Oct. 22, 1968 M. ROME 3,407,324

ELECTRON MULTIPLIER COMPRISING WAFER HAVING
SECONDARY-EMISSIVE CHANNELS

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FIG. 1

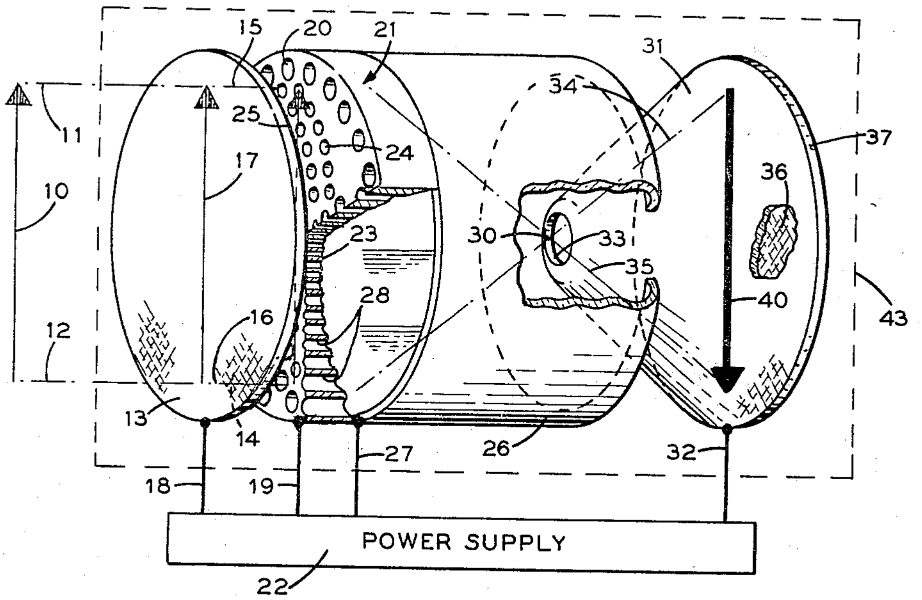

FIG. 2

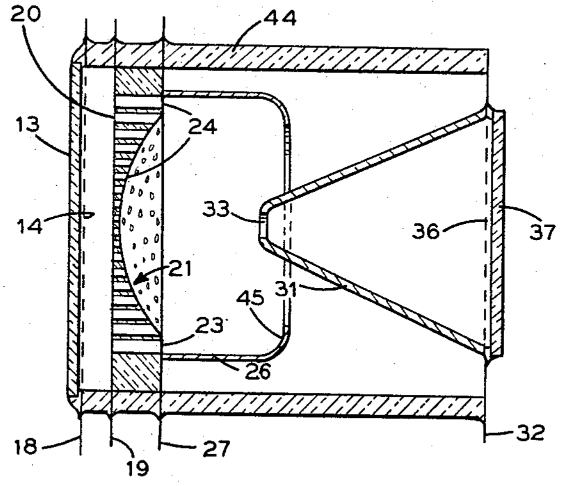

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FIG. 3

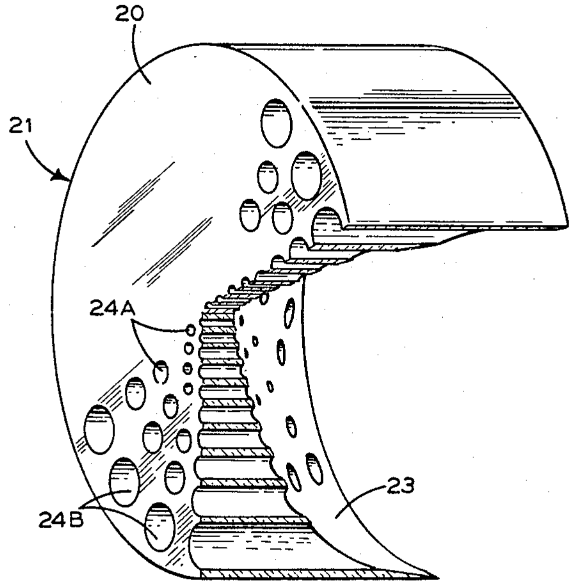
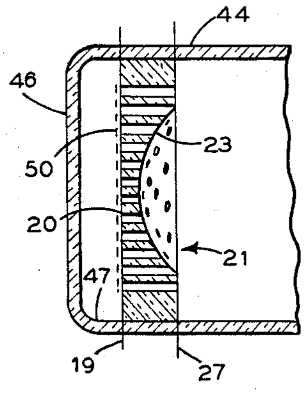


