Sept. 8, 1970 B. W MANLEY ET AL 3,528,101

ELECTRONIC IMAGE INTENSIFIER WITH SECONDARY EMISSIVE MULTIPLICATION AND AN ELECTRON-OPTICAL FOCUSSING SYSTEM BETWEEN A PHOTOCATHODE AND THE SECONDARY EMISSIVE ELECTRODE

Filed Feb. 20, 1968 2 Sheets-Sheet 1

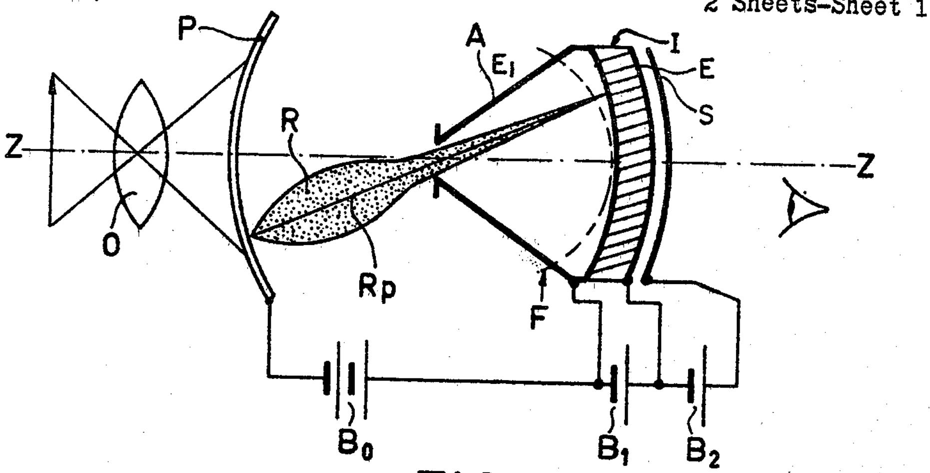

FIG.1

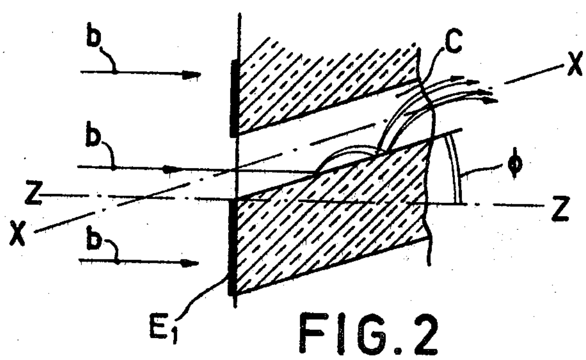

FIG.2

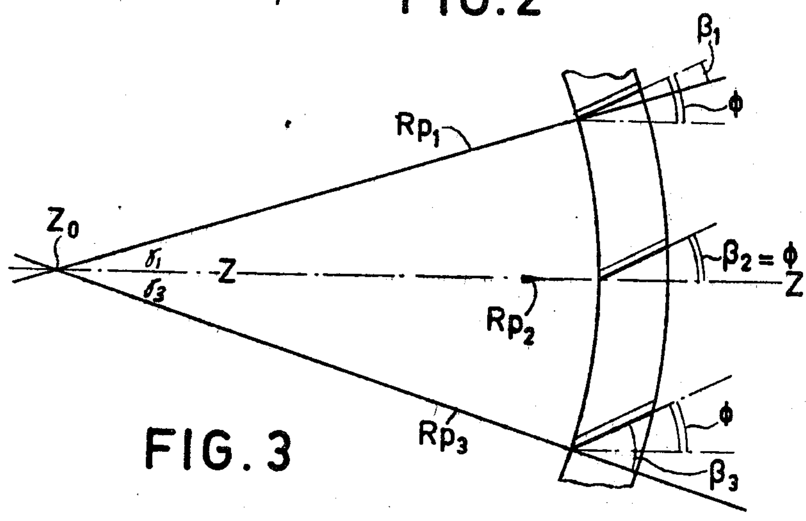

FIG. 3

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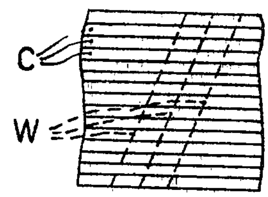

