A light amplification device such as an image intensifier or low level sensing device is disclosed which includes a photocathode spaced from an aluminized target electrode and a microchannel plate intermediate said cathode and target. A thin non-self-supporting substantially optically transparent layer of material of a substance and thickness so as to be essentially transparent to high energy electrons, on the order of 100 to 1,000 electron volts, and light is situated atop the front end of the microchannel plate, covering the passages therein, in order to trap ions, which otherwise would travel to the photocathode, neutral gas ions, and to absorb scattered low energy electrons generated by secondary emission at the rim portion of the individual tubes in said microchannel plate, which would otherwise travel into the microchannel plate passages and to pass any light which passes through the photocathode and transmit any light which penetrates through the photocathode. The microchannel plate is spaced by a predetermined first distance from the photocathode, with its covered end facing the photocathode, and is spaced by a second distance, larger than the first distance, from the aluminized target electrode. A first voltage is applied between the photocathode and the microchannel plate and a second voltage, at least twice as great as the first voltage, is applied between the microchannel plate and the target electrode, and a third voltage is applied across the microchannel plate.
Fig. 1

Form Lacquer Layer
Place Lacquer on Plate
Suction to Retain Layer

Bake in Air
Deposit Al on Lacquer

Fig. 2

Fig. 3
LIGHT AMPLIFIER DEVICE HAVING AN ION AND LOW ENERGY ELECTRON TRAPPING MEANS

This application is a continuation-in-part of my earlier filed application for patent, Ser. No. 124,107, filed Mar. 15, 1971 now abandoned.

This invention relates to light amplification devices and, more particularly, to image intensifiers and low light level sensing devices.

BACKGROUND OF THE INVENTION

Light amplification devices and, particularly, image intensifiers and low light level sensing devices find application for surveillance in all situations where limited lighting is available and, particularly, in those applications where the only available light is moonlight or starlight, lighting conditions which to the ordinary person with the unassisted eye are usually considered almost complete darkness. Under these conditions a prime application of such apparatus is to detect intruders in civilian area surveillance or to detect and locate enemy personnel in battlefield surveillance. The apparatus can be designed to permit the information to be acted upon locally or it can be designed to electronically relay the detected images by means of conventional and well-known television apparatus to a remote point.

In one conventional apparatus for those applications light amplification devices are incorporated within and made an integral part of conventional television image transmitting camera tubes, such as the vidicon or image orthicon. In such a camera tube the light amplification device serves as the "front end" which first detects and amplifies an image and places the amplified image upon an output trateg electrode. The target electrode, in turn, is serially scanned in the camera portion and the image is converted into a series of serial electrical signals which may be transmitted to a remote point by cable or radio and detected and displayed upon the cathode ray tube of a television receiver.

Another conventional apparatus for the use heretofore mentioned incorporates the light amplification device in combination with optical binoculars or "goggles" for direct viewing so that guard or field personnel can observe areas under their personnel surveillance under conditions of almost complete darkness and act upon that information.

In still other equipments light amplifying devices can be incorporated within cathode ray tubes to enhance the intensity of a reproduced image to be displayed and reference may be made to prior art sources for specific examples.

Basically, the operative elements of one common type of light amplification device are found within an evacuated (in-vacuum) housing or tube with an optically transparent front window. The images received at the window are directed to a photocathode, a material which emits electrons in proportion to the intensity of light incident thereon. The light image or pattern is projected upon a predetermined area of the photocathode surface and a corresponding pattern of charges or electron currents are generated in the photocathode. The electrons of this mosaic of electron intensities are directed under the influence of a supplied electrostatic field to an electron multiplying element. The electron multiplying element increases the number of traveling electrons and at its output provides a corresponding mosaic or image of electron currents. Under the influence of a second provided electrostatic field these electrons are accelerated either directly or through an electron lens focusing system toward a target, suitably phosphor, which, because of the electron multiplication, provides a displayed or otherwise usable image of a greater light intensity than the image received at tube window.

In one type of light amplifier device the electron multiplying element is a transmission-emission dynode. The transmission-emission dynode is of a high secondary emission material. Thus those electrons traveling from the photocathode and incident upon the dynode cause the re-emission of a larger number of secondary electrons.

A second conventional electron multiplying element uses as an alternative to the dynode a microchannel plate. The microchannel plate comprises a bundle of very small cylindrical tubes packed together parallel and forming essentially a thick layer of material with a very large number of passages or openings through the layer. The inner passage walls are coated with a high secondary emission material and an electric static field is placed thereacross. The end surfaces of the plate are coated with a layer of electrically conductive material which serves as electrodes. This coating does not cover the openings. Electrons traveling from a particular location on the photocathode are directed by the electrostatic field to and enter a correspondingly located passage in the microchannel plate, and is incident upon the passage walls. Since the walls of each passage are coated or formed with a material having a characteristic high coefficient of secondary emission the incident electron knocks out, re-emits, from the wall surface at least two more electrons and they, in turn, travel in a general direction toward the end of the tube. By design, the length and diameter of the passage is such that these electrons, in turn, again strike the passage walls at subsequent locations and increase further the number of electrons traveling toward the end of the passage. The increased number of electrons, hence "amplified" electron intensities, exits from the individual passage in the microchannel plate. Under the influence of another supplied electrostatic field the exiting electrons are accelerated toward a corresponding location on the target electrode, typically a phosphor screen. By similar action at all other locations on the photocathode and microchannel plate, a visual image or mosaic representative of the original image received by the amplifier tube and first focused on the photocathode is displayed upon the target electrode.

By way of example of light amplifier devices and the possible arrangements of the basic photocathode-electron multiplier-target electrode and the additions and variations thereto and thereof the following U.S. patents can be considered: U.S. Pat. Nos. 3,497,759; 3,480,782; 3,478,213; 3,346,752; 3,345,554; 3,440,470; 3,387,137; 3,513,345; 3,528,101; and 2,903,596.

Because of its potentially greater amplification and performance, light amplifier devices using a microchannel plate as the electron multiplying element are the present day choice in second generation light amplifier tube structures. The device, however, has heretofore had several significant limitations.

