Dec. 31, 1957 R. W. ENGSTROM ET AL 2,818,520

PHOTOCATHODE FOR A MULTIPLIER TUBE

Filed Dec. 30, 1954 2 Sheets-Sheet 1

Fig. 1.

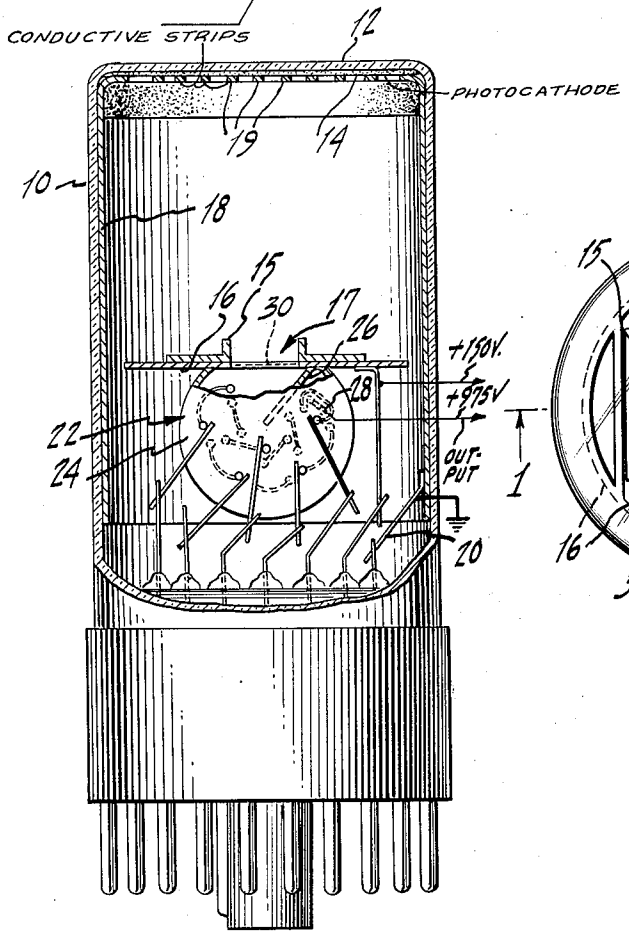
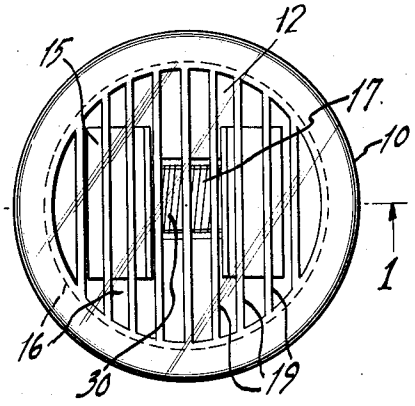


Fig. 2.



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Dec. 31, 1957 R. W. ENGSTROM ET AL 2,818,520

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Filed Dec. 30, 1954 2 Sheets-Sheet 2

Fig. 3.

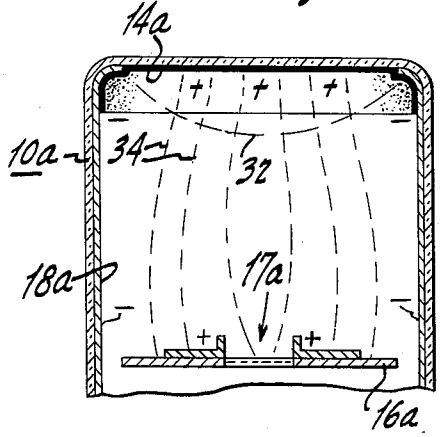


Fig. 4.

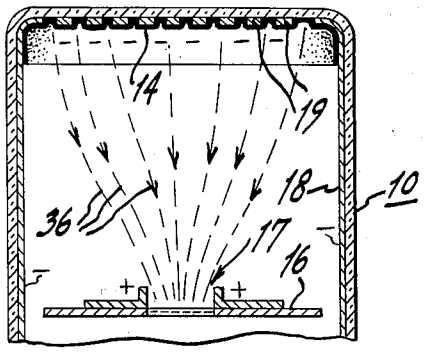


Fig. 5.

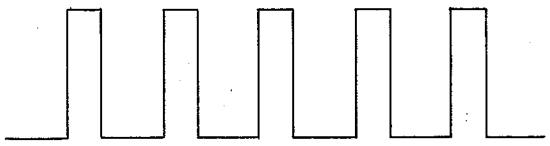


Fig. 6.