FIG. 4a

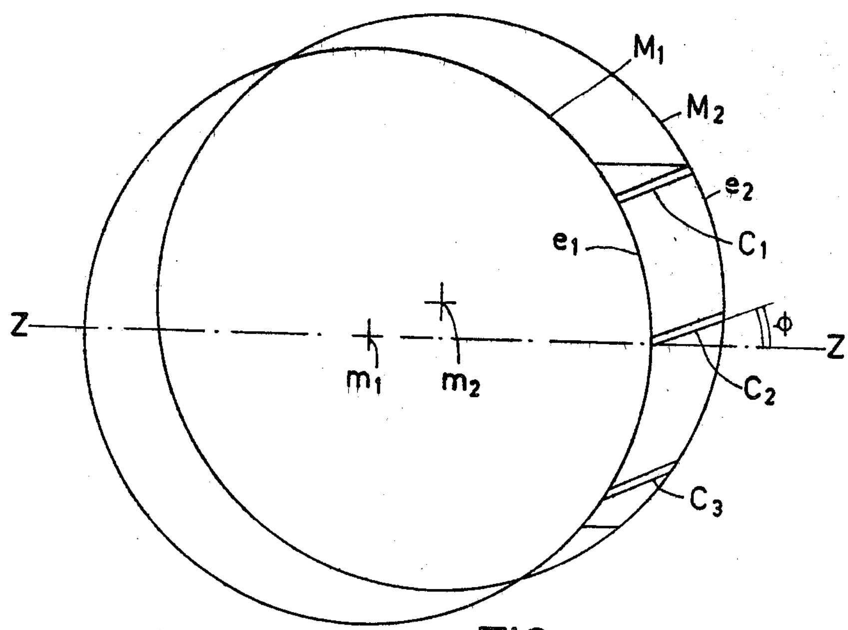

FIG. 4b

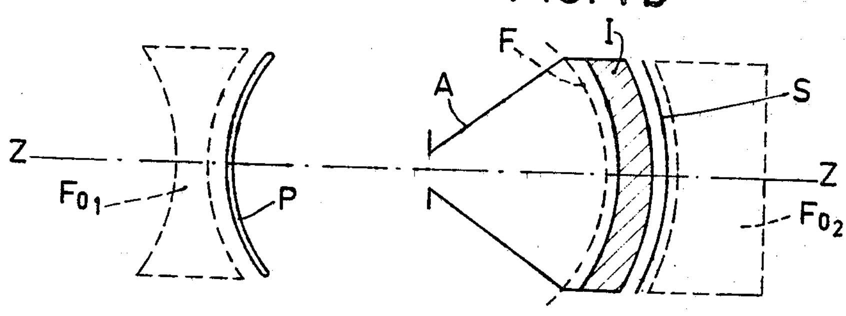

FIG. 5

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ELECTRONIC IMAGE INTENSIFIER WITH SECONDARY EMISSIVE MULTIPLICATION AND AN ELECTRON-OPTICAL FOCUSSING SYSTEM BETWEEN A PHOTOCATHODE AND THE SECONDARY EMISSIVE ELECTRODE

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Int. Cl. H01j *39/00, 39/14*
U.S. Cl. 313—95 6 Claims

ABSTRACT OF THE DISCLOSURE

An image intensifier device employing a photocathode, a channel intensifier device, i.e., a secondary emissive electron multiplier device comprising a plate having a large number of channels in the thickness direction and having conductive layers on major opposite faces serving, respectively, as input and output electrodes, and an electron-optical system located between the photocathode and the input electrode. The device is so constructed that the electron-optical system has rotational symmetry, and an electron-optical axis coincident with its axis of rotational symmetry, the electron-optical axis being normal to the surface of the photocathode and the faces of the channel intensifier. The principal rays of the photocathode diverge between a cross-over point and the channel intensifier while the channels are all parallel to each other and the channel intensifier and the image plane of the electron-optical system are both curevd and are both concave as viewed from the photocathode.

