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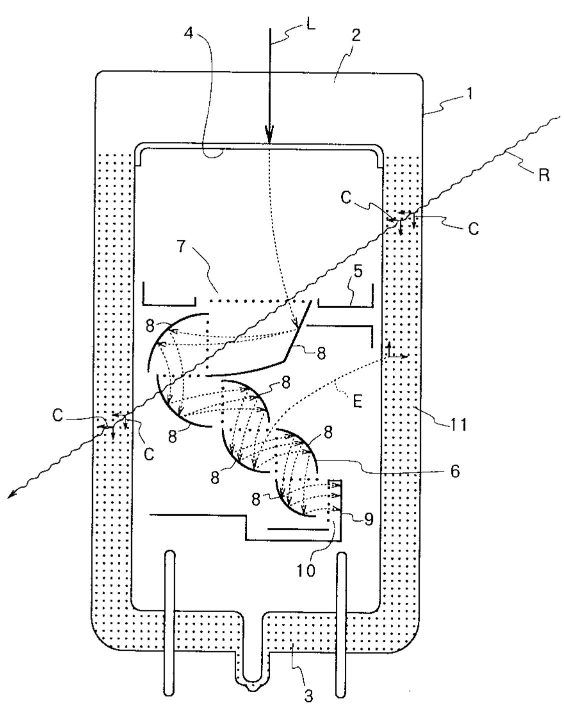
(54) Photomultiplier tube

(57) A photomultiplier tube includes a photocathode (4), a focusing electrode (7), a dynode array (8), and an anode (9), all contained within a vacuum sealed container (1). The container (1) is configured from a glass bulb having a transparent portion (2) on which light is incident and which guides the light to the photocathode (4) and a colored portion (11) which is colored black. In this configuration, even if cosmic rays or ambient gamma rays or leakage electrons from inside the dynode array (8) generate light in the side wall of the glass bulb (1), the light will be absorbed or trapped in the colored portion (11). Therefore, light which becomes a source of noise will not reach the photocathode (4).

FIG. 1



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Description

The present invention relates to a photomultiplier tube.

A photomultiplier tube is highly sensitive light detecting device to detect light having weak intensity into an amplified electrical signal. The photomultiplier tube basically includes a vacuum sealed vessel in which are contained a photocathode, a focusing electrode, an electron multiplying portion or a dynode array, and an anode. The photocathode is adapted for converting light incident thereto into photoelectrons. The focusing electrode is adapted for guiding photoelectrons to the dynode array. The dynode array is adapted for emitting secondary electrons at a predetermined multiplication rate upon incidence of an electron by secondary emission effect. The anode is adapted for collecting the multiplied secondary electrons emitted from the dynode array and for outputting an electrical signal to thereby convert the light having weak intensity into the amplified electrical signal corresponding thereto.

Normally, the vacuum sealed vessel of a conventional photomultiplier is made from a transparent glass bulb. Sometimes Cerenkov radiation can be generated in the glass wall because of incident cosmic rays or ambient gamma rays. Light is also sometimes generated by electrons, multiplied by the dynode array, and colliding with the glass bulb.

The generated light may be transmitted through the transparent glass bulb so that the generated light portion falls incident on the photocathode, thereby causing emission of photoelectrons. When these photoelectrons are guided to the dynode array, they are multiplied by the dynode array and detected as a noise signal.

Japanese Patent Publication No.Sho 56-40941 discloses a photomultiplier tube in which a surface roughening treatment is effected onto an inner surface of a glass bulb so as to reduce the generation of light due to the impingement of electrons subjected to multiplication onto the glass bulb. However, the disclosed photomultiplier cannot prevent generation of Cerenkov radiation due to the incidence of external cosmic rays or ambient gamma rays.

For this reason, it is conceivable to cover the inner periphery or the outer periphery of the transparent bulb with a metal layer so that intrusion of light generated from cosmic rays or ambient gamma rays into the interior of the glass bulb can be restricted. Alternatively the bulb is made from a metallic vacuum sealed vessel.

