

April 22, 1969

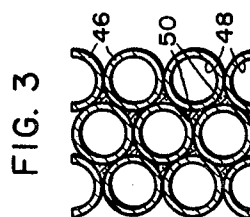
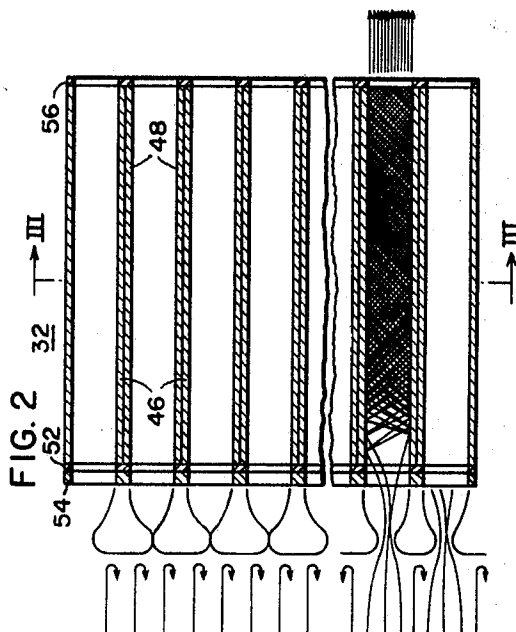
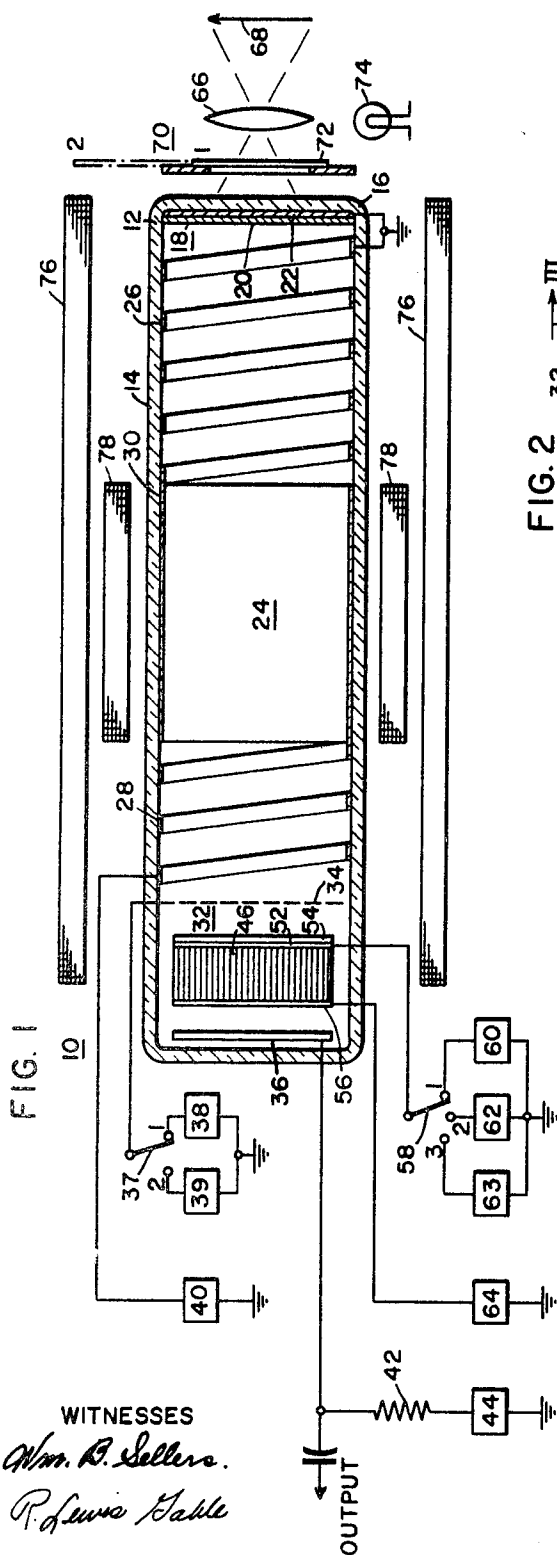
R. W. DECKER

3,440,470

IMAGE STORAGE TUBE MULTIPLIER ELEMENT

Filed Sept. 14, 1965

Sheet 1 of 2



INVENTOR
 Richard W. Decker
 BY
Charles F. Remy
 ATTORNEY

April 22, 1969

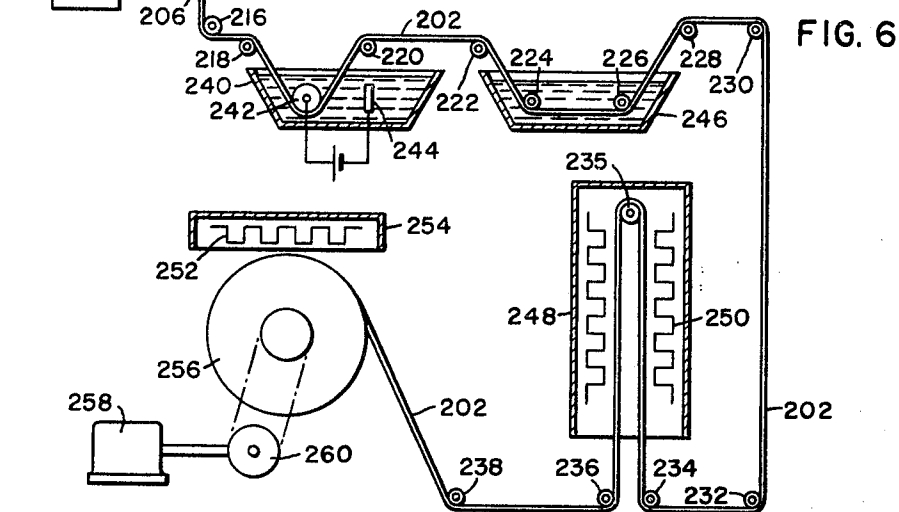
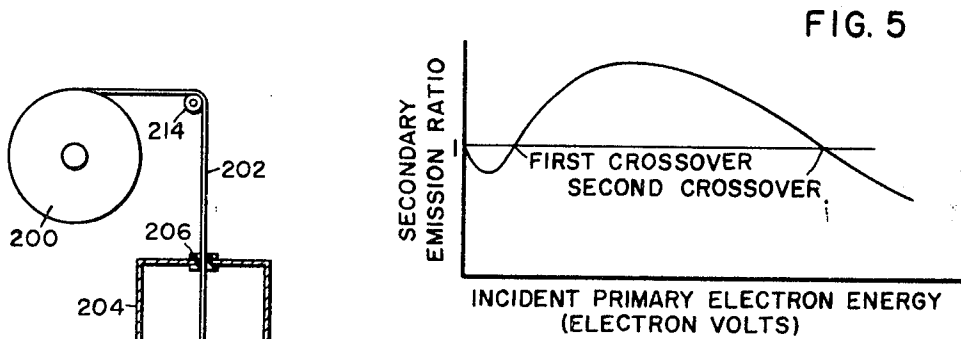
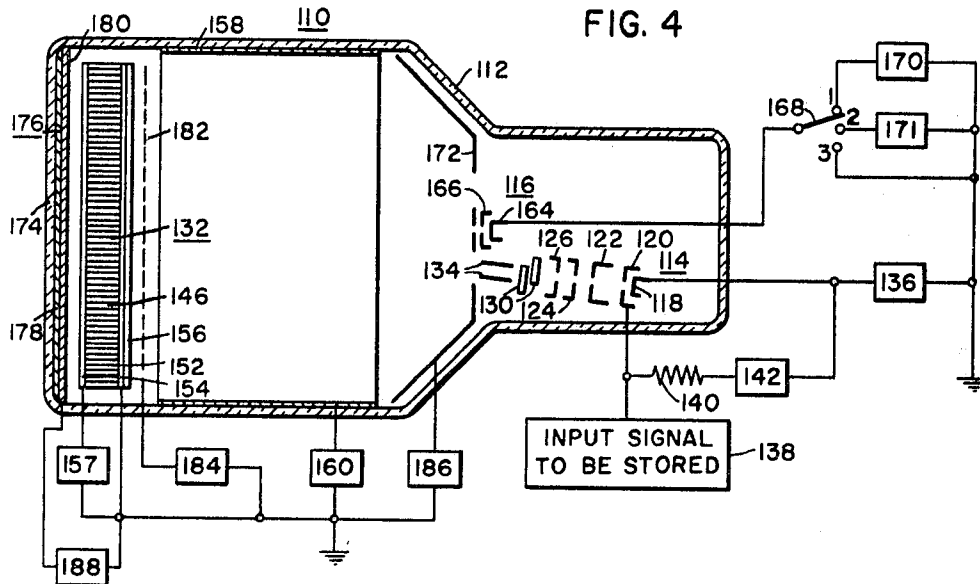
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IMAGE STORAGE TUBE MULTIPLIER ELEMENT

