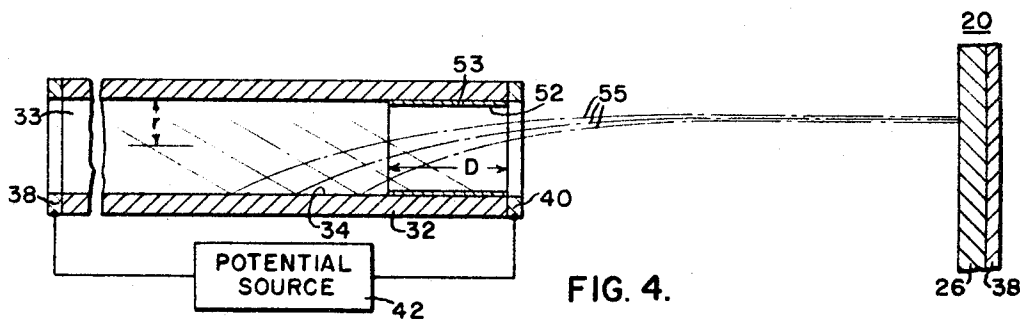
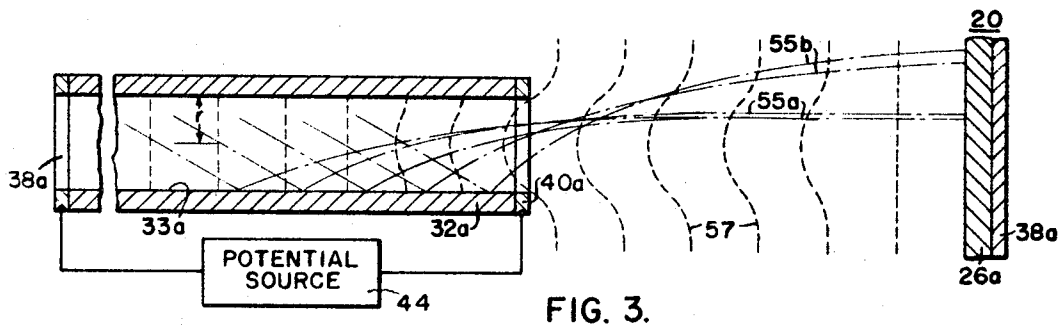
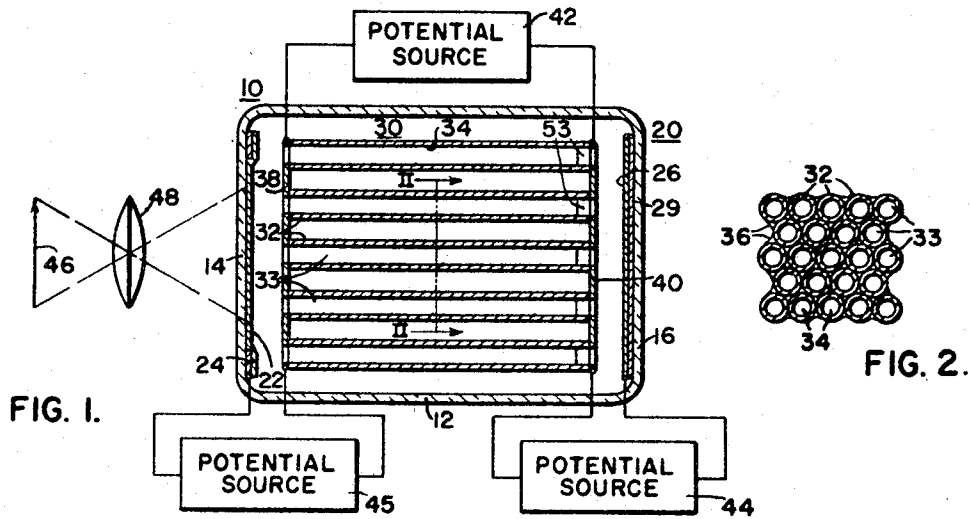


June 10, 1969

W. M. SACKINGER
ELECTRON MULTIPLIER DEVICE HAVING AN ELECTRICALLY
INSULATING SECONDARY EMISSION CONTROL SURFACE
Filed Feb. 2, 1966

3,449,582



1

2

3,449,582

**ELECTRON MULTIPLIER DEVICE HAVING AN
ELECTRICALLY INSULATING SECONDARY
EMISSION CONTROL SURFACE**

William M. Sackinger, Horseheads, N.Y., assignor to
Westinghouse Electric Corporation, Pittsburgh, Pa.,
a corporation of Pennsylvania

Filed Feb. 2, 1966, Ser. No. 524,974

Int. Cl. H01j 39/12

U.S. Cl. 250—213

6 Claims

ABSTRACT OF THE DISCLOSURE

This invention is directed to an electron multiplier including at least one tubular element having a first portion upon the interior surface capable of emitting secondary electrons in response to the bombardment by primary electrons. The interior surface of the tubular element has a second portion adjacent the exit opening through which the electrons are directed from the tubular element. This second portion is made of a suitable semiconductive or insulating material having a low secondary emission ratio.

