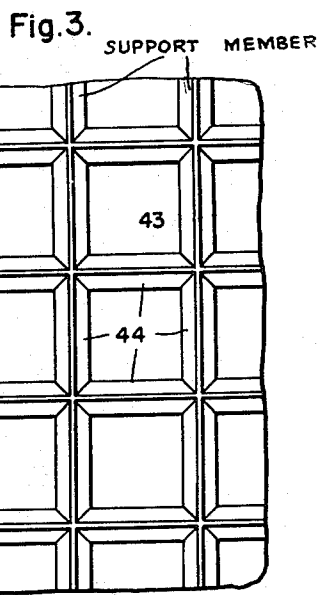
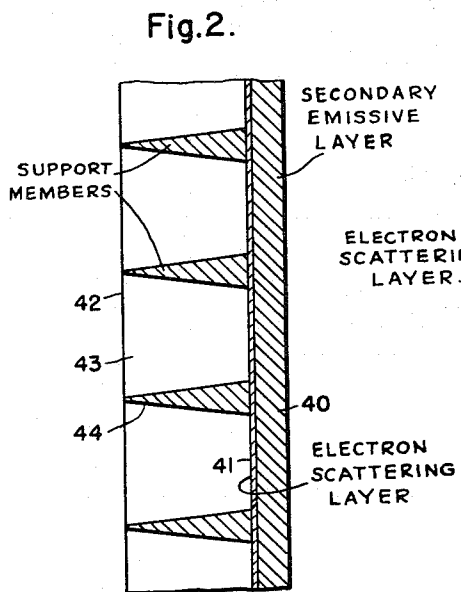
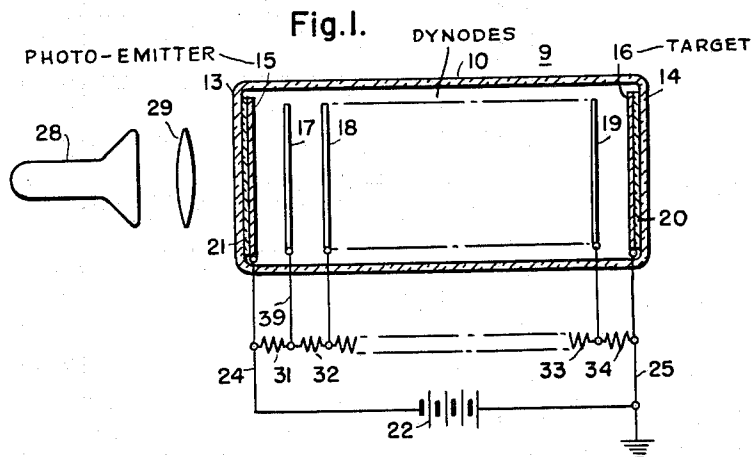


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E. J. STERNGLOSS
ELECTRON DISCHARGE DEVICE

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WITNESSES:

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ELECTRON DISCHARGE DEVICE

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This invention relates to electron discharge devices, and more particularly to those devices having secondary electron emissive electrodes.

It is an object of this invention to generate secondary electrons on the side opposite to which primary electrons strike thin films of secondary electron emissive material.

It is another object to provide improved efficiency of secondary electron emissive electrodes or dynodes.

It is another object to provide a stable secondary electron emissive surface for operation over a long period of time.

It is another object to provide an improved secondary electron emissive electrode that does not require complicated activation procedures.

It is another object to provide a secondary electron emissive electrode that may be exposed to air and other gases without deterioration.

It is another object to provide a secondary electron emissive electrode that permits out-gassing of the enclosing envelope at elevated temperatures without destroying the secondary emissive electrode.

It is another object to provide a secondary electron emissive electrode that may be operated at elevated temperatures without destroying its secondary emissive properties.

It is another object to provide a secondary electron emissive electrode having a zero-signal dark current.

It is another object of my invention to provide a device for the multiplication of electron images without appreciable loss of information in the spatial distribution of the original electron image.

