United States Patent

Wolski

[15] **3,660,668**

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[54] **IMAGE INTENSIFIER EMPLOYING CHANNEL MULTIPLIER PLATE**

[72] Inventor: **Adolph J. Wolski,** Morton Grove, Ill.

[73] Assignee: **Zenith Radio Corporation,** Chicago, Ill.

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[52] **U.S. Cl.** .....**250/213 VT,** 313/68

[51] **Int. Cl.** **H01j 31/50**

[58] **Field of Search** 250/213, 207; 313/67, 68, 74, 313/104, 105, 95, 96

[56] **References Cited**

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Primary Examiner—Walter Stolwein

Attorney—Francis W. Crotty

[57] **ABSTRACT**

A photocathode in response to an incident light image develops a corresponding electron image which is accelerated and focused upon the input of a channel multiplier plate. The input of that plate is covered with a layer of a material having the property of transmission secondary electron multiplication, hereafter referred to as TSEM. Secondary electrons developed in that material in response to the incident electron image enter the channel multiplier where they are further multiplied and, finally, are focused on a phosphor screen where conversion to a light image takes place.

6 Claims, 6 Drawing Figures

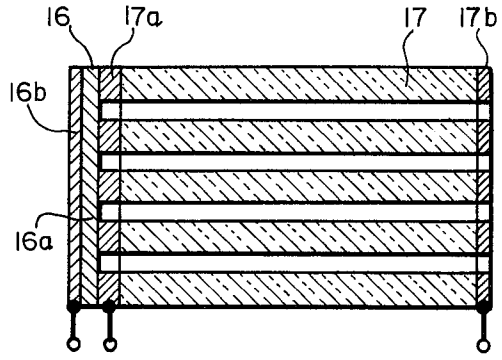
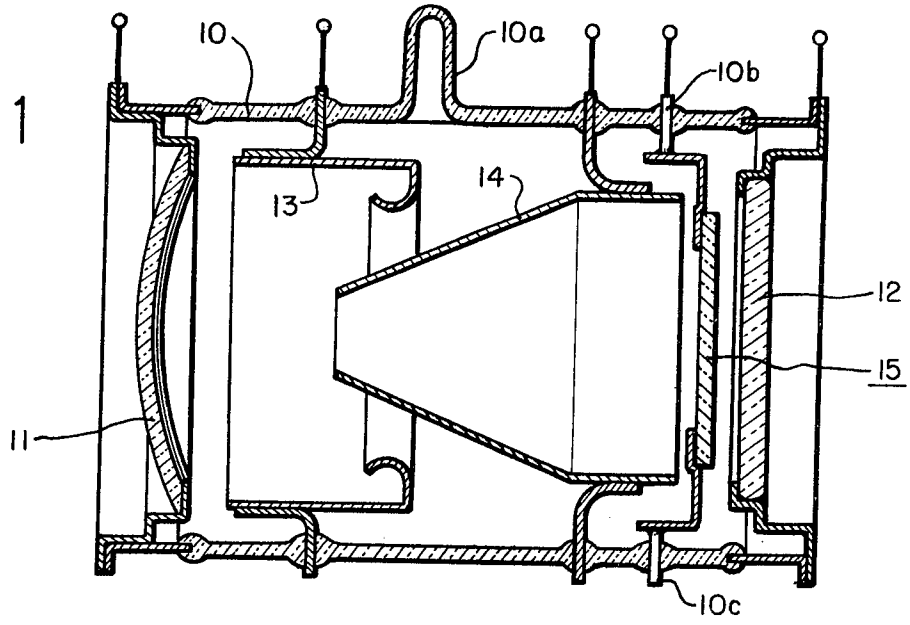


