local electric field amplitude enhancement proper to generate in said gas an electron avalanche from one of said primary electrons, said gas electron multiplier operating thus as an amplifier of given gain for said primary electrons.

2. The radiation detector of claim 1, wherein said local electric field amplitude enhancement generated by each of said condensing local areas is substantially symmetrical in relation to an axis of symmetry of said condensing local area, said local electric field amplitude enhancement being thus at a maximum at the center of symmetry of said condensing local area.

3. The radiation detector of claim 1, wherein said electric field condensing areas are substantially identical in shape and regularly distributed within said solid surface so as to form said matrix.

4. The radiation detector of claim 1, wherein said matrix of electric field condensing areas comprises:

- a foil metal-clad insulator on each of its faces so as to form a first and second metal-cladding sandwiching said insulator, to form a regular sandwich structure ;

- a plurality of bored-through holes traversing said regular sandwich structure ;

- biasing means adapted to develop a bias voltage potential which is applied to said first and second metal cladding so as to generate at the level of each of said bored-through hole one of said electric field condensing areas.

5. The radiation detector of claim 4, wherein said regular sandwich structure being put in operation substantially perpendicular to said electric field, said first metal cladding forms an input face for said drift electrons and said second metal cladding forms an output face for any electron avalanche generated at the level of each bored-through hole forming one of said electric field condensing areas.

6. The radiation detector of claim 5, wherein said bored-through holes are substantially identical and quite circular in shape when regarded along a direction substantially perpendicular to said regular sandwich structure.

7. The radiation detector of claim 5, wherein each of said bored-through holes is formed by a first and a second frusto-conical bored hole, said first frusto-conical bored hole substantially extending from said first metal-cladding to an intermediate surface of said regular sandwich structure and said second frusto-conical bored hole substantially extending from said second metal-cladding to said intermediate surface of said regular sandwich structure, said first and second frusto-conical bored holes each comprising a first circular opening of a diameter of a first given value at the level of said input and output face respectively and a second circular opening of a diameter of a second given value, smaller than the first ones, said second circular opening of said first and second frusto-conical bored holes joining together at the level of said intermediate surface of said regular sandwich structure so as to form said bored-through hole.

8. The radiation detector of claim 4, wherein said bored-through holes are identical in shape and regularly distributed over all of the metal clad faces of said insulator foil.

9. The radiation detector of claim 4, wherein said bored-through holes are identical in shape and regularly distributed over a part of the metal clad faces of said insulator foil so as to form at least one blind detection zone for said radiation detector.

10. The radiation detector of claim 1, wherein said solid surface is a planar surface.

11. The radiation detector of claim 1, wherein said solid surface is spherical in shape.

12. The radiation detector of claim 1, wherein said solid surface is cylindrical in shape.

13. The radiation detector of claim 1, wherein said solid surface consists of adjacent elementary solid surfaces, each of said elementary solid surfaces forming thus one elementary gas electron multiplier comprising at least one matrix of electric field condensing area.

14. The radiation detector of claim 1, in which said collecting electrode is adapted to operate at unity gain, in ionization mode, said collecting electrode at least consisting in a plurality of elementary anodes allowing an electronic detection of each electron avalanche.

15. The radiation detector of claim 1, comprising a plurality of successive matrices of electric field condensing areas, said successive matrices being put parallel to one another to define homothetic matrices over a comon center forming said gas electron multiplier and two successive matrices of said successive matrices being spaced apart from each other at a given separating distance value in a direction parallel to said electric field forming a first electric field so as to define therebetween successive electric fields and to allow any electron of one electron avalanche to drift as a primary electron along said separating distance by means of its corresponding electric field, said gas electron multiplier operating thus

as an amplifier the gain of which is the product of the gain yield from each successive matrix.

16. In a radiation detector in which primary electrons are released into a gas by ionizing radiations and drifted to a collecting electrode by means of a substantially parallel electric field, a gas electron multiplier comprising at least one matrix of electric field condensing areas, said electric field condensing areas being distributed within a solid surface which is substantially perpendicular to said parallel electric field, each of said condensing areas being adapted to produce a local electric field amplitude enhancement proper to generate in said gas an electron avalanche from one of said primary electrons, said gas electron multiplier operating thus as a preamplifier of given gain for said primary electrons upstream said collecting electrode of said radiation detector.

17. The gas electron multiplier of claim 16, wherein said local electric field amplitude enhancement generated by each of said condensing local areas is substantially symmetrical in relation to an axis of symmetry of said condensing local area which is perpendicular to said plane, said local electric field amplitude enhancement being thus at a maximum at the center of symmetry of said condensing local area.

18. The gas electron multiplier of claim 16, wherein said matrix of electric field condensing areas comprises:

- a foil metal-clad insulator on each of its faces so as to form a first and second metal-cladding sandwiching said insulator, to form a planar sandwich structure ;

- a plurality of bored-through holes traversing said planar sandwich structure ;

- biasing means adapted to develop a biased voltage potential which is applied to said first and second metal cladding so as to generate at the level of each of said bored-through hole one of said electric field condensing areas.

19. The gas electron multiplier of claim 16, comprising a plurality of successive matrices of electric field condensing areas, said successive matrices being put parallel to one another and two successive matrices of said successive matrices being spaced apart from each other at a given separating distance value in a direction parallel to said parallel electric field forming a first parallel electric field so as to define therebetween successive electric fields and to allow any electron of one electron avalanche to drift as a primary electron along said separating distance by means of its corresponding parallel electric field, said gas electron multiplier operating thus as a preamplifier the gain of which is the product of the gain yield from each successive matrix upstream said collecting electrode of said radiation detector.

20. A radiation detector in which primary electrons are released into a gas by ionizing radiations and drifted to a collecting electrode by means of an electric field, said radiation detector including a gas electron multiplier comprising at least one matrix of electric field condensing areas, said electric field condensing areas being distributed within a solid surface which is substantially perpendicular to said electric field, wherein said matrix of electric field condensing areas comprises:

- a foil metal-clad insulator on each of its faces so as to form a first and second metal cladding sandwiching said insulator, to form a regular sandwich structure ;
- a plurality of bored-through holes traversing said regular sandwich structure, each of said bored-through hole having an opening aperture diameter comprised between 20 μm and 100 μm.

21. The radiation detector of claim 20, wherein

said insulator foil is made of polymer material of thickness comprised between 25 μm and 500 μm, said bored-through holes being spaced apart from one another at a distance comprised between 50 μm and 300 μm.

22. The radiation detector of claim 20, wherein each bored-through hole of said plurality of bored-through holes is provided with an internal lateral surface delimited by said insulator, said lateral surface comprising at least one local zone in which permanent electric charges are implanted, said permanent electric charges being distributed within said insulator and local zone thereof so as to further enhance and stabilize said electric field at the level of each corresponding electric field condensing area.

23. The radiation detector of claim 20, wherein each bored-through hole of said plurality of bored-through holes is provided with an internal lateral surface delimited by said insulator, said lateral surface comprising at least one local zone of electric conductivity comprised between 10^{15} and 10^{16} Ω/square.

24. The radiation detector of claim 20, wherein each of said bored-through holes of said plurality of bored-through holes has a cross section along a longitudinal plane of symmetry of said bored-through hole which is conical in shape, each of said bored-through holes comprising a first and a second circular opening of given value different from each other forming thus a first and a second opening aperture diameter of different value, said radiation detector further comprising controllable direct and reverse biasing means adapted to develop a direct and a reverse biasing voltage respectively which are applied to said first and second metal cladding so as to generate at the level of each of said bored-through holes one of said electric field condensing areas which is thus functionnally reversed.

25. A radiation detector for photons emitted by an external source, said radiation detector comprising at least, in a vessel containing a gas adapted to generate an electron avalanche from a primary electron through an electric field:

- an inlet window and a transparent electrode laid onto the inner face of said inlet window, said inlet window and transparent electrode being adapted to transmit said photons within said gas;

- a photocathode layer facing said transparent electrode, said photocathode layer being adapted to generate one photo-electron as a primary electron under impingement of each one of said photons thereof;

- a gas electron multiplier comprising at least one matrix of electric field condensing areas, said matrix of electric field condensing areas comprising:
    - a foil metal-clad insulator on each of its faces so as to form a first and second metal cladding onto said foil insulator, said photocathode layer being laid onto said first metal cladding so as to face said transparent electrode, said photocathode layer, first and second metal cladding forming thus a regular sandwich structure with said insulator foil,
    - a plurality of bored-through holes traversing said regular sandwich structure, each of said bored-through holes allowing thus free flowing therethrough for the gas and any electrically charged particle generated therein;

- first biasing means adapted to maintain said transparent electrode and first metal cladding substantially to the same voltage potential value, so as to allow extraction of any photo-electron generated by said photocathode layer under impingement thereof of each one of said photons;

- second biasing means adapted to develop a bias voltage potential which is applied between said first and said second metal cladding, so as to form at the level of each of said bored-through holes one of said electric field condensing areas, in which a condensed electric field is generated, said condensed electric field operating thus so as to convey each of said photo-electrons to one given electric field condensing area and then to generate from said photo-electron regarded as a primary electron one electron avalanche which is passed through said bored-through hole forming said given electric field condensing area;

- a collecting electrode consisting at least of a plurality of elementary anodes, said collecting electrode facing said second metal cladding and being spaced apart thereof, so as to define a detection region within said vessel;

- third biasing means adapted to develop a bias voltage potential which is applied to said collecting electrode so as to allow the detection of said electron avalanche.

26. The radiation detector of claim 1, wherein said collecting electrode comprises on an insulator foil:

- a first set of elementary anodes laid onto a first face of said insulator foil, said first face of said insulator foil and first set of elementary anodes facing said gas electron multiplier, said first set of elementary anodes consisting at least of a plurality of parallel electric conductive strips extending along a first given direction;

- a second set of elementary anodes laid onto a second face of said insulator foil, said first and second sets of elementary anodes being thus separated by said insulator foil, said second set of elementary anodes consisting at least of a plurality of parallel electric conductive strips extending along a given direction, transverse to the first one,

said first and second sets of elementary anodes allowing thus a detection of said electron avalanche along said second and first directions respectively so as to form a bidirectional radiation detector;

27. The radiation detector of claim 25, wherein said collecting electrode comprises on an insulator foil:

- a first set of elementary anodes laid onto a first face of said insulator foil, said first face of said insulator foil and first set of elementary anodes facing said gas electron multiplier, said first set of elementary anodes consisting at least of a plurality of parallel electric conductive strips extending along a first given direction;
- a second set of elementary anodes laid onto a second face of said insulator foil, said first and second sets of elementary anodes being thus separated by said insulator foil, said second set of elementary anodes consisting at least of a plurality of parallel electric conductive strips extending along a given direction, transverse to the first one,

said first and second sets of elementary anodes allowing thus a detection of said electron avalanche along said second and first directions respectively so as to form a bidirectional radiation detector ;

28. A parallax-free X-ray imager in which a parallel X-ray beam is directed to a crystal so as to generate a conical X-ray beam for illuminating an entrance window of said X-ray imager, said X-ray imager at least comprising a vessel containing a ionizing gas for generating primary electrons under impingement of said conical X-ray beam within said ionizing gas through said entrance window, said X-ray imager further comprising, within said vessel :

- a spherical conversion volume chamber associated with said entrance window, said conversion volume chamber comprising a first and a second parallel electrodes adapted to generate in operation electrical equipotential surfaces of spherical shape and corresponding radial electric field lines within said spherical conversion volume chamber, said electrical equipotential surfaces of spherical shape being thus each centred at a focus common centre point substantially corresponding to the location of said crystal so as to allow any primary electron generated within said spherical conversion volume chamber to substantially drift along said radial field lines;

- a third electrode substantially parallel with said second electrode, said second and third electrode forming thus a gas electron multiplier as claimed in one of the claims 16 to 19;

- a signal readout electrode provided with an array of elementary electrodes, said signal readout electrode being formed onto a wall of said vessel and parallel to said third electrode; and

outside said vessel :

- electrical bias means connected to said first, second and third electrodes and adapted to deliver adequate voltage potentials so as to drift said primary electrons within said spherical conversion volume chamber and multiply corresponding drifted primary electrons through said avalanche phenomenon within said gas electron multiplier structure;

- detection means connected to said readout electrode and adapted to allow a bi-dimensional readout of the position of any generated avalanche phenomenon thanks to said gas electron multiplier structure in the absence of a substantial parallax readout phenomenon.

29. The parallax-free X-ray imager of claim 28, wherein said first, second and third electrodes are each

provided with electrical conductive field rings engraved onto said electrodes, said electrical conductive field rings having a common centre and being each distributed over the external surface of said electrodes.

30. The parallax-free X-ray imager of claim 28 or 29, wherein said second and third electrodes are each provided with concentric electrical conductive field rings spaced apart from one another on one face of said electrodes by a circular grove, one grove and one electrical conductive field ring of said second electrode facing one corresponding grove and electrical conductive field ring of said third electrode so as to allow, on the one hand, said electrical conductive field rings of said second electrode when set at an adequate electrical potential to define corresponding limit electrical potential values for said electrical equipotential surfaces in a direction parallel to the surface of said second electrode and, on the other hand, said second and third electrodes to perform said gas electron multiplier function in the absence of any substantial distortion.

31. The parallax-free X-ray imager of anyone of preceding claims 28 to 30, wherein said vessel is cylindrical in shape, said entrance window, first, second, third and readout electrodes being shaped as a disk, each of said disks being thus joined together thanks to a lateral curved surface so as to form said cylindrical vessel.

32. The parallax-free X-ray imager of claim 31, wherein said lateral curved surface joining said first and second electrodes is further provided with edge shaping electrodes, said first and second electrodes, corresponding lateral curved surface and edge shaping electrodes forming thus said spherical conversion volume chamber, said edge shaping electrodes being set at an adequate electrical potential so as to generate adapted

limit electrical potential values for said electrical equipotential surfaces of spherical shape.

33. The parallax-free X-ray imager of one of the claims 28 to 32, wherein said electrical conductive rings of said first, second and third electrodes being spread from a central electrical conductive ring over the surface of said corresponding electrode and said readout electrode being set in operation at a reference potential, said central electrical conductive ring of said third, second and first electrodes are set at relative decreasing bias electrical potentials with respect to said reference potential, each of said electrical conductive ring belonging to one of said third, second and first electrodes being further set to successive increasing bias electrical potential with respect to the corresponding bias electrical potential of its corresponding central electrical conductive ring, thanks to said electrical bias means.