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Sheet 2 of 2



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3,440,470 IMAGE STORAGE TUBE MULTIPLIER ELEMENT

Richard W. Decker, Baltimore, Md., assignor to Westinghouse Electric Corporation, Pittsburgh, Pa., a corporation of Pennsylvania

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3 Claims

ABSTRACT OF THE DISCLOSURE

This invention is directed to a storage multiplier electrode which may be incorporated into an image storage device for storing a pattern of charges and intensifying the output signal derived from said pattern of charges. The electron multiplier includes a plurality of tubular elements with the storage surface disposed on one end thereof.

This invention relates to image storage devices and more specifically to storage devices in which information may be stored as a pattern of charges and then extracted at a later time.

This invention is more particularly directed to a storage multiplier element which may be incorporated into an image storage device for storing a pattern of charges and intensifying the output signal derived from said pattern of charges. Further, this invention relates to a method of manufacturing an improved multiplier element.

One particular application of this invention is in an image correlation device such as described in the copending application entitled, "Method and Apparatus for Performing Image Correlation," Ser. No. 470,108 filed, July 1, 1965, by A. S. Jensen and assigned to the assignee of this invention. Generally, correlation refers to the technique of comparing two images and deriving an output signal related to the displacement of the elements within the two images. Correlation is performed in the device described in the above-mentioned copending application by first storing a pattern of charges corresponding to the first image on a storage target element. Next, an electron beam or image representing the second image is directed toward the storage element and an output signal is obtained by collecting the second electron image which has been effectively modulated or influenced by the pattern of charges representing the first image. Further, by displacing the second electron image with respect to the pattern of charges stored upon the storage element, maximum or minimum values may be obtained and a comparison between the first and second images is provided as a function of this displacement. The electron image device as described in the above-mentioned copending application includes a photocathode element for converting the light radiation from the first and second scenes into corresponding electron images which are in turn directed upon the storage element. In one particular embodiment, the storage element comprises a conductive backplate upon which there has been disposed a plurality of dielectric elements capable of being charged to a form a pattern of charges corresponding to the first electron image. As explained above, the second scene is then directed upon the photocathode element and a corresponding second electron image is deflected across the target element as by an electromagnetic coil disposed between the photocathode element and the storage target element; an output signal is derived from the electrically conductive backplate upon which is directed the second electron image that has been modulated by the pattern of charges stored upon the dielectric elements.

A problem related to this type of image device and more particularly to photocathode elements occurs when a particularly intense light beam is focused on a portion of the photocathode element. More specifically, the intense light beam causes the photoemissive layer of the photocathode element to emit a correspondingly intense beam of electrons. The beam of electrons is drawn as a current through the conductive layer of the photocathode element and is emitted as a beam of electrons from the photoemissive surface. Typically, the electrically conductive layer presents a high resistance in the order of thousands of ohms per centimeter to the current drawn therethrough. Even if only a microamp or less current is drawn by the emitted photoelectron beam, a potential in the order of several hundred volts may be developed over a portion of the electrically conductive backplate. As a result, the point of electron emission upon the photocathode element may be disposed at a potential of several hundred volts whereas the peripheral portions may be disposed at ground potential. In order to focus the electron beam emitted by the photocathode element it is necessary to dispose other electrodes about the path of the electron beam with correspondingly increasing positive potentials applied thereto. However, if a potential of several hundred volts is developed upon a portion of the face of a photocathode element, the focusing voltages between the photocathode element and the accelerating electrodes is radically changed and the electron image generated by the photocathode element will no longer be focused upon the storage element.

In another application, this invention may be applied to storage type, cathode ray display tubes. In general, the display type storage tube consists of a perforate storage grid member which controls the electron flow from a flood-type electron gun to a luminescent screen. A space distributed charge image is produced on the surface of the storage grid by an intensity modulated, scanning electron beam. The charge image so recorded on the storage grid controls or modulates the flow of electrons from the flood type reading gun to the screen; thus a visual light image of the charge pattern is produced on the display screen.

In a display type storage tube, the reading and writing electron beams are produced by typical electron guns which, in contradistinction to the image devices for correlation as described above, are capable of providing an electron beam with ample current density without fear of being defocused as it lands upon the luminescent screen. However, in order to provide sufficient illumination from the screen, the charge pattern disposed upon the storage grid member is written by a high density electron beam. Of necessity, a high density electron beam has a greater width or spot size which prevents the deposition of a high resolution pattern of charges upon the storage grid member. Further, in order to achieve the desired degree of brightness, the flood electron beam as emitted from the reading gun must be accelerated under a high voltage in order to bombard the display screen with sufficient energy. Thus it may be understood that the reading electron beam may not be sufficiently controlled or modulated by the pattern of charges and resultant deformities may be introduced in the visual light pattern projected from the luminescent screen.