One limitation in the microchannel plate type light amplifier is contrast resolution. As previously described, the microchannel plate element consists of a bundle of small tube forming passages. Each of these...
tubes has a rim or edge surrounding the passage opening. Even with the multitude of passages through the plate the area taken up by the tube edges is on the order of fifty percent. Hence, electrons traveling toward the microchannel plate are incident sometimes upon the tube edges. Such electrons are bounced back or collide with other electrons at the plate surface and knock out from the surface one or more such electrons. These electrons first move in a direction against the now opposed electrostatic field where they are deaccelerated and then are turned around under the influence of such electric field and then accelerated into the tube passages in the microchannel plate. In passing into the microchannel plate these electrodes act like any other electron in normal operation as previously described. Unfortunately, there is an uncertainty as to into which one or more of the tube passages all or any one of such electrons will proceed. In being knocked out from an edge surface of one tube at a random velocity and direction the electron when turned around under the influence of the electric field may go through that particular tube or any one of the closely packed adjacent tubes.

The reproduction quality of photographic image reproduction requires that a point of light received from one location be reproduced or "imaged" at a second location as a point. If, for some reason due to defects in the optical system or otherwise, the light emitted from a point is "scattered" and reproduced at several closely adjacent points essentially a "blur" is obtained. The limit of resolution can be determined in one manner by locating another point of light closely adjacent the first light point and moving the two together. The reproduced light images should be distinguishable and it is apparent that if the two light sources show up at the image location as one single blur that the distance between light sources at which this occurs is a limit to the resolution capability of the imaging system.

The electrons emitted from particular spacial locations on the photocathode surface in the light amplifiers may be considered analogous to the previously described light points. Thus, if the electrons generated at the microchannel plate surface by electron collisions can flow into one or more adjacent passages somewhat randomly the output image of the intensifier essentially appears blurred. This means that the point source of electrons is not 100 percent accurately reproduced at the image location and that, with respect to the transfer function defined by the MCP resolution, degradation in performance results.

This characteristic is specified by those skilled in the art in terms of the number of "raster" or "TV" lines per unit of raster height which can be placed upon the display screen and be discernible. As the number of lines per unit height are increased the more densely packed together these lines become until the limit of resolution is reached: the point at which time these adjacent lines merge together or blur and it is impossible to determine the edge of any one line and the beginning of any space between lines. As a result of the problem previously discussed present light amplifier devices have typically maximum resolution capabilities on the order of 400 TV lines per unit of raster height with the raster height, in turn, being specified as four-tenths of 1 inch.

A further limitation is inherent. As is apparent to those familiar with television type pickup and display apparatus, there are instances, however infrequent, where an electron current instead of colliding with the wall and causing the emission of other electrons will, instead, cause the desorption of an atom as a positively charged ion, an atomic particle that is of a mass several hundred times larger than an electron. In the light amplifier device the original electrons are directed to the microchannel plate under the influence of a large electric field the latter of which by the convention adopted points in a direction from the photocathode to the microchannel plate. This same electric field, however, is oriented such as to accelerate any such large mass positive ions for travel in a direction toward the photocathode. Thus the positive ions, when generated, travel to and collide with the photocathode with deleterious effect. The structure and method of fabrication of microchannel plates is such that those positive ions derived from the microchannel plate structure may be, for example, water ions, H\textsubscript{2}O\textsuperscript{+} or Cesium ions, Cs\textsuperscript{+}. In colliding with the photocathode consisting of a different chemical substance, such as S–20, the ion can combine with the photocathode material to form compounds that do not possess photocathode properties. And in colliding the kinetic energy released by the ion erodes the photocathode mechanically. Both due to the release of large kinetic energy at the photocathode and the chemical changes caused to the photocathode, the photocathode deteriorates resulting in a serious loss of sensitivity in the amplifier tube, evidenced by a faded picture with diminishing brightness and diminishing contrast. As a result, the normal operating life of the presently available microchannel type intensifier tubes in which images of acceptable quality are provided may be on the order of 50 to 100 hours.

The ion bombardment problem thus described is not significant in many of those light amplifying devices which use the transmission-emission dynode electron multiplier structure. This is because the dynode acts as a trap for any ions generated due to electron incidence upon other elements in the tube and the proximity of the dynode to the photocathode precludes large ion velocities. However, because of the other advantages of the microchannel plate, primarily substantially higher gain, the light amplifying devices using the microchannel plate are superior and are preferred.

Ion bombardment problems are not unique to light amplifiers and are recognized in the prior art with various means heretofore devised or proposed to minimize or eliminate the problem. One common example is provided in television cathode ray tubes in which a magnetic field diverts the traveling positive ion to the side of the tube envelope. Absent this diversion the positive ion would proceed instead to the phosphor faceplate and gradually erode a spot in the middle of the screen. Another example of a type of ion trap appears in a direct view light amplifier as disclosed in U.S. Pat. No. 3,350,594, issued Oct. 31, 1967, to Davis, illustrating a light amplifier device of the "first generation" type which does not include a microchannel plate or equivalent electron multiplying element. The approach therein suggested is to coat the backside of the phosphor display screen with a porous coating of aluminum atop the normal aluminum layer conventionally applied to the back of the screen for other purposes, the object being to capture any positive ions produced at the phosphor screen within the porous layer so that they cannot travel back toward the photocathode. This
structure appears to be necessitated because the light amplifying device shown simply does not incorporate any electron multiplier or multiplying elements such as a dynode or microchannel plate, which elements would necessarily provide a large obstacle to the travel of the positive ions from the phosphor screen back to the photocathode which, if included, minimizes this problem.