FIG. 1



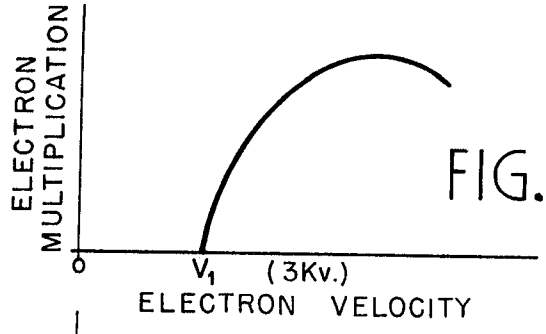


FIG. 3

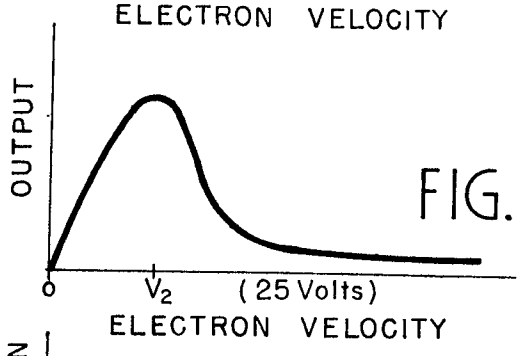


FIG. 4

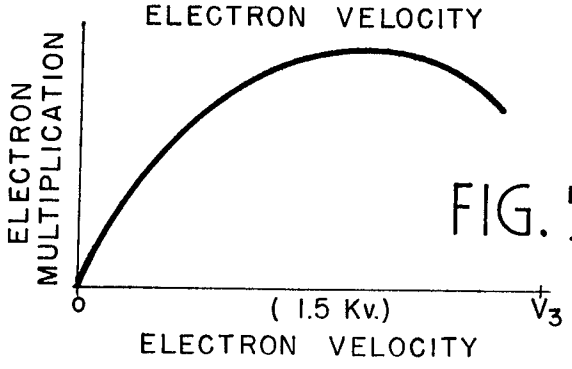
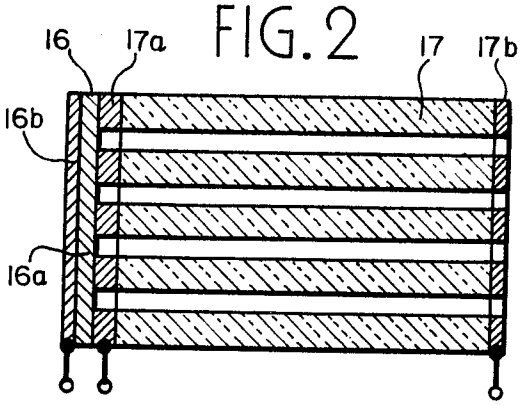


FIG. 5

FIG. 2



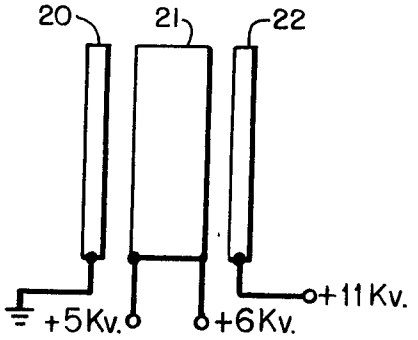


FIG. 6

Inventor
Adolph J. Wolski

By Francis W. Crotty
Attorney

IMAGE INTENSIFIER EMPLOYING CHANNEL MULTIPLIER PLATE

BACKGROUND OF THE INVENTION

The invention is directed to image intensifiers of the type that employ a channel multiplier plate. In general, intensifiers of this type exhibit enhanced gain because the channel multiplier responds to incident electrons which represent an image and accomplishes electron multiplication as the electrons of that image traverse the channels of the multiplier plate in reaching a target, such as a phosphor screen, where image conversion takes place and a light image is developed. Frequently, such image intensifiers have at their input a photocathode structure or such like upon which a radiant energy image is focused to develop a corresponding electron image that is then directed to the input of the channel multiplier for electron multiplication. Of course, this is not a necessary limitation on image intensifiers even though it is a very common form. Instead of generating an entire electron image at one time and focusing it upon the entrance to the channel multiplier, it is totally practical to have image information conveyed by intensity modulation of an electron beam which is caused to scan the channel multiplier, particularly where the multiplier structure has the unique features of the subject invention. For convenience, however, the intensifier will be discussed as to background and improvement in the more customary form of a device featuring a photocathode for developing an electron image that is to be intensified by way of electron multiplication.