These and other objects are effected by my invention as will be apparent from the following description taken in accordance with the accompanying drawings, in which:

Figure 1 is a diagrammatic view of an electron multiplier tube embodying my invention;

Fig. 2 is a sectional view of a portion of a secondary emissive electrode, utilized in the device shown in Fig. 1; and

Fig. 3 is a front view of the structure shown in Fig. 2.

Referring now to Fig. 1, an electron discharge tube is shown comprising an envelope 9 having a cylindrical portion 10 and end plates 13 and 14 positioned at opposite ends thereof. A planar cathode or electron emissive surface 15 is positioned near to or on the end plate 13 and an anode or target element 16 is positioned at the opposite end of the envelope 9 near to or on the end plate 14. A plurality of the secondary electron emissive electrodes or dynodes 17, 18 and 19 are interspaced between the cathode 15 and target 16. The planar electron emissive surface 15 positioned near the end plate 13 may be of any suitable type such as thermionic or photoemissive. In my specific embodiment, a photocathode planar surface 15 is utilized as the source of electrons for the discharge device.

The photocathode surface 15 may be of a suitable

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material, such as caesium antimony, capable of emission of electrons upon light impingement. The end plate 13 is of a transparent material such as glass so as to permit passage of light. The photo-emitting surface 15 may be mounted on a suitable supporting transparent conductive surface or may be deposited on the interior surface of the end plate 13. It is desirable in most cases to provide a conductive coating 21 on the end plate 13 prior to the depositing of the photocathode material so as to obtain an electrode for the photo-emitting surface. A suitable transparent conductive coating may be of a material such as Nesa.

The target electrode 16 is positioned at the opposite end of the envelope 9 near the face plate 14. The target 16 may be of any electron sensitive material so as to develop a signal representative of the electron bombardment. In my specific embodiment a phosphor screen is utilized as the target electrode 16 of the electron discharge device. The phosphor screen 16 is of a suitable material such as zinc sulphide which may be placed on a suitable transparent conductive supporting member or deposited on the end plate 14. If the phosphor screen 16 is deposited on the end plate 14 as shown in my specific embodiment, it is desirable that a transparent conductive layer 20 such as Nesa be deposited on the end plate 14 prior to the phosphor screen 16 to serve as an electrode. The phosphor screen 16 may also be deposited directly on the end plate 14 if desired and a thin electron permeable conductive layer such as aluminum be deposited upon the exposed surface phosphor screen to serve as the voltage electrode. The aluminum backing will also enhance the light output of the phosphor screen.

Positioned between the cathode 15 and the image screen 16 are a plurality of secondary electron emissive electrodes or dynodes 17, 18 and 19 and by way of example, I have shown only 3 dynodes. The number of dynodes within the envelope 9 is dependent on the amount of amplification desired from the device and a single dynode may be sufficient in some applications.

The requisite potential for the electrodes within the envelope 9 may be obtained from a potentiometer, or any other suitable device. In the specific device shown in Fig. 1, I have utilized a battery 22 having its negative terminal connected by means of a conductor 24 to the conductive layer 21 to supply a potential to the cathode 15 and the positive terminal of the battery 22 is connected by means of a conductor 25 to the conductive layer 20 to supply a potential to the image screen 16. A plurality of resistors 31, 32, 33, and 34 of equal value connected in series are connected across the conductors 24 and 25 so as to be shunted across the battery 22. A lead 39 is provided from the first dynode 17 to a point between resistors 31 and 32 while the second dynode 18 is connected to a point between the resistances 32 and 33, and the third dynode 19 is connected to a point between the resistors 33 and 34. The free end of resistor 31 is connected to the conductor 24 while the free end of resistor 34 is connected to conductor 25. In this manner, the successive electrodes 17, 18, 19 and 16 following the cathode 15 have progressively increasing steps of positive potential with respect to the cathode 15 so as to accelerate the electrons from electrode to electrode. Although I have shown equal steps of voltages between the electrodes 17, 18, 19 and 16, it may be desirable to operate the image screen 16 at a substantially higher voltage than the other electrodes 17, 18 and 19.