FIG. 4



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ELECTRON MULTIPLIER COMPRISING WAFER HAVING SECONDARY-EMISSIVE CHANNELS

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ABSTRACT OF THE DISCLOSURE

An illustrative embodiment of the invention discloses a plano-concave wafer of channel electron multipliers in an electron-optical system that produces inverted and intensified images of faintly illuminated objects. The individual channels are relatively short at the center of the wafer and gradually increase in length toward the periphery in order to produce the concave equipotential surface needed for electron image inversion. The respective channel diameters are varied in accordance with each channel length to maintain a generally constant ratio of length to diameter and the associated electron gain for all of the channels in the wafer.

BACKGROUND OF THE INVENTION

Field of the invention

This invention relates to improvements in electron-optical techniques and, more particularly, to specially shaped channel electron multiplier wafers for image intensification and inversion, and the like.

Description of the prior art

A need exists for a compact, lightweight, rugged and relatively inexpensive device that can invert and intensify images of poorly illuminated objects. In astronomy, for example, the study of stars of lesser brightness will benefit from equipment of this character through the improved visual image resulting from the intensification of the light emitted by the body. Fluoroscopy is another field that requires equipment of this sort. The application of desirably low radiation dosages to the patient undergoing an examination produces a poor fluoroscopic image that must be intensified to bring out satisfactory contrasts.

In the past, this need has been satisfied, at least in part, by electrostatic focus image intensifiers. Intensifiers of this sort, however, are heavy and complex.

Channel electron multiplier wafers also have been suggested for use in image intensifiers. Basically, these wafers are comprised of thousands of passageways or channels so arranged in a thin disk that the axes of the channels are more or less perpendicular to the parallel sides of the disk. The diameter of the individual channels in disks of this sort typically are about .001 inch, while the wafer thickness usually is about .05 inch.

In order to operate a wafer of this sort, a potential of approximately 2000 volts is applied across the opposite sides of the disk. A photocathode that emits electrons in response to light stimulation is placed adjacent and parallel to the low potential side of the wafer. Upon exposure to light, the photocathode emits electrons in proportion to the intensity of the light. These electrons enter the adjacent wafer channels and, under the influence of the applied voltage, strike the walls of the channels and release "secondary electrons." If the wafer is made of a substance that has a high coefficient for secondary electron emission, such as lead or vanadium-phosphate glass, there is a net increase in the number of electrons in the channel after each collision. Consequently, subsequent

collisions with the walls produce an amplified electron output at the high potential side of the disk that is generally prooprtional to the electron input from the adjacent portion of the photocathode.

The electrons from the high voltage side of the disk are accelerated by an electrical field across a gap to an anode, or a luminescent screen, that emits light in proportion to the intensity of the electron bombardment. Accordingly, the screen provides an intensified visual image of the object that caused the initial electron emission from the photocathode.

The intensified images produced by these devices, however, are not inverted. This is a serious inadequacy when these intensifiers are used in systems that invert the optical image. In this circumstance the image on the luminescent screen is "up-side down," an undesirable situation that leads to confusion and error.

It is an object of the invention to provide a channel electron multiplier wafer for an inverted image intensifier.

It is another object of the invention to provide an improved image intensifier.

It is still another object of the invention to provide a method for manufacturing an improved channel electron multiplier wafer.

It is still a further object of the invention to provide a channel electron multiplier wafer that has improved electron-optical characteristics.