It also appears known to merely place a thick metal layer on and at the front end of a microchannel plate merely to stop or trap positive ions. In the specification of U.S. Pat. No. 3,603,832 a low light level amplifier tube structure is disclosed in which it is proposed to remove the conventional thick light opaque aluminum backing, the light and ion trap, located on the back of the phosphor target electrode or display screen, as variously termed, a combination referred to as an "aluminized" screen located spaced in back of the rear end of the microchannel plate, and to place that thick metal layer instead as an alternative at the front end of the microchannel plate atop an insulator layer. In so doing, patent U.S. Pat. No. 3,603,832 notes that the metal backing as applied to the phosphor display screen in prior devices requires a very high voltage, suitably on the order of 5,000 volts, to give those electrons exiting the rear end of the microchannel plate sufficient kinetic energy and momentum to pass through the thick metal layer backing to the phosphors of the display screen and the application of such a large voltage requires a large physical spacing between the display screen and the microchannel plate to avoid destructive voltage arc-overs. Further according to that patent, the large physical spacing between the aluminized display screen and the microchannel plate reduced the light output intensity from the phosphor display screen and caused other undesired optical effects. As a compromise the patent hence proposed to remove the thick aluminum layer from the phosphor display screen, which permits a lower accelerating voltage between the microchannel plate and the phosphor display screen, from 5,000 volts down to 1,500 volts, by example, and position the display screen more closely to the exit of the microchannel plate. Hence the light intensity output from the electron bombarded phosphors in the display screen is the same as or better than in preceding devices. Because some ion trap is necessary the cited patent suggests locating the thick metal layer at the front end of the microchannel plate and this required additional modifications to the prior devices. Namely as taught in the cited patent the physical distance between the front end of the microchannel plate and the photocathode is increased and the accelerating voltage between the photocathode and the front end of the microchannel plate is also increased, from a low voltage of perhaps 1,000 volts to a high voltage of 5,000 volts, in order to sufficiently accelerate electrons to pass through the "repositioned" thick metal layer, just as in the case of the prior art device where the metal layer was located on the back of the phosphor display screen. In so doing, U.S. Pat. No. 3,603,832 effects a compromise or selection in location of a tube element, the thick metal layer, rather than proposing an entirely new device. There is no disclosure that a metal layer can be placed on both the front end of the microchannel plate and the back of the phosphor display screen or that the distance between photocathode and microchannel plate should remain small and the accelerating voltage therebetween should remain low, so that the low energy secondary electrons created on the input end surface of the microchannel plate can be reabsorbed by the trap layer and increase resolution, and the number of elastically scattered secondary electrons, which do have the higher energy and can penetrate into randomly located adjacent microchannel plate holes, is kept to a minimum; or that low energy electrons can be absorbed by a metal layer in combination therewith to provide substantially increased contrast resolution and noise reduction and whereas by increasing the voltage between the photocathode and microchannel plate more higher energy secondary electrons are being generated which would not be absorbed by the metal layer and which would therefore decrease contrast resolution.

A further limitation is inherent in the nature of the photocathode itself. While characterized as an opaque element, considered quantitatively it is approximately 90 percent opaque and can actually transmit as much as 10 percent of the incident light. Should light pass through the photocathode and be incident upon the metal layer located at the front end of the microchannel plate, that light can be reflected from the metal layer back to the photocathode and circulates between the metal plate and the photocathode to generate improperly positioned electrons by further photocathode emission. And thus a point source of light becomes displayed as an enlarged point on the phosphor screen, a phenomenon characterized as "blooming".

OBJECTS OF THE INVENTION

Accordingly, it is an object of the invention to provide an improved light amplifier device.

It is an additional object of the invention to provide a light amplifying device having improved contrast resolution capabilities.

It is a still additional object of the invention to provide a new light amplifier device having improved life and resolution capabilities and avoids blooming.

It is a still further object of the invention to minimize or eliminate entirely in a light amplifier tube positive ion bombardment of the photocathode and eliminate low energy electrons without reducing the amplifier gain.

And it is still another object of my invention to increase the operational life of and the quality of performance during that life of a light amplifier tube.

SUMMARY OF THE INVENTION

In accordance with the foregoing objects of the invention, the invention comprises in a light amplification device a photocathode spaced from a target electrode, suitably a phosphor screen backed by a thick metal layer, and a microchannel plate type of electron multiplier between the cathode and screen, with the plate spaced more near to the cathode than to the screen. A very thin optically transparent layer of a material having a low atomic mass is situated atop and covers the front end of the microchannel plate which confronts the photocathode. The layer is of a thickness in the range of 50 to 400 A, and, in one example, comprises the metal aluminum. The front of the microchannel plate is positioned close to the photocathode and a voltage in the range of 200 to 1,000 volts is applied therebetween to establish an electric field gradient, within the range of 1 x 10^4 volts/cm to 4 x 10^4 volts/cm
3,742,224

therebetween. A substantially larger voltage in the range of 3,000 to 8,000 volts is applied between the rear end of the microchannel plate and the metal backed phosphor screen to establish therebetween an electric field gradient, suitably in the range of $3 \times 10^4$ to $6 \times 10^4$ volts/cm. In accordance with the invention, the covering metal layer absorbs or dissipates scattered low energy electrons generated by secondary emission at the front surface of the microchannel plate and thereby prevents such electrons from entering the plate passages. Additionally, the covering layer acts as a barrier to positive ions traveling from the microchannel plate in the direction of the photocathode and to any existing neutral gas atoms. And any light which passes through the substantially opaque photocathode is permitted to pass through the metal layer rather than allowed to create multiple reflections in the space between the photocathode and metal layer.

The foregoing and other objects and advantages of my invention together with modifications, substitutions and equivalents thereof and other variations and additional advantages thereunto become more readily apparent from consideration of the following detailed description together with the figures of the drawing in which:

**DESCRIPTION OF DRAWINGS**

FIG. 1 illustrates symbolically a light amplifier device which embodies the principles of my invention;

FIG. 2 illustrates pictorially a small section, $A$, of the microchannel plate and metal layer used in connection with the illustrated embodiment of FIG. 1; and

FIG. 3 illustrates schematically the steps of manufacturing a microchannel plate and layer combination in accordance with a novel method.

**DETAILED DESCRIPTION OF INVENTION**

Inasmuch as all elements and details of light amplifiers, other than the improved element, are conventional and known to those skilled in the art, FIG. 1 illustrates the basic elements of a direct view type light amplifier device, which incorporates the invention, in symbolic form. The light amplifier includes an envelope or housing 1 represented by the dashed lines, suitably glass or ceramic materials, and the inside of the housing is in vacuum. The housing includes an optically transparent faceplate 2, represented by dashed lines, with which to permit entry of an optical image and, in the direct view tube, an optically transparent rear window 4 through which to view the displayed "amplified" image.

The conventional electron or light optical system 3 is indicated by the dashed lines. This element as is well known can simply be a transparent space with which to allow the light image to pass, or a complicated, though conventional, structure for converting the received light image into a source of electrons representative of that image, i.e., an electron image and then into an intermediate display. Additionally, a conventional optical lens focusing system, not illustrated, may be located in a conventional manner in front of faceplate 2.