A light image may be projected onto the cathode surface 15 by any suitable means so as to activate the photo-emitting cathode 15. By way of example, I have shown a kinescope 28 with a suitable lens system 29 between the kinescope 28 and a photocathode surface 15 for pur-

poses of directing the light image obtained on the kinescope onto the photocathode surface 15.

Referring to Figs. 2 and 3 for the detailed structures of the dynodes 17, 18 and 19 shown in Fig. 1, I have shown a portion of a dynode for purposes of illustration. The dynode structure is comprised of at least a secondary electron emissive layer 40. The secondary emissive layer 40 is of a crystalline insulator material such as an alkali-halide (For example KCl or NaCl) which has the property of allowing the flow of secondary electrons within the material for a long distance before being absorbed. It has also been found that the higher the atomic number the higher the emission, for example cesium iodide has a high average atomic number. The term average atomic number as used herein refers to the atomic number of the element or the average of the atomic numbers of the elements in a compound. An alkaline earth oxide is also a suitable secondary emissive material. The secondary electron emissive layer 40 is of a thin planar sheet having substantially the same area as the photocathode surface 15 and parallel thereto. The thickness of the secondary emissive layer is of the order of 100s to 1000s of angstrom units, or 10^{-6} — 10^{-5} cm.

The secondary electron emissive layer 40 may be deposited on an even thinner layer 41 of a high atomic number material such as gold or uranium. The thickness of this heavy metal layer is on the order of 100 angstroms or less. The function of the heavy metal film 41 is to aid in scattering the incident electrons so that the electrons entering the secondary electron emissive layer 40 will be at an angle with the incident electrons trajectory which is normal to the surface of the layer 40 thereby enhancing the secondary emission of the secondary emissive layer on the side opposite to that on which the primaries are incident. The heavy metal layer 41 is in turn supported by a fine mesh grid 42. The grid 42 in the preferred embodiment of the device is fabricated from a thin sheet of conducting material such as copper or nickel. The metal grid 42 may then be plated or coated if desired with an inert metal such as gold or platinum in order to insure greater resistance of the grid 42 to oxidation and corrosion. The holes or apertures 43 in the grid 42 may be etched in a sheet of suitable material so as to provide a large open area screen of about 70 to 90%. In my specific embodiment, the sides 44 of the apertures 43 are tapered toward the cathode 15. The grid 42 may also be considered as a cellular or honeycomb structure with the sides 44 of the cells or apertures 43 tapered towards the source of incident electrons. By designing the grid 42 in this fashion, many of the incident electrons that would be lost in conventional type grids are scattered by the sloping or tapered sides 44 of the apertures 43 in the grid member 42 so as to produce secondary electrons in the secondary electron emissive layer 40. The tapered grid design permits the grid 42 to be made mechanically quite strong by making the walls 44 of the apertures relatively thick near the heavy metal layer 41 and relatively thin at the opposite side of the grid 42 and thereby still retain a large open area screen of transmission. In my specific device to obtain the desired resolutions in an image intensifier, it is desirable to have on the order of 500 apertures per inch of screen. Fewer apertures per unit distance may be used when no imaging is desired.

The dynodes 17, 18 and 19 may be constructed by suitable methods known in the art. For example, an organic film such as nitrocellulose lacquer is settled on the grid structure by covering the grid with water and applying the organic solution with solvent on the surface of the water. As the organic solution spreads out on the surface of the water the solvent evaporates leaving the organic film. The water is then removed allowing the film to settle on the grid. The organic film is dried and the heavy metal film, if used, is evaporated onto the free

surface of the organic film. The secondary electron emissive layer is then evaporated onto the organic film or the heavy metal film (if used). It has been found desirable to use the heavy metal film with the alkali-halide of lower average atomic number while it may be omitted with the alkali-halides of higher average atomic number. The higher average atomic number alkali materials sufficiently scatter the incident electrons while the lower atomic numbered require the heavy metal layer. The organic film may then be baked off leaving the heavy metal layer on the grid and the secondary electron layer upon the heavy metal layer. This is only one of many methods of depositing the layers on the grid. The etched-foil type of mesh for the grid 42 is preferred to the woven mesh structure because of a flat surface available for supporting the thin layer of secondary electron emissive material.