34. The parallax-free X-ray imager of claim 33, wherein the potential gradient between two electrical conductive rings facing each other onto said second and third electrodes has substantially the same value so as to generate a substantially same amplifying electric field within the whole gas electron multiplier structure.

35. The parallax-free X-ray imager of one of the preceding claims 28 to 34, wherein said electrical bias means comprise adjustable bias voltage potential means adapted to deliver a bias voltage potential of adjusted value within a given voltage range value, said bias voltage potential value being applied to said first and second electrodes so as to vary the focus location along an axis orthogonal to said entrance window.

36. The parallax-free X-ray imager of one of the preceding claims 28 to 35, wherein said gas electron multiplier structure is made of a sandwich structure, said

sandwich structure comprising:

- a first conductive layer and its conductive rings forming said second electrode;
- a first resistive layer;
- an insulating foil;
- a second resistive layer;
- a second conductive layer and its rings forming said third electrode,

said first and second resistive layers allowing thus to put said rings at stepped bias potential voltages adapted to maintain a substantially constant voltage gradient over the whole surface of the gas electron multiplier structure.

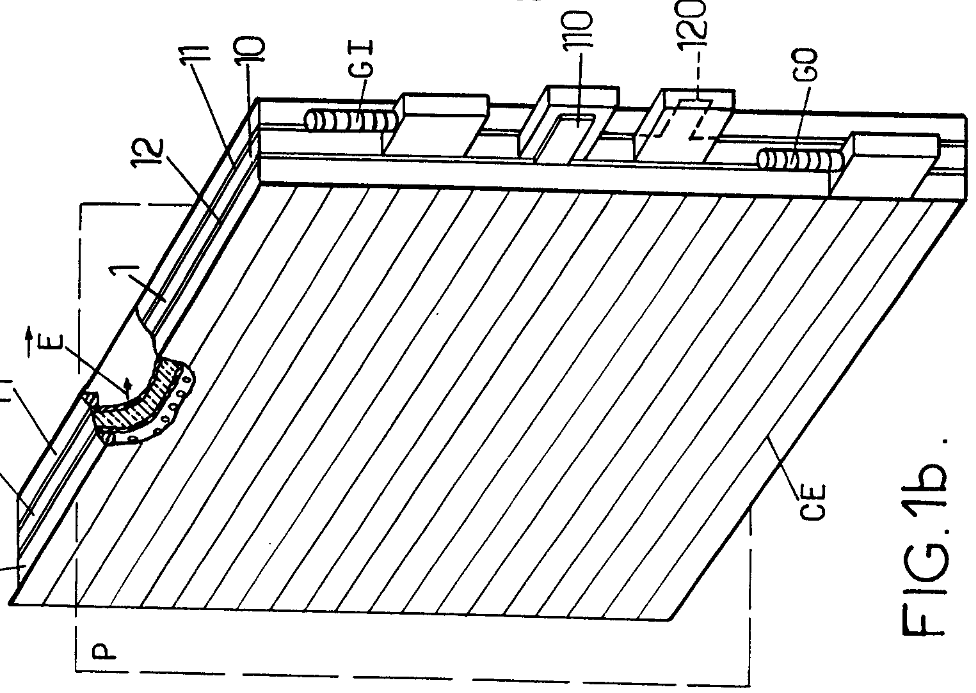

10
11
12
GI
110
120
GO
1
E
F1
V
F2
P
CE

FIG. 1b.

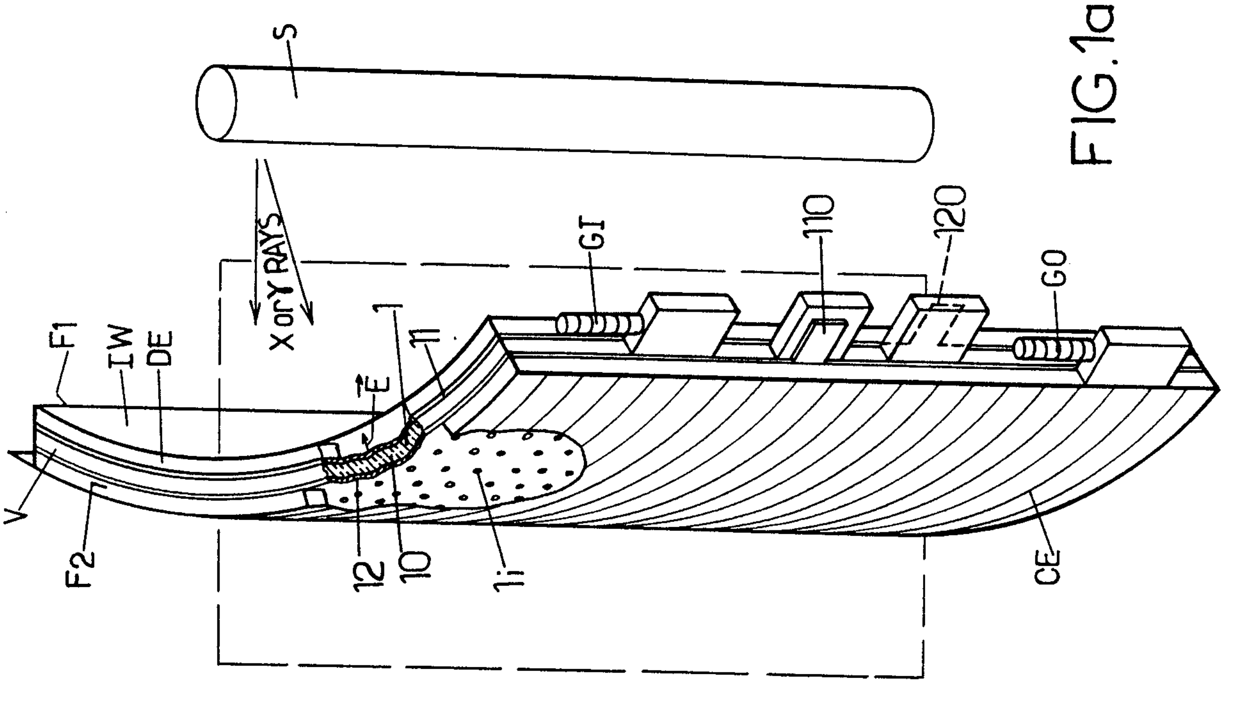

S
X or Y RAYS
F1
IW
DE
V
F2
E
1
11
12
10
1i
GI
110
120
GO
CE

FIG.1a

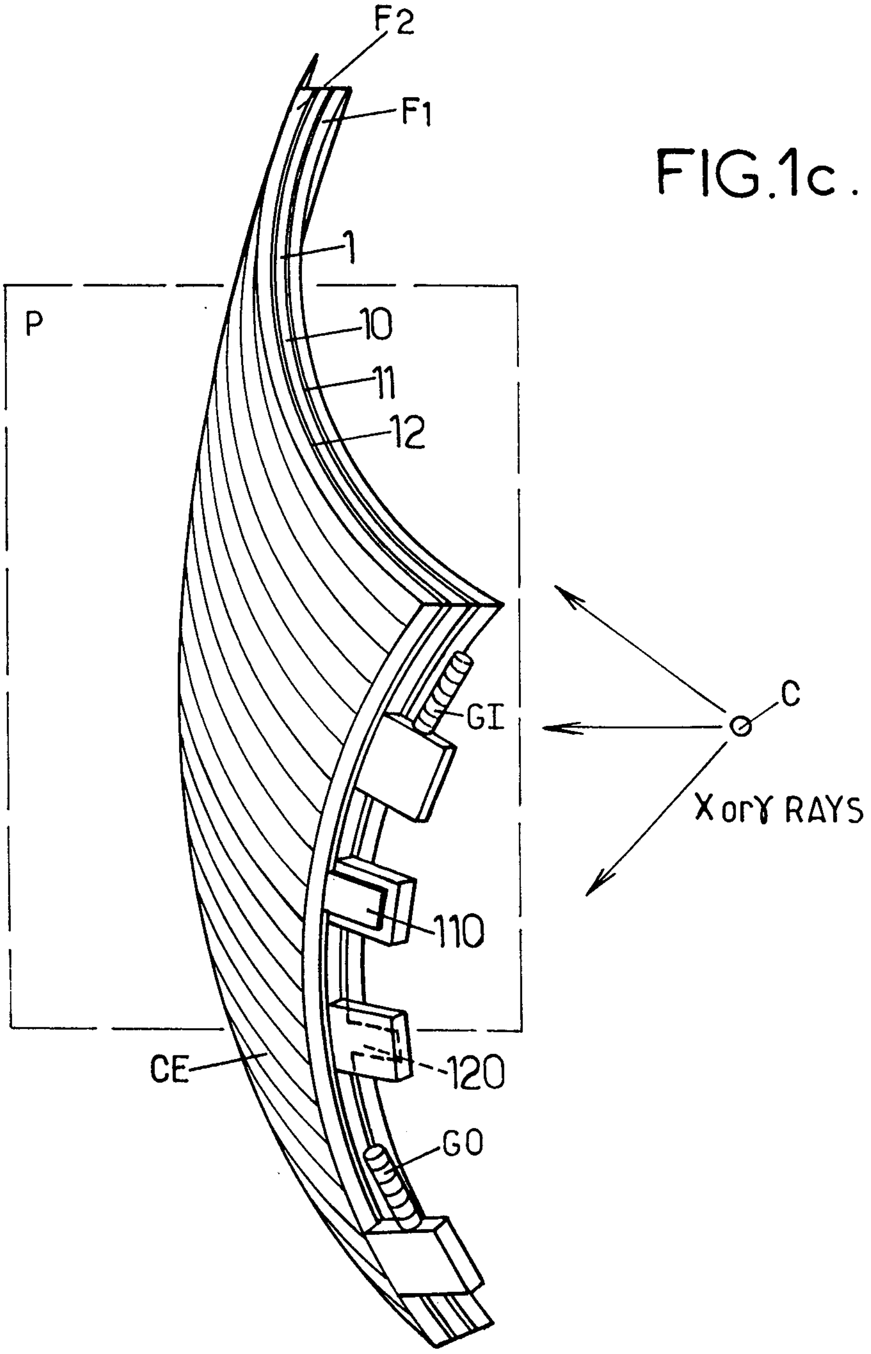


FIG.1c.

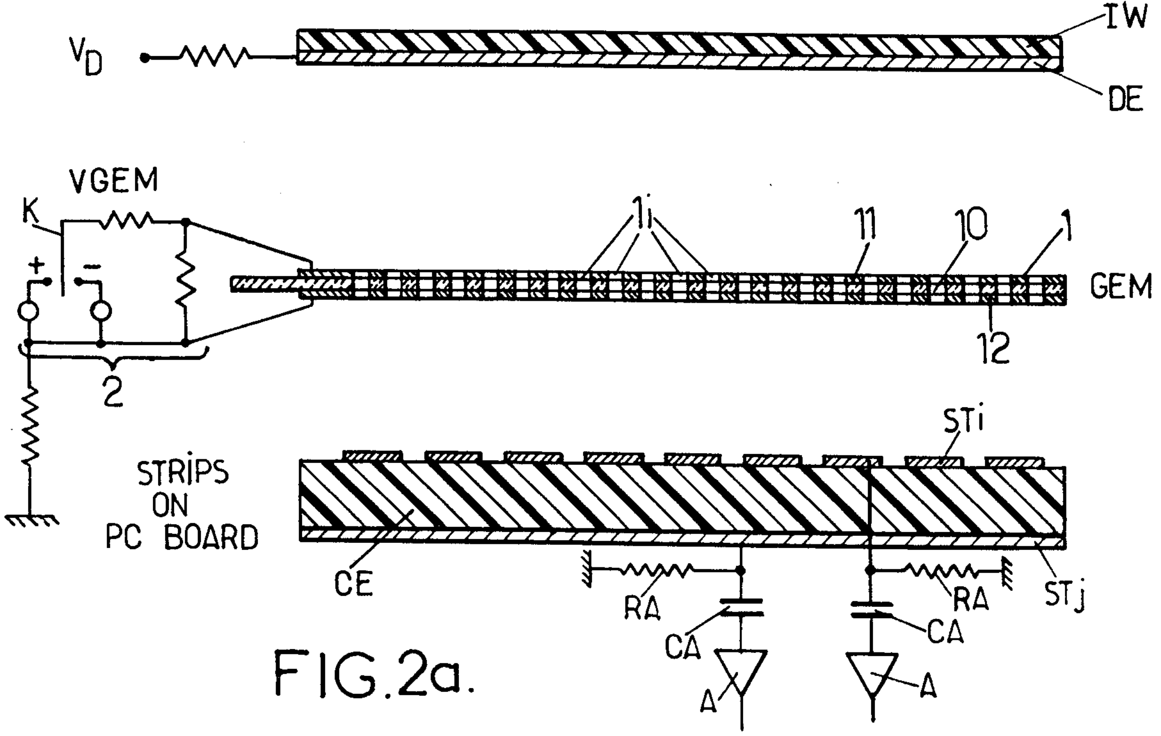

VD
IW
DE
VGEM
K
+
-
2
1i
11
10
1
GEM
12
STRIPS ON PC BOARD
STi
CE
RA
RA
STj
CA
CA
A
A

FIG.2a.