A photocathode 5 is situated at the front end of the tube to receive the light image upon its surface. Photocathode 5 is a circular disk having a predetermined area constructed and supported within the tube envelope in a well-known manner. Suitable photocathode materials are cesium and antimony and the preferred material is sodium potassium—cesium antimony combination, commercially sold under the designation S-20.

A target or display electrode 13 is located at the rear of the envelope 1. By target electrode 1 refer generically to the last electron receiving electrode in the light amplifier tube, whether it be a direct display type or storage type of tube. As is conventional in a display type of light amplifier the target electrode 13, usually referred to as the "screen" in a direct view tube, is usually of a circular disk-shaped geometry and consists of a coating of an electroluminescent material, such as P-20 phosphor. Suitably the phosphor target is formed as a coating on the tube window 4. In turn the phosphor is conventionally backed or coated with a thick electron permeable layer of aluminum 16, suitably 500 to 1000 A in thickness, to enhance its electrical conductivity and function as an electron trap and a light trap.

Spaced from and located in between photocathode 5 and target 13, and supported by conventional means, not illustrated, is a microchannel plate 7. The microchannel plate is a conventional type of electron multiplier and is cylindrical in geometry. Microchannel plate 7 consists typically of a plurality of glass tubes of small diameter closely packed together and fused into a unit. In the conventional case in excess of 100,000 individual tubes are incorporated within and make up this plate. Each of the tubes contains a passage 9 therethrough opening on both the front and back faces or sides of the plate. Typically, the diameter of this passage is on the order of 2 mils and the openings approximate 50 percent of the total face area. By conventional techniques the outer edges or rims of these tubes on both front and back sides are coated with a conductive metal, lead or lead oxide, not illustrated, to form electrically conductive end surfaces for the microchannel plate and so as to place all the tube ends on the front and on the back sides, respectively, electrically in common. The inside walls 11 of the glass tubes in microchannel plate 7 are coated with a highly resistive electrically conductive material and a high secondary emission coating. Usually this comprises a lead and lead oxide coating conventionally produced by hydrogen reduction of lead oxide glass. While the internal coating is considered electrically conductive it is highly resistive and on the order of 100 megaohms, and thus is not an electrical short circuit.

The embodiment of FIG. 1 may be modified to include an electron focusing arrangement in the space between the microchannel plate and target 13. Such elements are conventional and can be included by choice without departing from the invention.

Suitable conductor means symbolically illustrated in FIG. 1, and labeled 8, 10, 12, and 14, provide electrically conductive paths from the photocathode 5, front end of microchannel plate 7, back end of microchannel plate 7, and target 13, respectively, to corresponding terminals on the exterior of tube envelope 1.

A thin film or layer 15 of metal, suitably aluminum, is attached or coupled to the front end of microchannel plate 7 and covers the entire front surface thereof and hence, covers the open ends of passages 9 in the microchannel plate. The film layer is of a thickness, $d_3$, preferably in the range of 50 to 400 A, or 75 A by way of specific example, and is of a material which has a low atomic mass or low specific gravity of 1.0 to 4.0. Suitably the layer 15 comprises aluminum which in this di
mension is "substantially" transparent to electrons having energies in excess of several hundred electron volts while opaque, absorptive, or dissipative, however affected, of electrons having energies of less than 20 electron volts and is transparent substantially to light. In addition the aluminum layer forms a positive barrier to relatively large mass large volume positive ions and neutral gas atoms. One obvious addition to be noted at this point is to provide in addition a very thin aluminum oxide skin on the aluminum layer on the underside abutting the front face of the plate. The front of the microchannel plate is spaced by a distance, $d_1$, as close as is practical to the rear of photocathode; within the range of 0.005-inches to 0.020-inches, and 0.012-inches by way of specific example. In one example the length of the microchannel plate with the layer is approximately 0.025-inches in length front to back. And the distance between the rear end of the microchannel plate and the metal backed phosphor display screen 13, $d_2$, is within the range of 0.030-inches to 0.050-inches preferably and is 0.038-inches in this specific example.

For operation of the light amplifier suitable sources of electrical energy or "bias" supplies are provided and symbolically illustrated as batteries in FIG. 1. A battery 17 has its positive polarity output connected to lead 10 and its negative polarity output connected to lead 8 to place the battery voltage between the photocathode and the microchannel plate. Typically the voltage of this supply is on the order of 400 to 1,000 volts, particularly 600 volts, in order to establish an electrostatic field of a predetermined intensity gradient between the front face of the microchannel plate and photocathode 5, which field is represented symbolically in FIG. 1 by the arrow labeled E1. Such a gradient E1 is equal to $V_1/d_1$. The gradient E1 is preferably on the order of 32 $\times 10^4$ volts per centimeter within the range of 15 $\times 10^4$ volts/cm to 40 $\times 10^4$ volts/cm. A second bias source voltage is represented by battery 19. Battery 19 has its positive polarity terminal connected to lead 12 and its negative polarity terminal connected to lead 10 of the light amplifier. Battery 19 may be of a voltage on the order of 300 to 1,000 volts, typically 800 volts. This places the battery voltage between the front and rear ends of the microchannel plate and establishes an electric field of predetermined intensity between the front and back ends of microchannel plate 7 in a direction toward the back of plate 7. This electric field is represented by the arrow and labeled E2 in FIG. 1 and is typically 12.6 $\times 10^4$ volts per centimeter. A third bias source voltage is represented by battery 21 in FIG. 1. Battery 21 has its positive polarity terminal connected to lead 14 and its negative polarity terminal connected to lead 12 of the light amplifier. This places the voltage of battery 21 between the rear of the microchannel plate and the aluminized phosphor screen 13. Battery 21 provides voltages on the order of 3,000 to 8,000 volts, typically 5,000 volts, which establishes a predetermined electric field between and in a direction from the back end of microchannel plate 7 to aluminized phosphor display screen 13. This field is represented in FIG. 1 by the arrow and symbol E3 and is preferably within the range of 3 $\times 10^4$ to 7 $\times 10^4$ volts/cm. In one specific example the gradient E3 is 5 $\times 10^4$ volts/cm.

An exploded view of a segment of the front end of microchannel plate cut out by the dashed lines in FIG. 1, which are labeled 5, is presented in FIG. 2 to assist in the explanation of the operation and effects of invention. Thus FIG. 2 illustrates the microchannel plate 7, several of the individual tubes 9 which form the microchannel plate, the walls 11 of tubes 9, and the layer 15 situated atop microchannel plate 7.