Another method of construction is to deposit the crystalline layer 40 on to a permanent film of a suitable material such as SiO of thickness equal to tens of angstroms previously deposited by techniques similar to that described above for the organic film. It is also possible, if the voltage between dynode structures is sufficiently high, to use a self-supporting thin metallic foil instead of the supporting grid 42 and the secondary electron emissive layer 40. Also the dynodes may be mounted at different angles to the direction of the incident electrons, while at the same time the secondary electron emissive layer may be made thinner, so as to cause incident electrons to have larger angles of incidence with the dynode so that secondaries form close to the surface of the crystalline layer 40.

If a greater mechanical strength is desired in the dynode, a second grid may be placed in coincidence with the first grid but on the opposite side of the secondary electron emissive layer. Such a double-grid arrangement has the further advantage of reducing the undesirable emission of electrons at large angles relative to the normal surface. It also may be desirable in some cases to evaporate the secondary electron emissive material over the sides of this second grid supporting mesh in order to further enhance the ratio of secondary electron emission to incident electrons within the dynode structure.

In the operation of the device shown in Fig. 1 an image is projected by the kinescope 28 through the optical means 29 upon the photocathode surface 15. The photocathode layer 15 in response to the light image projected thereon will generate an electron image representative of the light image projected thereon. Under the influence of the potential applied to the first dynode 17 the electron image emitted from the photocathode layer 15 will be accelerated to a sufficient velocity to the ingressive side of the dynode 17, such that the incident electrons in passing through the secondary emissive layer 40 will be reduced substantially to zero. As previously described, substantially all of the incident electrons, striking the grid 42 and not passing directly through the grid aperture 43 will be scattered or diffused by the tapered walls 44 into the secondary electron emissive layer. It has been found that the number of secondary electrons emanating from the emissive side of the secondary electron emissive layer 40 is many times greater than the number of impinging primary electrons. In a typical layer of about 300 angstrom units of KCl deposited on 40 angstrom units of gold, at an incident energy of 2-4 kilovolts between 4 to 7 secondary electrons were found to be emitted for each primary electron striking the layer 40. Consequently, an electron multiplication is obtained in the primary current obtained from the photocathode surface 15 by the first dynode 17. The secondary emissive electrons released from the first dynode 17 are accelerated to the second dynode 18 where this procedure is again repeated. The secondary electron emission from the emission side of the secondary emission layer 40 of the second dynode 18 is many times greater than the incident electron thereon. Similarly, the

secondary electrons released from the second dynode 18 are accelerated to the third dynode 19, where again the electron current is amplified and further multiplication occurs. The electrons emitted from the third dynode 19 are accelerated to the phosphor screen 16 where an enhanced light image is obtained corresponding to the light image projected on the photocathode 15.

By utilization of the grid structure as previously described and by virtue of the large number of apertures per unit area, the dispersion of the electron image flowing between the photocathode 15 and the image screen 16 is limited to a small amount so that substantially no reduction of details is lost from the original light image projected thereon. It has also been found that a close spacing of the order of a few tenths of an inch between dynode members 17, 18 and 19 also aids in insuring that a satisfactory picture is obtained on the image screen 16 without the aid of electromagnetic focussing. It has been found that by controlling the accelerating voltages between dynode stages 17, 18 and 19 so that the incident electrons are not able to completely penetrate the secondary electron emissive layer 40, an excellent image is obtained on the screen 16.

Although it has long been realized that secondary electron yield from various simple insulating material such as an alkali halide for example potassium chloride and calcium chloride is large, certain practical obstacles have been in the way of actual utilization of such materials in electron multipliers. It has previously been found that even a very thin layer of the order of 10 to 100 atoms deposited on a heavy metal backing charges up under electron bombardment when used as a simple front surface secondary electron emitter. This results in secondary emissive yields that depend critically on the beam current and the thickness of the layer. The resulting instability has made it impossible, prior to this time, to build a workable device using alkali halide as a secondary emitting substance in electron multipliers.