SUMMARY

In accordance with the invention, a channel electron multiplier wafer is provided with electron-optical characteristics in order to manipulate electrons in a way that is somewhat analogous to the control of light rays with lens system. Thus, by imparting a lens-like shape to a channel electron multiplier wafer, the electron output from the wafer can be converged, diverged, or otherwise controlled, to produce specific image effects; as, for example, by converging the electrons to produce an inverted image.

For a given applied voltage and electron input, the electron multiplication factor, or gain, of each channel generally is a function of the ratio of the channel length to the channel diameter. Consequently, a failure to provide a substantially uniform gain from all of the channels in a wafer will produce irregularities in the intensity of the light emitted by the luminescent viewing screen relative to the electron input and thereby cause a brightness variation of the visual image. Thus, for example, if a plano-concave wafer is produced without further consideration to the gain characteristics of the individual channels at a given voltage, the longer peripheral channels will have different gains than the shorter central channels because the length to channel diameter ratio is greatest at the wafer periphery.

This problem has been overcome through a further aspect of the invention. Accordingly, the diameters of the channels in the lens-shaped wafer are controlled relative to the respective channel lengths in order to establish a predetermined gain relationship between all of the channels. In this manner, a substantially uniform gain is established for all of the channels in a lenticular wafer in order to prevent the visual image from being distorted through gain irregularities.

Alternatively, in those applications for which controlled shading of image brightness is desirable, the channel length to diameter ratios can be varied to establish a predetermined relation. Controlled gain variations among the channels within a wafer thus produce the desired shading in an entirely novel manner.

More particularly, an illustrative embodiment of an image intensification and inversion device according to the present invention comprises a photocathode faceplate spaced about one millimeter or less from the low-potential side of a plano-concave channel electron multiplier wafer. Electrons are emitted from portions of the photocathode in proportion to the respective incident light stimulation. The electrons traverse the spacing and, under the influence of an applied electrical field, enter adjacent channels at the low-potential, planar side of the wafer.

The diameter of the channels increase as the wafer periphery is approached, to keep the length to diameter ratio for all of the channels at a constant value in the range from about 30 to 1 to about 100 to 1 so the electron gain from each channel in the wafer is generally the same.

The concave nature of the high potential side of the wafer, and the uniform voltage applied to that side, establish an electrical field that focuses the electrons and causes the electron output from the wafer to converge. The focal effect of the electrical field established by the concave shape of the high potential side is enhanced further by a hollow cylinder that protrudes from the wafer toward the luminescent viewing screen. This cylinder is at the same voltage as the concave output side of the wafer and provides an "electrode lens," the electrical field of which increases the converging influence of the wafer concavity. The converging electrons are accelerated toward a cross-over point and the luminescent screeen by a hollow conical anode. The apex of the anode is positioned at the electron crossover. An aperture is formed in the apex to enable the converging electrons to enter the interior of the conical anode and strike the phosphor on the luminescent viewing screen that forms the base of the cone.

In traversing the cross-over, the electrons diverge and reverse their relative spatial relation in order to establish an inverted image on the screen. When coupled to systems that invert the object, the intensified image produced in accordance with the present invention is, in effect, a re-inverted image. Thus, the intensified image is not up-side down and is oriented correctly relative to the object under consideration. This feature of the invention eliminates the bulk and complexity of a subsequent inverter in conjunction with prior art intensifiers that failed to provide a properly oriented image.

As an alternative embodiment of the invention, the photocathode can be deposited directly on the planar and low-potential side of the wafer.

The method of manufacturing the wafer provides still a further aspect of the invention. Accordingly, a group of tubes of uniform inside diameters that are formed from an appropriate secondary electron emitting material, is organized as a central and hexagonal bundle. A circumferential layer of similar hexagonal tube bundles, in which the tubes have larger inner diameters greater than those of the central bundle, is placed around the periphery of the central bundle. Additional layers of bundles containing tubes of a larger inner diameter greater than the tubes in the adjacent innermost bundles are arranged concentrically about the central bundle so that the tube diameters increase progressively with distance from the center of the entire array. This array is heated and drawn or stretched out one or more times to fuse all of the bundles together and to reduce proportionately the inner diameters of the individual tubes.