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

Another object of this invention is to provide a new and improved storage target element capable of providing an intense output signal.

It is another object of this invention to provide a new and improved electron image device capable of maintaining the focus of an electron image as emitted by a

photocathode element even while sensing intense light radiation.

It is a still further object of this invention to provide a new and improved electron image device capable of storing a high resolution pattern of charges and displaying an intense light image corresponding to said pattern of charges.

It is another object of this invention to provide a novel method of forming a multiplier element with a plurality of tubular elements having a uniform configuration and a surface exhibiting uniform secondary emissive characteristics.

Briefly, the objects of this invention are accomplished by providing an electron image device incorporating a target element including at least one tubular element having an interior surface capable of emitting secondary electrons in response to an electron bombardment and a storage means such as a layer of dielectric material disposed upon the entrance portion of the tubular element. Typically, a plurality of the tubular elements are combined together so that an electron image may be stored upon the layer of dielectric material and a multiplied output signal may be obtained by bombarding the interior surface of the tubular elements with an electron beam that has been modulated by said pattern charges. Further, the electron image device of this invention includes a means for producing an electron beam to be directed upon the layer of dielectric material of the storage elements and a means for collecting the intensified electron beam generated within the tubular element of the target element.

In one exemplary embodiment of this invention, an electron image device is provided with a photocathode element for converting a first and second light image incident thereon into corresponding electron images. The storage target element as described above is disposed between the photocathode element and a means such as an electroconductive plate for receiving the electron beam as intensified by the storage target element. Further, there is disposed about and between the photocathode element and the storage element a means for deflection such as an electromagnetic coil to displace the electron image representing the second scene with regard to the pattern of charges stored upon the storage element and representing the first scene.

In another exemplary embodiment of this invention, an electron image device is provided with an electron gun for emitting a pencil like beam of electrons onto the above-described target element and a luminescent display screen for displaying a visual image corresponding to the pattern of charges stored upon the target element. Further, a second electron gun is provided to direct a flood beam of electrons onto the target element; the flood beam of electrons is modulated by the pattern of charges disposed upon the storage element and intensified by repeated bombarding against the interior surface of the tubular elements. The intensified electron beam is then directed to the display screen and converted into a visual light image.

It is a further aspect of this invention to provide a new and novel method of manufacturing a multiplier element having a plurality of uniformly spaced tubular elements having a regular, defined configuration and presenting an interior surface with uniform secondary emissive characteristics. In accordance with the teachings of one aspect of this invention, this method includes the steps of forming a uniform filament having a smooth exterior surface. Next, the surface of the filament is oxidized to provide a material having the property of emitting secondary electrons in response to a bombardment of primary electrons. The interior portion of the filament is removed so as to expose the surface region having the property of secondary emission. Lengths of the filament are joined to each other and are cut to form a composite multiplier element as described above. In one illustrative

embodiment of this invention, a core made of a suitable material such as nylon is coated with a thin aluminum or magnesium coating as by evaporation. Next, the aluminum coating is oxidized and the filament is coated with an adhesive material. Next, while the adhesive material remains in an unset condition, the filament is wound about a reel and the adhesive material hardened. Finally, the wound filament is cut into sections and the inner core is removed by an etching solution to thereby provide a multiplier element having a plurality of regularly formed tubular elements. Alternatively a solid aluminum wire could be used, in this method the outside surface of the aluminum is wire oxidized and the center portion is then removed by an appropriate reactant such as hydrochloric acid.

Further objects and advantages of the invention will become more apparent as the following description proceeds and features of novelty which characterize the invention will be pointed out in particularity in the claims annexed to and forming a part of the description.

For a better understanding of the invention, reference may be had to the accompanying drawings, in which:

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

FIG. 2 is an enlarged, sectional view of the storage multiplier element which has been incorporated within the device as shown in FIG. 1;

FIG. 3 is an enlarged, sectional view taken along the line III—III of FIG. 2 of the storage multiplier element which has been incorporated in the device of FIG. 1;

FIG. 4 shows a sectioned view of an alternative embodiment of the electron image device of this invention;

FIG. 5 is a characteristic curve of effective secondary emission ratio of a dielectric material as a function of the energy of bombarding electrons upon the surface of the material; and

FIG. 6 is a schematic diagram showing a method of fabricating a filament into a multiplier element in accordance with the teachings of this invention.

Referring now to the drawings and in particular to FIG. 1, there is shown an image storage device 10 incorporating a storage multiplier element 32 in accordance with the teachings of this invention for electronically performing correlation between the two images. The image storage device 10 comprises an envelope 12 with a cylindrical portion 14 made of a suitable insulating material such as glass and enclosed upon one end by a face plate 16 made of a suitable light transmissive material such as glass. A photocathode element 18 is disposed on the interior surface of the face plate 16 and includes a photoemissive coating 20 which is sensitive to the input radiation and a suitable electrically conductive contact formed as a layer 22. In the instance where the input radiation is visible light, the photoemissive coating 20 may be made of a suitable material such as cesium antimony which may be evaporated onto the conductive layer 22 by well known techniques.

Further, an electron accelerating means 24 is provided along the length of the inner surface of the cylindrical portion 14 in order to accelerate the electrons emitted by the photocathode element 18. The electronic accelerating means 24 includes a first spiral electrode 26 adjacent the photocathode element 18 having one end thereof connected exteriorly of the envelope 12 to ground. A second spiral electrode 28 is disposed at the outer end of the cylindrical portion 14 of the envelope 12 and is electrically connected exteriorly of the envelope 12 to a potential source 40. An equipotential electrode 30 is disposed intermediate of and in electrical connection with the first and second spiral electrodes 26 and 28. Typically, the first and second spiral electrodes 26 and 28 and electrode 30 may be formed by first evaporating a thin layer of approximately 100 Å in thickness of a suitable electrically resistant material such as chromium upon the

interior surface of the cylindrical portion 14. Next, portions of this thin layer may be removed as by a lathe-type scraping tool to form the first and second spiral electrodes 26 and 28.

Within the opposite end of the image storage device 10, there is disposed the storage multiplier element 32. A mesh electrode 34 is disposed in a plane parallel to and spaced from the surface of the storage multiplier element 32. Further, a collector electrode 36 is disposed on the other side of the storage multiplier element 32 in order to receive an electron beam directed through the element 32. The collector electrode 36 is in turn connected through an impedance 42 and a potential source 44 to ground, and an output signal is derived from the voltage developed across the impedance 42. Further, the mesh electrode 34 is connected externally of the envelope 12 as by a switching means 37 to either of potential sources 38 and 39 which are in turn connected to ground.

