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ELECTRON LENS FOR MULTIPLIER PHOTOTUBES
WITH VERY LOW SPHERICAL ABERRATION

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Fig. 1.

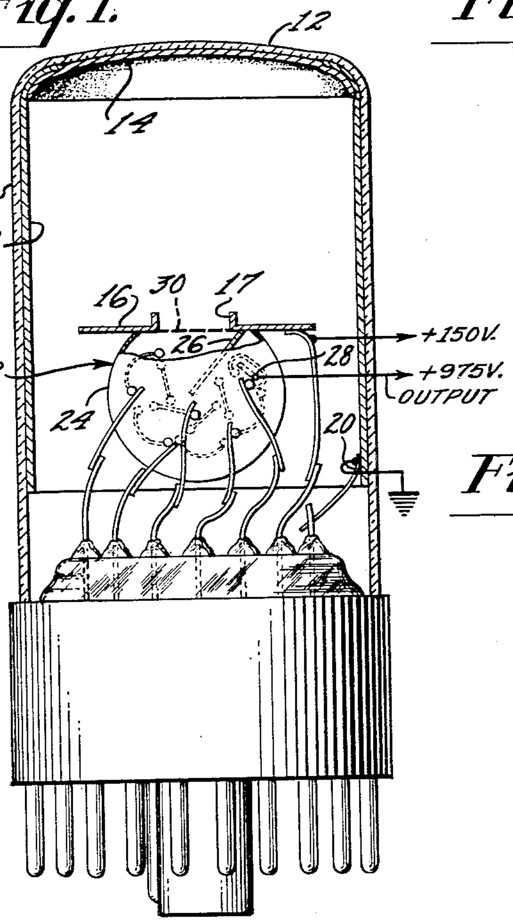


Fig. 2.

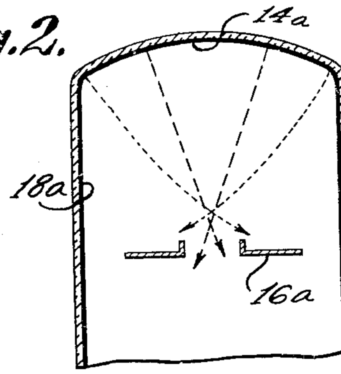


Fig. 3.

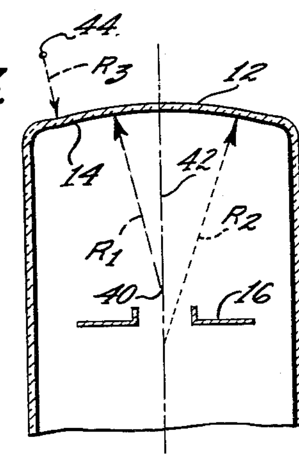


Fig. 5.

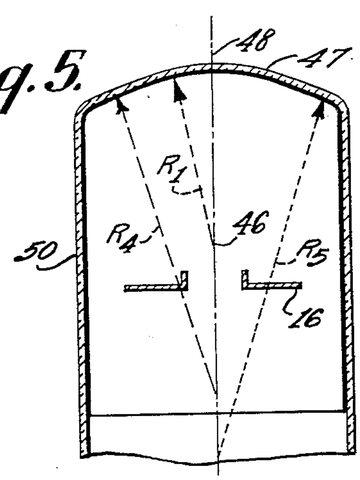
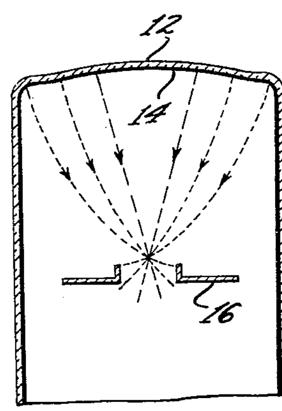


Fig. 4.



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ELECTRON LENS FOR MULTIPLIER PHOTOTUBES WITH VERY LOW SPHERICAL ABERRATION

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7 Claims. (Cl. 313—95)

This invention relates to a phototube, and more specifically to a large area photoemissive cathode for use in phototubes, such as high vacuum photomultiplier tubes.

