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(54) Electron multiplying apparatus

(57) An electron multiplying apparatus such as an electron multiplying detector, comprising: a housing (2) having a wall defining an enclosure (3), the wall having an inner surface within the enclosure and an outer surface outside the enclosure; a source of electrons (4); an electron multiplier (7) positioned within the enclosure (3) so as to receive electrons (6) from the source of electrons (4) and to emit multiple electrons (9) for each electron (6) received; a plurality of pairs of electrodes (12, 14), each pair comprising a first electrode (12) on the inner surface of the wall and a second electrode (14) on the outer surface of the wall adjacent to the first electrode (12) and separated from the first electrode by the wall.

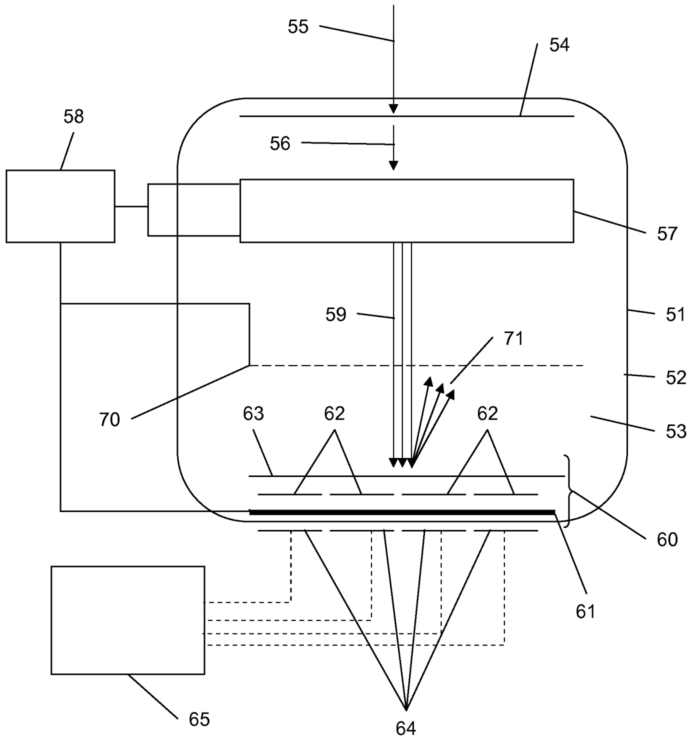

Fig 4

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Description

[0001] This invention relates to electron multiplying apparatus, and to methods of use and manufacture thereof.

[0002] Electron multipliers are well known in the prior art; electrons are accelerated by a potential difference in an evacuated enclosure and bombard a second electron emissive material, thus releasing many secondary electrons at each collision. A relatively small initial signal - perhaps a single electron generated by the collection of one or a small number of photons - can be multiplied many times to generate a detectable signal.

[0003] Generally, the output of such a device involves the multiplied electrons being incident upon an anode. Inevitably, there is secondary electron emission from the anode, which can be a concern when looking for a very fast signal. In simple terms, detecting current from the anode, there is a negatively rising pulse as electrons approach and land on the anode followed by a positive going signal as secondary electrons leave the anode. If the secondary electron emission coefficient of the anode is one, then in some circumstances both signals cancel each other. Consequently, it is usual practice to try to suppress secondary electron emission from the anode by coating it with material chosen for this purpose. By coupling sense wires from the anode through the walls of the enclosure, the electric signal generated by the incident electrons can be measured, and in some cases the position determined.

[0004] However, coupling wires through the walls of the enclosure is undesirable. In order for the walls of the enclosure to withstand atmospheric pressure, the walls have to be thicker for larger detectors; for a 40 millimetre diameter detector, the walls generally need to be around 2 millimetres thick, increasing as the size of the detector increases.

[0005] US Patent number 5 686 721 discloses a system where a single high resistance electrode is provided as the output anode, and three electrodes are provided externally to the enclosure capacitively coupled to the output anode. Interpolation of the signals received at each electrode allows the position of the incident electron to be estimated.

[0006] A disadvantage of such an arrangement is that, in some cases, it is difficult to determine the position of an event such as an incident electron without interpolating the relative charge spreading between several external anode circuits. The spatial resolution is dependent on the thickness of the dielectric wall of the detector which, as discussed above, can be significant for larger detectors.