This invention relates to electronic image intensifier devices. More particularly the invention relates to "channel intensifier" devices and to electronic image tubes employing such devices. Such devices will be defined later but, briefly, they are secondary-emissive electron-multiplier devices comprising a matrix in the form of a plate having a large number of elongated channels passing through its thickness, said plate having a first conductive layer on its input face and a separate second conductive layer on its output face to act respectively as input and output electrodes.

Secondary-emissive intensifier devices of this character are described, for example, in British patent specifications No. 1,064,073, No. 1,064,074 and No. 1,064,076 while methods of manufacture are described in patent specifications No. 1,064,072 and No. 1,064,075.

In the operation of all these intensifier devices (when incorporated in electronic imaging tubes) a potential difference is applied between the two electrode layers of the matrix so as to set up an electric field to accelerate the electrons, which field establishes a potential gradient created by current flowing through resistive surfaces formed inside the channels or (if such channel surfaces are absent) through the bulk material of the matrix. Secondary-emissive multiplication takes place in the channels

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and the output electrons may be acted upon by a further accelerating field which may be set up between the output electrode and a suitable target, for example a luminescent display screen.

As a summary of this art, the devices referred to herein as "channel intensifier" devices are defined in the patent specifications referred to above in a definition given in the following terms:

A channel intensifier device is a secondary-emissive electron multiplier device for an electronic imaging tube which device comprises a resistive matrix in the form of a plate the major surfaces of which constitute the input and output faces of the matrix, a conductive layer on the input face of the matrix serving as an input electrode, a separate conductive layer on the output face of the matrix serving as an output electrode, and elongated channels each providing a passageway from one face of the assembly consisting of matrix and input and output electrodes to the other face of said assembly, the distribution and cross-sections of the channels and the resistivity of the matrix being such that the resolution and electron multiplication characteristic of any one unit area of the device is sufficiently similar to that of any other area for the imaging purposes envisaged.

In the operation of such devices, various problems arise, and some arise particularly when the device is used not in an imaging tube of the "proximity" type (i.e. one in which the photo-cathode is placed very near to the channel intensifier device without intermediate electron-optics) but in an imaging tube (for example a so-called electron-optical diode) in which electrons are directed along diverging paths towards the channel intensifier device, i.e., some of these electrons strike the edges of the plate without entering the channels where secondary emissive multiplication takes place.

It is an object of the invention to provide an improved imaging tube construction which in spite of the presence of diverging electron paths, results in the electrons entering the channels where secondary emissive multiplication occurs.

The invention provides an electronic imaging tube comprising a photo-cathode, a channel intensifier device as herein defined, and an electron-optical system located between said photo-cathode and the input electrode of said channel intensifier device, the device being so constructed that:

(a) The electron-optical system is symmetrical about an axis of rotation and has an electron-optical axis coincident with this axis;

(b) The said electron-optical axis is normal to the surface of the photo-cathode and to the faces of the channel intensifier device at the respective points of intersection;

(c) Principal rays of the photo-cathode (as herein defined) diverge between a cross-over point or area and the channel intensifier device;

(d) The channels of said channel intensifier device are all parallel to each other; and

(e) The channel intensifier device and the image surface or image plane of the electron-optical system are both curved and are both concave as viewed from the photo-cathode.

The term "principal ray" is defined as follows. The electron-optical system demands that all electrons emitted from any given point of the photo-cathode be brought substantially to one point on the image or focal surface or "plane." Electrons are emitted at all angles (within a wide cone) from such an object point on 'the photo-cathode. The terms "principal ray" and "principal electron" are used to denote the path of that electron (or the electron itself) which is emitted from the particular object point in the direction normal to the surface of the photo-cathode.

As for the term "image surface," it will be convenient to refer to it, according to normal practice, as the image or focal "plane" in spite of its curvature.