This invention relates to electron image devices and more particularly to electron multipliers which may be incorporated in such devices.

In typical electron image devices, a source of electrons such as a photocathode element is provided for establishing an electron image the intensity of which is subsequently increased by an electron multiplier element. The resultant, intensified electron image is directed upon a display element such as a fluorescent screen to thereby provide a visual image of the electron image. Alternatively, the display screen could be replaced by a storage electrode and a television signal could be derived therefrom by scanning the surface of the storage electrode with a low voltage electron beam. The electron multiplier element may comprise an array of tubes which each define an electron multiplying path between the source of electrons and the display element. Each of the tubes presents a surface to the electron multiplying path which has the property of emitting secondary electrons in response to the incident primary electrons. In order to obtain the desired intensified electron image, the number of generated secondary electrons exceeds the number of incident primary electrons. Further, the intensified electron image is accelerated through each of the tubes and is directed as by a positive potential onto the display element. More specifically, an accelerating voltage is typically applied to the display element to withdraw electrons from the tubes of the multiplier device.

However, problems have arisen with the transmission of the electron image from the multiplier element to the display device. More specifically, it has been difficult to focus precisely the electrons from the multiplier element onto the display element; typically, there has been a tendency for the elemental portions of the electron image to diverge as they transverse the space between the multiplier device and display screen. This may be partially explained by the presence of an exit opening in each of the tubes which gives rise to a distortion to the equipotential lines as established by the voltage applied to the display element. More specifically, the equipotential lines in the regions adjacent to the exit openings tend to be curved towards the interiors of the tubes. Due to this distortion of the lines of equipotential, an electron lens is formed which tends to diverge the emerging electrons. Those secondary electrons which are emitted from the surface of the tube near the exit opening see a transverse accelerating field which imparts to them a greater transverse

velocity than their initial velocity of emission. These secondary electrons tend to diverge with respect to the axis of the tube and, as a result, the electron image cannot be precisely focussed upon the display element. The additional increment of transverse velocity causes these electrons to spread excessively after only a short distance and to overlap the spreading electrons emerging from adjacent channels, with consequent loss of resolution.

A possible solution to this problem would be to place the display element at extremely close distances to the exit opening of the tubes to thereby focus the electron image before it has had an opportunity to substantially defocus. However, unless the distance between the exit openings of the tubes and the display element was less than 3 or 4 tube radii, or of the order of .003" to .004", the diverging electron image could not be focussed upon the display element. However, such close spacing between the array of tubes and the display element would be very difficult to accomplish in practice. Typically, a potential difference of several kilovolts is applied between the exit openings of the array of tubes and the display element. As a result, voltage breakdowns might occur if such close spacing was attempted.

Accordingly, an object of the present invention is to provide a new and improved electron image device and multiplier element therefor.

Another object of this invention is to provide a new and improved multiplier element capable of focussing the intensified electrons generated therein.

It is another object of this invention to provide a new and improved electron multiplier element for an electron image device capable of eliminating the problems of defocussing the electrons emitted from the exit portions of the multiplier element.

Briefly, the objects of this invention are accomplished by providing an electron multiplier including at least one tubular element having a first portion upon the interior surface capable of emitting secondary electrons in response to a bombardment of primary electrons. Further, the interior surface of the tubular element has a second portion adjacent the opening through which the electrons are directed from the tubular element; the second portion is made of a suitable semiconductive or insulating material having a low secondary emission ratio. More specifically, the second portion of the interior surface should extend from the exit opening of the tubular element for a distance equal to at least 1.5 radii of the element.

Further objects and advantages of the invention will become more apparent when considered in view of the following detailed description and drawings, in which:

FIGURE 1 is a diagrammatic illustration of an electron image device incorporating the teachings of this invention;

FIG. 2 is an enlarged, sectional view taken along the line II—II of FIG. 1 of the multiplier element which has been incorporated in the device of FIG. 1;

FIG. 3 shows a sectional view of an electron multiplier device which does not incorporate the teachings of this invention; and

FIG. 4 shows a sectional view of an illustrative embodiment of the electron multiplier device as incorporated within the device shown in FIG. 1.