[0007] According to a first aspect of the invention, there is provided an electron multiplying apparatus, comprising:

a housing having a wall defining an enclosure, the wall having an inner surface within the enclosure and an outer surface outside the enclosure;
a source of electrons;
an electron multiplier positioned within the enclosure so as to receive electrons from the source of electrons and to emit multiple electrons for each electron received;
a plurality of pairs of electrodes, each pair comprising a first electrode on the inner surface of the wall and a second electrode on the outer surface of the wall adjacent to the first electrode and separated from the first electrode by the wall.

[0008] Thus, rather than having to make multiple connections through the wall, each pair of electrodes will capacitively couple together and so it will be possible to determine the position of the electrons incident on the first electrodes by determining the second electrode on which a signal is generated.

[0009] Preferably, the apparatus comprises a layer of secondary emissive material on the first electrodes (which may function as an anode) on the inner surface of the wall, positioned so that electrons emitted by the electron multiplier are incident on the layer. Thus, by providing an extra layer of secondary emissive material, which has a high secondary emission coefficient, over the first electrodes, extra electrons can be generated, increasing the sensitivity of the apparatus without loss of spatial resolution.

[0010] Preferably, the apparatus comprises a metallic grid between the electron multiplier and the first electrodes. The metallic grid may be positioned to collect the electrons generated by the layer of secondary emissive material.

[0011] In many applications a very high count rate is required at high pixel density. The development of integrated circuits capable of reading, for example, 64 channels with a time resolution of better than 100 picoseconds requires a corresponding improvement in detector technology to take advantage of these new circuits. Previously, the count rate of typical electron multipliers was limited by space charge and the R-C time constant of the multiplier. However, the provision of the layer allows for the amplification of electron signals independent of the electron multiplier, so reducing space charge within the electron multiplier, allowing the use of higher count rates. Furthermore, the provision of discrete first electrodes allows for an improved spatial resolution over the prior art resistive sea.

[0012] The apparatus may comprise a semi-insulating anode joining the first electrodes together. The apparatus may also comprise a voltage source arranged to provide a potential difference between the anode and the electron multiplier, and typically also across the electron multiplier, and between the anode and the metallic grid.

[0013] Either of the first and second electrodes can be formed of metal or metallic materials.

[0014] In one example, the anode can comprise sapphire and the first electrodes can be formed of silicon. This is particularly convenient when the wall is formed of alumina ceramic. In such a case, the layer may be formed of diamond, typically polycrystalline diamond. The diamond may be doped, typically with boron; this allows the degree of insulation of the layer to be controlled.

[0015] In another embodiment, the anode can comprise sapphire or borosilicate glass, preferably expansion matched to the wall. The first electrodes can each comprise a metal film, which can be formed by screen printing a metal film or thermal evaporation of a metal film in vacuum. The layer can be formed over the first electrodes by means of a process such as atomic layer deposition of a material having high secondary electron emission, such as Magnesium Oxide (MgO) doped with a small percentage, say around 60%, typically between 50-70%, of Zinc Oxide (ZnO). Many other materials are possible, the important parameters leading to the selection of the secondary emitter relate to high secondary emission, cost, convenience, vacuum compatibility and so on.

[0016] The apparatus may further comprise a detection circuit for detecting at each second electrode an electric signal generated by the incidence of an electron at the corresponding first electrode. The detection circuit may have a time resolution being the precision with which it can determine the arrival time of the electric signal; the time resolution may be better than or at most 200 picoseconds, and preferably better than or at most 100 picoseconds.

[0017] The detection circuit may be electrically coupled to each second electrode. The detection circuit may only be electrically coupled to each first electrode via each second electrode. This therefore reduces the need for connections to be made through the wall.

[0018] The capacitance between each pair of first and second electrodes may be significantly more than the capacitance between any pair of first electrodes, and in particular between adjacent pairs of first electrodes. As such, the capacitance between each pair of first and second electrodes may be in the region of 0.1 to 10 picofarads, typically around 1 to 2 picofarads.

[0019] Each of the first electrodes may each have a length along the wall, being the maximum linear extent along the wall; the maximum length of the first electrodes may be less than 10 mm, 5 mm, 2 mm or 1 mm. As such, the first electrodes can be made to be relatively small, thus increasing spatial precision.