As previously described, aluminum layer 15 is of a thickness of 75 A. Layers of this minute thickness are not self-supporting and would crumble and fall apart if an attempt were made to form such a layer, lift it, and place it upon the microchannel plate. Accordingly special techniques are necessary to satisfactorily couple to aluminum layer 15.

One alternative is to form the layer in place on the microchannel plate by a conventional phosphor filming technique. Such a technique requires the immersion in water during processing of the plate but does not require the film 15 to be self-supporting.

A second approach is to take a thick self-supporting film of aluminum oxide produced by conventional means such as anodization and then evaporate aluminum onto the front side of the aluminum oxide film. This layer can then be placed atop the microchannel plate. For adhesion the film and plate may be fused together by simply passing electrical current between the film and the plate. In this the aluminum oxide remains and serves to give increased transmission-secondary emission multiplication.

I prefer, however, to fabricate the aluminum film by the novel method illustrated in connection with FIG. 3. In this method a thin self-supporting film of lacquer (nitrocellulose) is first formed by conventional techniques. This step is represented in FIG. 3 as block 22. The lacquer film is then taken and placed atop the microchannel plate as represented by block 23. Preferably prior to placing the lacquer film in place I connect a vacuum pump to the back side of the microchannel plate in order to produce a suction at the front surface as is represented by the dashed lines of block 24. When the lacquer film is placed atop the microchannel plate the vacuum assists holding this film in place. Because the lacquer material is very thin and electrostatically charged the lacquer film adheres to the microchannel plate immediately and the vacuum pump is removed. The microchannel plate with lacquer layer is then placed in a conventional bell jar for aluminum deposition.

By conventional means such as measurement of quartz crystal oscillation frequency as a function of aluminum deposition the desired thickness of aluminum is then evaporated atop the lacquer film as is represented by block 25. In this way the thin aluminoid coating which is not self-supporting is maintained as a layer by the thin self-supporting lacquer layer. Subsequently, the entire assembly is then placed in an oven where the assembly is baked in an air atmosphere at a temperature of about 325° Centigrade for approximately one to two hours as is represented by block 26. It is noted that this and other processing may permit the aluminum to oxidize on its surfaces, forming aluminum oxide, an electrical insulator. While unconfirmed, as hereinafter becomes apparent the existence of the oxide does not detract from and possibly enhances the operation of the invention.

The lacquer vaporizes during baking and disappears while the aluminum layer sinks down into place atop the microchannel plate. Normal electrostatic forces assist in retaining the aluminum in place. The aluminum
is in electrical contact with the electrode coating on the front surface of the microchannel plate.

In operation an image is received at the front face plate of the light amplifier illustrated in FIG. 1, and this image is directed upon the surface of photocathode 5. Photocathode materials produce electron currents in proportion to the magnitude of the incident light. Thus photocathode 5 at its output back surface produces an electron image or, as otherwise stated, an image of electron currents. Electric field E1, where E1 = V1/d1, accelerates all the electrons toward the electron multiplying structure, namely, microchannel plate 7 and aluminum layer 15. These electrons are accelerated through the voltage V1. Upon reaching aluminum layer 15 the electrons have been accelerated up to an energy level of 400 to 1,000 electron volts corresponding to the voltage applied between photocathode 5 and microchannel plate 7.

As previously discussed the thickness and substance of aluminum layer 15 is such as to make the layer "effectively" transparent to electrons of such high energy levels in that such electrons either pass through the aluminum layer 15 or knock out a corresponding electron and the electron travels forward into a correspondingly located one of the tube passages.

Otherwise stated, the electrons which are generated due to electron collisions with the front surface of the microchannel plate are low energy level electrons typically on the order of 3 to 5 electron volts, a rather small energy level in contrast to the approximately 600 electron volt energy of the incident electron traveling from the photocathode. The low energy electron travels into the aluminum layer and therein loses what little energy it has due to interaction and collision with the multitude atoms and electrons in the aluminum layer and is therefore unable to pass through the length of aluminum layer into one of the passage openings. By contrast, any conductive material plated or otherwise formed on the front surface of the microchannel plate which, for example, is the electrode element previously described, which is found on the plate in the form provided by the manufacturer, does not cover the entire open ends of the passages and does not present any barrier to scattered electrons. Further, because the plate 7 is located close to the photocathode, permitting use of voltages on the order of 600 volts, higher accelerating voltages which create scattered electrons of higher energy levels that might pass through layer 15 are avoided.

For clarity of explanation the path of one electron, e1, serves to illustrate the conventional operation of the microchannel plate 7. Electron e1 is derived from the photocathode 5 due to the incidence of light, h, at the indicated location on the photocathode and is accelerated toward the electron multiplier. The electron goes through "transparent" metal layer 15 and then into a passage 9 where it comes under the influence of electric field, E2, established by source 19. Because of its random transverse travel the electron collides with the passage walls. The passage walls are coated with high secondary emission material having a secondary emission coefficient of at least 2, or, in other words, greater than one at average impact velocity. Thus the electron knocks out at least two additional electrons and these, in turn, accelerate and travel, due to the electric field E2, in general toward the back of the passage. As illustrated in the example in FIG. 1 these two electrons having random velocity vector angles, in turn, strike the walls of the passage at a subsequent location and, in turn, knock out four electrons. By suitable choice of the length and diameter of the tubes this process of increasing the quantity of electrons continues. And a large number of electrons exit from the back side of microchannel plate 7. Hence, the initial electron e1 which entered the front of the plate is amplified or "multiplied" many, many times. Upon exit from the rear of the passage 9 in microchannel plate the electrons enter high level electric field, E3. The electric field accelerates the electrons to a large energy level, through 5,000 volts typically, and they travel and pass through metal backing 16 and strike the surface of the phosphor screen or target 13, as variously termed, at a corresponding predetermined location. With conventional electron focusing systems between the plate and target this location can be varied, but in the embodiment illustrated, it is a direct corresponding location. As is conventional, the phosphor emits light, λ, in proportion to the amount of electron bombardment and thus the initial low level of light responsible for the generation of the single electron from photocathode 5 is amplified to a much higher light level or brightness at the phosphor screen 13, much higher than the light which would have been produced by the single original electron.