Two transverse slices are made in the drawn and fused array of tubes in order to produce a thin disk in which the ratio of the length of the outermost concentric annulus of channels to the respective channel diameters is in the range from about 30 to 1 up to about 100 to 1. The concave surface of the wafer can subsequently be formed by grinding to establish the appropriate radius of curvature and the correct inner channel lengths required to maintain about the same length to diameter ratio as the outermost channels.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings, the scope of the invention being pointed out in the appended claims.

Brief description of the drawing

FIG. 1 is a perspective view of one embodiment of the invention, in which some portions of the structure have been broken away or shown in section. The view in FIG. 1 is not drawn to scale in order to illustrate better some of the novel features of the device;

FIG. 2 is a longitudinal section of the embodiment of the invention shown in FIG. 1;

FIG. 3 is a perspective view in partial section of a typical channel electron multiplier wafer according to one embodiment of the invention, in which the longitudinal dimension of the device has been greatly exaggerated for illustrative purposes; and

FIG. 4 shows, in full section, an illustrative alternative wafer structure for the image intensifier of FIG. 2.

Description of the preferred embodiments

The embodiment of the image intensifier shown in FIG. 1 provides a more complete appreciation of the principles of the invention. Accordingly, a faintly illuminated object **10**, which may be a low intensity source of light or a poorly illuminated object, radiates, or re-radiates, the schematically shown light rays **11** and **12**. The light rays **11** and **12** strike a transparent glass input faceplate **13**.

A photocathode material **14** coating the surface of the faceplate **13** opposite from the object **10** responds to these light rays by emitting electrons from the stimulated portion of the photocathode material **14** in an abundance that is proportional to the intensity of the respective light rays **11** and **12** incident thereupon. These electrons, schematically shown by the lines **15** and **16**, emitted in response to an image **17** formed on the input faceplate **13** by the light rays **11** and **12** traverse a short space of about one millimeter or less to a planar, low-potential side **20** of a plano-concave channel electron multiplier wafer **21**.

A power supply **22** applies a positive potential through conductors **18** and **19** to the low potential side **20** of the wafer **21** relative to the photocathode **14**. This positive potential is uniformly distributed across the flat surface of the wafer **21** by an electrically conductive film (not shown) of gold or a similar conductive layer. This positive voltage gradient accelerates the electrons **15** and **16** directly across the gap from the photocathode **14** to the wafer **21**.

The power supply **22** also applies a positive potential of about 2000 volts through a conductor **27** to a concave high potential side **23** of the wafer **21** relative to the longitudinally opposite low voltage side **20**. The voltage applied to the concave surface **23** also is distributed uniformly through an electrically conductive film (not shown).

The electrons **15** and **16** from the photocathode **14** enter adjacent longitudinal channels **24** that are formed in and pass through the wafer **21**. Under the influence of the positive voltage gradient established in the channels **24** by the potential applied to the wafer **21**, the electrons **15** and **16** are accelerated through the channels **24** and strike the channel surfaces **28** with sufficient energy to produce secondary emission electrons. Because the wafer **21** is formed of a material, such as lead glass, that has a high secondary emission coefficient, each collision between an electron and a channel surface **28** produces several secondary electrons that, in turn, are accelerated further through the channel to strike the surface thereof and generate still more secondary electrons. In this manner, the channels **24** amplify or multiply the electron input to the wafer **21**, in proportion to the input intensity.

As hereinbefore mentioned, the electron gain of each channel is, for a specific input electron intensity and applied voltage, a function of the channel length to diameter ratio. As shown in FIG. 3, to provide the planar surface **20** and the concave surface **23** of the wafer **21**, the central channels **24A** necessarily must be shorter than the peripheral channels **24B**. The electron gain of the shorter channels **24A** is maintained at about the same value as the gain of the longer channels **24B** by reducing the shorter channel diameters to an extent that is commensurate with the respective channel lengths, in order to keep the length to diameter ratio of both groups of channels approximately the same.