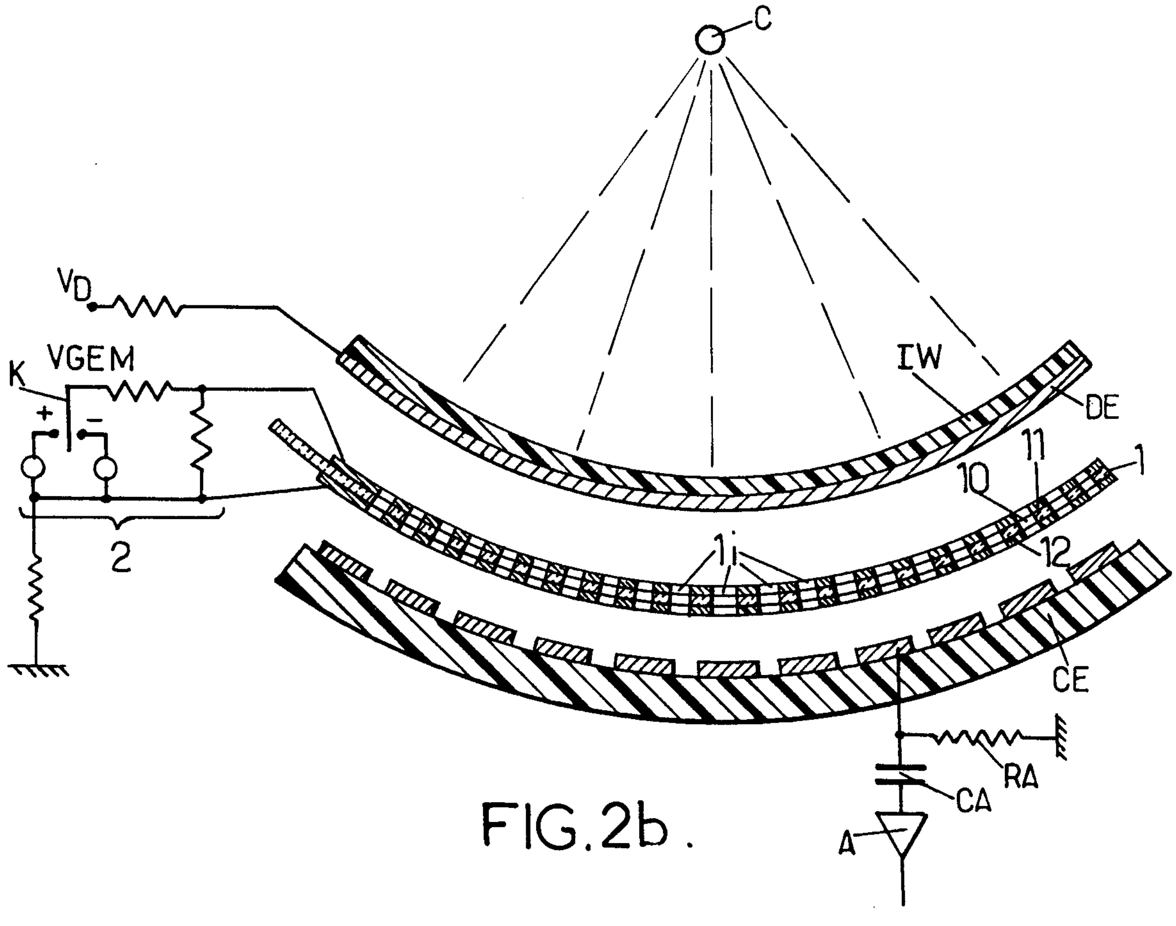

C
VD
VGEM
K
+
-
2
IW
DE
11
10
1
12
1i
CE
RA
CA
A

FIG.2b.

FIG.3a.

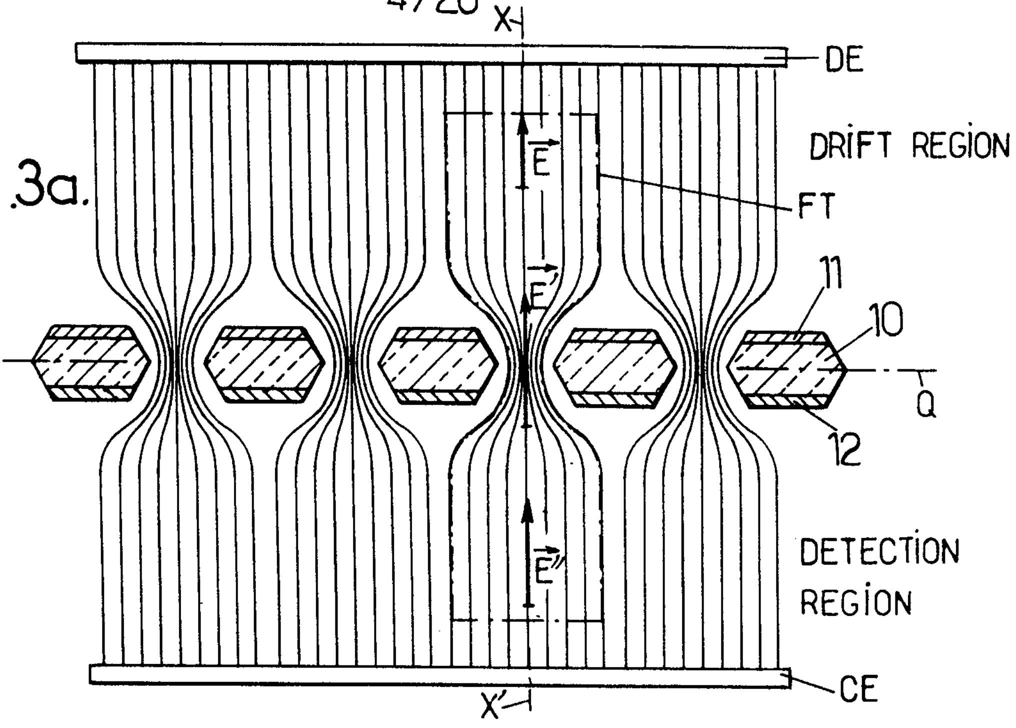
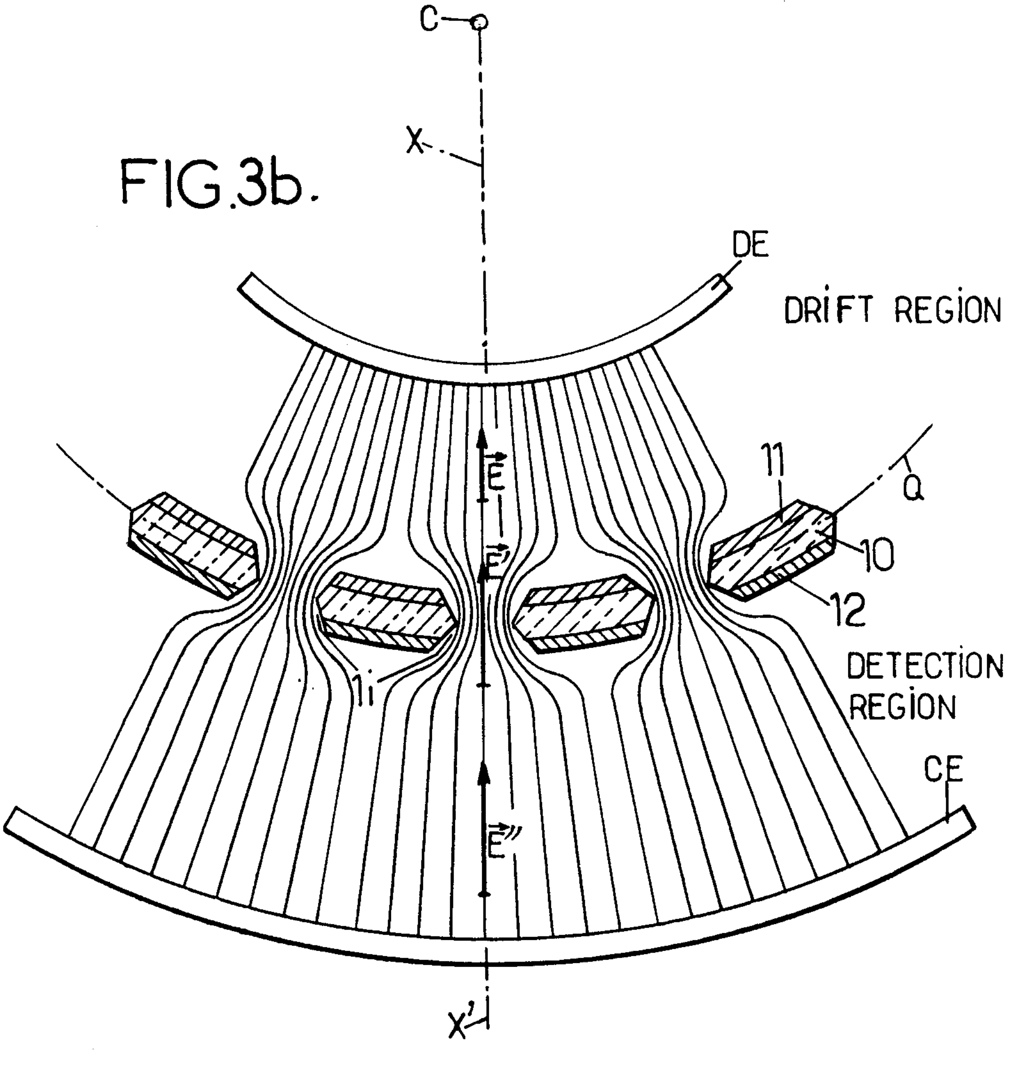

X
DE
DRIFT REGION
$\vec{E}$
FT
$\vec{E'}$
11
10
Q
12
DETECTION REGION
$\vec{E''}$
CE
X'

FIG.3b.


C
X
DE
DRIFT REGION
$\vec{E}$
$\vec{E'}$
11
Q
10
12
1_1
DETECTION REGION
CE
$\vec{E''}$
X'

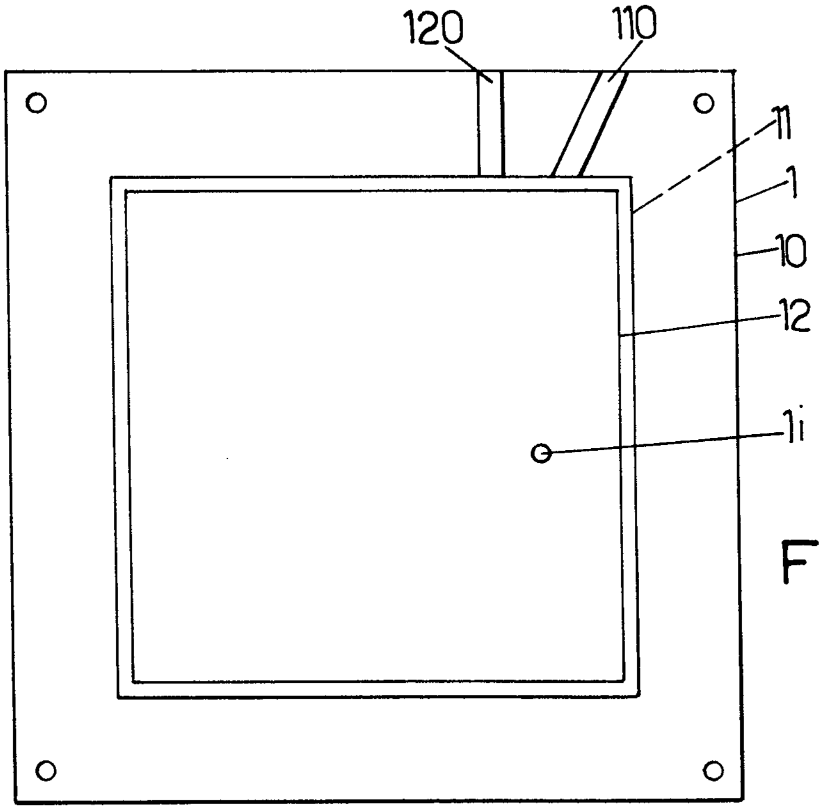


FIG.4a.

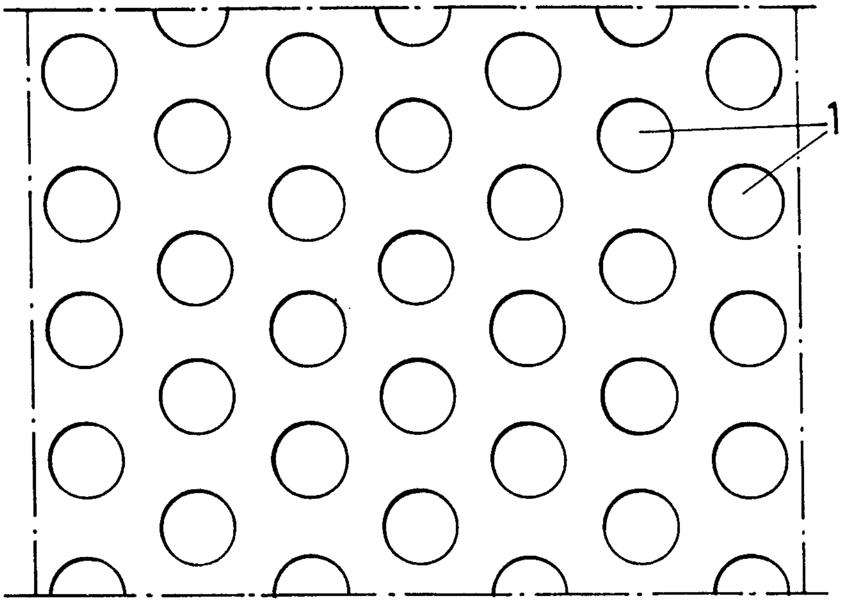


FIG.4b.

FIG.4c.

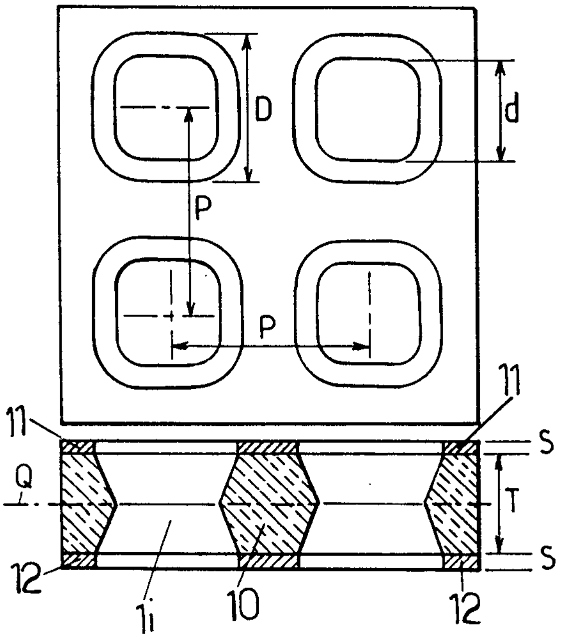


FIG.4d.

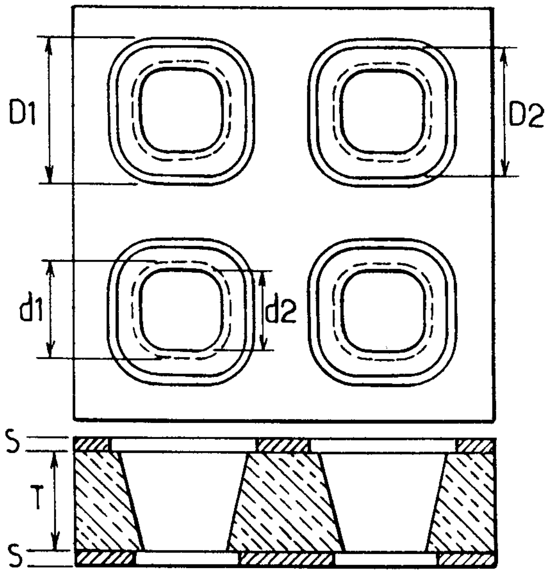


FIG.4e.