Photomultiplier tubes having large area photocathode surfaces wherein the photosurface is closely coupled with a phosphor layer, have been used as scintillation counters. The operation of the tube is such that radiations from radioactive materials are caused to fall upon a phosphor surface and activate it to luminescence, the light of which in turn causes photoemission from the photocathode of the tube. In such applications, it is necessary that all electrons emitted by the photocathode be directed into the multiplier section of the tube to contribute to the output signal. To achieve this, it is necessary for electrons emitted from any point on the photocathode surface to be directed or focussed into a restricted region or point. Normally, the larger the photocathode of such tubes, the more pronounced are the aberrations of the focussing system which increase the size of the focussed spot. Thus, electrons, particularly those originating from the edges of the photocathode, are scattered and not collected by the multiplier section. This results in a loss of signal.

It is thus an object of the invention to provide a phototube having a large area photocathode and wherein the electrons from the photocathode are directed into a restricted region.

It is another object of the invention to provide a phototube having a large area photocathode in which the focusing of the photoemission from the photocathode is of low aberration.

It is a further object of the invention to provide a photomultiplier tube having a large area photocathode and adjacent tube portions designed to direct the photoemission into a restricted region.

The foregoing and related objects are achieved in accordance with the invention by providing a tubular envelope for said phototube. The tubular envelope is closed by an end wall having, at its center, a substantially concave spherical surface and, at its peripheral portions, annular concave surfaces of increasing radii with respect to the distance from the center. Also the peripheral surfaces of the face plate may be formed with a negative radius of curvature forming a convex inner surface.

Figure 1 is a sectional view of a photomultiplier tube having a photocathode in accordance with the invention.

Figure 2 is a schematic showing of electron paths in a tube having a single spherical surface.

Figure 3, 4 and 5 schematically show sectional views of photosurfaces in accordance with the invention.

The invention is disclosed in Figure 1, as applied to a photomultiplier tube of standard form and dimensions. Such a tube is used in applications involving low-level, large-area light sources, such as scintillation counters for the detection and measurement of nuclear radiation. The tube comprises essentially, a glass envelope **10**, closed at one end with a transverse wall section **12**, upon which is formed a transparent photocathode surface **14**.

In one tube of this type, 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, substantially flat cathode area which permits good optical coupling between the photocathode and the surface of a phosphor screen, used in scintillation counters, for example.

Spaced from the photocathode and along the tube axis is an accelerating electrode or portion **16** formed as a disc and having an aperture **17** at its center. A metallic wall coating **18** is formed on the inner surface of the tube envelope and extends from the photocathode film **14** axially down the tube to a portion below the accelerating electrode portion **16**. Wall coating **18** provides electrical contact between the photocathode **14** and a lead **20**, connecting the photocathode and the metallic film **18** to a source of ground potential, as shown.

As indicated in Figure 1, a potential difference of 150 volts is maintained as an optimum value between accelerating electrode **16** and the photocathode **14**. Photoelectrons emitted from cathode **14** are thus accelerated toward electrode **16**. Wall coating **18** aids in directing the photoelectron toward the opening **17**.

Photoelectrons passing through opening **17** are collected by an electron multiplier section **22**, which consists of a plurality of dynode electrodes (shown in dotted lines) enclosed in a cylindrical metal shield **24**. The photoelectrons will impinge upon an anode collector electrode which is also a first dynode electrode **26** and will 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 electrons striking it to form an ever-increasing stream of electrons until those emitted by the last dynode are collected by a collector or anode electrode **28**. The current collected by collector electrode **28** constitutes the current utilized in the output circuit of the tube. This type of electron multiplier is fully described in U. S. Patent 2,285,126, of Rajchman et al. The specified details of the multiplier do not constitute my invention.

Opening **17** into the multiplier section **22** is covered by a mesh grid **30**. This grid is connected electrically to the anode collector or first dynode **26** and tends to prevent secondary electrons, from dynode **26**, from passing back toward the photocathode **14**. The first dynode electrode portion **26** is fixed to the accelerating disc portion **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.