Devices of the prior art which employ a channel multiplier plate upon which an accelerated inverted electron image is focused are subject to a distortion or non-uniform gain which manifests itself in a dark spot on the phosphor screen where a final, intensified light image is developed. The dark spot represents an incremental surface area of the screen having less light than the remainder of the screen and reflects a non-uniformity of the relative gain of the many channels constituting the multiplier plate. It is found that the channels of inferior or lesser gain are those that are essentially aligned along the path of electron travel which is usually along the axis of the intensifier because electrons accelerated along that axis penetrate the channels that they enter to a greater depth than electrons entering other channels of the multiplier at an angle or from an off-axis position. The deeper penetration of the on-axis electrons is equivalent to an effective reduction in length of the on-axis channel members which is the cause of their loss of gain and the appearance of a dark spot on the screen. It has been proposed that the dark spot be shifted away from the center of the screen by arranging the geometry of the intensifier, accomplished by bias cutting the multiplier plate relative to the tube axis. If this approach is taken to extremes so that the dark spot is displaced to the edge or perhaps even off the screen, a condition of astigmatism is encountered which is undesirable.

Another limitation of prior image intensifiers utilizing a channel multiplier plate has to do with the degree of resolution that is possible by proximity focusing of the output electrons of the multiplier plate upon the phosphor screen. Where that screen is aluminized, which is common practice, an electrostatic field exists between the screen and the output of the multiplier plate and imposes a limitation on the spacing between the aluminum backing layer of the screen and the output of the channel multiplier. Where the spacing is too small, and of course small spacings are required for improved proximity focusing, the aluminum tends to be pulled away from the screen under the influence of the electrostatic field. If the aluminum layer does peel off the screen, it may short the amplifier at least in part and, consequently, there is a distinct limit to the resolution that may be obtained through proximity focusing in the presence of a reflecting conductive backing layer on the image screen.

Another factor which imposes a limit on the resolution capabilities of prior intensifiers of the type under consideration has to do with the magnitude of the anode voltage employed in accelerating the electron image onto the input of the channel multiplier. In the usual case with channel multipliers of conventional construction optimum gain is realized with an anode voltage in the range of 500 volts to 1 or 2 kilovolts but with anode voltages in that range the radial component of electron movement, as electrons issue from the emissive surface of the photocathode, is sufficiently strong and influential to cause spreading of the electrons with respect to their intended paths of travel with a consequent loss of resolution. It has not been feasible in the past to overcome this limitation by increasing the value of anode voltage because of the gain versus incident-electron-velocity characteristic of the channel multiplier.

Accordingly, it is an object of the present invention to provide an image intensifier employing a channel multiplier plate which avoids one or more of the aforediscussed limitations of prior structures.

It is a particular object of the invention to provide such an image intensifier which is free of dark spot effects.

It is yet another object of the invention materially to improve the resolution of such an image intensifier.

Still another object of the invention is to provide an image intensifier having improved gain and also improved operating characteristics such as resolution and contrast.

SUMMARY OF THE INVENTION

An image intensifier in accordance with the invention comprises an envelope and means, including a cathode structure supported within the envelope, for developing an electron image whether in the form of an entire image field or an intensity modulated electron beam. A transmission secondary electron multiplication of TSEM device is disposed transversely of a reference axis, usually the longitudinal axis of the envelope and responds to incident electrons having a velocity of at least a predetermined minimum value to emit secondary electrons with a predominant velocity distribution in a range of values that is substantially less than the aforesaid predetermined minimum value. An electron optical system is provided for accelerating the electrons of the image to at least the aforesaid predetermined minimum velocity and for focusing the electrons on the TSEM device. A channel multiplier plate for developing further secondary electrons is also provided. It exhibits optimum response to electrons having a velocity within a range which includes the aforesaid predominant velocity values of the secondary electrons issued by the TSEM device although the optimum velocity range for the multiplier plate has a maximum value that is much less than the aforesaid predetermined minimum value of significance to the TSEM device. The multiplier plate is essentially of the same size as the TSEM device and is disposed in relation thereto to receive the secondary electrons emerging from the TSEM device. Finally, a target electrode is disposed in spaced relation to the output of the multiplier plate and has a potential level with respect thereto for effecting proximity focusing thereon of the further secondary electrons that are emitted by the multiplier plate.