While the foregoing theory of operation has been discussed in connection with a single electron, the operation occurs concurrently with all of the incident light in the image or mosaic placed over the entire surface of the photocathode and with all the passages in the microchannel plate so that the electron image formed at photocathode 5 appears as a light image at the display target electrode 13.

Prior to my invention by the addition of aluminum layer 15 to the front of the microchannel plate 7 it was possible for an electron such as illustrated by e2 in FIG. 1, to enter a passage in the microchannel plate and knock out a positive ion, "+." Due to the nature of construction of the microchannel plate tube this would most likely be a cesium ion or an oxygen ion or a water ion. Electric field E1 which accelerates negatively charged electrons toward plate 7, instead accelerates positively charged ions toward the photocathode. In striking the photocathode these particular ions would combine with the photocathode material to form a different compound, a compound which would not possess photocathodic properties and lowered or destroyed, eventually, the effectiveness of the photocathode.

Secondly, the mass of an ion is, of course, hundreds of times greater than an electron and when accelerated through the electric field possess relatively large amounts of kinetic energy. Upon striking the photocathode the ion releases this energy and erodes the photocathode material and reduces its photocathodic properties.

As a result of the foregoing effects, the light amplifiers lost sensitivity, presented a faded picture with diminishing brightness and diminishing contrast typically after an operating life of no more than 50 to 100 hours.

Instead, in the construction of the invention aluminum layer 15 absorbs or acts as a barrier to and prevents these large ions from reaching the photocathode 5, and in this way acts as an "ion trap." In addition, any ions or neutral gas molecules originating from any
other tube components behind the microchannel plate cannot pass through layer 15.

Image amplifiers under life test have presently been in operation for in excess of 1,000 hours in contrast to the 50 to 100 hours provided with prior art tubes and this is accomplished without reduction in the gain overall of the light amplifier. Theoretically, the ultimate increase in the operating life of the light amplifier expected from this improved construction and which will be demonstrated in the future is expected to increase by a factor of 100 to 1,000 times over that previously available.

Further consideration of the invention is better illustrated and understood in connection with FIG. 2 which shows a cutaway section A from FIG. 1. In normal operation of the light amplifier, electrons such as e3, of 400 electron volts, pass through aluminum layer 15 and enter one of the tubes 9 in microplate 7.

With the modification to the aluminum layer suggested in which a skin of high secondary emission material, suitably aluminum oxide, is applied to the underside of the aluminum layer, electron e3 as represented in FIG. 2 passes through the aluminum and strikes the high secondary emission material. Inasmuch as such material has a secondary emission coefficient preferably greater than 2, two electrons, e31 and e32, are shown emerging from the back surface of layer 15 and traveling into the passage. In this the layer functions in addition as a transmission-emission dynode. However even without the suggested coating, it is possible in many instances for such electrons, such as e3, to knock out some secondary electrons.

Assuming momentarily the deletion from FIG. 2 of aluminum layer 15 the prior art microchannel plate light amplifier devices and an attendant disadvantage of same as well as a prime and unexpected feature of the invention can be better understood. Electrons such as e4, as represented in FIG. 2, traveling from the photocathode are many times incident upon an edge surface bordering the passages, 9. This is not uncommon. As previously noted, approximately 50 percent of the apparent surface area of the microchannel plate open to the passage while the other 50 percent represents actual material. This represents the manufacturer's compromise between the desire of as many passages as possible in a given space versus the mechanical requirements of rigidity for the multichannel plate element.

In those instances the electron knocks out from the surface one or more additional electrons, which are represented by way of example as e41 and e42. These electrons depart the surface and travel at an angle with respect to the surface of the microchannel plate but with a component of velocity in the direction of the photocathode. These electrons are low energy level "scattered" electrons and, typically, possess energies on the level of 3 to 5 electron volts. The electric field E1 previously described in connection with FIG. 1 decelerates and turns these electrons around and they travel into passages in the microchannel plate. In the passages 9 these electrons act and are "multiplied" in substantially the same manner as any other electron as previously described in connection with the electron multiplication properties of the microchannel plate.

Unfortunately, because these electrons are "scattered" in any direction and of varying low energy levels there is an uncertainty as to which one of the passages in microchannel plate into which they will travel. In FIG. 2, electron e41 is shown traveling into one passage while electron e42 is shown traveling into an adjacent passage. As is also apparent, there are additional passages above and below the illustrated passages in the 3-dimensional body. It is also possible for the energy level of the scattered electrons to be such that it can travel, instead, to the next adjacent tube into which the previously discussed electron e3 traveled.

Inasmuch as each of the electrons represents light of a received image, it is apparent that light intended to be positionally located on the phosphor display screen at a position corresponding to the juncture of the adjacent passages where e4 is incident the light is, instead, displaced a predetermined position and presented at one location, that through which electron e41 emerges, or, in addition or alternatively, at a second location, the one to which e42 will travel, as well as many other passages above and below and around those illustrated to which the scattered electrons can travel. Thus it is possible to obtain instead of a sharp point location on the phosphor screen a rather "blurred" representation; the contrast or resolution is thus not so great as possible. This factor is referred to in the design and specification of cathode ray tubes and light amplifying tubes as a "limiting resolution factor" and this limiting resolution factor is specified in the number of television lines (scanning lines) per unit of raster height. The limit of resolution is specified as the number of lines on the screen for a given height which can be viewed before the lines merge and blur and become indiscernible. Typically, on prior art microchannel plate light amplifying tubes the upper threshold of resolution was 400 TV lines per unit of raster height, the raster height being typically four-tenths of 1 inch. The capability of resolution of a phosphor screen itself is limited by phosphor spot size and conventionally the display screen 13 of FIG. 1 is inherently capable of a resolution greater than 1,000 lines per unit of raster height.