However, if the inner periphery of the transparent glass bulb is covered with metal, a strong electric field is generated between the metal surface at the inner periphery and the electron multiplication portion. This produces the problem of increased noise. The same problem exists with the metallic bulb. Cosmic rays, ambient gamma rays, and the like can pass through the metal if only the outer periphery of the transparent glass bulb is covered with metal. Therefore, Cerenkov radiation, and noise, is generated in the same manner as the conventional transparent glass bulb.

Japanese Patent Application Kokai No.Sho 61-68848 discloses a photomultiplier tube in which a Cr-deposition layer is provided onto an inner surface of a glass bulb at portion other than a light incident window so as to prevent light from being entered through an area other than the window thereby avoiding reduction in S/N ratio. Even though the Cr deposition layer can perform light shielding function, Cerenkov radiation may still occur when cosmic rays or ambient gamma ray propagate in a manner of total reflection in a wall of the glass bulb and finally enter into the interior of the glass bulb through the non deposited portion, i.e., window.

Thus, it is an object of the present invention to provide a photomultiplier tube that can restrict noise from light generated in a glass bulb, particularly by the Cerenkov radiation.

According to this invention, a photomultiplier tube includes an improved vacuum sealed container having a container wall, a photocathode, a dynode array, a focusing electrode, and an anode. The photocathode is provided at a surface of the container for emitting photoelectrons upon reception of light. The dynode array is disposed in the container for multiplying photoelectrons emitted from the photocathode. The focusing electrode is disposed in the container for guiding photoelectrons from the photocathode to the dynode array. The anode is disposed in the container for catching electrons multiplied by the dynode array. The container is made from a glass bulb having a transparent portion for guiding light incident thereon onto the photocathode and a colored portion for absorbing therein unwanted light generated in the container wall.

In more concrete terms, when the photomultiplier is a head-on type, that is, when a substantially cylindrical glass bulb with both ends sealed and with the one sealed end formed with a photocathode is used as the vacuum sealed vessel, the sealed end portion at the side formed with the photocathode is the transparent portion and the side wall portion of the glass bulb is the colored portion. Also, the sealed portion at the other side of the glass bulb can also be colored. Black is a desirable color for the color of the colored portion.

With the above-described structure even if cosmic rays, ambient gamma rays, or electrons leaked from inside the electron multiplication portion collide with the colored portion of the glass bulb and generate light, the light will be absorbed or trapped in the colored portion. Therefore, generation of noise signal can be reduced. Accordingly, the type of photomultiplier according to the present invention can be particularly effectively used in liquid scintillation counters, high-energy neutrino detectors, experiments for confirming annihilation with electrons of positrons, and other measurement of weak light.

Particular embodiments of photomultiplier tubes in accordance with this invention will now be described with reference to the accompanying drawings, in which:-

Fig. 1 is a cross-sectional view schematically showing a photomultiplier tube according to an embodiment of the present invention;

Fig. 2 is an explanatory view schematically showing test equipment for comparing performance of a photomultiplier tube according to the present embodiment with a conventional photomultiplier tube;

Fig. 3 is a graph showing results of experiments according to the test equipment of Fig. 2; and

Fig. 4 is a cross-sectional view schematically showing a photomultiplier tube according to a second embodiment of the present invention.

A photomultiplier tube according to a first embodiment of the present invention will be described while referring to Figs. 1 through 3.

The first embodiment concerns a head-on type photomultiplier tube. A cylindrical glass bulb 1 serves as a vacuum sealed vessel, whose both ends are sealed to maintain a vacuum in the interior. One sealed end (the end at the upper side of the drawing) is referred to as a head portion 2 and the other sealed end is referred to as a stem portion 3. A photocathode 4 is formed to the inner surface of the head portion 2 by deposition of a photoelectron emitting material.

A focusing electrode 5 is positioned at the position opposing the head portion 2. An electron multiplying portion 6 is positioned below the position of the focusing electrode 5. An opening 7 for focusing photoelectrons from the photocathode 4 and introducing them to the electron multiplying portion 6 is formed to the focusing electrode 5.

Although there are various types of electron multiplying portions 6, the electron multiplying portion 6 of this embodiment is formed from a multi-step box-and-grid type dynode 8. Also, a plate-shaped dynode 9 is positioned at the final step of the electron multiplying portion 6. An anode 10 for collecting electrons is positioned at the front surface of the dynode 9.