DESCRIPTION OF THE DRAWING

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The invention, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawing, in the several figures of which like reference numerals identify like elements, and in which:

FIG. 1 is a cross sectional representation of a light image intensifier constructed in accordance with the invention;

FIG. 2 is an enlarged cross sectional representation of a portion of the intensifier of FIG. 1;

FIGS. 3–5, inclusive, are curves used in explaining operating characteristics of the intensifier of FIG. 1; and

FIG. 6 is a schematic representation of a different form of image intensifier utilizing the subject invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The image intensifier of FIG. 1, except for the components thereof employed for electron multiplication, is of well-known construction and operation. It may be used to accept an image of one form of radiant energy such as light, X-ray, gamma ray, neutrons and the like or, alternatively, its input may be a fiber optic or similar coupling through which a light image from a preceding intensifier stage is translated to the stage to be described. For convenience, however, it will be assumed that the intensifier is to respond to a light image of an object focused on a photocathode by any suitable optical system (not shown). Accordingly, the intensifier has an envelope with the customary cylindrical section **10** of glass having a photocathode **11** at one end a target electrode in the form of a phosphor screen **12** at the other end. These end portions are integrated with the glass envelope by customary metal to glass seals serving not only to complete an envelope that may be evacuated through a tubulation **10***a* but also supporting the cathode and target structures.

The cathode structure **11** is provided in order to develop electrons representing an image and, for the assumed case in which a light image is to be intensified, a photocathode structure is utilized. This is a well-known component comprising a substrate that is transparent to the light image and upon which is deposited a light sensitive electron emitting layer. The photoemissive layer may be of antimony-cesium oxygen, commonly referred to as an S-11 photocathode, or any other of the known forms of photocathode.

Just beyond the photocathode in the direction of screen **12** is a focusing electrode **13**. This electrode is part of an electron optical system for accelerating the electron image developed at photocathode **11** and for focusing that image in a plane to be discussed more particularly hereafter. The electron optical system further includes the usual conically shaped anode **14** coaxially disposed about the longitudinal axis of envelope **10** with its small open end facing photocathode **11** and its opposite end encompassing an electron multiplying system **15** which also will be discussed more particularly presently. Conductive metal rings extending radially from focus electrode **13** and anode **14** serve to support these elements within envelope **10** and also have terminals to which operating potentials may be applied.

The electron multiplier **15**, as indicated in the enlarged detailed view of FIG. **2**, has two principal components; a transmission secondary electron multiplication or TSEM device **16** and a channel multiplier plate **17** each of which performs a separate function of electron multiplication. Subassembly **15** is disposed transversely of a reference axis, specifically the longitudinal axis, of the envelope with the TSEM device **16** in the focal plane of the electron optical system of the intensifier. It is only necessary that the TSEM device be aligned with and effectively close the entrance to the channels of multiplier plate **17** but it is more convenient to construct the TSEM device so that it has essentially the same principal dimensions and configuration as the input of multiplier plate **17**. Of course, it is further necessary that the TSEM device be positioned to the photocathode side of multiplier plate **17** and, while it may be spaced coaxially therefrom, it is convenient to have the TSEM device attached to the input end of the multiplier plate. A very practical structural arrangement is to affix to the front end of the multiplier plate a layer of material, such as an insulator, which exhibits the property of transmission secondary electron multiplication. This is a known effect exhibited by such materials as zinc sulphide, potassium chloride, potassium bromide, magnesium fluoride and calcium fluoride and is one in which an electron which impinges upon the surface of the material with a velocity exceeding a certain minimum value penetrates the layer and produces secondary electrons greater in number than the impinging electrons. As shown in FIG. **2**, the TSEM component is comprised of a layer **16***a* of TSEM material deposited over the conductive layer **17***a* usually applied to the input of a channel multiplier plate and a superposed conductive layer **16***b* of aluminum having a thickness of about 500 Angstroms. Experience indicates that outermost conductive layer **16***b* may be dispensed with to eliminate this energy loss of the primary image electrons in penetrating that layer to reach the TSEM layer.