The curvature of the channel intensifier device according to the present invention permits more uniform definition over the effective viewing area or, alternatively, it permits optimum definition to be obtained not only at the centre but also over all or most of the remainder of said area.

As will be understood more clearly from the drawings, this is due to the fact that curvature of the channel intensifier device permits its input face to be closer to (or substantially coincident with) the curved image "plane" of the electron-optical system than would be the case when using a flat channel intensifier device.

In the imaging device according to the present invention, the channel intensifier device may have all its channels parallel to the electron-optical axis, but it has been found that this tends to cause a dark patch at a substantially central area of the image where the greatest number of electron paths are substantially parallel to the axes of the channels. This is due to the fact that such an electron may pass straight through the channel without striking the channel surface and, hence, without causing any secondary emission, or it may only cause insufficient secondary emission.

Preferably, therefore, the channels are tilted as disclosed in co-pending application Ser. No. 706,969, filed Feb. 20, 1968. One result of this tilting of the channels is, in effect to displace any potential "dark patch" area to one side and away from the operative image field of the electron-optical and channel intensifier systems. As is explained in said specification and as will be explained later, the angles β between principal rays and their corresponding channels will vary from a minimum value to a maximum value, whereas the angle ϕ of inclination of the channels is the same for all channels.

In this connection it will be convenient hereinafter to use the term "second main axial plane" which is defined as follows. In a system comprising a matrix having all its channels parallel to each other and all tilted with respect to an electron-optical axis passing through the centre of the matrix, one of the axial planes (i.e. the planes containing said axis) contains also the axes of those channels which it intersects. This plane is referred to herein as the "first main axial plane" and the axial plane normal to it is referred to as the "second main axial plane."

The electron-optical system may be of the kind used in a so-called "electron-optical diode" as described in Philips Research Reports, vol. 7, pp. 119–130 (1952). This type of system is the one used in various embodiments which will now be described by way of example with reference to the accompanying diagrammatic drawings as applied to imaging tubes of the image intensifier or image converter type employing as the target a luminescent viewing screen.

In the drawing:

FIG. 1 is an axial section of a tube;

FIG. 2 is an enlarged fragmentary section of the channel intensifier device of the tube of FIG. 1, the plane of the drawing being the first main axial plane;

FIG. 3 is a diagram illustrating the conditions which obtain in the first main axial plane of the tube of FIG. 1;

FIGS. 4A and 4B illustrate a method of manufacturing curved matrices, and

FIG. 5 illustrates possible uses of fibre-optics.

In FIG. 1 external radiation is directed from an object 0 on to a photo-cathode P so as to form an image thereon. Photo-electrons are liberated simultaneously from all parts of the photo-cathode with varying local intensities dependent upon the image formed.

The photo-cathode P co-operates with a conical or substantially conical anode A to form an electron-optical diode of the kind previously mentioned. The electron-optics of this system are such that the emitted photo-electrons are formed into a so-called pencil of rays as indicated at R, said pencil being converged by the action of the spherical equipotential surfaces between the photo-cathode and the anode cone. On passing through the aperture in the anode cone, the pencil is made less convergent by the negative lens action at the cone aperture. The pencil of rays finally converges to a focus at the so-called image "plane" (indicated at F) which is in effect a focal plane or plane of best focus and has considerable curvatures as shown.

The anode A has a cylindrical skirt portion which is connected to the input electrode E1 of a channel intensifier device I, said device also having an output electrode E2. The electron-optical system P–A has rotational symmetry about an electron-optical axis Z—Z which is normal to the surface of the photo-cathode P and to the faces of the channel intensifier device I at the respective points of intersection.

The channels of the device I may be parallel to the axis Z—Z. Preferably, however, they are tilted as disclosed in said co-pending application, and this will be assumed in the remainder of this description except where otherwise stated. Thus, as will be seen from the enlarged fragmentary axial section shown in FIG. 2, the channel intensifier device I is traversed by a regular array of channels C each having its axis X at an angle ϕ to the second main axial plane (i.e. the axial plane normal to the plane of the drawing which contains the axis Z—Z).