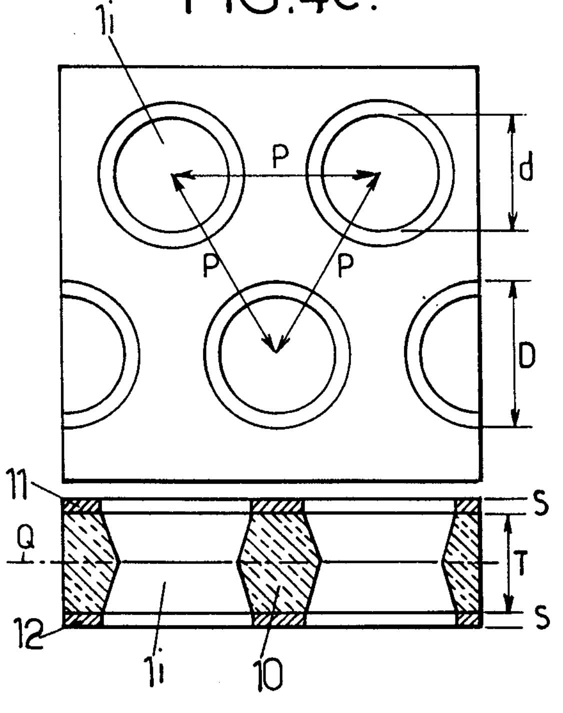
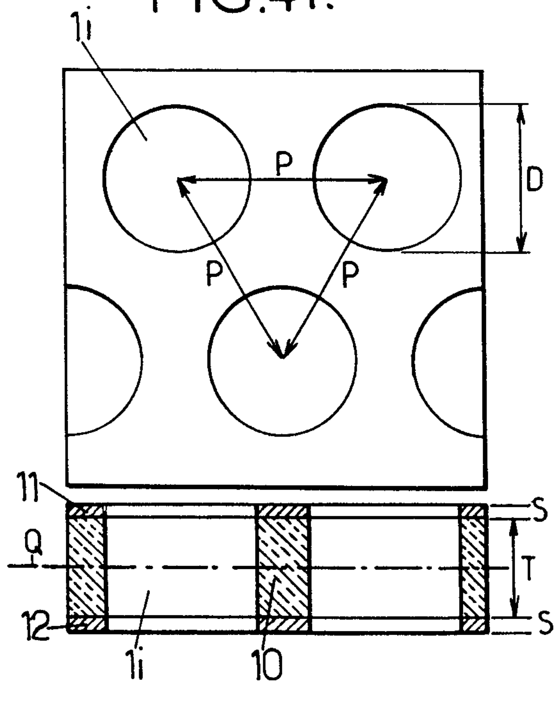


FIG.4f.



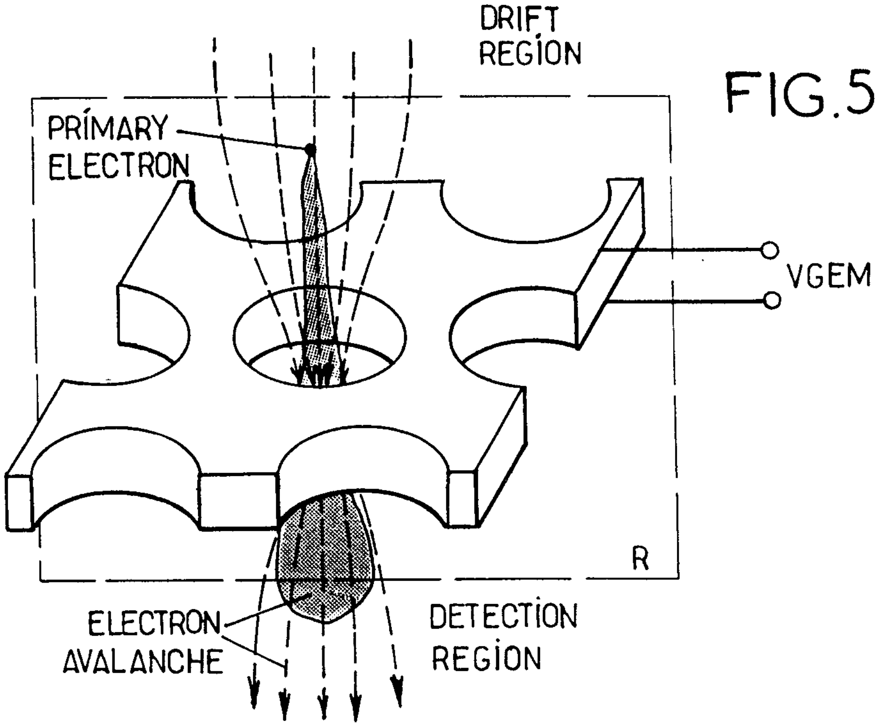
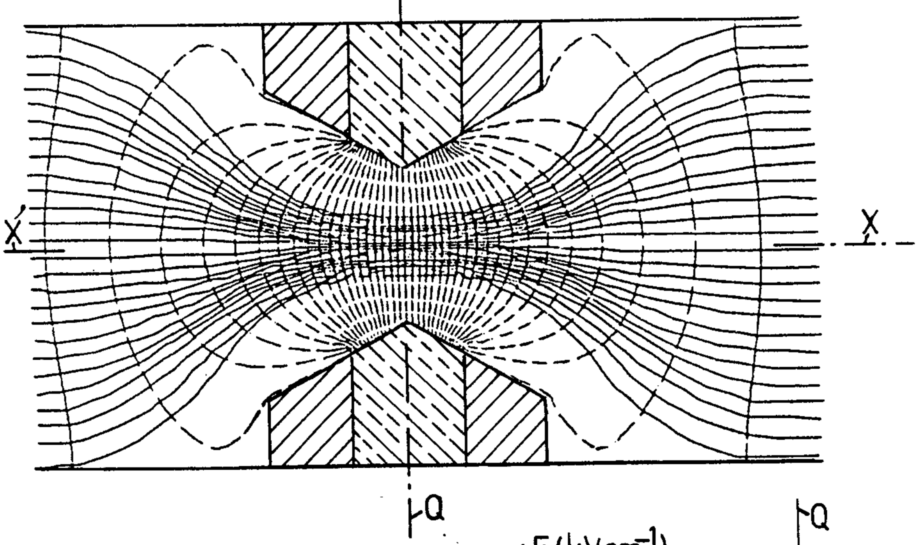


FIG.5a.

FIG.5b.



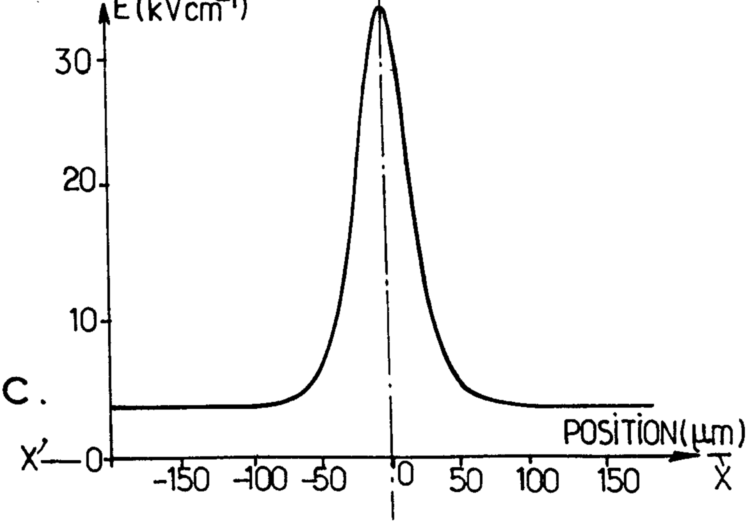


FIG.5c.

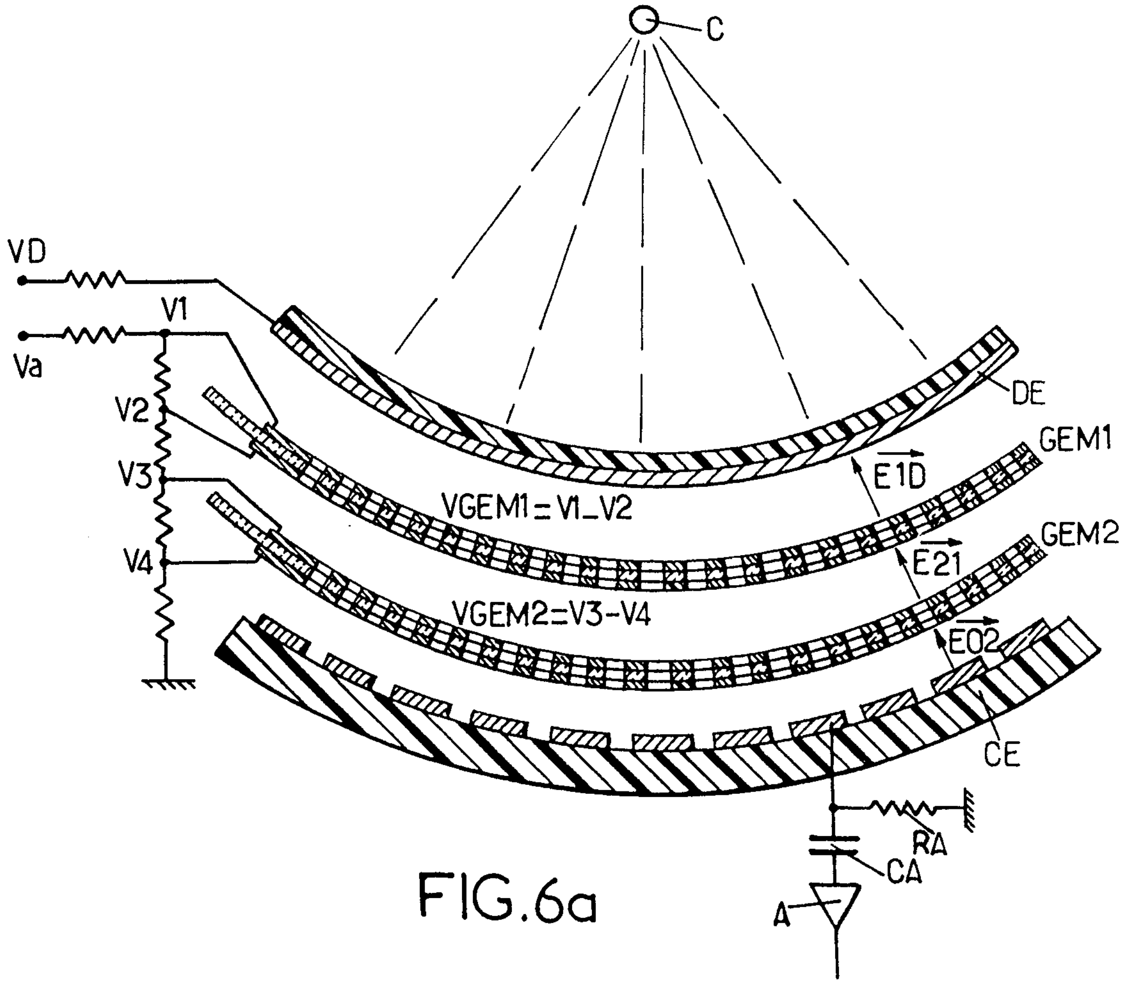

C
VD
Va
V1
V2
V3
V4
DE
GEM1
GEM2
E1D
E21
E02
VGEM1=V1_V2
VGEM2=V3-V4
CE
RA
CA
A

FIG.6a

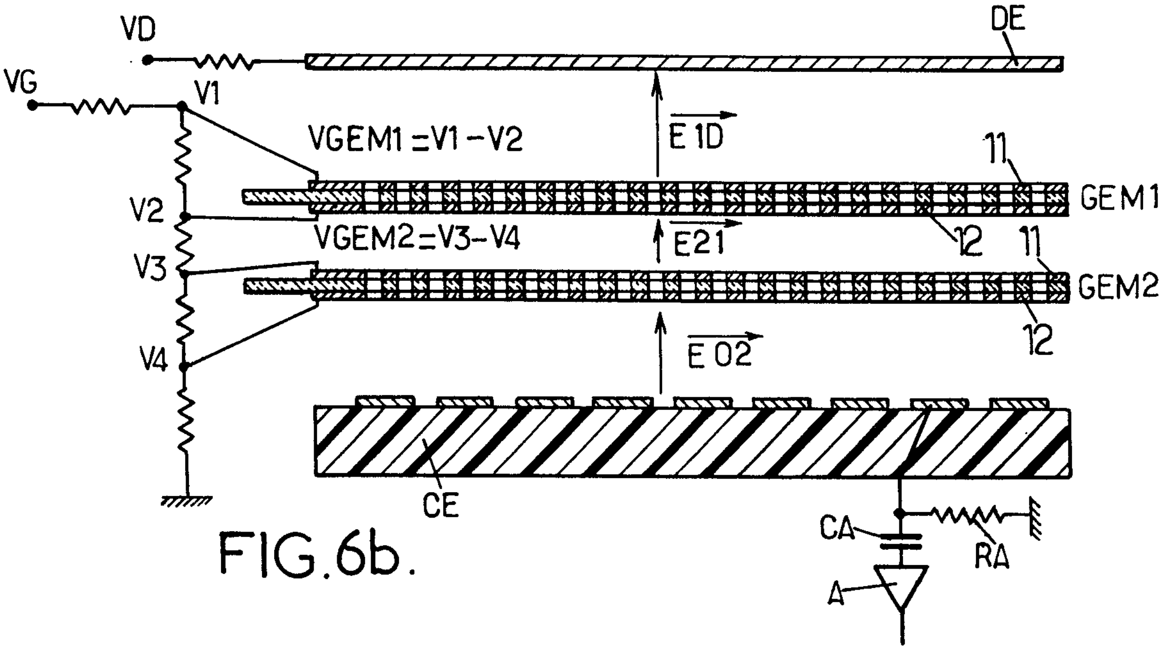

VD
VG
V1
V2
V3
V4
DE
VGEM1=V1-V2
VGEM2=V3-V4
E1D
E21
E02
11
12
11
12
GEM1
GEM2
CE
CA
RA
A

FIG.6b.