Turning again to FIG. 1, a hollow cylindrical electrode lens **26** of electrically conductive material is secured to and at the same potential as the concave side **23** of the wafer **21**. The electrode lens **26** protrudes longitudinally away from the wafer **21** and is concentric with the concavity in the side **23**. The lens **26**, moreover, terminates in a radially inward directed flange. The equipotential electrical field established by the electrode lens **26** and the concave side **23** of the wafer **21** causes the electrons emitted from the wafer to converge at a crossover point **30**. The electrons emitted from the wafer **21**, moreover, are accelerated to the crossover point **30** by a positive potential gradient of 10 to 20 kilovolts (kv.) established between the high potential side **23** of the wafer **21** and the voltage applied to a conical anode **31** by the power supply **22** through a conductor **32**.

The electrons converging at the crossover point **30** enter the conical anode **31** through an aperture **33** formed in the apex of the cone. The apex of the anode **31** is enshrouded by the flanged portion of the electrode lens **26**, and the aperture **33** is in substantial alignment with the crossover **30**. The precise longitudinal relation between the crossover **30** and the aperture **33** ordinarily is determined through adjustment to produce the brightest and most clearly defined visual image, as described subsequently in more complete detail.

Electron beams **34** and **35** emitted from the wafer **21** traverse the inner-electrode distance between the wafer **21** and the anode **31** and converge at the crossover **30**. Within the hollow anode **31**, the electron beams **34** and **35** diverge from each other. This initial electron beam convergence and subsequent divergence reverses the spatial relation between the electron beams in order to produce an inverted electron image **40**. Best shown in FIG. 2, the beams strike an aluminized luminescent phosphor **36** coated on the inner surface of a transparent glass output faceplate **37**. The phosphor **36** is at the same electrical potential as the anode **31**. The combined effect of the desired electron multiplication and inversion produces the intensified and inverted optical output image **40** shown in FIG. 1.

The image intensifier is maintained in a vacuum by an enclosure **43**, as indicated schematically by a broken line (FIG. 1). Appropriate gas-tight seals (not shown) are provided in the enclosure **43** to accommodate the input and output faceplates **13** and **37**.

Turning once more to FIG. 2, the vacuum enclosure shown in FIG. 1 may comprise a longitudinally disposed hollow cylinder **44**, formed of a suitable nonconducting material such as a ceramic or the like. In order to eliminate stray magnetic fields that tend to deflect the electrons within the image intensifier from appropriate paths, a sheath of material (not shown) of high magnetic permeability, such as μ-metal, can be placed around the cylinder **44**.

In accordance with a further aspect of the invention, a wafer of the sort shown in FIG. 3 is produced by assembling a central hexagonal bundle of perhaps fifty or more tubes formed of a material that exhibits a satisfactory coefficient of secondary electron emission. The central bundle is surrounded by other contiguous hexagonal bundles of tubes. The tubes in the surrounding bundles have a somewhat greater inside diameter than the tubes in the central bundle. An array of tubes thus is prepared by continuing the process of assembling concentric bundles of tubes in which the radially more distant bundles are comprised of tubes that have greater inner diameters than the tubes in the more centrally disposed bundles.

The assembled array subsequently is heated and stretched out, or drawn, in a vacuum to decrease proportionately the inner diameter of the channels. As a consequence of the drawing step, the outer diameter of the entire array also is reduced. Drawing the array may be accomplished in one or more steps and is discontinued when the individual diameters of the tubes in the outermost annulus are reduced to an acceptable size. Of course, the radii of the more centrally disposed tubes are proportionately smaller, as hereinbefore considered.

A small disk or wafer is formed from the drawn array by two transverse cuts so spaced that the thickness of the disk is slightly greater than or equal to a specific channel length for the outermost annulus of tubes. The channel length so chosen, when taken with the respective channel diameter establishes the predetermined ratio of channel length to diameter to which the more inwardly positioned tubes must conform. The planar and concave sides **20** and **23** (FIG. 3) of the wafer **21** subsequently are formed, for example, by grinding. Care, however, must be taken to avoid plugging up the channels with grinding debris. The radius or radii of curvature for the concave side **23** may be established not only on the basis of the desired electron-optical focusing considerations, but also to maintain a substantially uniform ratio of channel length to diameter for the centrally disposed channels.