Commercial tubes, of the type described, have been made with a photosurface formed by putting down on the end wall **12** a semi-transparent film of manganese which is oxidized and then depositing thereon a thin film or layer of antimony which is sensitized by condensing a deposit of cesium metal thereon. This type of photoemissive surface is fully described in the copending application of J. J. Polkosky, Serial No. 219,997 filed April 9, 1951, now U. S. Patent 2,676,282 which issued April 20, 1954. Such a photocathode surface has a spectral response, which may be varied over a range between 3000 A. to 6400 A. The response of the material is peaked at around 4800 Angstroms.

In the operation of tubes of the type shown in Figure 1, it is desirable that photoelectrons from all portions of the photocathode film **14** may 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 aperture **17**, so that they can pass into the multiplier section and strike the dynode electrode **26**. To focus or direct an electron emission from a large surface to a common point, a theoretically ideal cathode surface would be that having a spherical configuration. Thus, a positive voltage at the center of curvature of the surface would guide the electron emission into a small region at the center of curvature.

However, in tubes of the type described, the photocathode **14** is at the closed end of a tubular envelope portion **10**. Furthermore, to prevent the collection of charges on the tubular wall portion **10**, which would adversely effect the trajectories of the electrons leaving the cathode surface **14**, the tubular portion is coated with a conductive film **18**. Also film **18** is held at the potential of the photocathode surface to discourage the landing of photoelectrons thereon. In tubes in which the end wall is a single spherical surface, as shown in Figure 2, an additional effect of a negative wall coating **18*a*** upon electrons leaving the photocathode **14*a*** is to shorten the focal distance from the photocathode at which the electron paths cross. This effect is greatest in the region of the photocathode nearest the wall **10*a***. Electrons leaving the edge of the photocathode film **14*a*** will cross at points closer to the photocathode than will the paths of electrons leaving the center portions of the film. The paths of the electrons as shown in Figure 2 disclose considerable aberration in the electron optics composed of the anode **16*a***, the photocathode **14*a***, and wall coating **18*a***. Thus a tube made with a spherical end wall does not provide complete collection of photoelectrons from all points of the photocathode. Photoemission from the edge portions of the photocathode tend to miss the opening **17** into the multiplier section and strike portions of accelerating electrode **16**, instead. These electrons do not contribute to the output signal of the tube.

In accordance with the invention, all portions of the photocathode **14** (Fig. 1) are provided substantially with a common focal length by properly forming the shape of the wall portion **12** of the tube. As shown in Figure 3, the end wall **12** is formed with a central portion whose inner surface facing accelerating electrode **16** is concave and substantially spherical with a center of curvature **40** on the axis **42** of tubular portion **10** of the envelope. Between this center portion and the edge of the wall **12**, the intermediate annular portion is also substantially spherical with a larger radis of curvature, R_2 for example. The annular region at the periphery of the end wall **12** and contiguous to the tubular wall **10** may be flat in a plane perpendicular to axis **42**, or may have a negative radius of curvature, R_3 so that the peripheral annular region has a convex inner surface as seen from anode **16**, and as shown in Figure 3.

The effect of a photosurface, of the type described for Figure 3, is one in which the electrons emitted from photocathode **14** follow paths toward accelerating electrode **16**, which will converge to a common restricted region within or closely adjacent the opening **17** of the multiplier section and as indicated by the convergence of the dotted lines of Figure 4. Such a photosurface provides the minimum aberration effects of the focusing fields between cathode **14** and accelerating electrode **16**. The proper curvature of the inner surface of end wall **12** of Figure 3 can be determined on a rubber membrane model for the desired electrode structures used. In one commercially operated tube of the type described, shown in Figure 3, the radius of curvature R_1 of the center section is 3 inches. The radius of curvature R_3 of the peripheral region is $-\frac{1}{2}$ an inch and the center of curvature **44** of this surface is substantially ¾ of an inch from the axis **42** of the tube. The diameter of the tubular portion **10** is two inches.