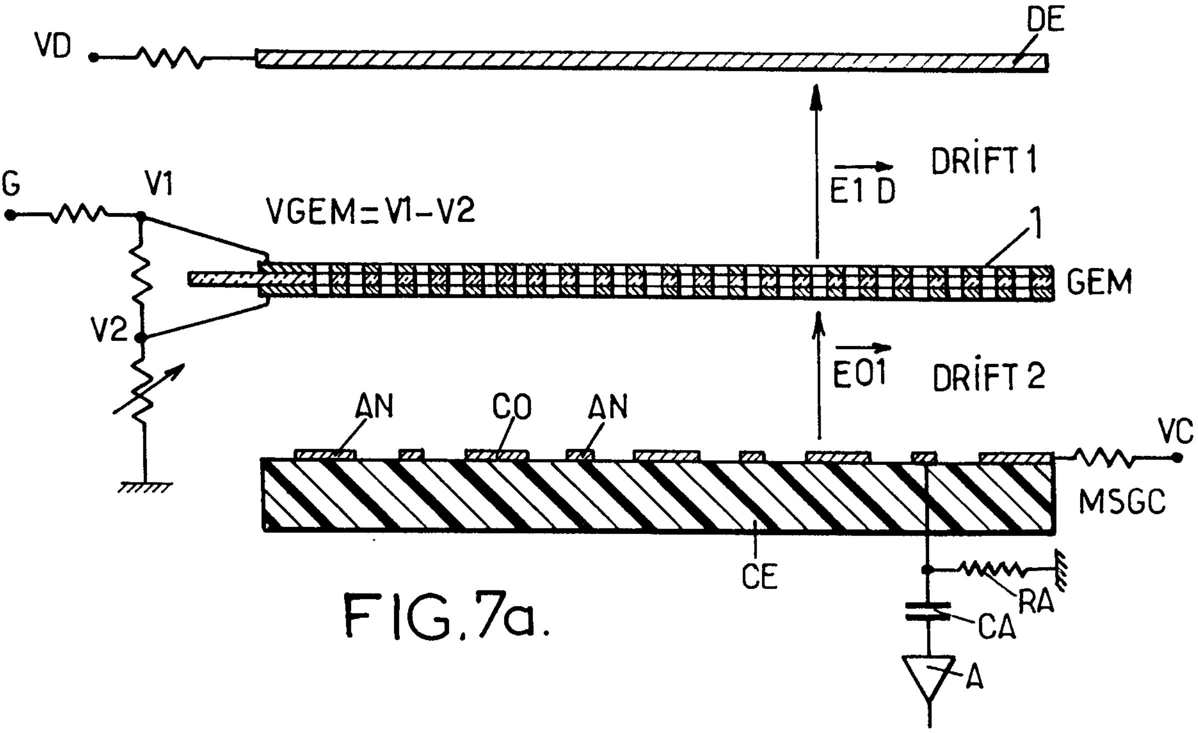

VD
DE
VG
V1
VGEM=V1-V2
$\overrightarrow{E1D}$
DRIFT 1
1
GEM
V2
$\overrightarrow{E01}$
DRIFT 2
AN
CO
AN
VC
MSGC
CE
RA
CA
A

FIG.7a.

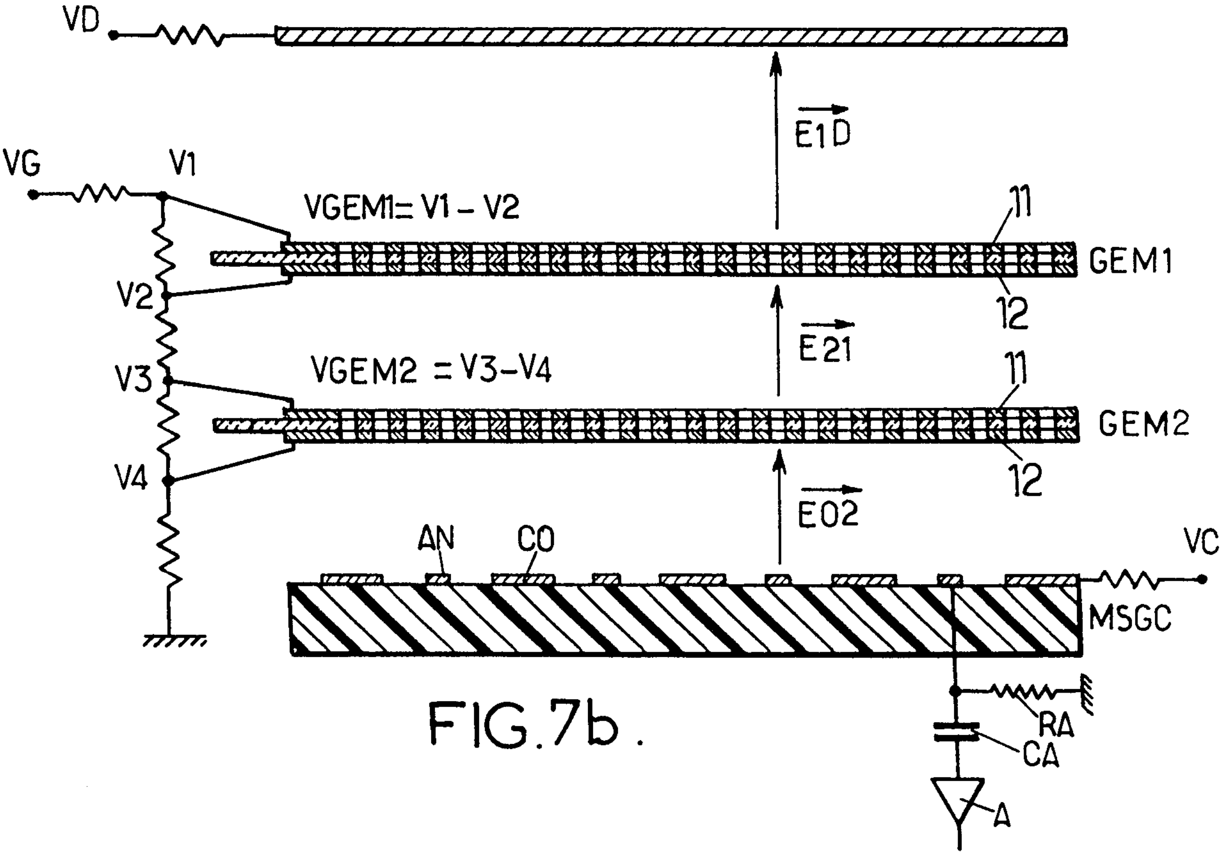

VD
$\overrightarrow{E1D}$
VG
V1
VGEM1=V1-V2
11
GEM1
V2
12
$\overrightarrow{E21}$
V3
VGEM2 =V3-V4
11
GEM2
V4
12
$\overrightarrow{E02}$
AN
CO
VC
MSGC
RA
CA
A

FIG.7b.

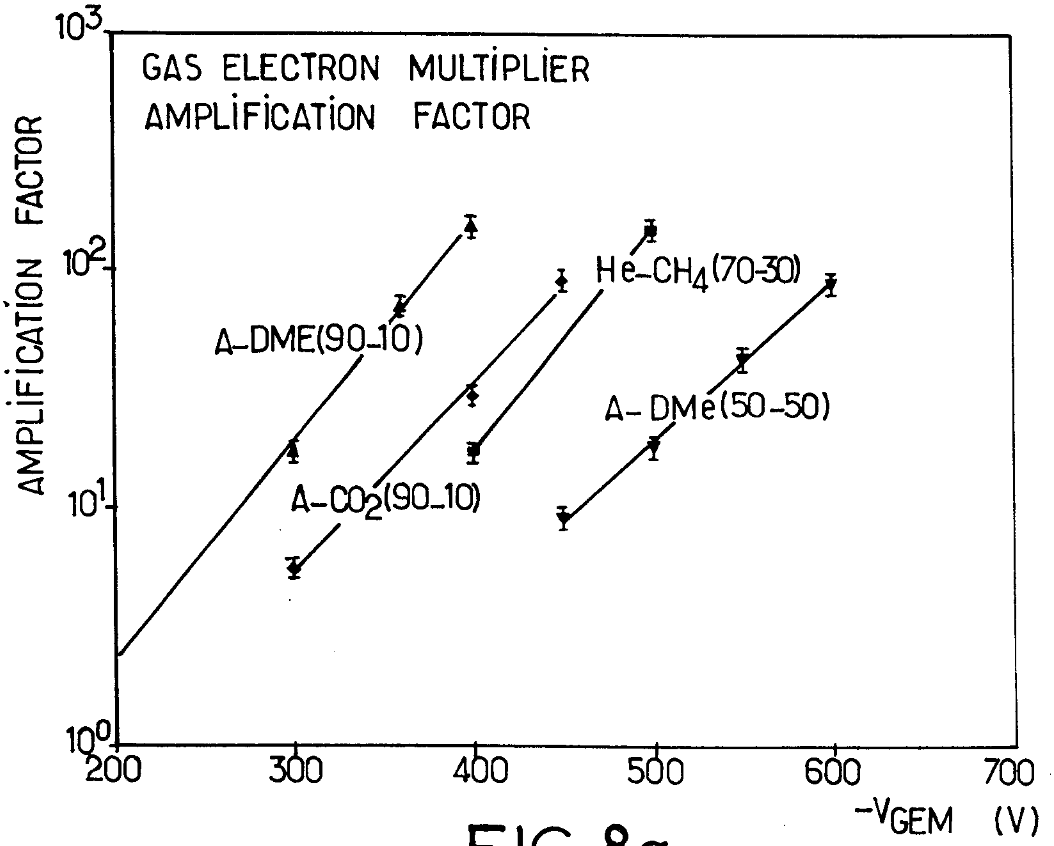

GAS ELECTRON MULTIPLIER
AMPLIFICATION FACTOR
AMPLIFICATION FACTOR
10^3
10^2
10^1
10^0
A-DME(90-10)
He-CH4(70-30)
A-CO2(90-10)
A- DMe(50-50)
200
300
400
500
600
700
-VGEM (V)

FIG.8a.

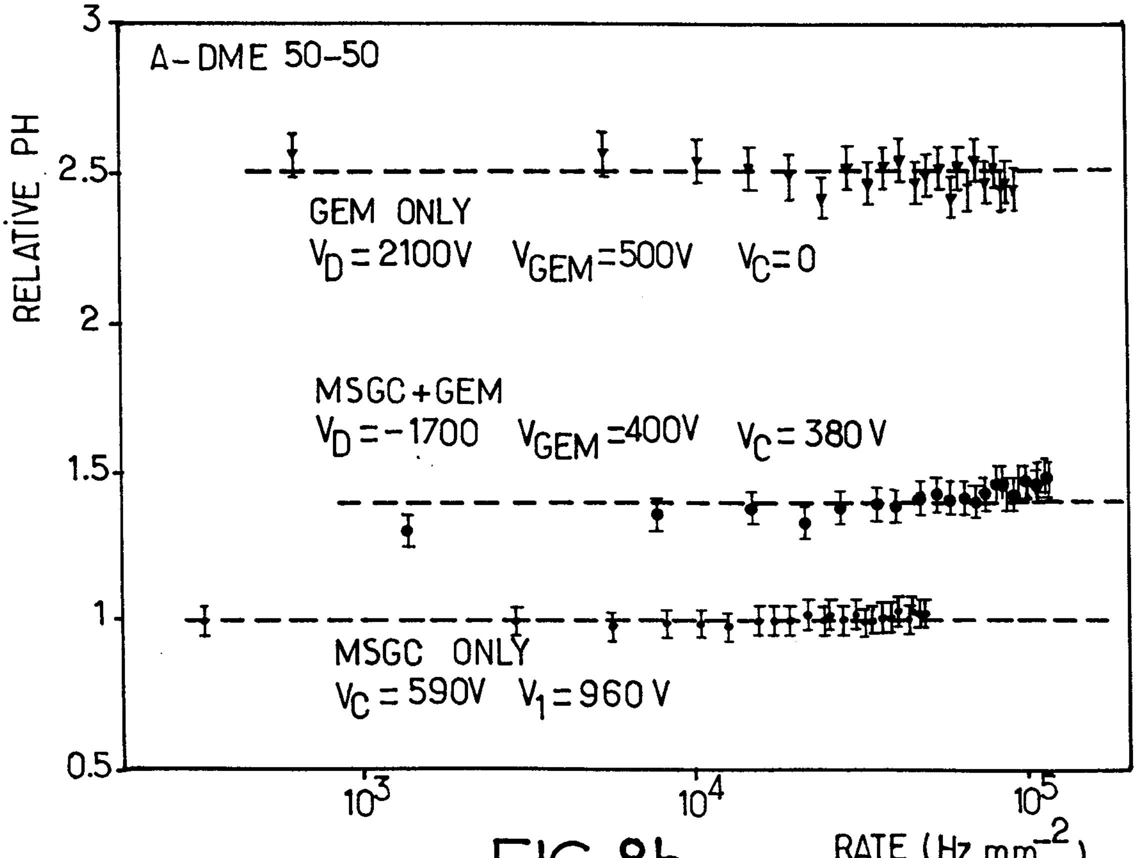

A-DME 50-50
RELATIVE PH
3
2.5
2
1.5
1
0.5
GEM ONLY
VD = 2100V VGEM=500V VC= 0
MSGC+GEM
VD = -1700 VGEM =400V VC= 380 V
MSGC ONLY
VC = 590V V1 = 960 V
10^3
10^4
10^5
RATE (Hz mm^{-2})

FIG.8b.