[0020] The layer, the first electrodes and the anode may be provided in any order on the wall; in a preferred embodiment, the anode can be on the inner surface of the wall, the first electrodes over the anode and the layer over the electrodes, so as to be closest to the incident electrons.

[0021] The electron multiplier will preferably comprise a microchannel plate. In order to achieve the desired time resolution, the microchannel plate may be a glass or silicon microchannel plate.

[0022] According to a second aspect of the invention, there is provided a method of manufacturing part of an electron multiplying apparatus, the method comprising applying, to an area of a wall of the apparatus:

- a plurality of first electrodes; and
- a layer of secondary emissive material.

[0023] Preferably, the electron multiplying apparatus is one in accordance with the first aspect of the invention.

[0024] The method may further comprise applying a semi-insulating anode to the area. The method may also comprise applying a plurality of second electrodes to an opposing side of the wall to the first electrodes, there being a second electrode for and adjacent to each first electrode.

[0025] The method may comprise providing a sapphire anode, typically with a layer of silicon thereon. The method may further comprise etching the silicon to form the first electrodes. The method may further comprise growing the layer of secondary emissive material over the etched electrodes, the layer comprising polycrystalline diamond. The method may include the step of doping the polycrystalline diamond, typically with boron. The level of doping can be used to control the degree of insulation of the anode.

[0026] The method may then comprise the step of joining the anode, first electrodes and layer to the wall; this can be by any suitable means, for example brazing, soldering or by using glass frits. This method is particularly applicable where the wall is formed of alumina ceramic. The step of joining may provide the steps of applying the first electrodes, the layer and the anode.

[0027] In an alternative embodiment, the anode is formed of sapphire or borosilicate glass. The method may comprise the step of applying the first electrodes to the anode, which may be formed as a flat plate made of sapphire or glass etc, typically by screen printing a metal film or thermal evaporation of a metal film. The method may then include the step of applying the layer over the electrodes, typically through atomic layer deposition. The layer may comprise Magnesium Oxide (MgO) doped with Zinc Oxide (ZnO). The method may therefore comprise the step of joining the structure thus formed to the wall.

[0028] Any of the optional features of the first aspect of the invention may be applied, where appropriate, to the present aspect.

[0029] According to a third aspect of the invention, there is provided a method of using an electron multiplying apparatus according to the first aspect of the invention, the method comprising determining the position of electrons incident on the first electrodes by determining on which second electrodes an electronic signal is received.

[0030] There now follows, by way of example only, embodiments of the present invention, described with reference to the accompanying drawings, in which:

Figure 1 shows a schematic cross section through an electron multiplying apparatus according to a first embodiment of the invention;

Figures 2a and 2b show a first example of the patterns formed by the first and second electrodes respectively;

Figures 3a and 3b show a second example of the patterns formed by the first and second electrodes respectively; and

Figure 4 shows a schematic cross section through an electron multiplying apparatus according to a second embodiment of the invention.

[0031] An electron multiplying apparatus according to an embodiment of the invention is shown in the accompanying drawings. The apparatus 1 comprising a housing 2 having walls which define an evacuated enclosure 3 which is kept at significantly below atmospheric pressure (typically Ultra High Vacuum, that is less than 100 nanopascals). Within the enclosure 3 there is provided a source of electrons, being a photoelectron conversion layer 4 such as the well known Bialkali photocathode.

[0032] Light 5 incident on the photoelectron conversion layer 4 (through a transparent part of the housing 2) causes the emission of electrons 6. Typically, 10% of incident photos result in the emission of a primary electron.

[0033] The primary electrons 6 emitted from the photoelectron conversion layer 4 to an electron multiplier 7, being a multichannel plate. The microchannel plate is formed of a plurality of narrow glass tubes embedded in a matrix. A power supply 8 external to the enclosure 3 provides a potential difference of around 1000V across the microchannel plate 7. The action of the potential difference on the microchannel plate 7 is to multiply the incident electrons 6, such that for each primary electron 6, many more (typically 100,000) secondary electrons 9 are emitted.

[0034] The secondary electrons 9 are emitted from the microchannel plate 7 and pass to an output structure 10 on the inside of the wall of the housing 2. This structure 10 comprises a semi-insulating anode 11, connected to the power supply 8 so as to be at a potential difference to the microchannel plate 7, with a plurality of individual conducting first electrodes 12 formed thereover. The shapes of the electrodes can be as desired; some example shapes are shown in Figures 2a and 3a of the accompanying drawings. A grid of such electrodes can then be built up, with the grid spacing being around 5 mm.

