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CROSS REFERENCE EXAMINER

May 19, 1970 G. R. FEASTER 3,513,345

HIGH SPEED ELECTRON MULTIPLIER

Filed Dec. 13, 1967

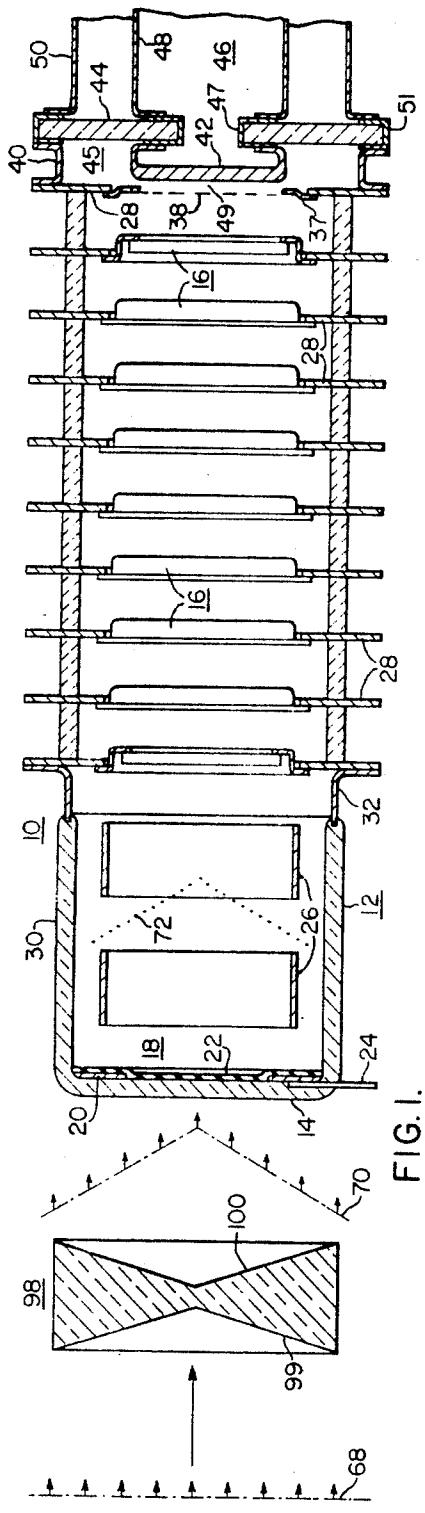


FIG. 1.

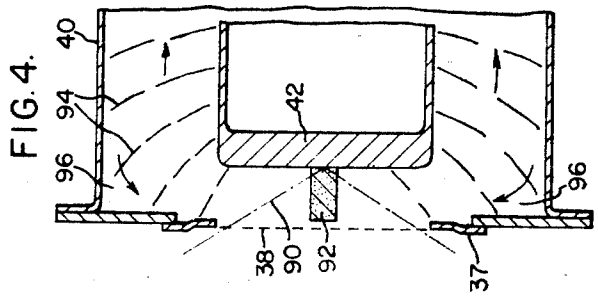


FIG. 4.

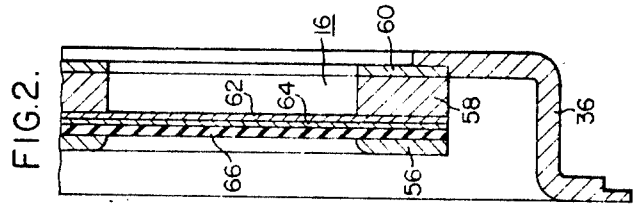


FIG. 2.

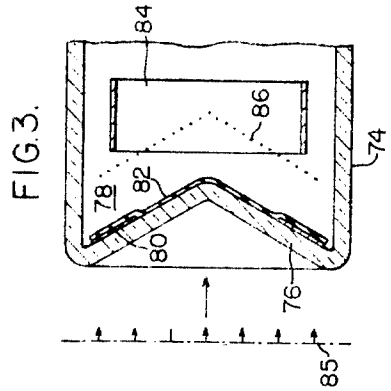


FIG. 3.

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HIGH SPEED ELECTRON MULTIPLIER

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ABSTRACT OF THE DISCLOSURE

This invention relates to ultrahigh speed electron multipliers and includes in one illustrative embodiment an electron discharge device having a photocathode element for converting incident radiation into a corresponding pattern of electrons, suitable electron multiplying transmission dynode elements, and a coaxial termination for providing a suitable electromagnetic output signal in response to the multiplied electrons directed thereon, and a suitable radiation delay means which may take the form of an optical lens having its peripheral portions of greater thickness than its central portions.

BACKGROUND OF THE INVENTION

Field of the invention

This invention relates generally to electron discharge devices and more particularly to high speed photomultiplier devices.