Referring now to FIGS. 2 and 3, a specific embodiment of the storage multiplier element 32 will be shown. The storage multiplier element 32 includes a plurality of tubes or tubular means 46 joined together so that the axis of each tube is disposed parallel with each other. Further, the tubes 46 are bound together as by an adhesive 50 such as an aluminum oxide which has been applied by a slurry technique and then dried in a non-oxidizing atmosphere. Further, the interior surface of the tube 46 is made of a suitable material such as aluminum oxide which will present a secondary emissive surface 48 to electrons which are directed within the tubes 46 as shown in FIG. 2. Further, the interstices formed by the entrance portions (or means) of the tubes 46 are coated with conductive layers 52 and 56 of a material such as gold to a depth in the approximate range of 500 to 1000 Å. In addition, a layer 54 of a suitable storage dielectric material such as magnesium fluoride is deposited upon the conductive layer 52. It is noted that the apertures as defined by the tubes 46 extend through the conductive layers 52 and 56 and the layer 54 of the dielectric storage material. As will be explained later, incident primary electrons will be directed within the tubes 46 and will be accelerated by a potential applied between the conductive layers 52 and 56 to thereby be repeatedly bombarded against the secondary emissive surface 48. In order to achieve electron multiplication within the tubes 46, the ratio of the axial dimension to the diameter of the tubes 46 should be maintained in excess of 10 to 1. However, in order to achieve electron gains which are high enough to be inserted in most tubes, a ratio of axial dimension to the diameter of the tube must exceed 40. It is noted that with a diameter of $\frac{1}{1000}$ inch and a diameter to length ratio of 100 that an electron multiplication in the order of 10^6 has been achieved.

Referring now to FIG. 1, the conductive layer 52 of the storage multiplier element 32 is connected through a switching means 58 through either of the potential sources 60, 62 or 63 to ground. In addition, the conductive layer 56 is connected externally of the envelope 12 through a potential source 64 to ground. Further, a suitable lens system 66 for focusing the radiations emitted from a scene 68 onto the photocathode element 18. A shutter 70 is disposed between the lens system 66 and the face plate 16 of the image storage device 10. In particular, the shutter 70 includes a movable element 72 which may be actuated from a closed position 1 to an open position 2 in order to allow the radiations to be focused by the lens system 66 unto the photocathode element 18. A suitable focusing means such as an elongated magnetic coil 76 is disposed along the length of the envelope 12 to focus the electrons emitted by the photocathode element 18 onto the storage multiplier element 32. Further, a deflection means 78 such as a standard image orthicon deflection coil is disposed about the cylindrical portion 14 of the envelope 12; more particularly, the deflection means 78 is disposed about the equipotential electrode 30

to insure that no rotational component is imposed upon the electron beam emitted by the photocathode element 18. Within the area defined by the electrode 30, the potential field established by the electrode remains substantially constant; as a result, the field generated by the deflection means will only impart a linear motion to the electron beam being directed upon the storage multiplier element 32. Further, a light source 74 such as a lamp is disposed to uniformly excite and flood the photocathode element 18 with light.

The operation of the image storage device 10 as shown in FIG. 1 requires the performance of a four part cycle. The four steps of the operation include (1) priming, (2) exposure to a first image, (3) exposure to a second image, and (4) erasing.

(1) *Priming.*—During the first step of the operating cycle, the conductive layer 52 of the storage multiplier element 32 is set at a potential with respect to that of the cathode element 18 of approximately 12 volts positive. This is accomplished by connecting the conductive layer 52 to the potential source 60 through the switching means 58 (position 1). The movable element 72 of the shutter 70 is disposed in a closed position (i.e. position 1) and the light source 74 is energized to cast a uniform light upon the photocathode element 18. In turn, the photocathode element 18 emits a uniform electron beam which is accelerated by the accelerating means 24 to flood the storage multiplier element 32.

As is well understood in the art, electron bombardment upon a dielectric storage material will cause the dielectric material of layer 54 to emit secondary electrons. Referring now to FIG. 5, it may be seen that in the region below first crossover and in the region above second crossover that less than one secondary electron will be emitted in response to one incident primary electron. In the region between first crossover and second crossover, which points are determined by the characteristics of the particular storage material, more than one secondary electron will be emitted for each incident primary electron. It is noted that the 12 volts applied to the conductive layer 52 to accelerate the electrons emitted by the photocathode element 18 is below the first crossover potential of the storage material of which the layer 54 is made. As a result, the surface of the layer 54 is driven negatively due to the accumulation of negative electrons. Thus, in this exemplary method of operating the image storage device 10, the surface of the layer 54 has been set at a potential of approximately 12 volts negative with respect to the potential of the conductive layer 52.

(2) *First exposure.*—After the priming step, the switching means 58 is disposed in its second position whereby the conductive layer 52 is connected to the potential source 62 which is approximately 22 volts positive with respect to ground. Due to the capacitive action between the conductive layer 52 and the surface of the layer 54, the surface of the layer 54 is set at a potential of approximately 10 volts positive with respect to ground. Next, the movable element 72 is moved to the open position (i.e. position 2) and the radiations from the scene 68 are focused as by the lens system 66 onto the photocathode element 18. The photocathode element 18 converts the radiation image into a corresponding electron image which is accelerated by the means 24 onto the storage multiplying element 32.

It is noted that during this writing step, that the voltage applied to the conductive layer 52 is likewise below the first crossover potential of the storage material of which the layer 54 is made. As a result, the electron image as emitted by the photocathode element 18 will tend to drive those bombarded portions of the layer 54 negatively due to the accumulation of electrons. After the electron image corresponding to the first image from the scene 68 has been integrated for a sufficient period of time upon the layer 54, the shutter 70 is closed (i.e. position 1). At

this point in the operating cycle, those portions of the layer 54 which have been bombarded with primary electrons will be charged to a level of approximately 7 volts positive with respect to ground or 15 volts negative with respect to the potential of the conductive layer 52. Further, those portions of the layer 54 which have not been bombarded with the primary electrons will be charged to a level of approximately 10 volts positive with respect to ground or 12 volts negative with respect to the potential of the conductive layer 52.

(3) *Second exposure.*—After a charge pattern has been disposed upon the surface of the layer 54 corresponding to the first image, the image storage device 10 may be switched to receive the second image. This may be accomplished by disposing the switching means 58 in its first position so that the electrically conductive layer 52 is connected to the potential source 60 of a value of approximately 12 volts positive with respect to ground. Due to the capacitive coupling between the conductive layer 52 and the surface of the layer 54, the surface of the layer 54 which has been charged during the first exposure is disposed at a potential of approximately 3 volts negative with respect to ground; those portions of the layer 54 which have not been charged are brought to a potential of approximately ground.