Photo-electrons from the photo-cathode P are shown arriving at b in FIG. 2. In each of the channels that receives photo-electrons at any given instant, initial multiplication takes place e.g. as shown schematically in the drawing under the influence of the electric accelerating field set up by connecting the electrodes E1–E2 to a source shown schematically at B1. A further accelerating field is provided by a source B2 between electrode E2 and a conductive coating (e.g. aluminium) forming part of a curved luminescent screen S (FIG. 1) situated on the output side of the device.

In the conditions illustrated in FIG. 2 the photo-electrons b are shown for simplicity all on parallel paths normal to the matrix face and therefore approaching the channels at a constant angle (which is equal to the angle ϕ) to the channel axes, although this is not a realistic situation except (as a first approximation) at the centre of the device I.

In reality the principal rays (e.g. the principal ray indicated at Rp in FIG. 1) strike the device I at varying angles so that they form (with corresponding channels) angles such as the angles $\beta1$–$\beta2$–$\beta3$ shown schematically in FIG. 3 (this represents conditions in the first main axial plane, i.e. the axial plane which contains the axis Z—Z and also the axes X—X of those channels which lie on the plane). As will be appreciated,

$$\beta3=\phi+\gamma3$$

where $\gamma3$ is the nominal angle at which the principal ray Rp3 diverges from a notional cross-over point Zo of the electron-optical system P–A (as will be appreciated, the principal rays, e.g. ray Rp of FIG. 1 and Rp1–Rp3 of FIG. 3, are not truly straight lines in normal practice, but they are nevertheless identified by the initially orthogonal electron path at the point of emission on the photo-cathode P). In a similar manner

$$\beta1=\phi-\gamma1$$

where $\gamma1$ is the angle of divergence of principal ray Rp1.

At the centre (on the axis Z—Z) the divergence of principal ray $Rp2$ is zero and

$$\beta 2=\phi$$

Provided that the smallest angle $\beta 1$ is sufficient to prevent electrons passing straight through the respective channel (or passing through with insufficient multiplication), the whole of the matrix indicated in FIG. 3 will be capable of operating effectively without any "dark spot" since all the other angles ($\beta 2$–$\beta 3$ etc.) are greater. However, it is desirable to limit the maximum values of angles β, as aforesaid, since a degree of astigmatism becomes increasingly apparent with increasing values of ϕ.

In a practical example suitable for an application such as that of FIG. 1, the dimensions of the tube may be approximately as follows (these proportions differ from the purely nominal proportions of the drawings which have been adopted for the sake of clarity):

TABLE

Diameter of matrix=5 cm.
Diameter of channel=30μ
Length of channel=2 mm.
Distance between E2 and S=4 mm. approximately
Maximum angle γ of divergence=12 degrees
Angle ϕ of channel tilt=15 degrees
Angle β minimum=3 degrees
Angle β maximum=27 degrees
Radius of curvature of E1=40 mm.

With an arrangement such as that of FIGS. 1 to 3 employing both curvature of the matrix and tilted channels, the advantages of both systems can be obtained simultaneously, namely the resolution can be of good quality all over the picture and at the same time the dark spot problem can be overcome. The small discrepancy between the curved image plane F and the input face of the device I can be substantially eliminated or kept to such low value as will cause no appreciable loss of resolution towards the edges of the picture displayed on screen S.

In its preferred form the matrix of the device of FIGS. 1 to 3 has all its channels at the same angle ϕ to the second main axial plane. This feature renders it suitabe for manufacturing by relatively simple methods which include the steps of slicing and machining a channelled block and are initiated by making inclined cuts W across the channels C of such a block at an appropriate angle thereto as shown schematically in FIG. 4A.