In the cylindrical glass bulb 1, only the head portion 2 is transparent and other portions, that is, the cylindrical side wall 11 and the stem portion 3 are colored, desirably black. The coloring is provided when producing a glass. That is, the glass is melted with addition of a coloring agent such as Fe and Mn. The colored molten glass is subjected to drawing to provide a tubular glass member. Then, the colored head portion of the tube is replaced with a transparent glass portion to provide the head portion 2.

With this arrangement, when a voltage is applied between the photocathode 4 and the anode 10 by connection to a high-voltage power source, emission of photoelectrons occurs resulting from the light L falling incident on the head portion 2 and transmitted through the head portion 2 and hitting the photocathode 4. The photoelectrons are guided to the electron multiplying portion 6 where they are multiplied by the secondary electron emission effect at the dynodes 8 and 9 of the dynode array 6. The photoelectrons are collected by the anode 10 as an output signal. Such operation mode is well known in the art.

When an external radiation ray R such as an ambient gamma ray or a cosmic ray falls incident on the side wall 11 of the glass bulb 1, Cerenkov radiation C is generated in the interior of the side wall 11 by mutual action of the external radiation ray R and the material of the glass bulb 1. However, the Cerenkov radiation C is absorbed or trapped in the black colored side wall 11 so that the Cerenkov radiation C is not emitted toward the internal space of the glass bulb 1 and so that almost no light resulting from the Cerenkov radiation reaches the photocathode 4. Therefore the detected noise signal is greatly reduced.

Further, the external radiation ray R passing through the side wall 11 passes through the internal space in the glass bulb 11 to the side wall 11 on the opposite side where it is transmitted from the inner periphery surface to the external periphery surface of the opposite side wall 11. in this case, Cerenkov radiation C is generated at this time also. However, the Cerenkov radiation C generated at the side wall 11 on the opposite side is also absorbed or trapped by the black-colored side wall 11 so that noise is suppressed. Although not shown in the drawings, Cerenkov radiation from external radiation rays transmitted through the stem portion 3 are of course absorbed in the same manner.

Furthermore, as shown by the letter E in Fig. 1, sometimes electrons leak from the dynode array 6. Sometime light is also generated when leakage electrons E reach the side wall 11 of the glass bulb 1 or reach the stem portion 3. However, in the same manner as with Cerenkov radiation, this light is absorbed by the black-colored side wall 11 or stem portion 3.

Comparative experiments were conducted to demonstrate superiority of the photomultiplier tube according to the present invention over a conventional photomultiplier tube having a transparent glass bulb. In the experiments, a box shaped lead shield 20 as shown in Fig. 2 was disposed in a dark room. The same type of photomultiplier tubes 21 and 22 serving as test samples were positioned in the lead shield 20 in opposition. A high-voltage power source 23 was connected to the photomultiplier tubes 21 and 22, respectively. The output signals from these photomultiplier tubes 21 and 22 were both inputted to a pulse addition circuit 24 and a high-speed simultaneous count circuit 25. Also, output signal from the high-speed simultaneous count circuit 25 and the pulse addition circuit 24 were inputted to a crest analyzer circuit 26. The test equipment was designed to count noise pulses generated by Cerenkov radiation emitted simultaneously at the interior of both the photomultiplier tubes 21 and 22 by action of cosmic rays, ambient gamma rays, and other external radiation rays that pass through the lead shield 20.

Test samples (a) through (k) were prepared. The samples (a) through (c) correspond to photomultiplier tubes configured as per the embodiment of Fig. 1, whereas samples (d) through (k) correspond to conventional transparent photomultiplier glass tubes. The photomultiplier tubes of the samples (a) through (k) have totally the same dimensions and internal construction. Also, the glass bulbs in the sample photomultiplier tubes (d) through (k) and the colored portion of the glass bulbs in the sample photomultiplier tubes (a) through (c) are composed as per the following Table 1:

Table 1

Composition of colored portion of glass bulb (Wt%)		Composition of transparent glass bulb (Wt%)	
SiO_2	54.0	SiO_2	68.25
Al_2O_3	4.0	Al_2O_3	3.34
B_2O_3	25.0	B_2O_3	16.79
NaO	2.0	NaO	1.17
K_2O	6.0	K_2O	7.81
Fe_2O_3	7.0	LiO	0.65
MnO	2.0		

The test results are represented in a graph shown in Fig. 3. According to the graph, a geometric mean of simultaneous count noise of samples (a) through (c) was 3.71 CPM (counts per minute). On the other hand, the geometric mean of simultaneous count noise of samples (d) through (k) was 4.43. CPM.