Considering now the incorporation of the aluminum layer 15 in the light amplifier. As previously described in connection with the operation in FIG. 1 the aluminum screen acted as a barrier to positive ions, which ions were many hundreds of times larger in both mass and volume than an electron. In addition, quite unexpectedly, the aluminum layer also absorbed or captured the electrons low energy level scattered electrons such as those generated by secondary emission from the edge surface of the microchannel plate. Thus electrons such as e41 and e42 are now absorbed or captured within layer 15 covering passage 9 and they cannot travel into the microchannel plate. The accelerating voltage within the range of 400 to 1,000 volts, as previously noted, is low and at most generates a minimum of higher energy secondary "scattered" electrons that might pass through layer 15 to diminish contrast resolution as a higher accelerating voltage could do. Because the existence of only these low energy level scattered secondary electrons was a substantial factor limiting the resolution of the light amplifier, their elimination without the generation of those of increased energy permits an increased resolution capability for the light amplifier. In point of fact, in a tube constructed in accordance with the teachings of this invention, a 30 percent increase was obtained in the limiting resolution over a corresponding tube constructed without the aluminum layer 15. As contrasted with an upper threshold of resolution of 400 TV lines per unit of raster height.
obtained with prior art tubes the structure of the invention makes it possible to distinguish 600 lines per unit of raster height.

Should any light pass through photocathode 5 and be incident upon the metal layer 15, it will pass through the transparent layer and through the microchannel plate without interfering in the operation of the image intensifier tube. This avoids the problem of reflecting light from layer 15 back to photocathode 5 and generation of electrons in a different position possible with an optically opaque thick metal layer and which could cause “blooming”, is avoided.

In the specific example of my invention the layer 15 which forms the ion and electron trap is a metal, aluminum. However other materials of a low density, suitably a specific gravity below 4, can be used as an alternative. Boron and beryllium are examples. Although the preceding examples are metals, I have also found that nonmetals, normally electrical insulators, are equally suitable. By way of example, some such nonmetals which can be used to form the layer 15 include boron carbide, aluminum oxide, silicon oxide, boron nitride, silicon dioxide, magnesium oxide and magnesium fluoride. Whatever alternative material is used, the layer 15 is formed in place on top of the microchannel plate by the same processes described previously for the specific example of aluminum. Thus the foregoing or any equivalent element compound or composition of matter may be used which can undergo processing by the preferred process. Basically, the material should not be water soluble, should not oxidize at temperatures less than 300° Centigrade, and do not reduce in a hydrogen atmosphere at temperatures on the order of 435° Centigrade.

Moreover, the structure of the invention requires the materials to be of a low density and hence they must have a specific gravity less than 4.0 and, preferably, the specific gravity of the material is in the range of 1.0 to 4.0.

As a further consideration and refinement to the invention, it is desirable that the materials used as the ion and electron trapping layer, such as layer 15, possess a high secondary emission coefficient suitably greater than 3.0 at 400 volts. This insures greater output for electron multiplication processes and renders the resulting tube of higher quality and less susceptible to “noise”. This characteristic is exhibited by most of the specific examples given.

As previously described, the front edge surface of the microchannel plate 7 as obtained from the manufacturer is electrically conductive. Hence if layer 15 is an electrical conductor it will be in direct contact with the front edge of the microchannel plate, and, accordingly, the voltage V1 which is applied to the microchannel plate and the photocathode 5 creates a voltage drop across a distance d1 slightly shorter by the distance d3, the thickness of the layer, and, accordingly, a slightly greater voltage gradient E1, which is equal to V1/d1. However inasmuch as the thickness of the layer is insignificant in relation to the distance d1 between the photocathode 5 and microchannel plate, for all practical purposes the effect of the thickness of the microchannel plate on the established electric fields may be disregarded. Thus, where the covering layer 15 is of a nonmetal which is not electrically conductive but electrically dielectric, the voltage extends across the space between photocathode 5 and front edge surface of microchannel plate 7. However as in the preceding case, the thickness of the layer is so small relative to the distance between the photocathode and microchannel plate that its effect upon the voltage applied therebetween or the voltage gradient E1 thereacross may be disregarded. Hence, with either type of construction I may refer to the potential difference or voltage between the photocathode and the front edge of the modified microchannel plate as that between the photocathode and the front edge of the microchannel plate, disregarding the existence of the thin layer 15, and likewise the electric field gradient E1 established between the photocathode and microchannel plate is the same for all practical purposes as that gradient established by disregarding layer 15. And thus it is understood where I describe a voltage or field between the microchannel plate and photocathode that such voltage or gradient may actually appear across an insignificantly foreshortened space in the case where layer 15 is an electrically conductive metal and is intended to cover such structure. Likewise, essentially the same is true of the distance between the rear of the microchannel plate and the target electrode. Hence where I refer to a voltage V3 between the two elements or a field E3, (V3/d2), between those two elements it is understood such language is intended to cover the distance between the microchannel plate and the metal backing layer on the target electrode.

The foregoing detailed description and illustration of the preferred embodiment of my inventions are presented solely for purposes of explanation and not by way of limitation. As is apparent to those skilled in the art many modifications, substitutions and equivalents to the foregoing details can be made without departing from the spirit and scope of my invention. It is therefore understood that the inventions are to be broadly construed limited only by the breadth and scope of the appended claims.

What is claimed is:

1. An image intensifier which includes:
front end means for receiving an optical image;
a photocathode for receiving said optical image and generating electrons representative of said image;
a target electrode, said target electrode including a layer of metal covering a back side of said target electrode;
an electron multiplying microchannel plate located between said target electrode and said photocathode with said microchannel plate having a front side facing said photocathode and a back side facing said back side of said target electrode, said microchannel plate spaced by a first predetermined distance from said photocathode and spaced by a second predetermined distance from said target electrode, said second predetermined distance being at least 1.5 times greater than said first predetermined distance;
a very thin substantially optically transparent non-self-supporting layer of material having a thickness in the range of 50 A. to 400 A. situated upon and covering the front side of said microchannel plate for trapping ions and low energy level electrons and passing other electrons and incidental light to thereby increase the contrast resolution capability of the tube and the operational life thereof;
means for applying a first predetermined voltage between said photocathode and said microchannel plate;
means for applying a second predetermined voltage between said microchannel plate and said target electrode; said second predetermined voltage being more than twice as large as said first predetermined voltage;
and means for applying a third voltage between the front and rear ends of said microchannel plate.

2. The invention as defined in claim 1 wherein said material comprises a specific gravity in the range of 1.0 to 4.0.

3. The invention as defined in claim 2 wherein said material comprises a metal.

4. The invention as defined in claim 3 wherein said metal comprises aluminum.

5. The invention as defined in claim 2 wherein said material consists of a member selected from the group comprising aluminum, aluminum oxide, boron, beryllium, boron carbide, silicon oxide, silicon dioxide, magnesium oxide, and magnesium fluoride.