The subsequent machining of the slices from flat to curved form is facilitated if the input and output faces of the finished matrix are to be of geometrically spherical form (as distinct from other surfaces of revolution which can also be used). In a particular case, such spherical machining can be carried out in such manner as to obtain (as is desirable) a constant channel length in all parts of the matrix. For the tilted channel case this is illustrated schematically in FIG. 4B in which $e1$–$e2$ represent the desired input and output faces (i.e. the surfaces on which the respective electrode layers will be formed) and M1–M2 represent the spherical surfaces to be followed in machining said faces. As will be seen, the two spheres have identical radii and the centres $m1$–$m2$ of these spheres are related in the same way (in spacing and orientation) as the ends of a central channel C2 tilted at the desired angle ϕ to the axis Z—Z. As will also be seen from representative channels C1, C2 and C3, all channels have the same length while the thickness of the matrix varies. A further point which arises is that the output face of this matrix (and hence also the electrode E2 and screen S) will have its centre of curvature above the axis Z—Z and will therefore not quite partake of the rotational symmetry of the electron-optical system.

If desired, the effects of the curvature of the photo-

cathode P and the effects of the curvature of the display screen S of FIG. 1 can be overcome or mitigated in known manner with the aid of fibre-optics. Thus, it is possible to use a fibre-optic input plate having appropriate concave curvature on one side to match the curvature of the photo-cathode while presenting a substantially flat or (as shown at F01) oppositely curved face to the incoming radiation (at the same time this permits the use of greater curvature on the photo-cathode so as to reduce the curvature of the image plane F which can then more readily be made substantially coincident with the input face of device I). As an alternative, or in addition thereto, a second fibre-optic element may be used as a face-plate on which the screen S is formed, said face-plate having an output face which may for example be flat as shown at F02 in FIG. 5 (the screen S has in this, and in preceding cases, a concave curvature such as to match the curvature of the electrode E2 in the sense of ensuring as far as possible equal field strength between E2 and S at all points).

Although the cone A and electrode E1 have been described as being connected together, it may in some cases be desirable to modify this "diode" arrangement by separating A from E1 so that different potentials may be applied to these two elements e.g. for the purpose of obtaining an optimum energy of entry for the electrons approaching the channels (this may be done by keeping A at the same potential but reducing the E1 potential). Such a modification produces, in effect, a triode structure and the notional cross-over point Zo (FIG. 3) may become a virtual cross-over.

What is claimed is:

1. An electronic imaging tube having an electron optical system comprising a photocathode, and a channel intensifier comprising a plate of resistive material having opposite major faces constituting input and output faces thereof, a conductive layer on the input face constituting an input electrode, a separate conductive layer on the output face constituting an output electrode, said plate having a plurality of elongated channels having secondary emissive surfaces connecting said input and output faces each providing a passageway between said faces, and means for applying a potential between said input and output electrodes whereby electrons from said photocathode enter said channels, the photocathode and the channel intensifier being so constructed and arranged that:

(a) the electron-optical system is symmetrical about an axis of rotation and has an electron-optical axis coincident therewith;
(b) the said electron-optical axis is normal to the surface of the photocathode and to the faces of the channel intensifier device at the respective points of intersection;
(c) principal rays of the photocathode emitted from a particular point in a direction normal to the surface of the photocathode diverge between a cross-over point or area and the channel intensifier device;
(d) the channels of said channel intensifier device are all parallel to each other; and
(e) the channel intensifier device and the image surface or image plane of the electron-optical system are both curved and are both concave as viewed from the photocathode.

2. An imaging tube as claimed in claim **1** employing a luminescent viewing screen on the output side of the channel intensifier device.

3. An imaging tube as claimed in claim **1** wherein the electron-optical system is of the electron-optical diode type employing a substantially conical anode electrically connected to the input electrode of the channel intensifier device.

4. An imaging tube as claimed in claim **3** wherein the input electrode of the channel intensifier device and the image surface or image plane of the electron-optical system are substantially coincident.

5. An imaging tube as claimed in claim **4** wherein the channels are all tilted with respect to the axis and are all of substantially the same length.

6. An imaging tube as claimed in claim **5** employing a channel intensifier having substantially spherical input and output faces.

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U.S. Cl. X.R.

250—213; 313—101, 102