It can be understood from the test results that the photomultiplier tube configured as per Fig. 1 suppresses generation of noise compared to the conventional photomultiplier tube.

A photomultiplier tube according to a second embodiment of the present invention is shown in Fig. 4. In the first embodiment, the stem portion 3 and the side wall 11 of the glass bulb 1 are being colored. However, in the second embodiment, the stem portion 3 is transparent and only the side wall 11 is colored. The reason is that, the dynode array 6 acts as an optical barrier between the stem portion 3 and the photocathode 4, so that the dynode array 6 blocks most light generated at the stem portion 3 from reaching the photocathode 4. Therefore, the stem portion 3 could be transparent and only the side wall 11 colored. Modifications may be made, for example, in the Table 1 above, the glass bulb 1 was colored black by adding Fe_2O_3 and MnO to its composition. However, the composition for coloring is not limited to the that noted in the Table 1. Also, coloring is not limited to black. When it is desirable to absorb light of a particular wavelength, any color could be used that absorbs that wavelength of light.

Further, the present invention is not limited to a head-on type photomultiplier tube. The present invention could be applied to other tube types, for example, a side on type photomultiplier tube. Of course, when the present invention is applied to a side-on type photomultiplier tube, all portions, except the light incidence window opposing the reflection type photocathode, would be colored.

Claims

1. A photomultiplier tube comprising:

a vacuum sealed container (1) made from a glass bulb having a transparent light entrance window (2);
a photocathode (4) provided at a surface of the container (1) for emitting photoelectrons upon reception of light through the entrance window (2);
a dynode array (8) disposed in the container (1) for multiplying photoelectrons emitted from the photocathode (4);
a focusing electrode (7) disposed in the container (1) for guiding photoelectrons from the photocathode (4) to the dynode array (8); and
an anode (9) disposed in the container (1) for catching electrons multiplied by the dynode array (8);
characterised in that the glass bulb (1) has a colored portion (11) for absorbing therein unwanted light generated in it.

2. A photomultiplier tube as claimed in Claim 1, wherein the glass bulb (1) comprises a substantially cylindrical glass tube having a tubular side wall portion (11), one sealed end portion (2) and another sealed end portion (3), the one sealed end portion being transparent, forming the entrance windows (2) and formed with the photocathode (4) to provide a head-on type photomultiplier, and the tubular side wall portion (11) being the colored portion.

3. A photomultiplier tube as claimed in Claim 1, wherein the glass bulb comprises a substantially cylindrical glass tube having a tubular side wall portion (11), the tubular side wall portion including the transparent entrance window and the colored portion to provide a side-on type photomultiplier.

4. A photomultiplier tube as claimed in Claims 2 or 3, wherein the other sealed end portion (3) is also part of the colored portion.

5. A photomultiplier tube as claimed in any preceding claim, wherein the colored portion (11) is colored black.

6. A photomultiplier tube as claimed in any preceding claim, wherein the colored portion (11) contains a glass material and a coloring agent mixed therewith.