[0035] In order to couple the output of the apparatus 1 outside of the enclosure 3, each first electrode 12 is provided with a corresponding second electrode 14 on the outside of the wall of the housing 2 adjacent to the first electrode 12 (and so also forming a grid). Each pair of first and second electrodes is capacitively coupled together, such that an electron incident on a first electrode 12 will cause an electric signal to be generated at the corresponding second electrode 14. This electric signal is picked up by a detector circuit 15. As such, by determining which second electrode 14 that a signal is received on, the detector circuit 15 can determine the location of the electron that caused that signal to be generated on the first electrodes. The position of the photon which caused the original primary electron emission can therefore be estimated.

[0036] In order to improve the performance of the apparatus, a layer of secondary emissive material 13 is provided over the electrodes. Electrons incident on the structure 10 will first hit the layer 13, in which further secondary electron emission will occur. This amplifies the electron signal externally to the microchannel plate 7, so reducing the space charge within the microchannel plate 7, given that the microchannel plate can only sustain a limited current in terms of amperes per square centimetre of face area. By providing gain after the microchannel plate, higher count rates can be used.

[0037] It can be seen that the detector circuit 15 can be coupled to the second electrodes by means of a simple electrical contact (be it silver epoxy, springs or so on). There is no need, as far as the detection circuit is concerned, to make any connections through the walls of the housing 2. This reduces the number of through connections that are required, thus making the apparatus much easier to manufacture. Furthermore, there is less cross talk between first electrodes than there would be if a single resistive electrode were to be used.

[0038] Where the walls of the housing 2 are formed of alumina ceramic, the semi-insulating anode 11 can be formed of sapphire and can be joined to the housing 2 by brazing, soldering or with glass frits. The first electrodes 12 are formed of silicon; silicon-on-sapphire discs of several centimetres in diameter are available commercially. The first electrodes can be formed by etching patterns into the silicon on those discs to define the gaps between the electrodes. The layer 13 can then be formed as a layer of polycrystalline diamond on the silicon electrodes 12 by plasma deposition. The degree of insulation is controllable by boron doping the diamond film during deposition.

[0039] In an alternative embodiment, the semi-insulating anode 11 is made from sapphire or a borosilicate glass chosen to match other manufacturing requirements. An array of first electrode 12 patterns is made by, for example, screen printing a metal film or thermal evaporation of a metal film in vacuum through a metal mask. Onto this, Atomic Layer Deposition (ALD) is used to deposit a semi-insulating film which also has high secondary electron emission. This film could for example be magnesium oxide (MgO) doped with a small percentage of zinc oxide (ZnO).

[0040] The secondary electron emission of diamond can reach 100 secondary electrons per primary electron, potentially improving the count rate by this same number, but is a relatively more expensive approach than the ALD route. Currently the ALD route achieves a much more modest improvement of about 8:1.

[0041] In either case, the capacitance between each pair of first 12 and second 14 electrodes will be very much more than the capacitance between adjacent first electrodes 12, typically in the region of 1 to 2 picofarads. This means that the second electrodes will typically be 3 to 5 mm in diameter, around 20 mm^2 in area. Some sample patterns that could be used are shown in Figures 2b and 3b of the accompanying drawings, which complement the patterns shown in Figures 2a and 3a respectively for the first electrodes. The second electrodes can be formed by metal sputtering or any other convenient method.

[0042] Figure 4 of the accompanying drawings shows an electron multiplying apparatus according to a second embodiment of the invention. This functions in much the same way as the apparatus of Figures 1 to 3, and to that end features that function in the same manner as in the previous embodiment have been given corresponding reference numerals, raised by 50.

[0043] This embodiment explicitly includes a metallic grid 70, which forms a collector mesh. The metallic grid is connected to the power supply 58. The power supply applies potential differences, so that the various components are at the voltages, relative to an arbitrary zero:

- Cathode 54: 0 volts
- Back face of microchannel plate 57: 200 volts
- Front face of microchannel plate 57: 1200 volts
- Metallic grid 70: 2000 volts
- Anode 61: 1700 volts

[0044] This means that electrons 59 emitted from the microchannel plate 57 will, on the whole, pass through the grid 70 and impinge upon the layer 63 over one of the first electrodes 62. That first electrode will see a negatively-going voltage due to the impact of the electron, followed by a positively-going voltage as the secondary electrons then leave, the positively-going voltage being generally greater than the negatively, because of the high second emission coefficient of the secondary material of the layer 63. These voltages are coupled to the second electrodes 64 and detected by detector 65. The secondary electrons 71 emitted by the layer 63 are then captured by the metallic grid 70.