The channel multiplier plate **17** is a known structure and is described, for example, in U.S. Pat. No. 3,341,730, issued in the name of George W. Goodrich et al on Sept. 12, 1967. As indicated, it is an array or stack of parallel-arranged individual channel or tubular elements usually formed of glass and treated to the end that the inner surface of each channel is a secondary emitter with an emission ratio, in response to input or impacting electrons, that is greater than unity. These channels, after having been arrayed to define a plate of desired dimension and configuration, are subjected to a heat treatment to fuse the channel elements to one another and form a single unitary multiplier channel plate. The diameter of the channels is usually very small compared with their length. It is necessary to apply an operating potential across the plate which is the reason for conductive layer **17***a*, mentioned above, at the input surface of the plate. A similar conductive layer **17***b* is applied to the opposite or output end of the plate. Obviously, with TSEM unit **16** and channel multiplier **17** arranged as an integrated subassembly, the secondary electrons emitted by the TSEM layer are received as input electrons by the several channels of the multiplier plate.

It will be apparent from FIG. **1** that the target electrode or screen **12** is disposed in parallel spaced relation with respect to the output end of electron multiplier **15**. Generally, it is comprised of a transparent substrate such as glass upon which is deposited a layer of a suitable phosphor and the screen is provided with a conductive layer in order that it may be established at a desired operating potential chosen with respect to the potential of the output of electron multiplier **15** for proximity focusing of the electron output from the multiplier upon the phosphor screen. Heretofore, a layer of aluminum, sufficiently thin to be electron permeable, has bee applied as a backing layer on the surface of the phosphor material which faces the electron multiplier. It serves as a light reflector and prevents light feedback to the photocathode as well as a vehicle for establishing the screen at its desired operating potential. That structure is suitable for the intensifier under consideration; but with an opaque TSEM film to prevent light feedback to the photocathode it may be preferable to omit the backing conductive layer and to use in its place a transparent conductive layer interposed between the phosphor and the substrate. Tin oxide is suitable for this purpose but must be sufficiently thin that it is transparent; an appropriate layer may be applied by evaporation.

Representative values of operating potentials for the components of the described image intensifier are as follows:

photocathode **11**	— zero to ground potential
focus electrode **13**	— +100 volts
anode **14**	— +5 kv.
conductive layers **16***b*, **17***a*	— +5 kv.
conductive layer **17***b*	— +6 kv.
screen **12**	— +11 kv.

In order to apply these potentials to electron multiplier **15**, the intensifier has two or more terminal pins **10***b*, **10***c* projecting from the envelope for connection to a voltage supply and connected internally of the envelope to appropriate portions of subassembly **15** as indicated in FIG. **1**. Before reviewing the operation of the intensifier, it is appropriate to consider the curves of FIGS. **3–5**, inclusive, depicting certain operating characteristics of electron multiplier subassembly **15**. The curve of FIG. **3** shows the variation in electron multiplication of TSEM layer **16** with velocity of the incident electrons. The layer responds and effects multiplication of incident electrons which have a velocity of at least a predetermined minimum

value v_1 thereby producing secondary electrons with a velocity distribution of the type represented by the curve of FIG. 4. The secondary electrons of the TSEM layer have a velocity distribution extending over a wide range but for the most part the velocities predominate around a value v_2 which is very much less than the minimum velocity v_1 required of incident electrons to stimulate a response and achieve electron multiplication. By way of illustration, the minimum velocity for effecting secondary emission within the layer will correspond to that achieved by an accelerating voltage of the order of 3 kv in the electron optical system of the intensifier and the velocities of the output secondaries preponderate in a range of values centered about 25 volts. The curve of FIG. 5 shows that multiplier plate 17 exhibits optimum response, in terms of electron multiplication, to incident electrons having a velocity within the range of essentially zero to v_3 with the maximum value of that range corresponding to the velocity achieved in response to an accelerating voltage of about 1.5 kv. This is very much lower than the minimum electron velocity required to achieve secondary emission effects in TSEM layer 16.