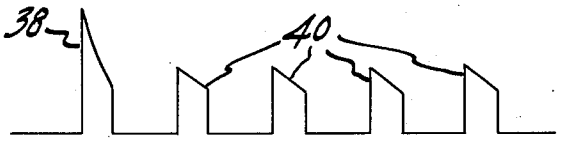
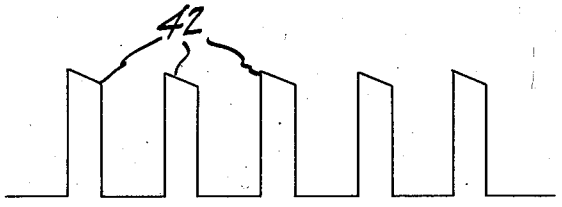


Fig. 7.



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PHOTOCATHODE FOR A MULTIPLIER TUBE

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7 Claims. (Cl. 313—95)

This invention relates to phototubes and has special reference to improvements in photoemissive cathodes for tubes such as high vacuum photomultiplier tubes.

Photomultiplier tubes, having large area photocathode surfaces wherein the photoemissive layer is exposed to a light source, have been used as scintillation counters. The operation of the tube is such that when radiations from radioactive materials are caused to fall upon a phosphor and activate it to luminescence, the light from the phosphor causes photoemission of electrons from the photocathode of the tube. The photoelectrons are then directed, by an electron-optical field, to a photomultiplier structure within the tube. Amplification of the current represented by these photoelectrons is then achieved by secondary emission phenomena. In such a tube it is necessary that the photoemissive layer be maintained at a substantially constant potential along all portions thereof so that electrons may be directed to the electron multiplier structure. This is ordinarily accomplished by connecting an edge of the photoemissive layer to a ground lead.

Since photoemissive layers or films are usually relatively poor electrical conductors, a potential drop takes place across the surface of the photocathode when current is emitted from the photocathode. This causes a distortion of the electron-optical field preventing photoelectrons from reaching the desired portion of the electron multiplier structure. Then, too, it takes time for the photocathode to be supplied with electrons from the lead to the center of the photoemissive layer; this time is usually referred to as the recovery time. The recovery time required by the photocathode of such a tube determines its maximum high frequency response. Since phototubes having relatively large areas of photoemissive materials have the center portions of the material at a relatively large distance from the edge portion thereof, the frequency response of the phototubes having large areas of photoemissive material has heretofore been relatively low.

It is thus an object of the invention to provide a phototube having a large area photocathode and which allows the drawing of a relatively high current from the photocathode layer while maintaining that layer at a substantially uniform field potential.

It is another object of the invention to provide a phototube having a large area photocathode and which exhibits a relatively high frequency response.

It is a further object of the invention to provide a phototube having a large area photocathode and which exhibits a relatively small recovery time.

It is yet another object of the invention to provide an improved phototube having a photocathode, an electron multiplier structure, and means for reducing the time required for the photocathode to come back to a substantially uniform potential after being overloaded by relatively strong light and consequent relatively large photoelectron emission from the photocathode.

It is still another object of the invention to provide improved means for lowering the effective resistance of a photocathode of a phototube so that a relatively high photocurrent may be drawn from the photocathode without a substantial distortion of an electron-optical photoelectron focusing field within the tube.

Stated generally, the foregoing and related objects are achieved in accordance with the invention by the provision of a photocathode having a substantially transparent insulating support member upon which is disposed a plurality of spaced apart conductive strips. Photoemissive means are disposed on the support member and between and in electrically conductive contact with adjacent strips. Thus all portions of the photoemissive means are adapted to be maintained at a substantially uniform potential.

The invention is described in greater detail in connection with the accompanying two sheets of drawings wherein:

Fig. 1 is a sectional view taken on the line 1—1 of Fig. 2, of a photomultiplier tube embodying the invention;

Fig. 2 is an end view of the tube of Fig. 1;

Fig. 3 is a fragmentary sectional view of a phototube similar to the one shown in Fig. 1 but employing a conventional photocathode, the drawing being marked with lines indicative of the paths of the photoelectrons emitted by such a cathode;

Fig. 4 is a view similar to Fig. 3 showing the paths of electrons emitted by the improved photocathode of the present invention;

Fig. 5 illustrates, schematically, a relatively high intensity light source pulsating at a relatively high frequency; and

Figs. 6 and 7 show, schematically, the outputs of the two photomultiplier tubes of Figs. 3 and 4 in response to the light source depicted in Fig. 5.