Referring now to FIG. 2, there is shown a cross sectional view of the storage multiplier element 32. As explained above, portions of the layer 54 have been disposed between 3 volts negative with respect to ground and ground potential. It may be understood that other portions of the layer 54, as shown in FIG. 2, may be charged to voltages intermediate zero and 3 volts negative with respect to ground to reflect various shades of the scene 68. As can be seen in FIG. 2, the portions of the layer 54 which have been charged negatively generate equal potential surfaces that tend to cut down the area through which the electrons emitted by the photocathode element 18 can be directed into the tubes 46. As the portions of the layer 54 are driven more negatively, the negative equal potential surfaces spread out and tend to prevent the entrance of the electron beams into the tubes 46. Thus, where there has been deposited a more negative charge upon the layer 54, the negative equal potential surfaces overlap with each other and less electrons are allowed to enter the tubes 46; on the other hand where a more positive charge has been disposed upon the layer 54, the negative equal potential surfaces provide a greater passage therebetween and a greater number of electrons are allowed to enter the tubes 46. It is particularly noted that due to the negative charge disposed on the layer 54 that the electrons emitted from the photocathode element do not land on the layer 54 and that the charge pattern established during the first exposure will remain and continue to influence or modulate the electron beam from the photocathode element 18.

Once the electrons have entered within the tubes 46, the electrical field as established between the conductive layers 52 and 56 tend to accelerate the electrons along the axial length of the tubes 46. As the electrons move along the length of the tubes 46, they tend to bombard the secondary emissive surfaces 48 with an energy sufficient to produce more than one secondary electron per incident primary electron. As a result, the electron beam modulated by the pattern of charges distributed upon the layer 54 is successively multiplied by repeated bombardment against the secondary emissive surface 48 and a greatly multiplied electron current is emitted from the plurality of tubes 46 to be collected upon the collector electrode 36. Typically, a voltage of approximately 2,000 volts positive with respect to ground is applied to the conductive layer 56 in order to accelerate the electrons through the tubes 46. Further, a potential of approximately 2,050 volts positive with respect to ground is provided by the potential source 44 upon the collector electrode 36 to thereby

attract the electron image derived from the storage multiplier element 32.

During the second exposure, the radiation from the scene 68, the elements of which have changed since the first exposure, is directed onto the photocathode element 18; an electron image corresponding to the second radiation image is directed over substantially the entire area of the storage multiplier element 32. Since the storage multiplier element 32 is not being scanned as in a typical television readout tube by a narrow pencil beam electron but rather by a flood type beam of electrons the distribution of which corresponds to the radiation from the scene 68, the signal derived from the collector electrode 36 is an instantaneous summation of all the electron currents directed through the plurality of tubes 46 and collected by the electrode 36. In other words, the signal derived from the collector electrode 36 represents an integration of the various currents derived from each portion of the collector electrode 36. Further, each of the electron currents directed upon the electrode 36 is in turn a function of the charge stored upon the layer 54 of dielectric storage material and, further, a function of the density of electrons emitted by the photocathode element 18 during the second exposure. This may be represented mathematically as:

$$I_{OUT} = \iint i_2(x,y) \cdot q_1(x,y) dx dy$$

where $i_2(x,y)$ represents the electron image directed upon the storage multiplier element 32 during the second exposure and $q_1(x,y)$ represents the charge distribution stored upon the storage layer 54 during the first exposure. Thus, it may be understood that the output signal derived from the collector electrode 36 accurately represents a correlation function of the first and second scenes taken respectively during the first and second exposure of the image storage device 10.

In order to sense a change in the composition of scene 68 between the first and second exposures, the pattern of charges as stored upon the layer 54 and the electron image representing the scene during the second exposure should be varied or displaced with respect to each other. Referring to FIGURE 1, there is shown an exemplary means for obtaining a linear displacement of the electron image emitted by the photocathode element 18 during the second exposure. In particular, a current source (not shown) supplies a sawtooth current wave to the deflection means 78 which in turn provides a deflection field across the cross-section of the envelope 12. The electron image is thereby displaced in accordance with the electric field generated by the means 78 and the points of incidence of the electron image upon the layer 54 will thereby vary in a linear manner. It is noted that the deflection means 78 is disposed about the equi-potential electrode 30 so that the electromagnetic field generated by the means 78 does not interact with a changing electrostatic field to produce an undesired rotation of the electron beam emitted from the photocathode element 18.

When two scenes which are identical to each other are viewed in a manner as described above, a minimum (or a maximum, depending upon the polarity of the signals) output signal will be derived from the collector electrode 36 at that point where there is no displacement between the scenes. As the second image is displaced from the first image, as by the means 78, the output signal will correspondingly be decreased due to the lack of correspondence between the elements of the two images being correlated with each other. It may be understood that where the images or scenes viewed upon the device 10 are not identical but where there is a deviation due to the movement of some object within the second image, there will be achieved a minimum (or maximum) output signal where there is the closest correspondence between the elements of the first and second images. The degree to which the first and second images are similar to each other is indicated by the scope, the amplitude, and the amount of displacement required to

derive the minimum output signal. The curve or curves so obtained may be compared with correlation curves for known changes in the image to thereby determine the nature of the movement in the second image. Further, the output signal derived from the collector electrode 36 may be viewed upon a display device such as an oscilloscope (not shown) which has in addition been connected to the current source attached to the means 78 to thereby provide a visual display of the output signal as a function of the displacement between the first and second images.

For a further explanation of the structure and operation of a device for performing correlation between two scenes, reference is made to the above-mentioned copending application of A. S. Jensen.

(4) *Erasing*.—In order to perform an additional correlation operation, it is necessary to remove the pattern of charges which have been disposed upon the layer 54 of storage dielectric material. In order to accomplish this fourth step, the switching means 58 is disposed in a third position in order to apply the potential source 63 to the conductive layer 52 of the element 32. Further, the switching means 37 is connected in a second position in order to connect the mesh electrode 34 to the potential source 39. During the erasing step, it is desired to bombard the layer 54 with electrons accelerated by a potential above the first cross-over of the storage material of the layer 54. As explained above, incident electrons which have been accelerated to a potential between the first and second cross over potentials will cause a dielectric material to emit more secondary electrons than the number of incident primary electrons. In a typical operation of the storage multiplier element 32, the potential source 63 is set at a value of approximately 300 volts and the potential source 39 is set at a value of approximately 310 volts. Further, the light source 74 is energized and the light therefrom is focused upon the photocathode element 18. A resultant electron beam is accelerated by the potential applied to the conductive layer 52. As the electron beam emitted by the photocathode element 18 strikes the layer 54, secondary electrons are emitted and collected by the mesh electrode 34; as a result, there is a loss of electrons and the surface of the layer 54 is driven positively to a voltage approaching that applied to the mesh electrode 34. At the end of this step, the entire surface of the layer 54 is charged positively and the pattern of charges disposed thereon during the first exposure is removed.