FIG. 1

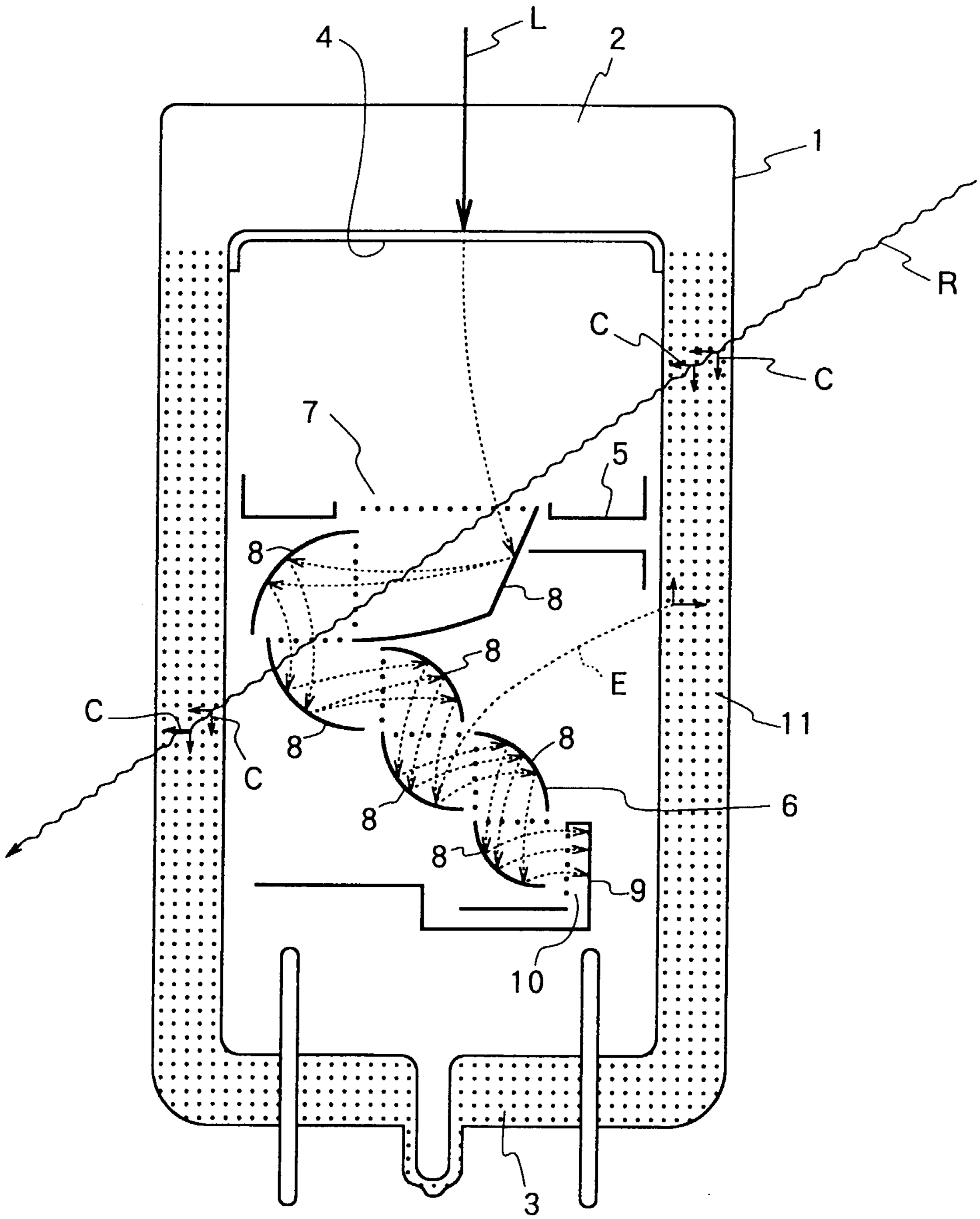


FIG. 2

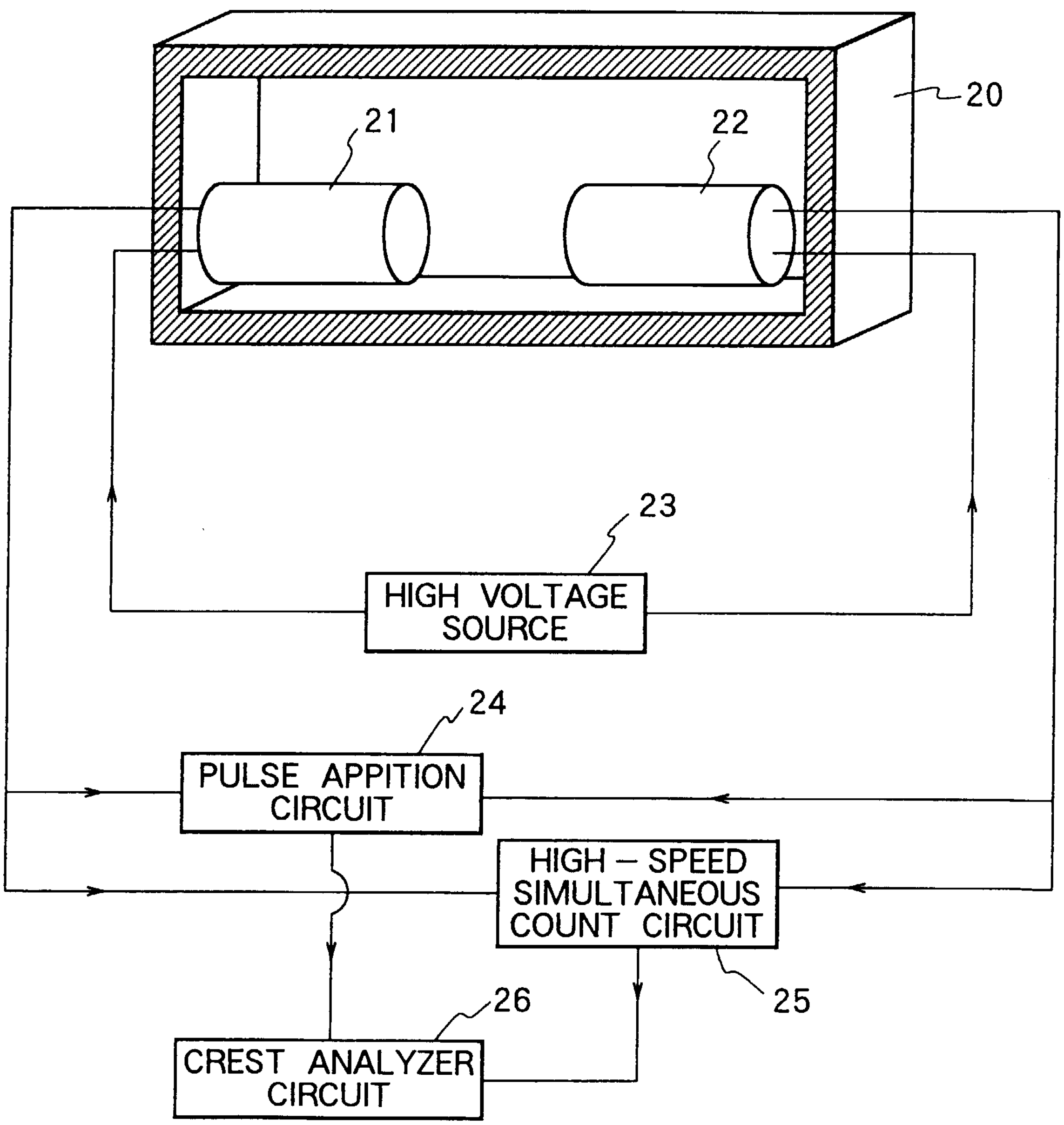

20
21
22
23
HIGH VOLTAGE SOURCE
24
PULSE APPITION CIRCUIT
HIGH - SPEED SIMULTANEOUS COUNT CIRCUIT
25
26
CREST ANALYZER CIRCUIT