I have found that these obstacles may be surmounted and a satisfactory transmission type secondary electron multiplier dynode structure may be constructed. I have found that if the electron beam completely penetrates the alkali halide layer or more precisely, when it penetrates such as to produce slow electrons capable of carrying a current throughout the body of the thin insulating alkali halide layer, the charging-up and instability are avoided. Both the metallic supporting grid and the employment of high energy electrons are instrumental in bringing about the desired effect in that the grid serves to reduce the conduction path for the replenishment of electrons, and the high energy electrons serve to reduce the electrical resistance by providing conduction electrons throughout the insulating layer. It should be also noted that it is necessary to use as pure and simple a crystalline material as possible in which the secondary electrons can travel relatively large distances and therefore escape from much greater depths than the case of metals, complex cesiated or activated metallic layer or insulators of an amorphous structure such as glass. The provision of a vacuum between successive amplification stages allows the acceleration of the slow secondary electrons coming out of the emissive side of the previous dynode. Furthermore, it is important that there be excellent insulation between stages so as to avoid large leakage current that would swamp out any signal current or even in extreme cases, destroy the layer by the large heating produced.

The utilization of an alkali-halide and grid supporting structure requires no special activation procedures nor is it affected by exposure to air unlike the complex surfaces such as cesiated silver presently employed for dynode surfaces. The alkali-halides and the gold or similar metals also possess a high melting point and high work-function and, therefore, do not suffer from most of the disadvantages of presently used complex secondary emitters. It has been found that these features are particularly

important for applications to low signal-level operation in that a greatly reduced thermionic and photoelectric emission as well as leakage current is obtained between stages. The low leakage current between stages results from the absence of caesium or similar vapors liberated in the "forming" of the secondary electron emission dynodes together with the greatly increased sensitivity at low temperatures inherent in the use of a pure crystalline insulator, a device incorporating the structure described above gives a superior and practical dynode structure.

This type of secondary emissive surface is also suited to problems of low-level electron-image amplification such as in infra-red and X-ray image tubes because of the small loss of definition to be expected resulting from the extreme thinness of the multiplying surfaces and the absence of fast stray electrons. Since the current densities encountered in this type of application are extremely low, about 10^{-9} amp./cm.² or less, and any possible deterioration of the crystalline surfaces as a result of bombardment is a function only of the total charge involved, the life of such a multiplying surface can be shown to be large compared to minimum requirements. Thus, I have obtained a sensitive electron multiplier dynode which permits the use of strong metallic supports for an extremely thin secondary electron emissive surface, the absence of any activation in the completed tube, the handling of the dynodes in open air, and the outgassing at temperatures as high as normally used in vacuum tubes.

Although I have shown the possible utilization of a heavy metal layer 41 in the structure shown in Figs. 2 and 3, I have also found that by increasing the thickness of the secondary electron emissive layer 40 that the dynode will operate at substantially the same efficiency.

In one model that I have built utilizing only 50% open mesh screen, a yield of greater than 3 secondary electrons was obtained from the dynode structure with one incident electron. The incident energies utilized in this device were of the order of 1500 volts.

While I have shown my invention in only one form, it will be obvious to those skilled in the art that it is not so limited, but is susceptible of various other changes and modifications without departing from the spirit and scope thereof.

I claim as my invention:

1. An electron multiplier comprising an envelope and having therein a cathode, a target and a plurality of dynodes positioned between said cathode and said target, said dynodes characterized in having a thin secondary emissive layer of insulating material having an ingressive surface and an emissive surface with said ingressive surface facing said cathode, a supporting member for said secondary emissive layer contacting said ingressive surface, said supporting member having a plurality of cellular openings.