In practicing the foregoing method, it often is advisable to use tubes that have their respective passageways filled initially with a material that is different from the surrounding tube structure. The heating, drawing, cutting and grinding steps remain substantially unchanged. The channels, however, are formed in the wafer by applying an etching solution that dissolves the filling material within the individual tubes in preference to the surrounding wafer structure.

An alternative photocathode structure in accordance with the invention is shown in FIG. 4. The transverse end of the tube envelope **44** is closed by a transparent glass plate **46** that has a flange **47** formed on the periphery thereof to provide a suitable gas-tight seal with the tube envelope **44**. A photocathode material **50** is deposited directly on the low potential side **20** of the wafer **21**. Thus, light quanta traversing the transparent glass plate **46** and striking the photocathode **50** produces photoelectrons in an abundance that is proportionate to the intensity of the incident light quanta. The electrical field established between the low and high potential sides **20** and **23** of the wafer **21** through the power supply **22** (not shown in FIG. 4) and the conductors **19** and **27** apparently draws the photoelectrons into the channels in the wafer **21** where the image is intensified and subsequently inverted as hereinbefore described.

Consequently, there is provided in accordance with the invention channel electron multiplier wafers of varied configuration for intensified image manipulation by controlling the gain of the individual channels. Thus, other electron "lens" structures, for example, plano-convex, concavo-convex, or "lenses" that have aspherical surfaces, are now possible through an application of the principles of this invention. The channel gain, moreover, need not depend entirely on control of the channel length to diameter ratio. In this connection, gain can be controlled by selecting tube materials that have differing coefficients of secondary electron emission in order to establish a uniform gain for all of the channels in the entire wafer in spite of a more relaxed control over the aforementioned ratio. Further in this connection, the application of the invention is not limited to light intensification devices, but can be applied to other types of equipment, such as neutron and X-ray image intensifiers.

While there have been described what are at present considered to be preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, intended to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. An electron multiplier comprising, a substantially circular disk of secondary electron emitting material having a first group of substantially parallel channels formed therein, said channels having a predetermined length and a substantially constant ratio of length to channel diameter determined by the distance of said first group of channels from the center of said disk, said disk having at least a second group of channels formed therein at a different distance from said disk center, said second channel group having channel lengths different from said first group lengths and having a substantially constant ratio of length to channel diameter, said ratios of lengths to diameters for both groups being selected to yield equal electron gain for all said channels, said first and second groups comprising at least a portion of the electron multiplier.

2. A substantially circular wafer comprising, a secondary electron emitting material, said material having an array of substantially parallel channels formed therein and passing longitudinally through the wafer at varying distances from the center of said wafer, said wafer having a transverse planar surface for terminating said channels on one side and a generally concave transverse surface for terminating said channels on the other side thereof, the diameters of said channels increasing with distance from the center of said wafer, the ratios of said channel lengths to diameters being proportioned to yield substantially equal electron gain from each of said channels.

3. An electron-optical system comprising, a photocathode for emitting electrons in response to light stimulation, a substantially circular wafer for receiving said electrons comprising, a secondary electron emitting material, said material having an array of substantially parallel channels formed therein and passing longitudinally through the wafer at varying distances from the center of said wafer, said wafer having a transverse planar surface for terminating said channels on one side and a generally concave transverse surface for terminating said channels on the other side thereof, the diameters of said channels increasing with distance from the center of said wafer, the ratios of said channel lengths to diameters being proportioned to yield substantially equal electron gain from each of said channels, an anode spaced from said disk for accelerating electrons from said wafer, and a target responsive to said accelerated electrons.

4. An electron-optical system according to claim **3** wherein said anode comprises, a hollow cone having an aperture formed in the apex thereof for passing said electrons therethrough, said luminescent material forming the base of said cone for responding to said accelerated electrons.

5. An electron-optical system according to claim **4** wherein said disk comprises, a peripheral portion having at least one group of said channels formed therein, and a central portion having another group of said channels formed therein, the ratio of said channel lengths and diameters in each group being substantially constant for both of said groups.

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