Further, it may be understood that in order to write a pattern of charges upon the layer 54 of the element 32 it would be necessary to prime the surface of the layer 54 as described above. Typically, this may be performed by displacing the switching means 58 in its first position and repeating the process as outlined above.

Referring now to FIG. 4, there is shown an image storage display device 110 comprising an evacuated envelope 112 of suitable shape and configuration. Positioned at one end of the envelope 112 are disposed a plurality of electron guns 114 and 116. In the specific embodiment shown, the electron gun 114 is provided for generating a pencil type electron beam which may be used to scan the entire surface of a storage multiplier element 132 positioned at the opposite end of the envelope 112. It is noted that the stored multiplier element 132 is substantially identical to that described with regard to FIGURES 2 and 3. The second electron gun 116 is centrally located within the envelope 112 to provide a flood electron beam over the entire surface of the storage multiplier element 132.

The electron gun 114, which may be referred to as a write gun, is comprised of a cathode element 118, a control grid 120, and beam forming and accelerating electrodes 122, 124 and 126. Electrostatic deflection means in the form of two pairs of plates 130 and 134 are provided in front of the beam forming electrodes for deflecting the electron beam generated within the electron gun

114 so as to scan a raster on a layer 156 of a storage dielectric material. Suitable voltages are applied to the electrodes 118, 120, 122, 124 and 126 in a well known manner in order to provide proper focusing and accelerating of the electron beam. The cathode element 118 of the write electron gun 114 is connected by means of a lead-in conductor to the negative terminal of a potential source 136. The control grid 120 is connected by means of a lead-in conductor to a video information source 138. The control grid 120 is also connected through a resistor 140 to the negative terminal of a potential source 142. The potential source 142 may be of the order of approximately 60 volts with the positive terminal of the potential source 142 and is connected to the cathode element 118.

The flood gun 116 is centrally located within the envelope 112 and consists of at least a cathode element 164, a control grid 166 and an anode element 172. The flood gun 116 produces a high current, diverging beam source to uniformly flood with electrons the entire surface of the storage multiplier element 132. The cathode element 164 of the flood gun 116 is provided with an exterior connection to a switching means 168. The switching means 168 is alternatively connected through a potential source 170 to ground (i.e. position 1) through a potential source 171 to ground (i.e. position 2), or directly to ground (i.e. position 3).

Enclosing the opposite end of the envelope 112 is a face plate 174 made of a visible light transparent material such as glass. Deposited on the inner surface of the face plate 174 is a coating 178 of a suitable luminescent material. The coating 178 is made of a suitable phosphor material for emitting light in the visible region such as zinc sulfide activated with copper. The coating 178 and an electron permeable coating 180 of an electrically conductive material together make up a display element 176 for visually reproducing the output signal of the device 110. The coating 180 may be made of a suitable conductive material such as aluminum and be deposited on the exposed surface of the coating 178. An external connection is made from the coating 180 of the electrical conductive material to a potential source 188 which is connected to ground.

Positioned adjacent and parallel to the display element 176 is the storage multiplier element 132 which consists of two conductive, perforated layers 152 and 154 between which has been inserted a plurality of tubes or tube means 146. On the surface of the conductive layer 152 remote from the display element 176 there is deposited the layer 156 of a suitable storage dielectric material having a very high resistivity such as silica or magnesium fluoride. Further, the conductive layer 152 is connected externally of the envelope 112 to ground and the conductive layer 154 is connected externally of the envelope 112 to ground through a potential source 157.

Positioned adjacent and parallel to the storage multiplier element 132 is a mesh electrode 182 which is typically in the form of a fine mesh having a comparable number of openings as the storage multiplier element 132. The mesh electrode 182 is connected externally of the envelope 112 to ground through a potential source 184. Further, an electrode 158 which may be formed as a layer of conductive material on the interior surface of the envelope 112 serves to collimate the electrons emitted from the electron gun 116 so that the electrons approach the storage multiplier element 132 normal to the plane thereof. The collimating electrode 158 is connected externally of the envelope 112 to ground through a potential source 160. In addition, the anode element 172 is connected to ground through a potential source 186. In one specific mode of operation, the potential sources 186, 160 and 184 may be respectively set at 100, 150 and 200 volts positive so that the electrons emitted from the flood gun 116 may be properly accelerated and focused upon the storage target element 132.

The operation of the image storage display device 110 shown in FIG. 4 is similar to the image storage device 10 of FIG. 1 in that it requires the operation of four steps which include (1) priming, (2) writing a pattern of charges, (3) reading, and (4) erasing.

(1) *Priming*.—During the first step of this operating cycle, the write gun 114 is biased to cutoff and the cathode element 164 of the flooding electron gun 116 is connected by the switching means 168 (i.e. position 1) to the potential source 170 which is approximately 12 volts negative with respect to ground. Electrons will thus be emitted from the flood electron gun 116, and focused and accelerated with an energy of about 12 volts over substantially the entire surface of the layer 156 of the storage dielectric material. Since 12 electron volts is below the first cross-over point (see FIG. 5), the bombarded surface of the layer 156 of the storage multiplier element 132 will charge in a negative direction to an equilibrium potential of about 12 volts negative with respect to ground. It is noted that the conductive layer 152 is connected to ground and that there will be a potential difference across the layer 156 of approximately 12 volts. Next, the switching means 168 is connected to ground (i.e. position 3) so that substantially no electrons from the flooding gun 116 can be transmitted to the storage multiplier element 132.

(2) *Writing*.—After the priming step, the input signal to be stored upon the storage multiplier element 132 is applied to the write gun 114 from the source 138. The electrons emitted from the cathode element 118 will be formed into a pencil-like electron beam and the current density thereof will be modulated by the input signal applied to the control grid 120. The modulated electron beam is focused and accelerated to strike the surface of the layer 156 of the storage dielectric material with an energy of about 22 volts negative with respect to ground, which is below the first cross-over point. Thus, the number of secondary electrons emitted from the layer 156 is less than the number of primary electrons, and therefore the surface will charge in a negative direction. By the application of suitable voltage to the deflection plates 130 and 134 associated with the write gun 114, a negative charge pattern is written on the surface of the layer 156 corresponding to the information received from the source 138. Thus, it may be understood that there is a pattern of charges upon the layer 156 including portions representing a "white" or maximum signal on which there has been stored a charge of a potential of approximately 17 volts negative with respect to ground and portions representing a minimum or a "black" signal upon which there has been disposed a charge to a potential of approximately 12 volts negative with respect to ground. It is, of course, noted that intermediate signals may be stored upon the layer 156 having charge potentials ranging between 12 and 17 volts negative with respect to ground.