Referring now to the drawings and in particular to FIG. 1, there is shown an electron image device 10 incorporating a multiplier element 30 in accordance with the teachings of this invention for intensifying or multiplying the electron image directed thereon. The electron image device 10 comprises an envelope 12 made of a suitable insulating material such as glass and enclosed upon each end by face plates 14 and 16 which are made of a suitable light transmissive material such as glass. A photocathode

element 18 is disposed upon or adjacent the interior surface of the face plate 14 and includes a layer 22 of a photoemissive material and a ring 24 of a suitable electrically conductive material such as silver, which may be painted upon the face plate 14. In an illustrative embodiment where the input radiation is visible light, the layer 22 may be made of a suitable material such as cesium antimony which may be evaporated onto the face plate 14 by well known techniques. At the opposite end of the electron image device 10, there is disposed a fluorescent screen 20 which includes a layer 26 of an electrically conductive material and a layer 28 of a luminescent material. In an illustrative embodiment, the coating 26 may be made of a suitable electrically conductive material such as aluminum and may be deposited upon a layer 28 to a depth which is readily permeable to electrons directed thereon.

Further, the multiplier element 30 is disposed within the evacuated envelope 12 between the photocathode element 18 and the fluorescent screen 20. The multiplier element 30 includes a plurality of tubular elements or tubular means 32 which are joined together in an array so that the axis of each tubular element 32 is disposed parallel with each other. Further, the tubular elements 32 are bound together as shown in FIG. 2 as by an adhesive 36 such as an aluminum oxide which has been applied by a slurry technique and then dried in a nonoxidizing atmosphere. Further, a portion of the interior surface of the tubular element 32 designated by the numeral 34 is made of a material such as aluminum oxide which will present a secondary emissive surface to the electrons which are directed within the tubular element 32. Further, the interstices formed by the entrance portions (or means) of the tubular elements 32 are coated with a layer 38 of an electrically conductive material such as gold to a depth in the approximate range of 500 to 1000 angstroms. In addition, a second layer 40 of a suitable electrically conductive material is disposed by like techniques upon the interstices formed by the exit portions of the tubular elements 32. It is noted that each of the tubular elements 32 define or form apertures or openings 33 which extend through the conductive layers 38 and 40. A layer 53 is deposited upon a second portion of the tubular elements 32 adjacent the exit opening of the tubular elements 32 of an electrically insulating or semiconductive material which will present a surface 52 having a secondary emission ratio (i.e., the ratio of incident primary electrons to generated secondary electrons) which is substantially less than that of the surface designated by the numeral 34. More specifically, the secondary emission ratio of the material of which the layer 53 is made must be less than one. In an illustrative embodiment, the layer 53 was made of a suitable material such as carbon.

As will be explained later, incident primary electrons will be accelerated through the tubular elements 32 by a potential source 42 applied between the conductive layers 38 to thereby accelerate the electrons emitted by the layer 38 to thereby accelerate the electrons emitted by the layer 24 of photoemissive material into the apertures 33 defined by the tubular elements 32. In addition, a potential source 44 is applied between the conductive layer 40 and the conductive layer 26 to thereby accelerate the electrons from the tubular elements 32 and onto the fluorescent screen 20. In order to achieve electron multiplication within the tubular elements 32, the ratio of the axial dimension to the diameter of the tubular elements 32 should be maintained in excess of 10 to 1. However, in order to achieve electron gains which are high enough for most applications, the ratio of the axial dimension to the diameter of the tube should exceed 40. In an illustrative embodiment of this invention, a tubular element 32 is made with a diameter of $\frac{1}{1000}$ inch and with a diameter to the length ratio of 100; an electron multi-

plication in the order of 10^6 can be achieved with such a tubular element.

Referring now to FIGS. 1 and 4, a brief explanation of the electron image device 10 will be given. First, the light radiation emitted from a scene 46 is focused as by an optical lens 48 onto the surface of the photocathode element 18. The light image directed thereon is converted by the photocathode element 18 into an electron image whose spacial distribution corresponds to that of the light image. The electron image is then accelerated as by the potential source 45 applied between the conductive layers 24 and 38 into the openings 33 defined by the tubular elements 32. The electron image generated by the photocathode element 18 may be thought of as a plurality of elemental portions which are directed into the array of tubular elements 32 wherein multiplication or intensification of the elemental portions of the electron image takes place. More specifically, the elemental portions of the electron image are not entirely directed along paths parallel to the axis of the tubular elements 32 but rather will bombard the secondary emissive surfaces 34. As a result, secondary emissive electrons will be emitted from the surface 34 in numbers in excess of that of the incident primary electrons. As the electrons are accelerated under the influence of potential source 42 along the length of the tubular elements 32, bombardments of the surface 34 will occur with the result that a large intensification or multiplication of the electrons will occur. In an illustrative embodiment of this invention, a potential of approximately 1500 volts may be applied between the conductive layers 38 and 40 to provide the necessary acceleration and multiplication of the electrons within the tubular elements 32. The electrons are further accelerated from the tubular elements 32 by a potential source 44 which is applied between the conductive layers 40 and 26 to thereby direct the electrons onto the fluorescent screen 20 which in turn provides a visual image which corresponds to the intensified electron image directed thereon.