Figure 5 discloses a modification of the invention in which the central portion of the end wall **12** of the tube is formed with a concave spherical inner surface having a radis R_1 and a center of curvature **46** on the axis **48** of the tubular envelope portion **50**. However, the annular peripheral regions extending between the center portion of radius R_1 to the edge of the end plate **12** have also substantially spherical surfaces of decreasing curvature with distance from axis **46**. That is the radius of curvature of the end plate **47** increases with respect to the distance from the axis **48** of the tube envelope, as indicated by R_4 and R_5, for example. A photocathode film, deposited on the end wall **47** of Figure 5, will also provide an electron emission which will be directed or focused to a small confined region on the axis of tube. Such a photosurface also will provide less aberration effects than that provided by a spherical surface of single radius as shown in Figure 2.

From the foregoing, it will be apparent that the invention provides an improved phototube having a large photocathode surface characterized by its improved electron focusing and collecting characteristics as disclosed.

We claim:

1. A phototube comprising, a photoemissive cathode, and an anode electrode spaced from said cathode, said cathode having a concave surface facing said anode, said cathode surface having at its center portion a substantially spherical curvature of one radius and an adjacent annular spherical portion having a curvature of larger radius than said one radius.

2. A photoelectron discharge device comprising, an envelope, a photoemissive film on the inner surface of a portion of said envelope, an anode electrode mounted within said envelope and spaced from said photoemissive film, said envelope portion having a curved surface of increasing radius of curvature relative to the distance of the surface from its center.

3. A phototube comprising, a tubular envelope, an end wall closing one end of said envelope, a photocathode film formed on the inner surface of said end wall, an anode electrode spaced within said envelope from said photocathode, said cathode surface having at its center portion a substantially spherical curvature of one radius and an adjacent annular spherical portion having a curvature of larger radius than said one radius.

4. A phototube comprising, an envelope having a tubular portion, a transparent end wall closing one end of said tubular envelope portion, a photoemissive film on the inner surface of said end wall, and an anode electrode on the axis of said tubular envelope portion within said envelope and spaced from said photoemissive film, said inner surface of said end wall at its center portion being concave outwardly, the portions of said end wall respectively having curvatures with increasing radii relative to the distance from the center of said end wall.

5. A phototube comprising, an envelope having a tubular portion, a transparent end wall closing one end of said tubular envelope portion, a photoemissive film on the inner surface of said end wall, and an anode electrode on the axis of said tubular envelope portion within said envelope and spaced from said photoemissive film, the center portion of said inner surface of said end wall, facing said anode electrode being a concave substantially spherical surface with a center of curvature on said axis of said tubular envelope portion, portions of said end wall between the wall of said tubular envelope portion and said center end wall portion having annular spherical surfaces concave relative to said anode electrode and of decreasing curvature relative to the distance from the center of said face plate.

6. A phototube comprising, an envelope having a tubular portion, a transparent end wall closing one end of said tubular envelope portion, a photoemissive film on the inner surface of said end wall, and an anode electrode on the axis of said tubular envelope portion within said envelope and spaced from said photoemissive film, the center portion of said inner surface of said end wall facing said anode electrode being a concave substantially spherical surface with a center of curvature on said axis of said tubular envelope portion, and peripherical portions of

said end wall contiguous the wall of said tubular envelope portion having an annular surface of convex curvature relative to said anode electrode, said photoelectric film extending over said convex annular wall surface.

7. A phototube comprising, an envelope having a tubular portion, a transparent end wall closing one end of said tubular envelope portion, a photoemissive film on the inner surface of said end wall, and an anode electrode on the axis of said tubular envelope portion within said envelope and spaced from said photoemissive film, the inner surface of said end wall facing said anode electrode being concave and having an increasing radius of curvature relative to the distance of the surface from its center, and the peripheral portions of said end wall which contact the wall of said tubular envelope portion having an annular spherical surface of convex curvature relative to said anode electrode.

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