6. The invention as defined in claim 2 wherein said material possesses a coefficient of secondary emission greater than 3.0 at a potential of 400 volts.

7. The invention as defined in claim 1 wherein said first predetermined distance is in the range of 0.005-inches to 0.020-inches and wherein said second predetermined distance is in the range of 0.030-inches to 0.050-inches, and wherein said first predetermined voltage is in the range of 400 to 1,000 volts and wherein said second predetermined voltage is in the range of 3,000 volts to 8,000 volts.

8. A light amplifier which comprises:
a phosphor display screen of a predetermined area;
a metal backing layer covering the backside of said phosphor display screen;
a photocathode spaced from said display screen for emitting electrons in response to incident light;
a microchannel plate type electron multiplying element located between said display screen and said photocathode, said electron multiplying element having a front input side facing said photocathode and a rear output side facing said display screen, said electron multiplying element being spaced from said photocathode by a first predetermined distance within the range of 0.005-inches to 0.020-inches and being spaced from said display screen by a second predetermined distance greater than said first predetermined distance in the range of 0.030-inches to 0.050-inches;
a thin non-self-supporting substantially optically transparent layer of electrically conductive material coupled to and covering the front end of said microchannel plate;
means for establishing a first voltage difference between said photocathode and said front end of said electron multiplying element to accelerate electrons in a direction from said photocathode toward said electron multiplying element;
means for establishing a second voltage difference between the ends of said electron multiplying element to create an electric field for accelerating electrons in a direction from the front to the back end thereof; and
means for establishing a third voltage difference between the rear end of said electron multiplying ele-

9. The invention as defined in claim 8 wherein said first distance comprises approximately 0.012-inches and wherein said second distance comprises approximately 0.038-inches.

10. The invention as defined in claim 9 wherein said first voltage comprises approximately 600 volts and wherein said third voltage comprises approximately 5,000 volts.

11. The invention as defined in claim 10 wherein said electrically conductive material comprises aluminum.

12. An image intensifier comprising:
front end means for receiving an optical image;
a photocathode;
means for directing said optical image upon said photocathode;
a target electrode, said target electrode including a metal backing layer;
a microchannel plate, said microchannel plate located between and spaced from said photocathode and target electrode with the distance between said plate and said photocathode being less than the distance between said plate and said target electrode, said microchannel plate having a front end facing said photocathode and a rear end facing said target electrode;
first voltage supply means for establishing a low potential difference in the range of 400 to 1,000 volts between said photocathode and said microchannel plate to accelerate electrons toward said target electrode;
second voltage supply means for establishing a high potential difference in the range of 3,000 to 8,000 volts between said microchannel plate and said target electrode to accelerate electrons toward said target electrode;
third voltage supply means for providing a potential difference between the front and back ends of said microchannel plate to cause electrons to travel from the front end to the back end of said microchannel plate; and
a very thin non-self-supporting layer of electrically conductive material situated upon and covering the front side of said microchannel plate for trapping ions and low energy level electrons;
whereby the contrast resolution capability and the operational life of the tube is enhanced.

13. The invention as defined in claim 12 wherein said thin non-self-supporting layer of electrically conductive material is substantially optically transparent.

14. The invention as defined in claim 13 wherein said layer comprises the material aluminum and is of a thickness within the range of 50 to 400 Å.

15. The invention as defined in claim 14 wherein said first voltage means comprises approximately 600 volts.

16. The invention as defined in claim 15 wherein said second voltage means comprises approximately 5,000 volts.

17. In a light amplification device of the type which includes in vacuum in an envelope;
a photocathode for receiving an optical image on a front surface and emitting a corresponding electron image from its back surface;
a phosphor screen electrode for converting electron images incident thereupon into a corresponding visual image, said phosphor screen including a metal layer covering its rear side;
electron multiplying microchannel plate means located intermediate said photocathode and said phosphor screen electrode, having a front end facing said photocathode and a rear end facing said phosphor screen electrode for receiving an electron image at an input end and emitting a corresponding electron image of greater intensity at its rear end, said microchannel plate being spaced from said photocathode by a first predetermined distance in the range of 0.005-inches to 0.020-inches and being spaced from said phosphor screen electrode by a second predetermined distance, greater than said first predetermined distance, in the range of 0.030-inches to 0.050-inches;
a thin non-self-supporting substantially optically transparent layer of material situated upon and covering said front face of said microchannel plate for trapping ions and low energy level electrons and passing incident light, said layer having a thickness in the range of 50 to 400 Å;
first means for providing a first voltage between said photocathode and said microchannel plate;
second means for providing a second voltage between the front and rear surfaces of said microchannel plate;
third means for providing a third voltage between the rear surface of said microchannel plate and said phosphor screen electrode, said third voltage being at least twice as large as said first voltage.

19. The invention as defined in claim 17 wherein said material comprises a metal.

19. The invention as defined in claim 18 wherein said metal comprises aluminum.

20. The invention as defined in claim 19 wherein said thickness of said layer is approximately 75 Å.

21. The invention as defined in claim 20 wherein said first voltage comprises approximately 600 volts and wherein said third voltage comprises approximately 5,000 volts.

22. The invention as defined in claim 21 wherein said first distance comprises approximately 0.012-inches and wherein said second distance comprises approximately 0.038-inches.

23. The invention as defined in claim 17 wherein said first voltage is in the range of 400 to 1,000 volts and said second voltage is in the range of 3,000 to 8,000 volts.

24. The invention as defined in claim 23 wherein said material consists of a member selected from the group consisting of aluminum, boron, beryllium, boron carbide, silicon oxide, silicon dioxide, magnesium oxide, magnesium fluoride, and aluminum oxide.

25. The invention as defined in claim 17 wherein said material possesses a specific gravity in the range of 1.0 to 4.0.

26. The invention as defined in claim 17 wherein said material possesses a secondary emission characteristic of at least 3 measured at 400 volts.

27. The invention as defined in claim 17 wherein said first voltage and said first distance define an electric field, E, in the range of $1 \times 10^4$ to $4 \times 10^4$ volts per centimeter and wherein said third voltage and said second distance define an electric field in the range of $3 \times 10^4$ to $6 \times 10^4$ volts per centimeter.