Referring now to FIG. 3, the difficulties associated with the prior art reside in their inability to precisely focus the electrons emitted from the exit opening of the tubular element onto the display element. In FIG. 3, the elements shown therein will be designated by similar numerals with the addition of an appropriate suffix. Thus, the electrons are directed within the tubular elements 32a and are accelerated along the length thereof by a potential source 44a which is applied between the conductive coatings 38a and 40a applied respectively upon the entrance and exit openings of the tubular element 32a. The problem may be more clearly understood by noting that a lens effect is created by the presence of the exit aperture in the tubular element 32a which gives rise to a distortion of the lines of equipotential as established by the potentials applied to the conductive layer 40a and the layer 26a of the fluorescent screen 20a. As shown in FIG. 3, the presence of the exit opening in the tubular element 32a imparts a bending to the lines 57 of equipotential in the region adjacent to the exit opening. More specifically, the lines 57 of equipotential are curved inward toward the interior of the aperture with a maximum point of deflection upon the axis of the tubular elements 32a. As a result of this lens effect, the secondary electrons, whose trajectories are designated by the numeral 55b and which are emitted from that portion of the secondary emissive surface 33a near the exit opening of the tubular element 32a, will be effected by a transverse accelerating field which imparts to these electrons a greater transverse velocity than their initial velocity of emission. The secondary electrons generated from this region are emitted with a comparatively low initial velocity and are more readily effected by the accelerating forces established by the lens effect. These electrons are thus transversely accelerated along trajectories 55b across the axial centerline of the tubular element 32a (as shown in FIG. 3) at an angle of about 22° at a point of about one radius length of the tubular ele-

ment from the exit opening of the element 32a. Thus, the electrons emitted from that portion of the surface 33a within 1.5 channel radii of the exit opening of the tube 32a will have a tendency to diverge excessively after only a short distance, overlapping the diverging electrons emerging from the adjacent tubular elements with consequent loss of resolution.

However, secondary electrons which are emitted from those portions of the surface 33a disposed further inside the tube 32a than 1.5 tube radii are directed along trajectories 55a which are more nearly parallel to the axis of the tubular element 32a. As shown in FIG. 3, the lines 57 of equipotential established within the interior of the element 32a are more nearly linear and perpendicular to the axis of the tubular element. As a result, the secondary electrons which are emitted from further within the channel or tubular element 32a are axially accelerated to a sufficient degree that the lens effect due to the exit opening does not substantially effect these electrons but instead focusses these electrons along trajectories designated by the numeral 55a which are essentially parallel or at least not diverging with respect to the axis of the tubular element 32a. It is noted that the lens effect of the openings may tend to converge the electrons towards the axes of the tubes 32. The trajectories 55a are much more desirable from a resolution viewpoint for they may be directed a distance of several tens of tube radii before overlapping or defocussing occurs. This latter overlapping is caused by statistical variations in the emission energy or direction.

Referring now to FIG. 4, a proposed solution for the difficulties encountered with the defocussing of those electrons emitted from the portions adjacent the exit opening of the tubular elements is shown. As pointed out above, the electrons generated from those portions of the tubes 32 at distances greater than 1.5 radii of the tubular element from the exit opening are directed along trajectories which are substantially parallel to or converging towards the axis of the tube for a distance of in excess of several tens of tube radii, whereas those electrons emitted from those portions of the secondary emissive surface within 1.5 tube radii of the exit opening of the tube are accelerated in diverging trajectories which will intercept the trajectories of electrons emitted from adjacent tubular elements. Thus, the proposed solution for improving the resolution utilizes means for focussing only those secondary electrons which are generated from those portions of electron emissive surface 34 which are at a distance from the exit opening of the tube 32 equal to or greater than 1.5 radii of the tubular element. More specifically, this result is accomplished by depositing the layer 53 upon the interior surface of the tubular element 32 extending from the exit opening continuously to a depth indicated by the letter D. In accordance with the teachings of this invention, the distance D is determined to be equal to or in excess of 1.5 radii of the tubular element 32. Further, the layer 53 presents a surface 52 whose secondary emission ratio is less than one and is substantially less than that of the surface 34 to thereby inhibit the generation of secondary electrons from this portion of the tubular element. Further, it is an important aspect of this invention that the layer 53 be made to be insulating or semiconductive. For the purposes of describing this invention, the terms semiconductive or insulating are used to describe a material or layer having a resistance in excess of 1000 ohms per cm.². The importance of making the layer 53 insulating or semiconductive may be realized by considering the effects of using a conductive layer. If the layer 53 is made to be electrically conductive, the lens effect due to the exit opening of the tubular elements 32 would be displaced to within the interior of the tube thus causing a portion of the electrons ejected from the tubular element 32 to be diverged.