Claims

1. According to a first aspect of the invention, there is provided an electron multiplying apparatus, comprising:

a housing having a wall defining an enclosure, the wall having an inner surface within the enclosure and an outer surface outside the enclosure;
a source of electrons;
an electron multiplier positioned within the enclosure so as to receive electrons from the source of electrons and to emit multiple electrons for each electron received;
a plurality of pairs of electrodes, each pair comprising a first electrode on the inner surface of the wall and a second electrode on the outer surface of the wall adjacent to the first electrode and separated from the first electrode by the wall.

2. The apparatus of claim 1, comprising a layer of secondary emissive material on the first electrodes on the inner surface of the wall, positioned so that electrons emitted by the electron multiplier are incident on the layer.

3. The apparatus of any preceding claim, comprising a metallic grid between the electron multiplier and the first electrodes.

4. The apparatus of any preceding claim, comprising a voltage source arranged to provide a potential difference in at least one of the following locations:

- between the anode and the electron multiplier,
- across the electron multiplier,
- between the anode and any metallic grid.

5. The apparatus of any preceding claim, comprising a semi-insulating anode joining the first electrodes together.

6. The apparatus of claim 5, in which the anode comprises sapphire and the first electrodes are formed of silicon, and in which the layer is preferably formed of diamond, typically polycrystalline diamond.

7. The apparatus of claim 5, in which the anode comprises sapphire or borosilicate glass, the first electrodes each comprising a metal film.

8. The apparatus of any preceding claim, comprising a detection circuit for detecting at each second electrode an electric signal generated by the incidence of an electron at the corresponding first electrode.

9. The apparatus of claim 8, in which the detection circuit is electrically coupled to each second electrode, but is only electrically coupled to each first electrode via each second electrode.

10. The apparatus of any preceding claim, in which the electron multiplier comprises a microchannel plate.

11. A method of manufacturing part of an electron multiplying apparatus, the method comprising applying, to an area of a wall of the apparatus:

- a plurality of first electrodes; and
- a layer of secondary emissive material.

12. The method of claim 11, comprising applying a semi-insulating anode to the area.

13. The method of any of claims 11 to 12, comprising applying a plurality of second electrodes to an opposing side of the wall to the first electrodes, there being a second electrode for and adjacent to each first electrode.

14. The method of any of claims 11 to 13, comprise providing a sapphire anode, with a layer of silicon thereon, etching the silicon to form the first electrodes and growing the layer of secondary emissive material over the etched electrodes, the layer comprising polycrystalline diamond.

15. The method of any of claims 11 to 13, in which the anode is formed of sapphire or borosilicate glass, the method comprising the step of applying the first electrodes to the anode and optionally the step of applying the layer over the electrodes, typically through atomic layer deposition.

16. A method of using an electron multiplying apparatus according to any of claims 1 to 13, the method comprising determining the position of electrons incident on the first electrodes by determining on which second electrodes an electronic signal is received.