FIG. 3

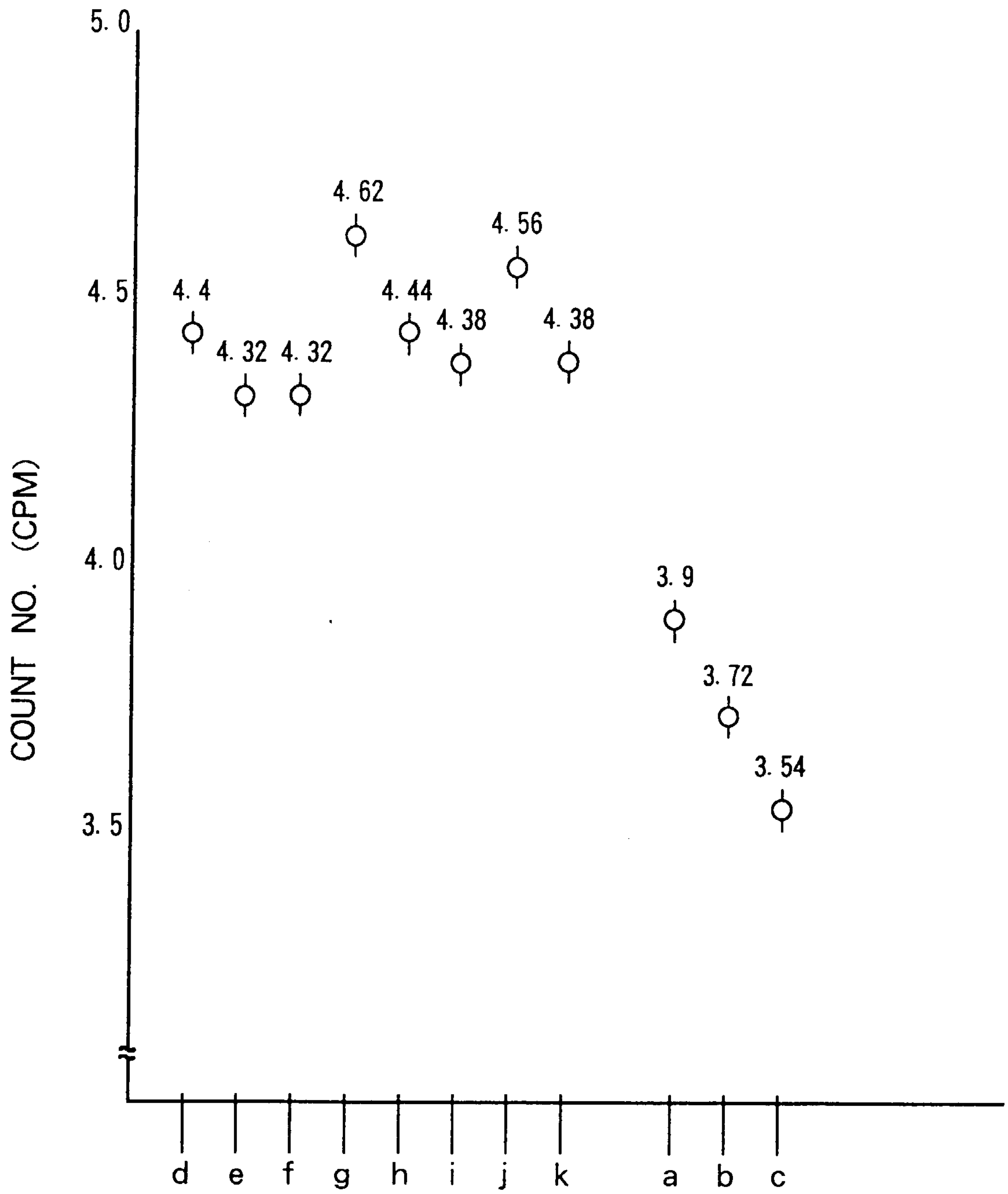
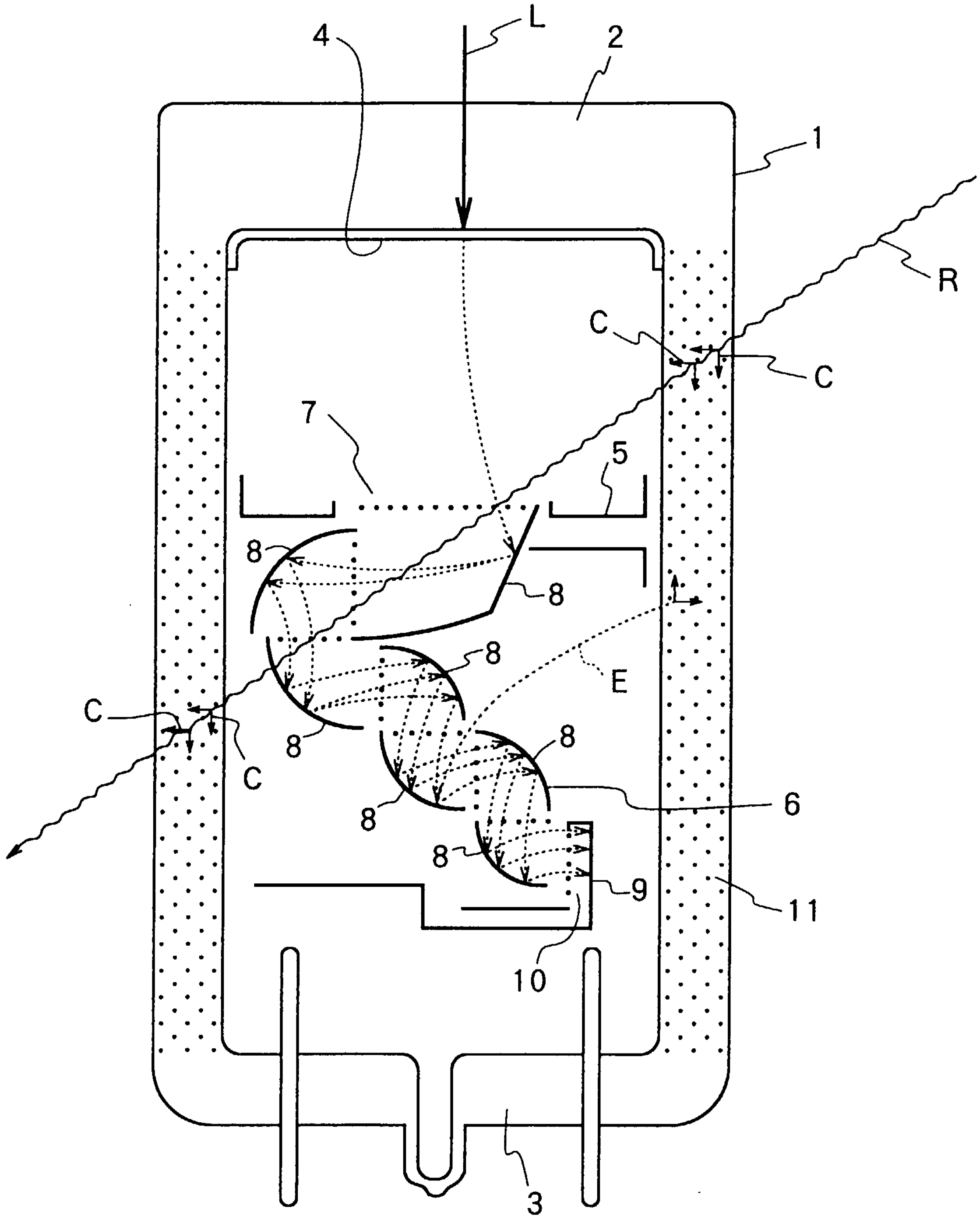