(3) *Reading*.—After a negative charge pattern has been disposed upon the surface of the layer 156, the write gun 114 is biased to cutoff and the flood gun 116 is reactivated as by disposing the switching means 168 in position 1 so as to connect the cathode element 164 to the potential source 170 of approximately 12 volts negative with respect to ground. Under these conditions, the high positive potentials as applied to the conductive layer 154 and the conductive layer 180 by the potential sources 157 and 188 respectively tend to draw electrons emitted from the flooding electron gun 116 through the storage multiplier element 132 and to cause the electrons to bombard the coating 178 thereby resulting in an emission of light from the display element 176. The electric field as established by the pattern of charges disposed upon the layer 156 acts to control or to modulate the flow of electrons through the tubes 146; thus in those portions of the layer 156 that have been charged more negatively, there will be less electrons flowing through the tubes 146 and where those portions of the layer 156 are

charged more positively, more electrons will be allowed to pass through the tubes 146 to bombard the display element 176.

As the modulated electron beams enter the tubes 146, a potential of approximately 2,000 volts positive with respect to ground is applied as by potential source 157 to the conductive layer 154. As the electrons proceed through the tubes 146 they strike a secondary emissive material which forms the inner surface of the tubes 146. Thus, the electron beams are repeatedly multiplied due to the repeated bombardment of the interior surface of the tubes 146. The intensified, modulated electron beams are then accelerated as by a potential of approximately 3,000 to 10,000 volts positive with respect to ground which is applied as by the potential source 188 to the conductive layer 180. Thus, the luminescent pattern appearing on the display element 176 is a replica of the charge pattern written and stored on the layer 156 of the storage multiplier element 132 by the write gun 114. It is particularly noted that a less positive voltage need be applied to the display element 176 to produce a corresponding intensity of the visual image generated thereby due to the multiplication of electrons by the storage multiplier element 132.

(4) *Erasing*.—In order to remove the pattern of charges established upon the layer 156 of the storage dielectric material, the write electron gun 114 remains in a cutoff condition and the cathode element 164 of the flood gun 116 is connected as by switching means 168 (i.e. position 2) to the potential source 171 of approximately 300 volts negative with respect to ground. The electrons emitted from the flood gun 116 are accelerated with an energy of about 300 electron volts which is between the first and second cross-overs of the storage material of layer 156 (see FIG. 5). In this area of the curve, the number of secondary electrons emitted from the storage layer 156 is greater than the number of primary electrons incident upon the surface and therefore the surface will charge in a positive direction. The secondary electrons emitted from the surface of the layer 156 are removed by the mesh electrode 182 and the display element 176. The potential of the layer 156 will thereby be driven positively toward an equilibrium potential determined principally by the potential applied to the mesh electrode 182. It is noted that the entire surface of layer 156 is driven positively to thereby erase the pattern of charges written thereon by the electron gun 114. As explained above, it will be necessary to prime the storage multiplier element 132 in order that another pattern of charges may be written thereon.

In an alternative method of operating the image storage display device 110, the writing of the pattern of charges upon the storage multiplier element 132 could be achieved by writing at a potential between the first and second cross over points. In this method, the step of priming the layer 156 storage dielectric material will be performed as set out above by driving the surface of a layer 156 to a potential of 10 volts negative with respect to ground. This could be accomplished by connecting the cathode element 164 of the flood gun 116 to a potential of approximately 10 volts negative with respect to ground. Then, the write gun 114 is activated by applying a potential of approximately 2,000 volts negative with respect to ground to the cathode element 118. The electrons emitted from the write gun 114 would be scanned as by the pair of plates 130, 134 across the surface of the layer 156. The incident writing electron beam would in turn produce more secondary electrons per incident primary electron to thereby drive the surface of the layer 156 positively. As a result, a positive pattern of charges would be established upon the surface of the layer 156 ranging in a potential from minus 10 volts negative with respect to ground for those portions where no input signal was applied to the write gun 114 to 5 volts negative with respect to ground for those portions of the surface of the layer 156 upon which a maximum input signal was ap-

plied. In order to provide a visual display upon the element 176, the write gun 114 is biased to cutoff and a potential of between zero and 10 volts negative with respect to ground is applied to the cathode element 164 of the flood gun 116. As explained before, the electrons emitted from the flood gun 116 are directed over the entire surface of the storage multiplier element 132. The flood electrons are first modulated by the pattern of charges disposed upon the layer 156 and are then multiplied as they pass through the tubes 146 to thereafter be directed upon the display element 176 to produce a visual output.

In the development of electron multiplying means such as the storage multiplier element 32, there has developed a significant problem in providing a method of fabricating the tubular or channel elements with a uniform configuration and a uniform spacing between the tubular elements. Further, there has been a difficulty in providing a tubular element having an interior surface exposed to the bombardment of primary electrons with uniform secondary emissive properties. Thus, in accordance with the teachings of this invention, it is an important aspect of this invention to provide an improved method of manufacturing a multiplier element and, in particularly, of forming the individual tubes or tubular means.

Referring now to FIG. 6, there is shown schematically an illustrative process for fabricating the individual tubular elements and of assembling them into a unitary multiplier element. In FIG. 6, a supply reel 200 on which a tubular form of filament 202 to be treated is wound, freely turns as a drive roller 256 pulls the filament 202 through a series of intermediate steps. Illustratively, the filament 202 may be made of a suitable material having a smooth surface such as nylon and have a diameter of approximately .001 inch corresponding to that of the tubes 46. The filament 202 is guided through an evacuated chamber 204 by idler wheels 214 and 216. Within the chamber 204 evacuated as by a pump 212, a suitable, dense metallic material such as aluminum or magnesium, which is disposed within a container 208, is evaporated by a heater element 210 onto the filament 202. Further, the vacuum within the chamber 204 is maintained as by resilient, annular members 206 disposed at either end of the chamber for maintaining a seal between the chamber and the filament 202. The metallic substance such as aluminum is evaporated onto the filament 202 to a depth that may be easily oxidized throughout; specifically, the aluminum may be deposited and oxidized to a depth not in excess of 1.5 microns.

Following the application of a layer of a metallic substance, the filament 202 is directed through a tank 240 for the purpose of thoroughly anodizing the layer of the metallic substance. The filament 202 is guided across an idler wheel 218 and about a rotating electrode 242 which is immersed within a suitable electrolytic solution such as acetic or boric acid within the tank 240. The filament 202 is directed from the electrolytic solution by an idler wheel 220. A suitable potential is applied between the electrode 242 and an additional electrode 244 also disposed within the electrolytic solution; specifically, a positive potential is applied to the electrode 242 to insure the anodization of the metal layer. The thickness of the layer to be anodized is dependent upon the voltage applied between the electrodes 242 and 244; typically, the electrolytic constant for these particular electrolytes is about 13 volts per angstrom of layer thickness to be anodized. In particular a voltage of approximately 750 volts would be required to thoroughly anodize a layer of aluminum of approximately 1 micron in thickness. It is pointed out, as will be emphasized later, that the formation of an aluminum oxide, a secondary emissive material with a coefficient of 2 to 4, provides the necessary structural rigidity and conformity as well as a good, uniform secondary emissive surface.