2. An electron discharge device comprising an envelope having therein a planar cathode positioned at one end thereof, and a target electrode near the opposite end of the envelope and a plurality of dynodes positioned between said cathode and said target, each of said dynodes being capable of producing secondary electrons transmissively at a ratio greater than unity and comprising a thin layer of secondary electron emissive insulating material of about 100 angstroms in thickness supported on a metallic structure.

3. An electron multiplier comprising an envelope and having therein a planar photo-emissive cathode positioned near one end of said envelope, a planar electron responsive electrode positioned at the opposite end of said envelope, a plurality of dynode structures positioned between said cathode and said electron-responsive electrode, said dynodes comprising a thin secondary emissive layer of insulating material of the order of 100 angstroms in thickness and a thin metallic coating.

4. An electron multiplier comprising an envelope and having located therein a planar photo-emissive cathode, an electron-responsive electrode positioned at the opposite end of said envelope with respect to said cathode, a plurality of planar dynode structures positioned between said cathode and said target, said dynode comprising a thin layer of crystalline insulating material and means for supporting said layer.

5. An electric discharge device comprising an envelope and having therein, a planar photo-emissive cathode positioned at one end of said envelope, an electron responsive planar target positioned at the opposite end of said envelope with respect to said cathode, and a plurality of planar dynodes positioned between said cathode and said target, each of said dynodes being capable of producing transmissive secondary electrons at a ratio greater than unity and comprising a thin layer of alkali halide material supported on a perforated metallic grid structure.

6. An electric discharge device comprising an envelope and having therein a planar cathode positioned at one end thereof, a target electrode positioned near the opposite end of said envelope and a plurality of dynodes positioned between said cathode and said target, each of said dynodes comprising a thin layer of pure crystalline insulating material exhibiting the properties of producing secondary electrons transmissively and of increasing conductivity upon electron bombardment supported on a metallic grid-like structure.

7. An electron multiplier comprising an envelope and having therein, a planar cathode and electron responsive target positioned at the opposite end of said envelope with respect to said cathode, a plurality of said dynodes positioned between said cathode and said target, each of said dynodes comprising a thin layer of secondary emissive insulating material supported on a metallic planar grid-like member, said grid-like member having a plurality of cellular openings therein with the sides of said openings tapered toward said cathode.

8. A transmissive dynode structure for an electron multiplier comprising a thin layer of a crystalline insulating material characterized in exhibiting the properties of producing transmissive secondary electrons at a ratio greater than unity and of an increasing conductivity upon electrode bombardment, a layer of high average atomic number material deposited on the bombardment side of said insulating layer to scatter bombarding electrons and means for supporting layers.

9. An electron multiplier comprising an envelope and

having therein a planar photo-emissive cathode, a planar electron responsive target positioned at the opposite end of said envelope and substantially parallel to said cathode, a plurality of dynodes positioned between said cathode and said target and substantially parallel to said cathode, each of said dynodes comprising a thin continuous layer of insulating material mounted on a grid-like metallic supporting structure, means positioning said dynodes in relatively closed spaced relationship, means to focus the electrons from said cathode on the first of said dynodes, means for focusing the secondary electrons from the last dynode upon the electron responsive target and means for maintaining said electrodes at increasingly positive potentials with respect to said cathode.

10. A secondary emissive dynode structure comprising a continuous layer of insulating material capable of the emission of secondary electrons from the opposite surface on which the bombarding electrons impinge, and a continuous layer of a conductive material of a higher average atomic number than said insulating material on the bombardment side of said insulating material for scattering the bombarding electrons into said insulating layer.

11. A transmissive type secondary electron emissive dynode structure comprising a continuous layer of insulating material capable of the emission of secondary electrons from the opposite surface with respect to the surface which is bombarded by primary electrons, said insulating material having a large energy gap between the filled valence band and the conduction band so that secondary electrons within the layer can travel relatively large distances and escape therefrom, electrical conductive means provided on the surface of said layer on which said bombarded electrons impinge to reduce the conduction path for replenishment of electrons over the emissive surface of said insulating layer.

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