Fig. 1 shows an embodiment of the invention as applied to a phototube of standard form and dimensions. Such a tube is used in applications involving large-area light sources, such as scintillation counters for the detection and measurement of nuclear radiation. The tube comprises a glass envelope **10**, closed at one end thereof with a transverse wall section **12**, upon which is formed a transparent photocathode **14** in the form of an electrically continuous photoemissive layer or film. In one tube of this type, the end-wall portion **12** has a diameter of approximately two inches. The exposed portion of the photocathode film **14** is approximately 1½ inches. This provides a useful, large, and substantially flat cathode area which permits good optical coupling between the photocathode and the surface of a phosphor screen such as that used, for example, in scintillation counters.

The tube is provided with an accelerating electrode **16** which is spaced from the photocathode. The accelerating electrode **16** is in the form of a disc and has an aperture **17** at its center. A pair of shield members **15** are fixed to the accelerating electrode on opposite sides of the aperture **17**. These shield members serve to shield electrode elements within the tube from contamination by material which is evaporated within the tube during a step in its manufacture.

A metallic wall coating **18** and **19**, which may for example be a relatively thin film or layer of aluminum, is formed on the inner surface of the tube envelope by well known aluminizing techniques. A side wall portion of the coating **18** extends from the photocathode film **14** axially down the tube to a portion below the accelerating electrode **16**. An end wall portion of the coating **19**, which is shown in greater detail in Fig. 2, extends across the photocathode film **14** in the form of a plurality of conducting strips. The metallic wall coating provides electrical contact between the photocathode **14** and a lead **20**, connecting the photocathode **14** and the metallic film **18** and **19** to a source of ground potential, as shown. The side wall portion of the coating **18** also prevents the

collection of charges on the tubular portion of the envelope **10**, which would adversely affect the trajectories of electrons leaving the photocathode film **14**. In addition, a negatively biased wall coating prevents the landing of photoelectrons thereon and contributes to an electron-optical field which directs electrons from the photocathode **14** to the aperture **17**. The operation of the electron-optical field will be described in greater detail below.

As indicated in Fig. 1, a potential difference of about 150 volts is maintained between the accelerating electrode **16** and the photocathode **14**. An electron-optical photoelectron focusing field is thus formed between the positively biased accelerating electrode and the photocathode. The side wall coating **18**, which is at the same potential as the photocathode film **14** to which it is electrically connected, aids in directing the photoelectrons toward the opening **17** into a multiplier structure **22**.

Photoelectrons passing through the aperture **17** are collected by the electron multiplier structure **22**, which is comprised of a plurality of dynode electrodes (shown as dotted lines in Fig. 1) enclosed in a cylindrical metal shield **24**. Photoelectrons from the photocathode **14** impinge upon a first dynode electrode **26** and initiate secondary emission therefrom having a ratio greater than unity. This secondary emission is accelerated and directed by a fixed electrostatic field along curved paths to successive dynodes. Each dynode provides an amplification of the current represented by the electrons striking it to form an ever increasing stream of electrons until those emitted by the last dynode are collected by an anode electrode **28**. The current collected by the anode electrode **28** constitutes the current utilized in the output circuit of the tube.

The opening **17** into the multiplier structure **22** is covered by a mesh grid **30**. This grid is connected electrically to the first dynode **26** and thus tends to prevent secondary electrons, from the first dynode **26**, from passing back toward the photocathode **14**. The first dynode electrode **26** is fixed to the accelerating disc **16** and is thus tied electrically to it. In normal tube operation a potential difference of about 75 volts is maintained between each of the succeeding dynode stages.

Tubes embodying the invention, have been made with an electrically continuous photocathode layer or film formed by putting down on the end wall **12**, and over the electrically conductive strips **19**, a substantially transparent film of manganese. The manganese film is oxidized and there is then deposited on the oxidized manganese film a relatively thin film or layer of antimony which is sensitized by condensing a deposit of cesium metal thereon. The electrically continuous photoemissive film as used in the phototube described is to be distinguished from the type of photoemissive film wherein a substantially non-conductive layer is exhibited. This latter layer is comprised essentially of a plurality of discrete globules of photoemissive material. The electrically continuous photoemissive film described is characterized in having a spectral response which may be varied over a range of between 3000 Angstroms to about 6400 Angstroms. The response of this material is peaked at about 4800 Angstroms. The electrical resistivity of the electrically continuous photoemissive material described is of the order of a megohm per square centimeter.