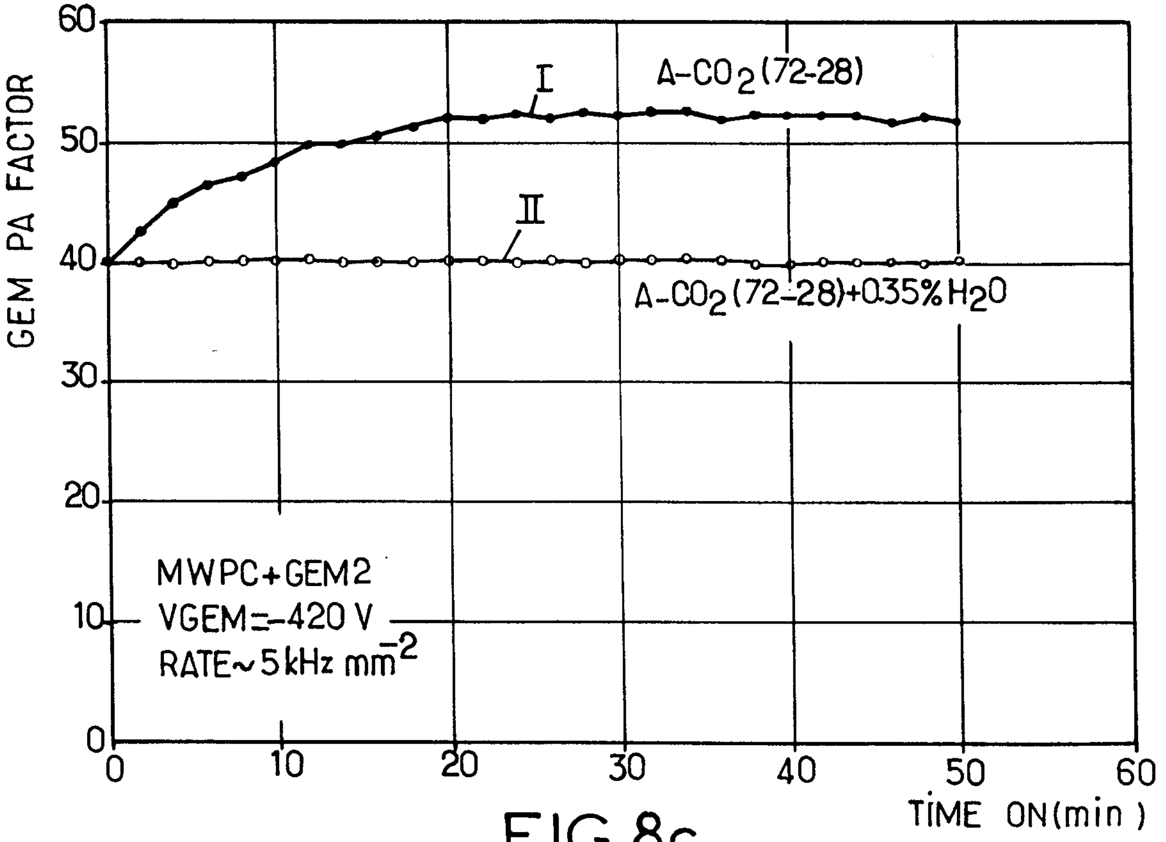

GEM PA FACTOR
60
50
40
30
20
10
0
I
A-CO_2(72-28)
II
A-CO_2(72-28)+0.35% H_2O
MWPC+GEM2
VGEM=-420 V
RATE~5 kHz mm^{-2}
0
10
20
30
40
50
60
TIME ON(min)

FIG.8c.

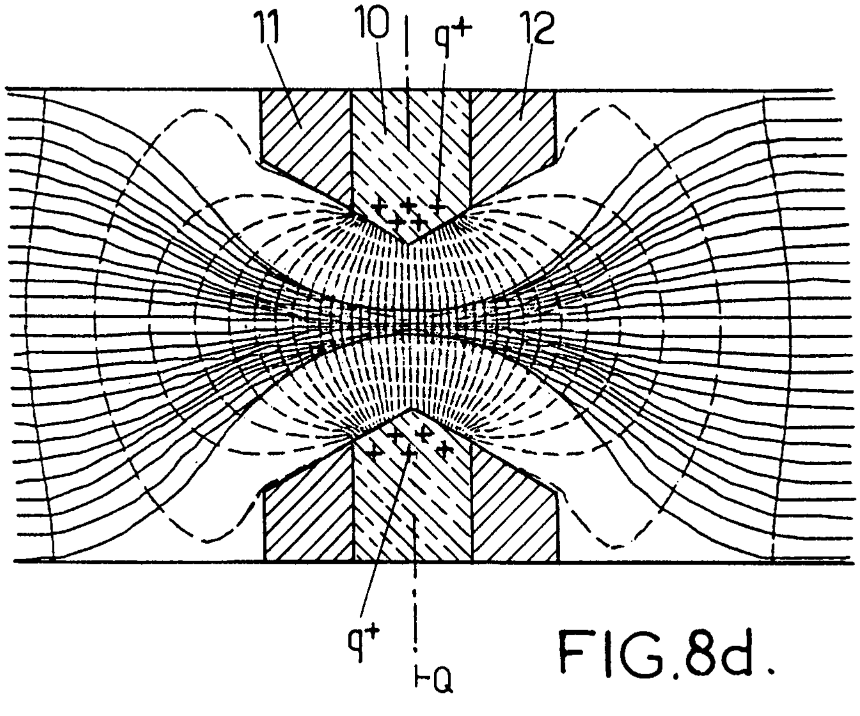

11
10
q+
12
q+
Q

FIG.8d.

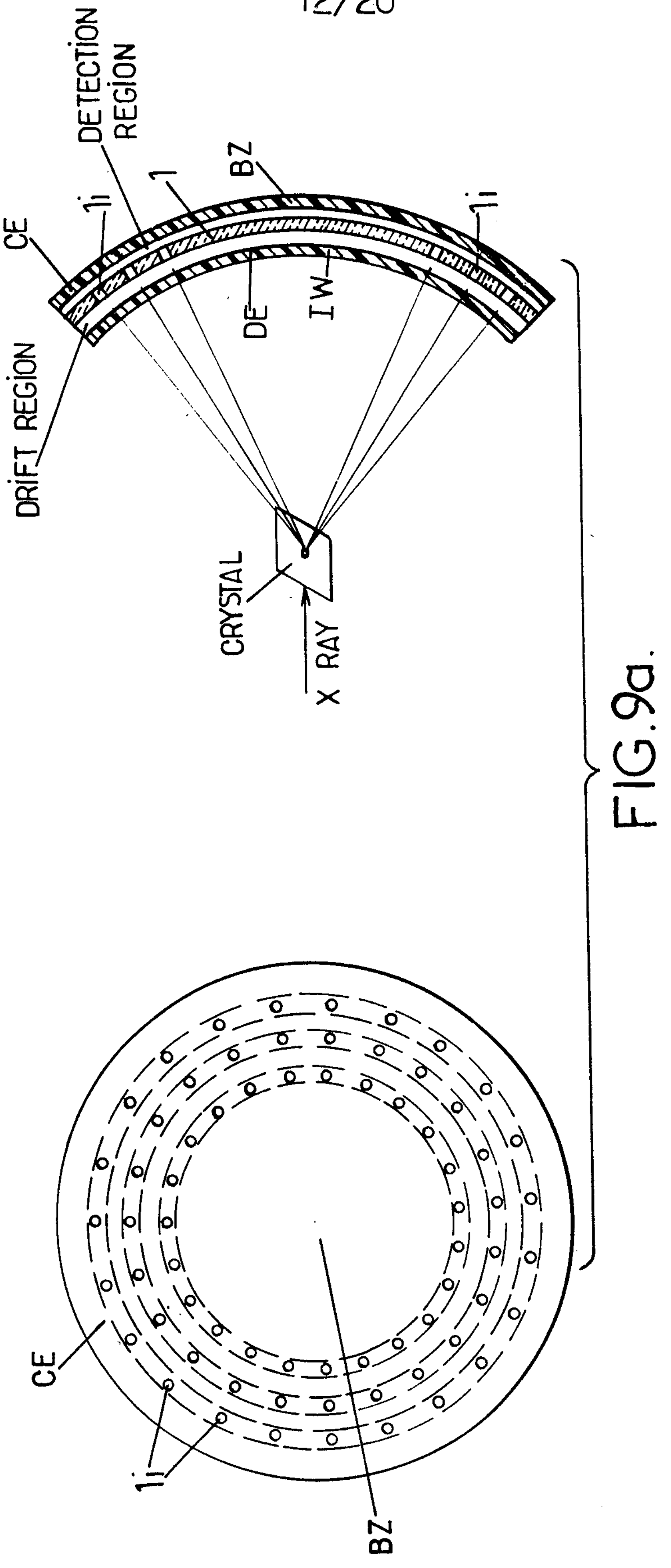
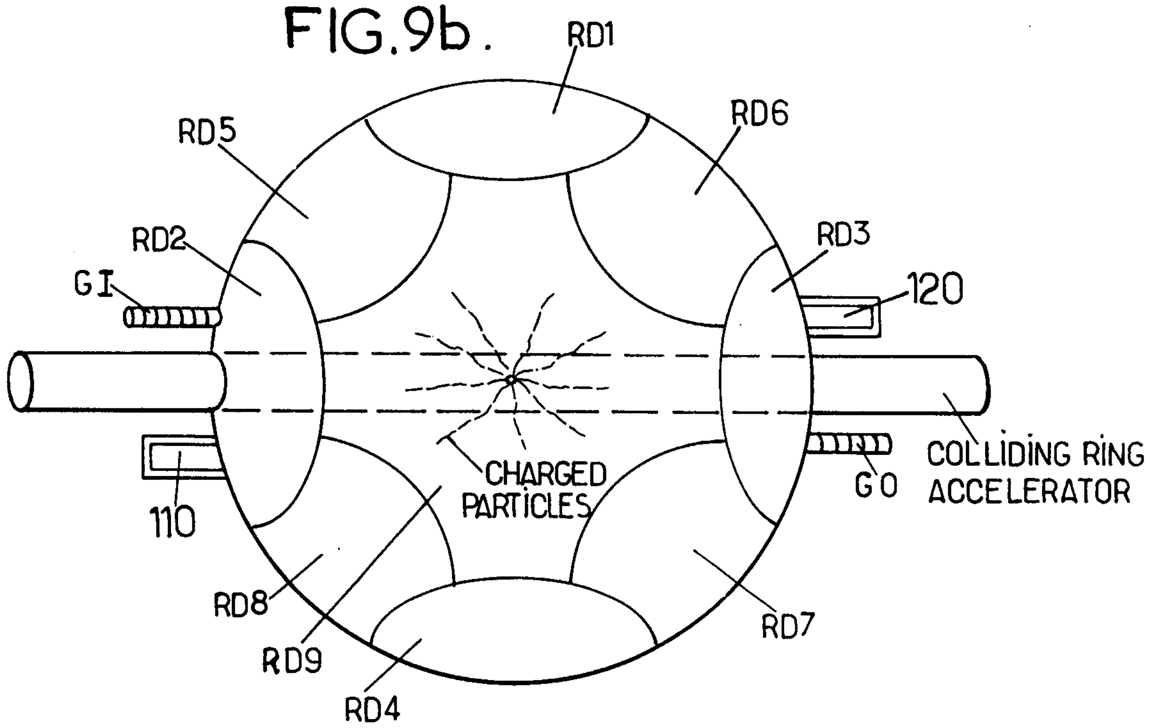

DRIFT REGION
CE
1i
DETECTION REGION
1
BZ
1i
DE
IW
CRYSTAL
X RAY
CE
1i
BZ

FIG.9a.

FIG.9b.


RD1
RD5
RD6
RD2
RD3
GI
120
CHARGED PARTICLES
COLLIDING RING ACCELERATOR
GO
110
RD8
RD9
RD7
RD4

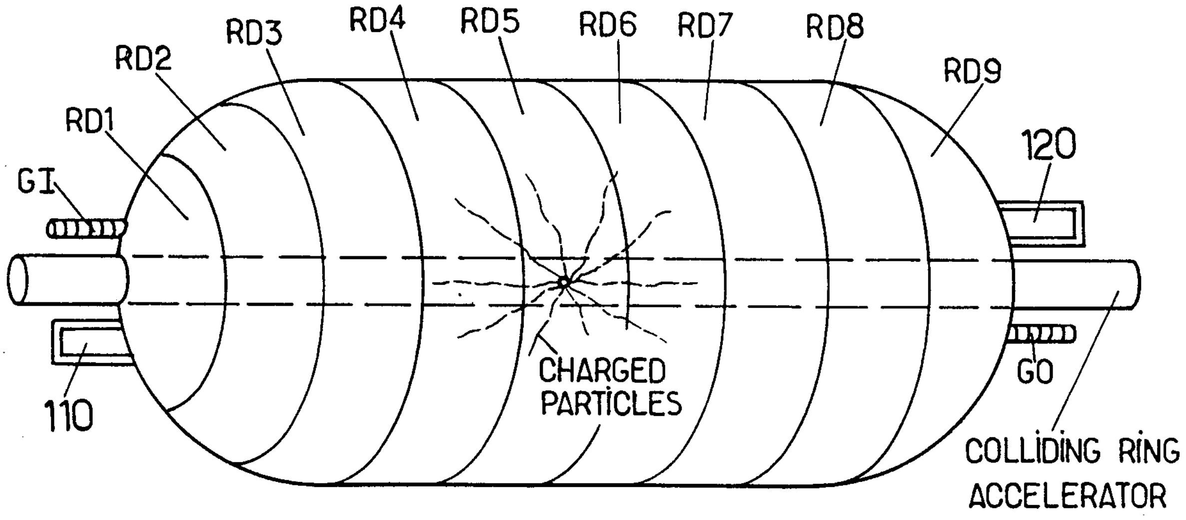

RD3
RD4
RD5
RD6
RD7
RD8
RD2
RD9
RD1
120
GI
CHARGED PARTICLES
GO
110
COLLIDING RING ACCELERATOR

FIG.9c.