Following the anodization of the metallic layer deposited on the filament 202, the filament 202 is drawn through an adhesive material as contained in a tank 246.

In particular, the filament is drawn successively over the idler rollers 222, 224, 226 and 228. In one illustrative process, the adhesive material may be ceramic material such as aluminum oxide (high alumina) disposed in a slurry solution within the tank 246. Next, the filament 202 is directed as by the idler rollers 230, 232, 234, 235 and 236 through a heating chamber 248 where the excess moisture within the slurry solution deposited upon the filament 202 is driven off by the heat generated by the heater elements 250. Illustratively, the heater elements 250 are raised to a temperature slightly less than 100° C. in order to drive out the water contained in the adhesive slurry deposited upon the filament 202.

Next, the filament 202 is directed as by an idler roller 238 onto the takeup reel 256; a suitable drive unit 258 is coupled to the takeup reel 256 as by a drive roller 260. After a sufficient length of the filament 202 has been wound upon the takeup reel 256, the wound filament 202 is subjected to heat provided by heater element 252 and directed thereon by a reflector 254. Illustratively, the filament 202, which is coated with a layer of a secondary emissive material and a layer of an adhesive material, is heated to a temperature of up to approximately 200° C. to thereby harden the adhesive material. The wound strands of filament 202 are removed from the roller 256 and sections therefrom are cut to form a multiplier element. Then, the inner, nylon filament 202 is removed as by dissolving the nylon with a solvent such as trichlorethylene, chlorinated hydrocarbons, or one of the concentrated mineral acids. Such a solvent acts to dissolve the nylon filament without attacking the ceramic material coated thereabout. Finally, the cut, assembled elements are heated to a temperature of approximately 1000° C. to fire the adhesive material into a fused, ceramic hard structure. The final firing or hardening treatment is performed after the filament of nylon has been removed because a filament of such a material cannot withstand these high temperatures.

In an alternate method of fabricating the tubular elements, the layer of secondary emissive material may be formed from a solid strand of a metallic substance such as aluminum or magnesium. Typically, aluminum could be processed so as to form a thin layer of aluminum oxide thereon to a depth of approximately 1 micron. Typically, this anodization process could be performed in a manner as described above wherein the aluminum filament could be disposed within an anodization tank. Next, the aluminum filament could be coated with a layer of an adhesive material and wound upon a reel. The wound filament could then be baked as at a high temperature approximately 1000° C. and cut into individual sections to form a multiplier element. Finally, the inner core of aluminum could be dissolved as by hydrochloric acid to thereby leave a plurality of tubular elements of the aluminum oxide. The advantage of the use of a metallic filament is that the final firing step may be performed before the filament is removed, thus avoiding a second heating treatment and possible variation of the discussions of the tubular elements.

An important aspect of this invention is the provision of a tubular element of a secondary emissive material that has a rigid, defined configuration which will withstand the winding and the cutting operations without deformation. Further, the interior surface of these tubular elements does present a dense, smooth surface with secondary emissive characteristics that are essentially uniform for each of the tubular elements. The formation of a secondary emissive material as by the oxidation or anodization of a metallic substance does form the required dense, structurally rigid element with the desired uniform secondary emissive surface. The uniformity of secondary emissive characteristics obtained by the above described method has a particular significance with regard to the image storage tubes of this invention. With regard to the storage tube 10 shown in FIG. 1, it is necessary to obtain

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an output signal which is proportional to the electron image emitted by the photocathode element 18; thus, the provision of tubes 46 having uniform secondary emissive characteristics ensures that the output current is uniformly multiplied and is an accurate measure of the electron image emitted by the photocathode element 18. Further, it is necessary to incorporate tubes 146 within the storage-display tube 110 of FIG. 4 with uniform characteristics to ensure that the visual image displayed upon the screen 176 has a uniform intensity of brightness.

While there have been shown and described what are considered to be the preferred embodiments of the invention, modifications thereto will readily occur to those skilled in the art. It is not desirable therefore, that the invention be limited to the specific arrangement shown and described and it is intended to cover in the appended claims all such modifications which fall within the true spirit and scope of the invention.

I claim as my invention:

1. A storage multiplier element comprising a plurality of tubes, each of said tubes defining an axial, multiplying path which is disposed in a substantially parallel relationship with the axial paths of the other tubes, the longitudinal dimension of said tubes exceeding by a factor in excess of 10 the lateral dimension of said tubes, said tubes having an inner surface exhibiting the property of emitting secondary electrons in response to an electron bombardment, each of said tubes having an entrance and an exit upon which there has been disposed an electrically conductive layer, a layer of a storage material being disposed upon said conductive layer associated with said entrance for storing a pattern of charges in response to an electron bombardment and for modulating electrons entering said entrances, and a potential source for providing an electrical field along said multiplying paths to accelerate the modulated electrons and to increase the number of the modulated electrons by repeated bombardments of said interior surfaces.

2. A storage multiplier element comprising a cellular structure with a plurality of tubes, said tubes defining a multiplying path the axis of which is disposed substantially parallel with the axes of the other tubes, the longitudinal dimension of said tubes exceeding by a factor in excess of 10 the lateral dimension of said tubes, said tubes having an inner surface exhibiting the property of emitting sec-

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ondary electrons in response to electron bombardment and having an entrance portion into and exit portion from said path defined by said tubes, a layer of electrically conductive material disposed about said entrance and exit portions to allow electrons to pass into and from said tubes, and a layer of storage material disposed on said layer of electrically conductive material associated with said entrance portions for storing a pattern of charges in response to electron bombardment and for modulating said electrons entering said tubes in accordance with said pattern of charges.

3. A storage multiplier element comprising a plurality of tubes each defining a multiplying path the axis of which is disposed in a parallel relation with the axes of other tubes, the longitudinal dimension of said tubes exceeding by a factor in excess of 10 the lateral dimension of said tubes, said tubes having an inner surface exposed to said path and made of a material selected from the group consisting of aluminum oxide and magnesium oxide for emitting secondary electrons in response to electron bombardment, said tubes having an entrance portion into and exit portion from said path defined by said tubes and being joined together so that said entrance and exit portions form interstices between said tubes, a layer of electrically conductive material disposed on said interstices associated with entrance and exit portions so as to allow electrons to pass through said tubes, and a layer of storage material disposed on said layer of electrically conductive material associated with said entrance portion for storing a pattern of charges in response to an electron bombardment and for modulating said electrons in accordance with said pattern of charges as they enter said tubes.

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RODNEY D. BENNETT, *Primary Examiner*.

D. C. KAUFMAN, *Assistant Examiner*.

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