The array of tubes 32 may be manufactured and assembled together as shown in FIGS. 1 and 2 in accordance with the method disclosed in the copending application,

Ser. No. 487,228, entitled "Storage Multiplier Screen For Image Correlation," by Richard W. Decker and assigned to the assignee of this invention. The method described therein includes the steps of evaporating a secondary emissive material such as aluminum oxide onto a filament made of a suitable material such as nylon and then applying an adhesive material of a material such as aluminum oxide. The filament is then rolled onto a mandrel to thereby form the desired array. Next, the adhesive material is hardened and the wound filaments are cut into the desired multiplier units. Finally, the nylon filaments may be removed by appropriate solutions to provide a plurality of tubes whose inner surfaces have a high secondary emission ratio.

Illustratively, carbon could be deposited upon the interior surface of the tubular elements 32 to form the layer 53. This could be accomplished by heating the ends of the tubular elements to a temperature of approximately 900° or 1000° C. while directing a benzene vapor thereon. The benzene vapor will penetrate into the openings 33 and the benzene will decompose to deposit a layer 53 of carbon. This method would have particular application where the tubular elements are made of a ceramic material such as Al₂O₃. Alternatively, the layer 53 could be formed while the metallic layer 40 is being evaporated upon the interstices of the exit portions of the tubular elements. Illustratively, a source of a suitable metal such as gold, chromium or aluminum is disposed at an angle of approximately 45° with respect to the axes of the tubular elements 32. A discontinuous layer of such a metal is evaporated at this angle upon the interior surface of the tubular element to a depth of less than about 100 Å. By evaporating one of these metals to this depth, a discontinuous layer appearing as a series of islands will be formed having the required insulating properties. This method would have particular application where the tubular elements are made of glass.

Although the multiplier element of this invention has been shown as in FIG. 1 to be incorporated within an image intensifying device 10, it is noted that the teachings of this invention could be incorporated into other devices such as a direct view storage tube or a Photocorrelator tube which are described in the above mentioned copending application.

Since numerous changes may be made in the above described apparatus and different embodiments of the invention may be made without departing from the spirit thereof, it is intended that all matter contained in the foregoing description or shown in the accompanying drawings, shall be interpreted as illustrative and not in a limiting sense.

I claim as my invention:

1. A tubular means for the intensification of electrons and defining a multiplying path, said tubular means including an electrically insulating surface exposed to said path having first and second portions, and an entrance and exit into and from said tubular means, said first portion of said surface exhibiting the property of emitting secondary electrons at a given rate in response to bombardment of primary electrons, said second portion of said surface disposed at said exit and exhibiting the property of emitting secondary electrons in response to bombardment of primary electrons at a rate substantially less than said given rate.

2. A tubular means as claimed in claim 1, wherein said second portion of said surface extends from said exit a distance equal to or in excess of 1.5 times the radius of said tubular means.

3. An assembly including a plurality of said tubular means as claimed in claim 2, wherein said plurality of tubular means are joined together in an array so that the axes of each of said tubular means is disposed parallel with each other.

4. An electron image device including the assembly as claimed in claim 3 comprising an envelope, first means

7

for providing an electron image, said assembly disposed so as to receive said electron image, and second means disposed at the other end of said envelope to receive the intensified electron image from said assembly of tubular means.

5 5. A tubular means as claimed in claim 1, wherein said second portion of said electrically insulating surface is formed of an electrically insulating material.

10 6. A tubular means as claimed in claim 1, wherein said second portion of said electrically insulating surface is formed of a discontinuous coating of metal.

8

References Cited

UNITED STATES PATENTS

3,260,876	7/1966	Manley, et al.	250—213
3,343,025	9/1967	Ignatowski et al	250—213
3,350,594	10/1967	Davis et al.	250—213

RALPH G. NILSON, *Primary Examiner.*

BRUCE L. ADAMS, *Assistant Examiner.*

U.S. Cl. X.R.

313—105, 107