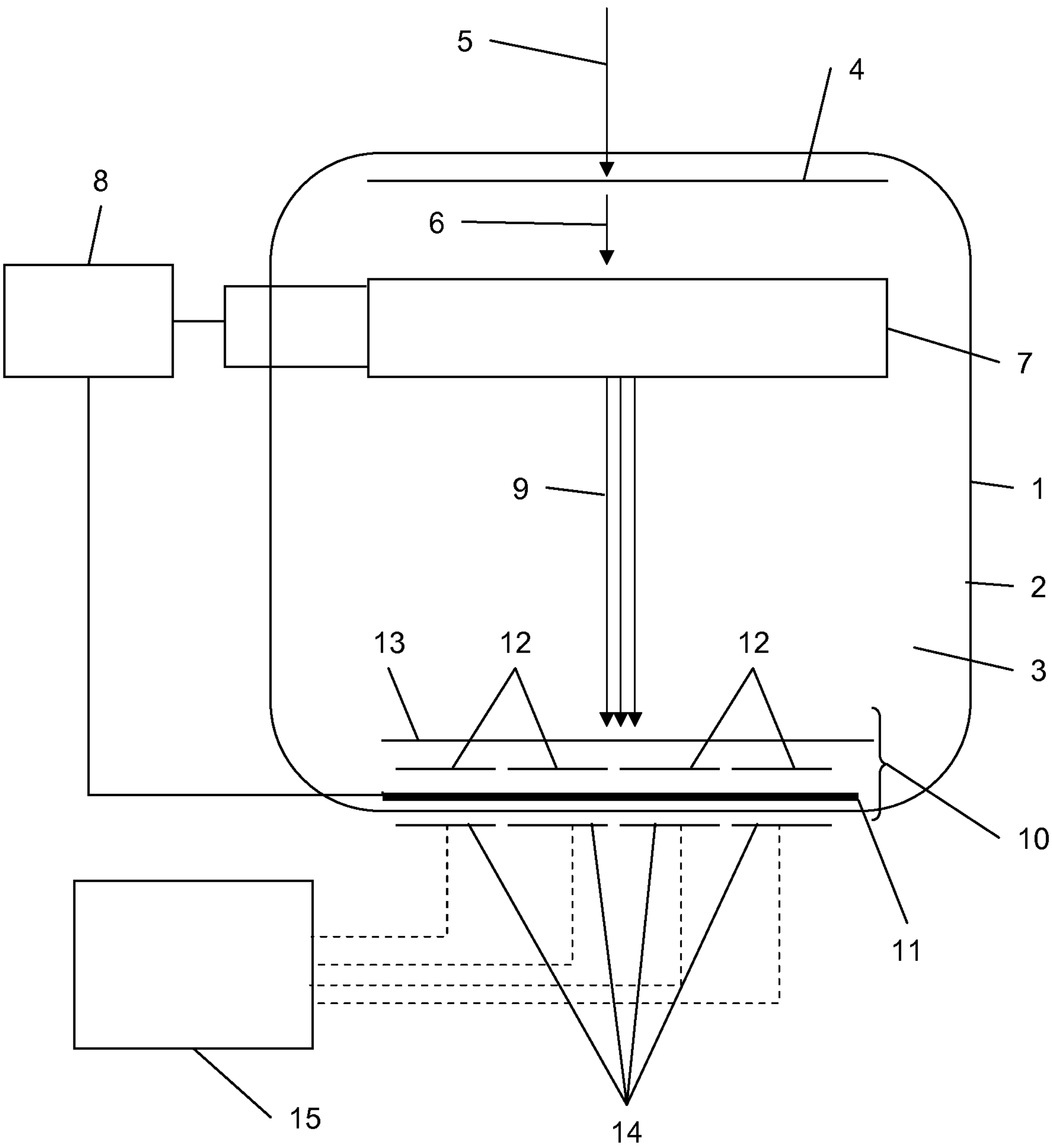

Fig 1

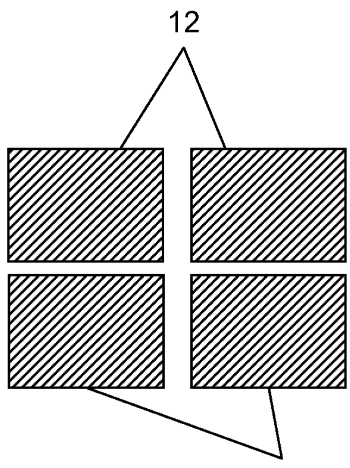

Fig 2a

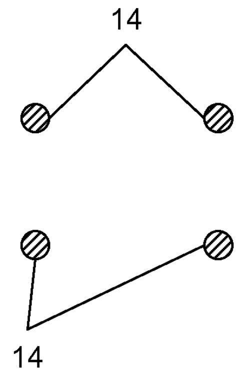

Fig 2b

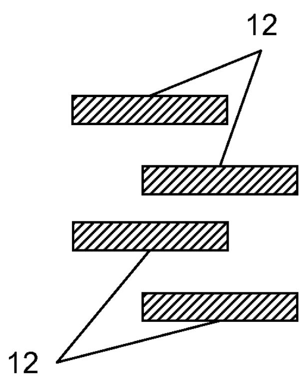

Fig 3a