COUNT NO. (CPM)
5. 0
4. 5
4. 0
3. 5
4. 4
4. 32
4. 32
4. 62
4. 44
4. 38
4. 56
4. 38
3. 9
3. 72
3. 54
d
e
f
g
h
i
j
k
a
b
c

FIG. 4



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EUROPEAN SEARCH REPORT

Application Number
EP 96 30 0391

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	IEEE TRANSACTIONS ON NUCLEAR SCIENCE, vol. ns-14, no. 6, December 1967, NEW YORK US, pages 190-194, XP002003380 A FAVALE ET AL.: "Electron induced noise in star tracker photomultiplier tubes" * page 191, right-hand column, paragraph 3 * * page 192, left-hand column, paragraph 3 * ---	1	H01J43/28
A	EP-A-0 565 247 (HAMAMATSU PHOTONICS KK) 13 October 1993 * column 1, line 5 - line 28 * * column 1, line 58 - column 2, line 11 * * column 2, line 29 - line 35 * * column - * ---	1	
D,A	PATENT ABSTRACTS OF JAPAN vol. 010, no. 236 (E-428), 15 August 1986 & JP-A-61 068848 (HITACHI LTD), 9 April 1986, * abstract * ---	1	TECHNICAL FIELDS SEARCHED (Int.Cl.6) H01J G01T
D,A	PATENT ABSTRACTS OF JAPAN vol. 004, no. 145 (E-029), 14 October 1980 & JP-A-55 095264 (HAMAMATSU TV KK), 19 July 1980, * abstract * -----	1	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	22 May 1996	Colvin, G

CATEGORY OF CITED DOCUMENTS

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