In operation, a light image to be intensified is focused upon photocathode 11 where, in known fashion, it is converted into an electron image. The electron optical system of the tube accelerates the electrons of that image to at least the necessary minimum electron velocity v_1 and focuses the electrons of the image on TSEM layer 16. As a consequence, the impinging electrons initiate transmission secondary electron multiplication, causing secondary electrons to be emitted from the surface of the TSEM layer that is contiguous to the input of amplifier plate 17. The ratio of the secondary electrons to the incident primaries is much greater than one and will vary as described hereafter with the type of TSEM layer that is employed. A multiplication of at least 5 is easily attained. The secondary electrons enter the several channels of multiplier plate 17 and as they travel there under the influence of the field resulting from the potential applied across multiplier plate 17 they impact on the walls of the channel and experience a further multiplication which, for each individual impact, will be a smaller multiplication than attained in the TSEM layer. In this multiplication accomplished by multiplier 17, further secondary electrons are developed which constitute the output of the multiplier plate and those further secondaries are focused by proximity focusing upon screen 12 where still another image conversion takes place. For the specific target 12, this conversion is from an electron to a light image which may be viewed through the substrate of screen 12.

The nature of target electrode 12 is of no particular consequence to the invention. It could, for example, be a fiber optic coupler for transferring the image from the described intensifier to the input of another intensifier stage. A storage electrode might alternatively be employed to store electrons issuing from electron multiplier 15. In such a case, scanning of the storage electrode with an electron beam permits developing a signal representative of a light image or whatever form of image that has been introduced at the input of the intensifier. It will facilitate matters, however, to consider the image intensifier represented in FIG. 1 with light images at both input and output because it facilitates pointing out various improvements realized with the described structure.

It will be observed initially that bonding of the TSEM layer to the input of multiplier plate 17 or simply the presence of that layer ahead of the multiplier plate permits the use of higher accelerating fields in the electron optical system of the intensifier, namely, an illustrative value in the range of 3 to 7 kv as distinguished from a value of about 1.5 in the absence of the TSEM device. With the higher accelerating fields that may be advantageously employed in the presence of the TSEM layer, the radial component of velocity of electrons issuing from the photocathode surface has less influence; there is less tendency of electron spreading with a consequent improvement in the resolution of the input electron optics.

Mention has been made of the fact that the multiplication factor of the TSEM layer exceeds that of the initial impact on the channel multiplier plate and, therefore, an improved signal to noise ratio is realized for the intensifier so long as TSEM layer 16 exhibits good quantum conversion efficiency. The quantum conversion efficiency is the ratio of the total number of electrons incident upon layer 16 to the number that effect transmission secondary emission. The choice of material used, the thickness of the layer, control of the primary or incident electrons as well as care in processing the layer to achieve homogeniety result in acceptable conversion efficiency and attractive signal to noise ratios.

Still another and most desirable result is the elimination of the dark spot effect exhibited by prior devices. This stems from the fact that the composite electron multiplier 15 has no significant variation in gain with angle of electron incidence upon its input surface. It can be expected that the secondary electrodes entering the channels of multiplier plate 17 from TSEM layer 16 will have a sufficiently uniformity of velocity distribution to have uniform high gains throughout the electron multiplier structure. Another improvement resulting from elimination of dark spot is the fact that it is not necessary to bias cut the channel plate which was the prior practice adopted in an effort to control dark spot effect. Accordingly, maximum channel plate resolution is obtained in both vertical and horizontal directions and astigmatism attributable to the bias cut structure is eliminated.

The TSEM layer 16 is impervious to ions and is opaque as well. This protects the electron multiplier 15 from ion spot phenomenon and at the same time prevents light feedback from screen 12 to photocathode 11.

If the aluminum backing layer of phosphor screen 12 is eliminated, still further improvement in contrast and resolution is realized. The backing aluminum layer, serving as a reflector, introduces loss of contrast and impairment of resolution because of diffuse reflections which is sometimes accepted in an effort to increase brightness but at low voltages it has been determined that a non-aluminized phosphor screen at 4 kv above the output of multiplier plate 17 has essentially the same brightness as an aluminized screen operating at a 5 kv potential difference. This suggests eliminating the backing layer, and for the described intensifier, it is not required for brightness enhancement, in order to make it possible to bring the output of electron multiplier 15 closer to screen 12 than is possible in the presence of the backing layer. In fact, spacings may be successfully employed which in the presence of the aluminum backing layer would result in peeling off of that layer due to the electrostatic field established between the output of amplifier 17 and the output screen. With the transparent conductive layer disposed beneath the phosphor of screen 12, which is the structure employed when the backing layer is omitted, close spacings of the screen and electron multiplier 15 can be readily tolerated with a consequent further improvement in resolution and contrast.