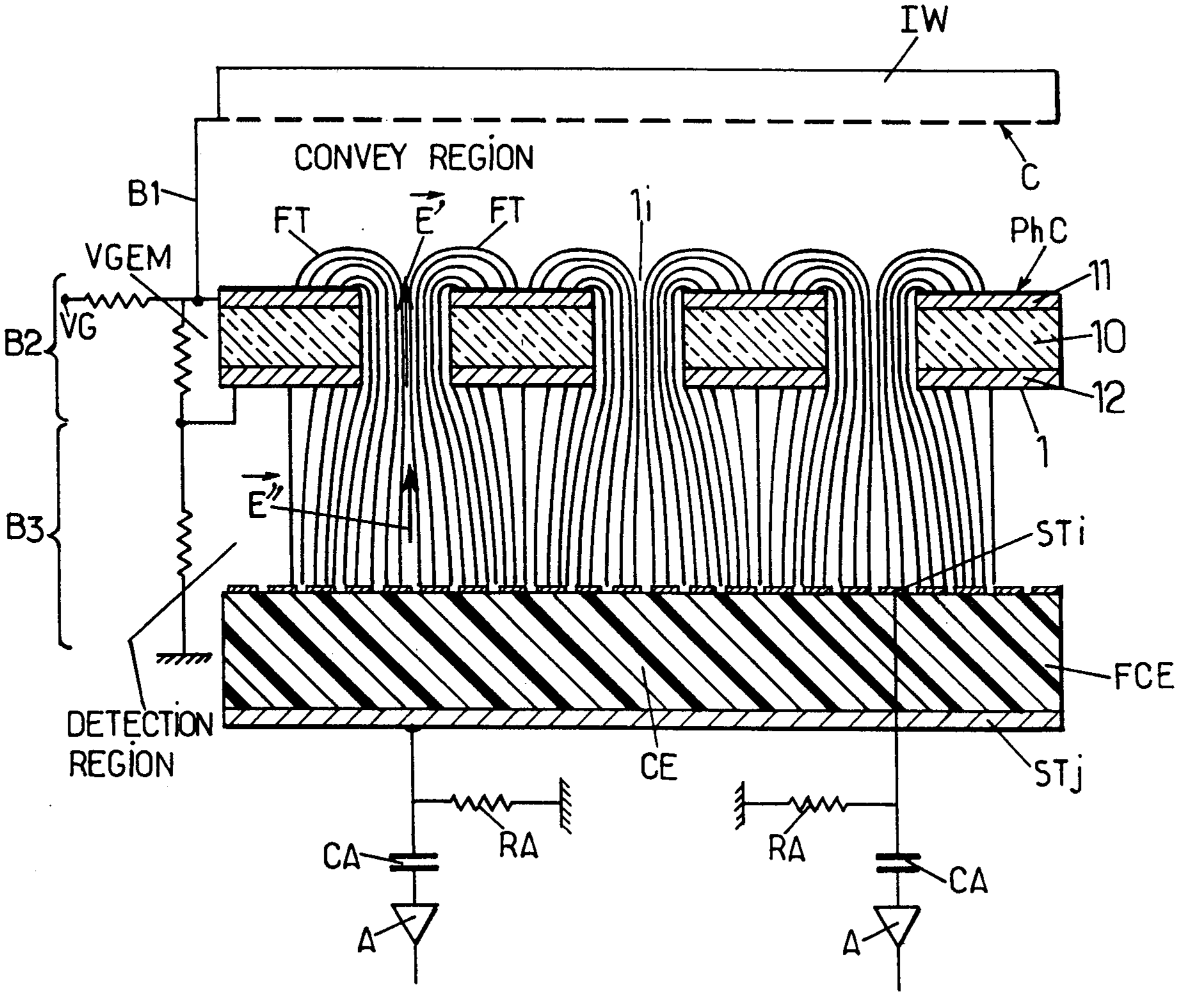

IW
C
CONVEY REGION
B1
FT
$\vec{E'}$
FT
1i
PhC
11
10
12
1
VGEM
VG
B2
B3
$\vec{E''}$
STi
FCE
DETECTION REGION
CE
STj
RA
RA
CA
CA
A
A

FIG.10.

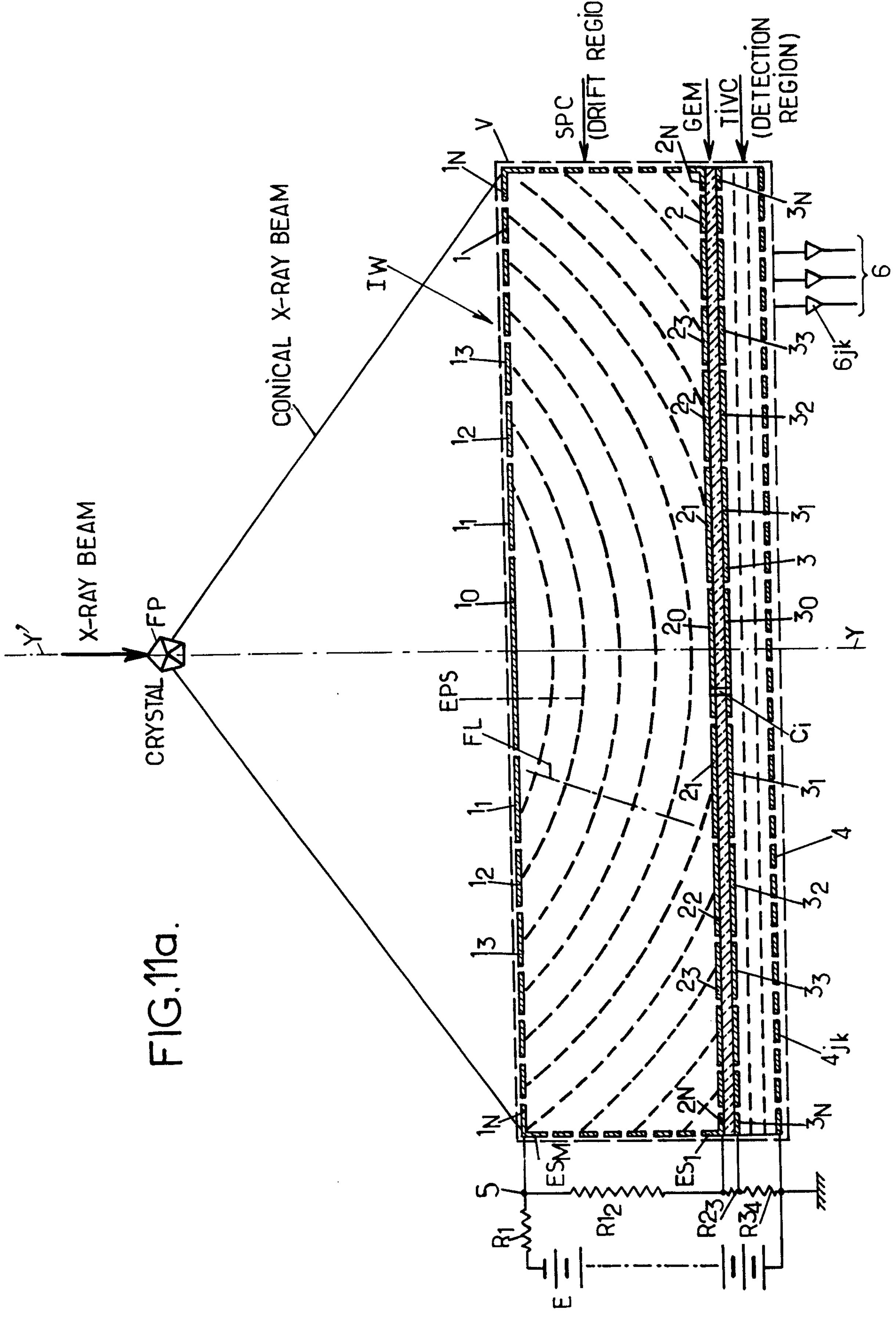


FIG.11a.
X-RAY BEAM
Y'
CRYSTAL
FP
CONICAL X-RAY BEAM
IW
1N
V
SPC
(DRIFT REGION)
2N
GEM
TIVC
(DETECTION REGION)
3N
1
2
6
23
33
6jk
13
12
22
32
11
21
31
10
3
30
20
Y
EPS
Ci
FL
4
4jk
X
ESM
ES1
5
R1
R12
R23
R34
E

FIG.11b.

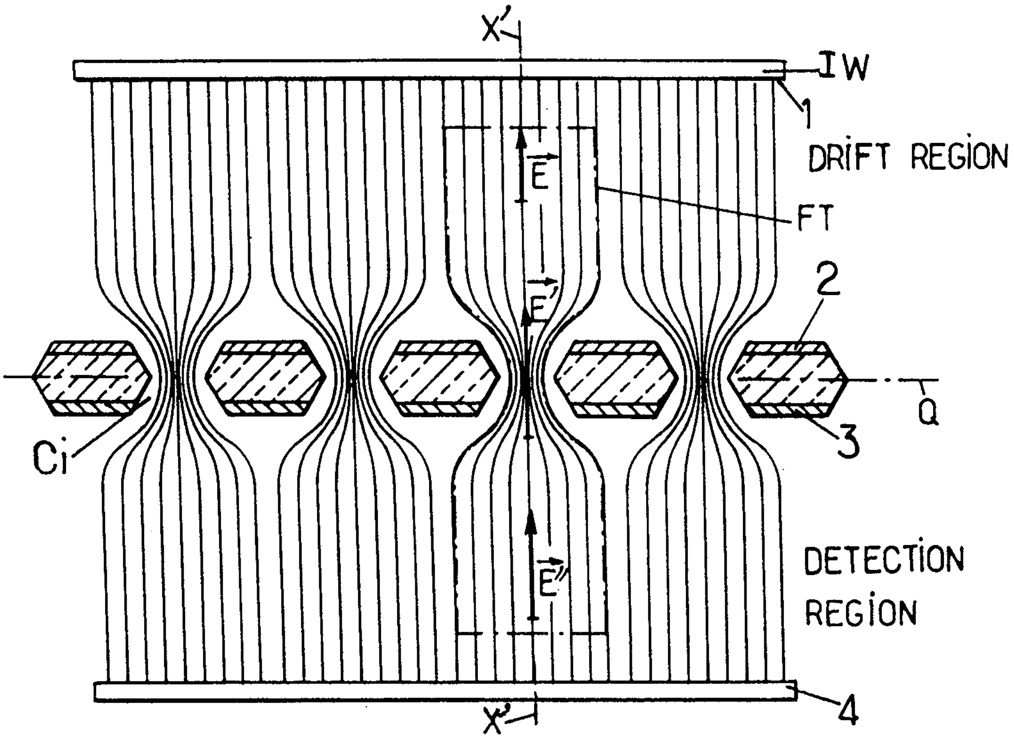
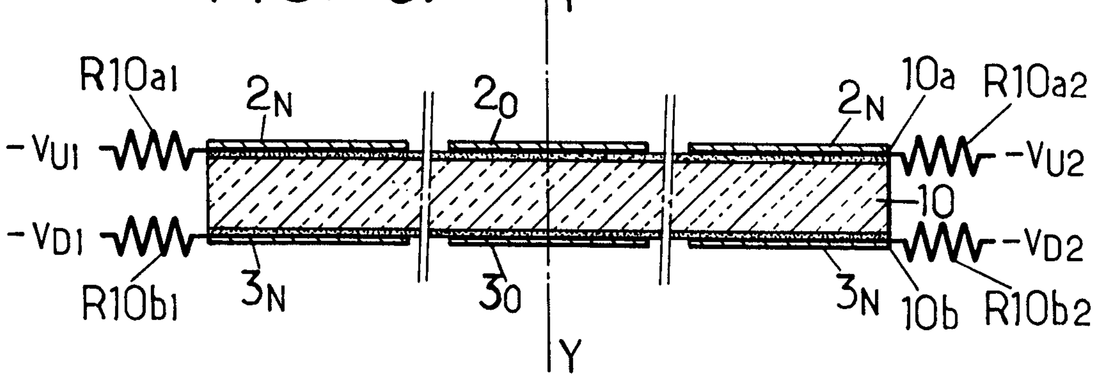


FIG.12c.



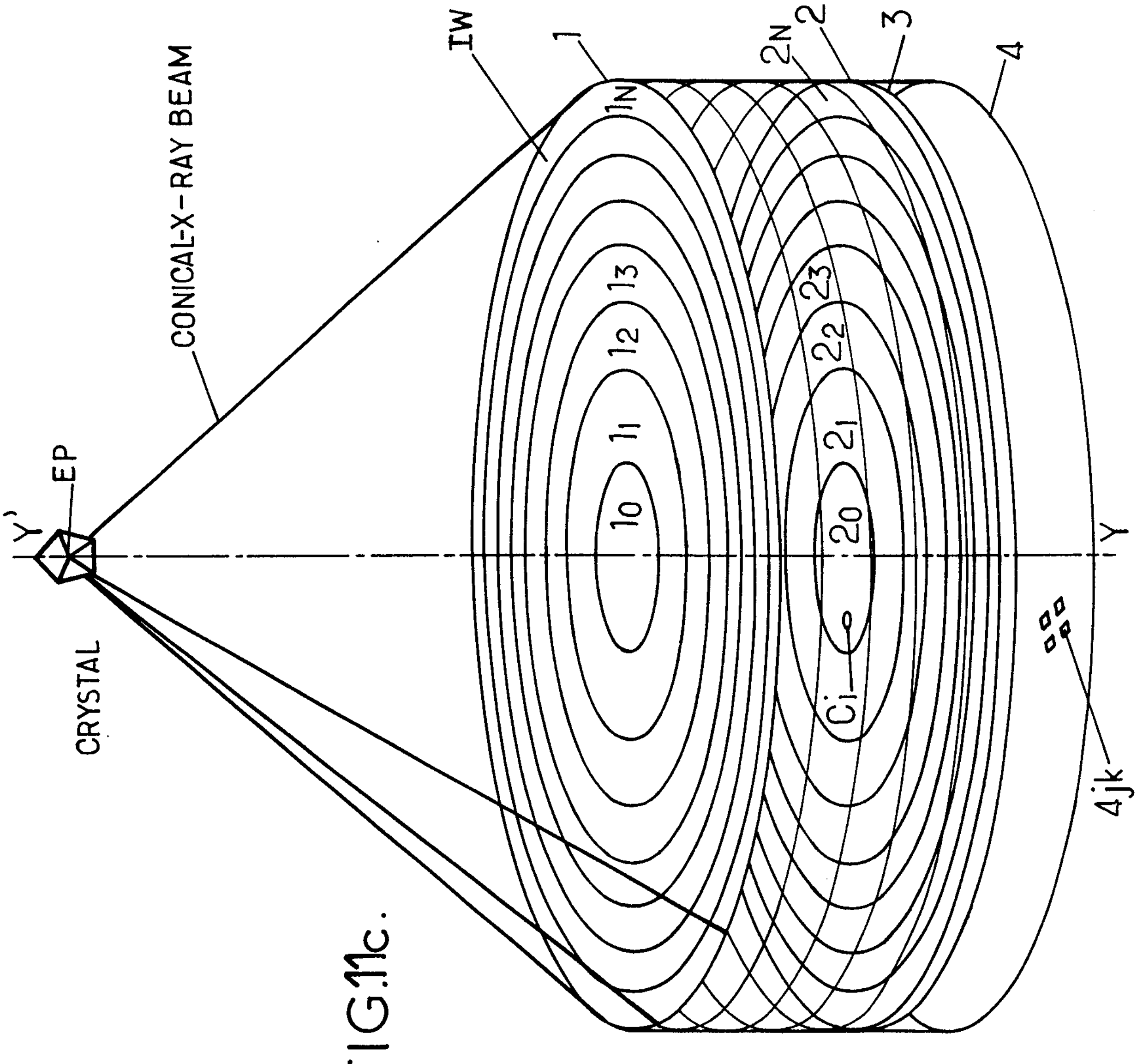

CONICAL-X-RAY BEAM
Y'
EP
CRYSTAL
IW
1
1_N
2_N
2
3
4
1_3
1_2
1_1
1_0
2_3
2_2
2_1
2_0
C_i
Y
4_{jk}

FIG.11c.