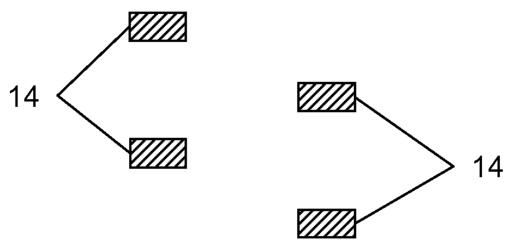

Fig 3b

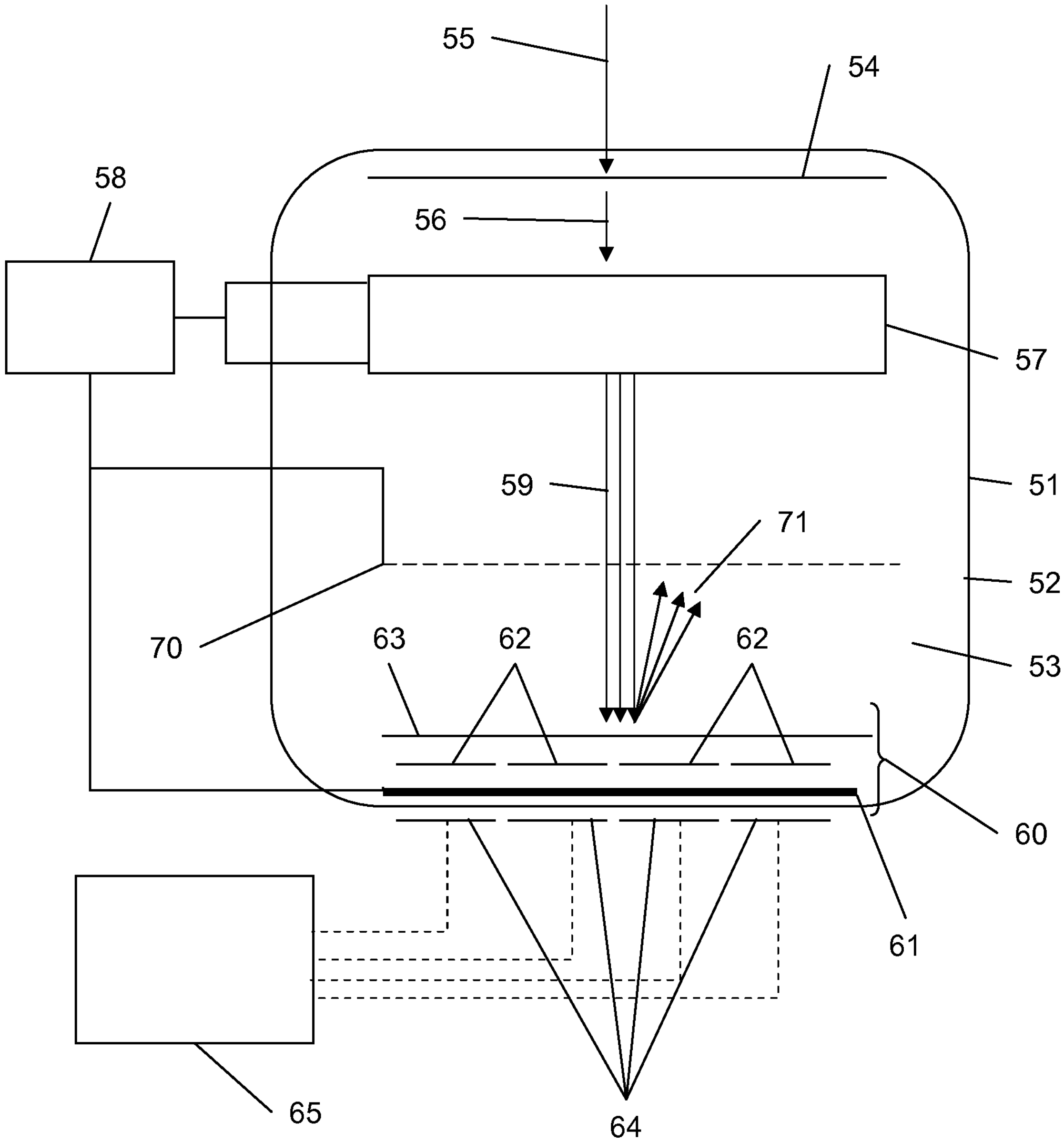

Fig 4

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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