When the TSEM device is a hard evaporated layer of TSEM material, that is to say a dense layer formed in high vacuum, having a thickness of 500 Angstroms, the multiplication factor is of the order of 5 but if it is a gaseous evaporated fluffy layer having a thickness of about 5 microns and low density, multiplication factors in a range of 20–100 may be expected. The preferred fluffy or hard layer may be formed by first applying a thin nitrocellulose film to the input side of the channel plate. The nitrocellulose film is prepared by the conventional flotation technique, e.i., allowing a drop of solution to spread over a container of water. The film is about 0.1 microns in thickness, and after solidification on the water it is removed using a metal hoop type of holder. The film stretched on the hoop is transferred to the channel plate whereupon it is heated to 100° C. The heating softens the film and allows intimate bonding to the peripheral area of the channel openings. Good film bonding is required or otherwise the subsequent TSEM evaporation will peel from the channel plate surface. It has been found that during heating a small vacuum (700 Torr.)

applied to the film through the channel openings aids in the intimate bonding of the film to the channel plate. Thereafter, the input of the channel plate is overcoated with TSEM material to which a superposed aluminum layer is then applied, both of these latter steps also taking place in vacuum or partial vacuum for low density layers. During subsequent bakeout of the intensifier tube, the nitrocellulose film bakes off leaving the TSEM layer bonded to the channel plate.

Further to demonstrate the general utility of the present invention, the schematic showing of FIG. **6** is a photocathode structure **20** followed by an electron multiplier **21**, in turn followed by a phosphor screen **22**. The electron multiplier is to be constructed in the manner described in connection with FIG. **2**. The voltage indications are illustrative and in this case there is proximity focusing of the electron image from photocathode **20** upon electron multiplier **21** and also of the electron output of the multiplier upon screen **22**.

While particular embodiments of the invention have been shown and described, it will be obvious to those skilled in the art that changes and modifications may be made without departing from the invention in its broader aspects, and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of the invention.

I claim:

1. An image intensifier comprising:

an envelope;

means including a cathode structure supported within said envelope at one end thereof for developing an electron image;

a planar transmission secondary electron multiplication device disposed transversely of a reference axis of said envelope and responsive to incident electrons having a velocity of at least a predetermined minimum value to emit secondary electrons with a velocity distribution in a range of values but predominantly of values substantially less than said predetermined minimum value;

an electron optical system for accelerating the electrons of said image to at least said predetermined minimum velocity and for focusing said electrons on said device;

a channel multiplier plate for developing further secondary electrons, exhibiting optimum response to incident electrons having a velocity within a range which includes said predominant values and which has a maximum value that is substantially less than said predetermined minimum value,

said multiplier plate being of essentially the same size as said device and being disposed adjacent thereto to receive secondary electrons emitted by said device;

and a target electrode disposed in spaced relation to said multiplier plate and having a potential level with respect thereto for proximity focusing thereon said further secondary electrons emitted by said plate.

2. An image intensifier in accordance with claim **1** in which said transmission secondary electron multiplication device is attached to the input end of said channel multiplier plate and closes the entrance to the channels of said plate.

3. An image intensifier in accordance with claim **2** in which said means for developing an electron image comprises a photocathode, said target electrode comprises a phosphor screen for developing a visible image in response to said further secondary electrons; and

said device is opaque and constitutes a barrier for preventing light feedback from said phosphor screen to said photocathode.

4. An image intensifier in accordance with claim **3** in which said device is a layer of a material having transmission secondary electron multiplication properties bonded to the input end of said channel multiplier plate.

5. An image intensifier in accordance with claim **4** in which said material is an insulator.

6. An image intensifier in accordance with claim **3** in which said phosphor screen comprises a coating of phosphor material deposited on a conductive transparent substrate and exposed directly to the output of said plate without an intervening electron permeable conductive layer.

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