The portion of the aluminum film across the photocathode layer, which is in the form of a plurality of conductive strips **19**, serves to lower the effective electrical resistivity of the photoemissive layer. Since the conducting strips **19** exhibit a resistivity of the order of a few ohms per square centimeter, substantially all portions of the photoemissive layer are disposed at a relatively close distance to the source of ground potential to which the conducting strips **19** are connected. Thus a photoemissive film having a resistivity of the order of a megohm per square centimeter is endowed with an effective resistivity of the order of a few ohms per square centimeter.

In the operation of phototubes, it is desirable that photoelectrons from all portions of the photocathode film **14** contribute to the signal. It is thus necessary that the photoelectrons originating at all points of the photocathode be directed or guided into the restricted region of the aperture **17** so that these photoelectrons can pass into the multiplier structure **22** and strike the dynode electrode **26**. When a phototube, having a photoemissive cathode without the conductive strips according to the invention, is used with a light source providing a relatively low level of illumination, a relatively small number of photoelectrons are emitted from the photocathode. Since low level illumination on the phototube results in a relatively small amount of photoemission from the photocathode, the resistivity of the photoemissive cathode does not prevent the more centrally disposed portions of the photocathode from being maintained at substantially the potential of the side wall coating **18** and thus at ground potential. Under relatively high level illumination, however, a relatively large number of photoelectrons are emitted from the photocathode. When a relatively large number of photoelectrons are emitted from the photocathode the portions of the photocathode remote from the relatively highly conductive side wall coating become positively charged as a consequence of the large loss of electrons and the remoteness of the center portions of the photocathode from the ground lead. Consequently the photocathode, under relatively high level illumination, tends to become relatively high positively charged at its center while remaining at ground potential at its edges.

Referring now to Fig. 3 there is shown a phototube **10*a*** without conductive strips across the photocathode. The phototube shown in this figure will be described with regard to the operation of the tube under relatively high level illumination. As has previously been explained, the center portion of the photocathode **14*a*** is positively charged under these conditions; the positively charged portion of the photocathode is indicated in the drawing by plus signs at the center of the photocathode.

Since the side wall coating **18*a*** is biased at ground potential, what is often referred to as a "potential well" is encountered. The "potential well" is schematically indicated in the drawing by a dotted line **32**. The electron-optical photoelectron focusing field which is formed between the photocathode **14*a*** and the accelerating cathode **16*a*** directs electrons from the photocathode toward the accelerating electrode along paths which are depicted in the drawing by the dotted lines **34**. It will be noted that only a relatively small number of the photoelectrons from the photocathode reach the opening **17*a*** in the accelerating electrode **16*a***.

There is shown in Fig. 4 a phototube **10** of the type described in Fig. 1 and thus employing an embodiment of the invention. The photocathode **14** is provided with a plurality of spaced apart conductive strips **19**. The electrically continuous photoemissive cathode film is in electrically conductive contact with the strips and is active between adjacent strips. Since the strips exhibit a relatively high electrical conductivity, the bias of the side wall coating **18** (ground potential) is maintained at all portions of the photocathode adjacent the strips. Thus the photoemissive material, which by itself is characterized by a relatively high resistivity, is provided with a relatively low effective resistivity and is thus adapted to be maintained at a substantially uniform potential. The minus signs along the photocathode indicate the fact that the photocathode is maintained at the potential of the side wall coating. Since the photocathode is maintained at a substantially uniform potential photoelectrons from the photocathode describe trajectories, which are indicated in the drawing by dotted lines **36**, toward the accelerating electrodes **16** and into the aperture **17** therein. It is thus seen that the conductive strips **19** enable a relatively high photocurrent to be drawn from the photocathode without

a substantial distortion of the electron-optical photoelectron focusing field within the tube.

While the invention has been described with respect to the use of substantially parallel strips across the photocathode surface and in electrically conductive contact with the electrically continuous photoemissive material on the cathode, other shapes of conductors in the form of films may be used. For example, a mesh of crossed parallel strips may be used. However, since conductive films of the type which exhibit good conductivity are usually opaque, and as it is desirable to maintain a relatively large area of the photocathode surface transparent since the active area of the photocathode surface is determined by the area of the transparent portion thereof, the conductive film pattern which exhibits the least opacity is desirable. The use of parallel, spaced-apart, conductive strips appears to give to a photocathode a relatively high effective conductivity with a relatively low conductive film opacity and is thus preferred. Conductive strips in parallel relation to each other and having a 0.5 millimeter width and a 3 millimeter spacing between adjacent strips and a thickness of between about 8000 Angstrom units to about 20,000 Angstrom units have proven effective.