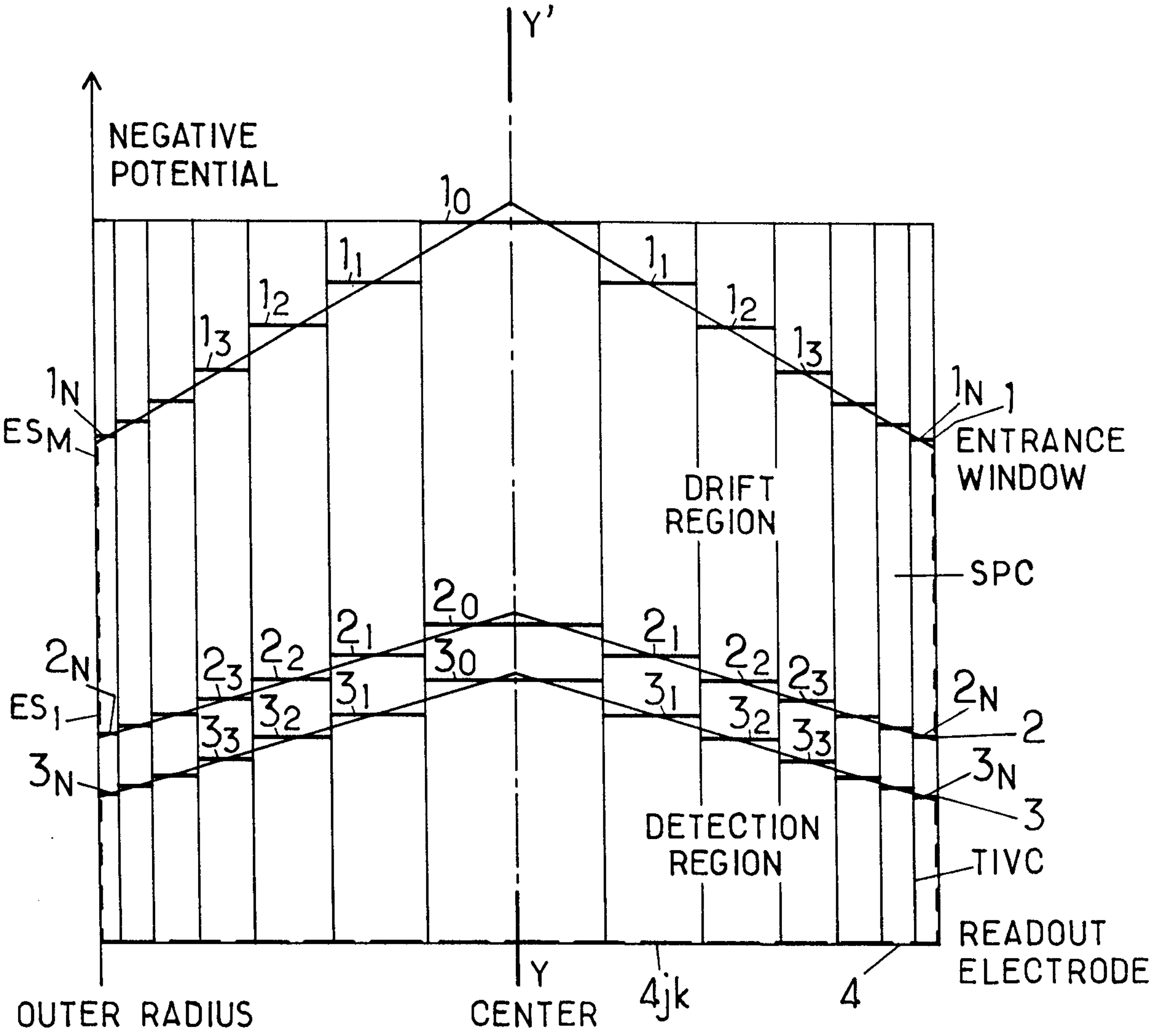
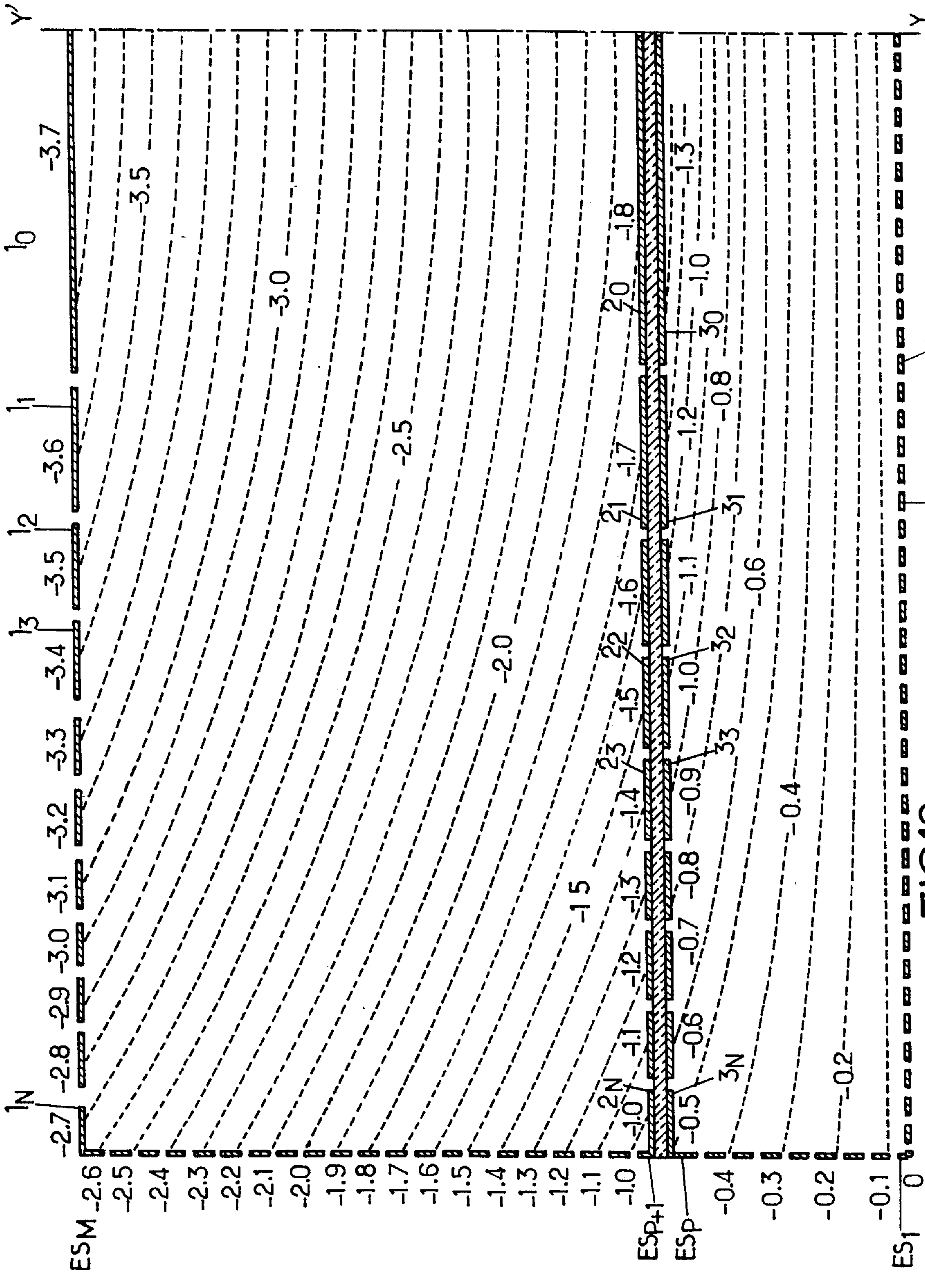

Y'
NEGATIVE POTENTIAL
1_0
1_1
1_2
1_3
1_N
ES_M
1
ENTRANCE WINDOW
DRIFT REGION
SPC
2_0
2_1
2_2
2_3
2_N
ES_1
3_0
3_1
3_2
3_3
3_N
2
3
DETECTION REGION
TIVC
READOUT ELECTRODE
OUTER RADIUS
Y
CENTER
4jk
4

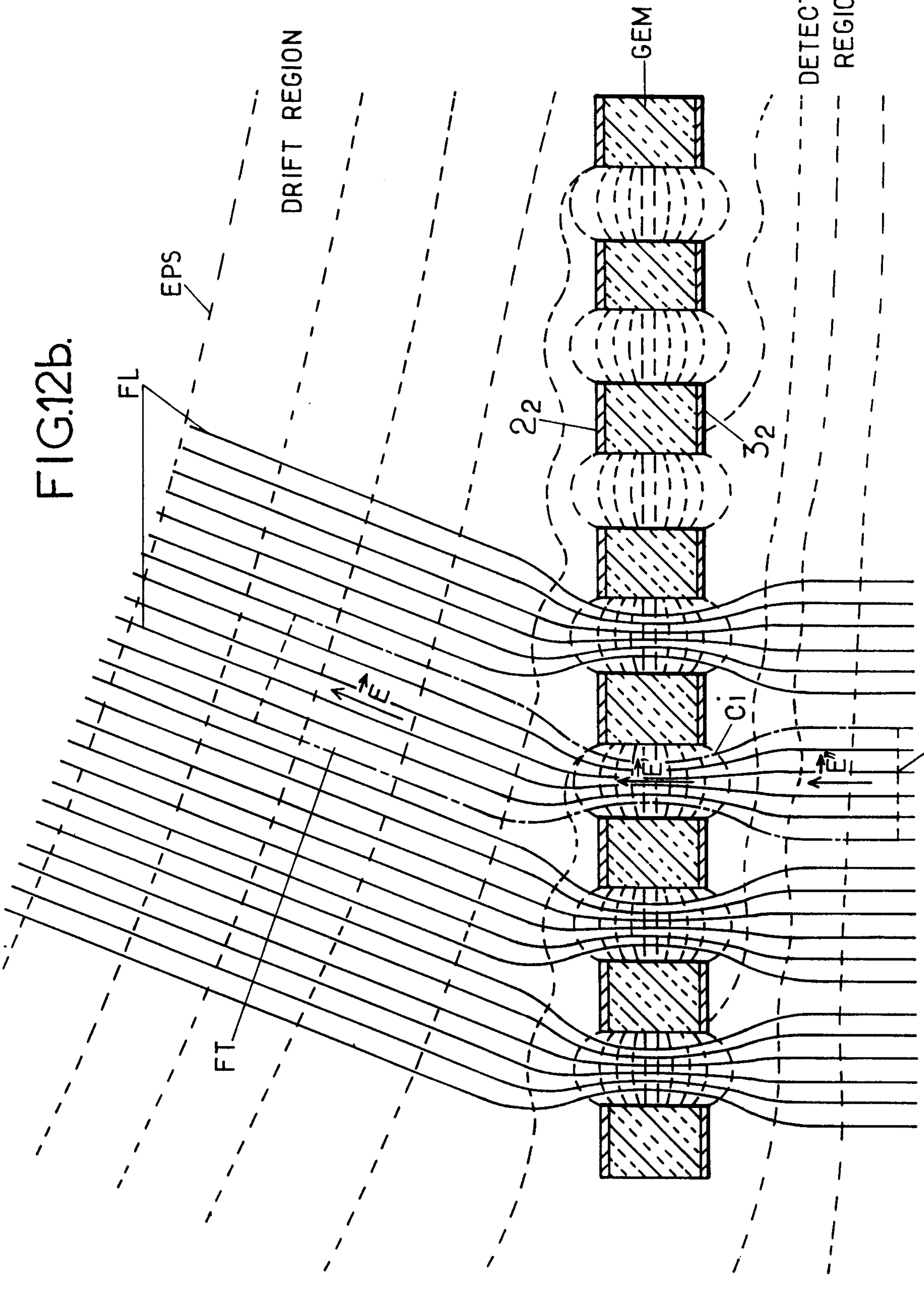
FIG.11d.



Y'
Y
1_0
1_1
1_2
1_3
1_N
2_0
2_1
2_2
2_3
2_N
3_0
3_1
3_2
3_3
3_N
4
4_{jk}
ES_M
ES_{P+1}
ES_P
ES_1
-3.7
-3.6
-3.5
-3.4
-3.3
-3.2
-3.1
-3.0
-2.9
-2.8
-2.7
-2.6
-2.5
-2.4
-2.3
-2.2
-2.1
-2.0
-1.9
-1.8
-1.7
-1.6
-1.5
-1.4
-1.3
-1.2
-1.1
-1.0
-0.9
-0.8
-0.7
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0

FIG.12a.

FIG.12b.



INTERNATIONAL SEARCH REPORT

Intern .ial Application No
PCT/EP 98/06569

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01J47/00 H01J47/02

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)
IPC 6 H01J

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

Electronic data base consulted during the international search (name of data base and, where practical, 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	R.BOUCLIER ET AL: "The Gas Electron Multiplier (GEM)" IEEE TRANS. NUCL. SCI, vol. 44, no. 3, 1996, pages 646-646-650, XP002093446 USA	1-8,10, 13, 15-21,24
Y	abstract see figures 2,4.9,10 ---	11,12, 25-28

-/--

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search 18 February 1999	Date of mailing of the international search report 25/03/1999
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Centmayer, F

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INTERNATIONAL SEARCH REPORT

Interr. nal Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication.where appropriate, of the relevant passages	Relevant to claim No.
X	BOUCLIER R ET AL: "New observations with the gas electron multiplier (GEM)" NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH, SECTION - A: ACCELERATORS, SPECTROMETERS, DETECTORS AND ASSOCIATED EQUIPMENT, vol. 396, no. 1-2, 1 September 1997, page 50-66 XP004097882	1-8,10, 13,14, 16-18, 20,21,24
Y	abstract see page 50, right-hand column - page 51, right-hand column; figures 1,2,4,12 ---	25-27
Y	ALLEMAND ET AL: "Nouveau Detecteur de Localisation" NUCLEAR INSTRUMENTS AND MTHODS, vol. 137, 1976, pages 141-149, XP002093949 abstract see page 141, left-hand column, paragraph 1 ---	11,12,28
Y	EP 0 450 571 A (YEDA RES & DEV) 9 October 1991 see page 6, column 25-31; figures 1E,3D see page 9, line 37 - page 10, line 23 -----	25-27

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inter... onal Application No

PCT/EP 98/06569

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0450571 A	09-10-1991	IL 93969 A US 5192861 A	15-04-1997 09-03-1993