The invention also provides means for reducing the time required for a photocathode to come back to a substantially uniform potential after being overloaded by being subjected to a relatively strong source of illumination and thus after a relatively high photocurrent has been drawn from the photoemissive cathode.

Figs. 5, 6 and 7 depict a comparison between a phototube having a photocathode without conductive strips (Fig. 3) thereacross and a photocathode using conductive strips (Fig. 4) according to the invention. Fig. 5 shows schematically a relatively high intensity light source which pulsates at a relatively high frequency. Fig. 6, directly below Fig. 5, depicts the performance of a phototube of the type shown in Fig. 3 and in response to light of the type depicted in Fig. 5. Fig. 7 depicts the performance of a phototube of the type shown in Fig. 4 and in response to light of the type shown in Fig. 5.

In Fig. 6 the first pulse 38 represents the output of the phototube of the type shown in Fig. 3, without the conductive strips. Pulses 40 represent successive pulses after the first one. It will be noted that the output of the tube is not uniform; the first pulse of output current is of a different order of magnitude than that of the succeeding output pulses. Thus, the tube exhibits a non-uniform response.

In contrast, the pulses 42 shown in Fig. 7 are all of substantially the same order of magnitude. The photocathode has, between successive pulses, recovered to the activity exhibited before the first pulse.

From the foregoing it will be apparent that the invention provides an improved phototube having a relatively large area photocathode which allows the drawing of a relatively high current from the photocathode while it is maintained at a substantially uniform field potential.

What is claimed is:

1. A phototube comprising an electron multiplier, a photoemissive member for supplying a stream of electrons to said electron multiplier in response to light impinging on said member, and a plurality of spaced apart conductive strips across and in electrically conductive contact with portions of said member and connected to each other, whereby all portions of said member are adapted to be maintained at a substantially constant potential while said member supplies electrons to said multiplier.

2. A phototube comprising an envelope having a transparent portion, an electron multiplier, electrically continuous photoemissive means on the inside surface of said transparent portion for supplying a stream of electrons to said electron multiplier in response to light impinging on said means, and a plurality of spaced apart conductive strips in the form of films across portions of said means and connected to each other at the ends thereof, whereby all portions of said means are adapted to be maintained at a substantially constant potential while said means supplies electrons to said multiplier.

3. A phototube comprising an envelope having a substantially transparent portion, a photoemissive member on the inside surface of said transparent portion for supplying a stream of electrons in response to light impinging on said member, an electron multiplier for amplifying the current represented by said stream of electrons, said photoemissive member and said electron multiplier being in spaced relation to each other and adapted to maintain an electron-optical field therebetween for directing electrons from said member to said electron multiplier, and a plurality of spaced apart electrically conductive strips in the form of aluminum films across portions of said member and in electrical contact therewith and connected to each other at the ends thereof and being adapted to maintain said portions of said member at a substantially constant potential thereby maintaining said electron-optical field free from distortion while said member supplies electrons to said multiplier.

4. A photocathode for a phototube comprising a substantially transparent insulating support member, electrically continuous photoemissive means on said support member, and a plurality of spaced apart conductive strips on said photoemissive means, whereby all portions of said photoemissive means are adapted to be maintained at a substantially uniform potential.

5. A photocathode for a phototube comprising a substantially transparent insulating support member, electrically continuous photoemissive means on said support member, and a plurality of spaced apart conductive strips on said support member, said strips being connected to each other at the ends thereof, whereby all portions of said photoemissive means are adapted to be maintained at a substantially uniform potential.

6. A photoemissive cathode for a photomultiplier tube comprising a substantially transparent insulating support member, a substantially transparent electrically continuous layer of photoemissive material on said support member, and a plurality of parallel aluminum strips in the form of films on said layer of photoemissive material, said strips being connected to each other at both ends thereof, whereby all portions of said layer are adapted to be maintained at a substantially constant potential while photoelectrons are emitted from said cathode.

7. In a photomultiplier tube having an electron multiplier structure, a photocathode adapted to form an electron optical field between said photocathode and said structure for directing to said structure electrons released from said photocathode in response to light impinging thereon, said photocathode comprising a substantially transparent insulating support member, a substantially transparent layer of photoemissive material on said support member, a plurality of spaced apart substantially parallel aluminum strips in the form of films on said layer of photoemissive material, said layer of photoemissive material having a higher resistivity than said strips, said strips being connected to each other, whereby all portions of said layer are adapted to be maintained at a substantially constant potential while photoelectrons are emitted from said cathode.

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