Description of the prior art

Typically, electron multipliers of the prior art took the form of an envelope in which there is disposed a photocathode element for converting incident radiation into photoelectrons, a plurality of dynode elements for successively multiplying the electrons, a coaxial termination including an anode element for collecting the electrons, and a suppressor grid disposed between the last dynode element and the anode element. It is generally desirable for the electron multiplier structure in such a device to amplify a pulse signal without producing a spread in the signal pulse width. Electron multipliers of the transmission dynode type are available and can theoretically obtain a pulse rise time of approximately 76 picoseconds if perfectly terminated. Pulse rise time may be defined as the time required for an output signal to pass from 10% to 90% of full amplitude for one electron leaving the photocathode element.

The performance of the currently available photomultipliers of the type described is limited by imperfections of the coaxial termination used to obtain the output signal of the device. One contribution to imperfect coupling arises from the finite width of the beam of radiation and the resulting electron beam which creates a dispersion effect and a resulting cancellation of a considerable portion of the high frequency output power. More specifically, the leading plane edge of the electron cloud arriving in the spacing between the anode element and suppressor grid launches an electromagnetic wave simultaneously at the center and the periphery of this space. Consequently, a phase difference occurs in the wave excited in this space, which causes a serious power loss at high frequencies.

The prior art has suggested that pulses of radiation may be directed on a photoemissive surface at a prescribed, acute angle so that the induced electromagnetic energy will be reinforced as it is propagated through a coaxial conductor. However, this solution is not readily adaptable to devices in which transmissive dynodes are employed. Typically, transmissive dynodes are of a planar

configuration and are disposed in a serial relationship to successively multiply a cloud of electrons. If the termination structure of the prior art was used in conjunction with a plurality of planar dynodes, the multiplied cloud of electrons could not be used effectively to induce the electromagnetic output signal.

It is therefore an object of this invention to provide an electron multiplier device in which the degradation of the high frequency response at the output termination is significantly reduced.

It is a further object of this invention to provide an electron multiplier device which is capable of efficiently extracting an output signal from an electron cloud that has been successively multiplied by a plurality of dynodes.

SUMMARY OF THE INVENTION

Briefly, the present invention accomplishes the above cited objects by providing an improved electron discharge device including means for converting an impulse of radiation into a cloud of electrons whose leading surface has central portions which precede the peripheral portions, and means such as an interaction space disposed to receive the cloud of electrons and for converting the electrons into an electromagnetic signal. In one illustrative embodiment, the means for converting the impulse radiation include a suitable lens structure wherein the peripheral portions are of greater thickness than the central portion in order to delay the peripheral portion of the radiation impulse, and a photocathode element for converting the delayed radiation impulse into a correspondingly shaped sheet of electrons.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects and advantages of the present invention will become more apparent in view of the following detailed description and drawings, in which:

FIG. 1 shows a diagrammatical view of an electron multiplier device in accordance with the teachings of this invention;

FIG. 2 shows a sectional view of a dynode element incorporated within the device of FIG. 1;

FIG. 3 shows a sectioned view of an alternative means for providing a sheet of electrons whose leading surface has its central portions precede its peripheral portions, which may be incorporated into the device of FIG. 1; and

FIG. 4 shows an enlarged view of the suppressor grid and the anode element structure of the device of FIG. 1.

DESCRIPTION OF A PREFERRED EMBODIMENT

Referring now to the drawings and in particular to FIG. 1, there is shown an electron discharge device **10** of the photomultiplier type including an evacuated envelope **12** having a cylindrical section **30** enclosed upon one end by a faceplate **14**. A photocathode element **18** is disposed upon the interior surface of the faceplate **14**. Illustratively, the photocathode element **18** includes an annularly shaped electrode **20** made of an electrically conductive material which is deposited directly upon the faceplate **14** and a layer **22** of a suitable photoemissive material such as cesium antimony which is deposited thereon. A terminal **24** may be connected with the photocathode element **18** and extends through the envelope **12** as shown in FIG. 1. A pair of electrodes **26** are disposed within the cylindrical portion **30** in order to accelerate and direct the photoelectrons emitted by the photocathode element **18** onto a plurality of dynode elements **16**. As shown in FIG. 1, a plurality of dynode elements **16** are disposed in a substantially parallel relationship with each

other in order to successively multiply the photoelectrons emitted by the photocathode element **18**.

Each of the dynode elements **16** is supported within the envelope **12** by a ring-shaped flange **36** (see FIG. 2), which in turn is supported upon a ring **28**. Typically, the rings **28** are made of electrically conductive material such as Kovar (a trademark of the Westinghouse Electric Corporation for an alloy of nickel, iron and cobalt), and serve as electrical terminals for applying successively greater potentials to the dynode elements **16**. The annularly shaped support rings **28** are spaced and insulated from each other by a plurality of cylindrically shaped spacers **34** which are made of a suitable insulating material such as alumina ceramic. The insulating spacers **34** are disposed between the support rings **28** and are secured thereto by brazing. As shown in FIG. 1, the spacers **34** are of approximately the same diameter and are secured to the support rings **28** in order to form a portion of the envelope **12**. The dynode structure is connected to the cylindrical portion **30** by flange **32** which is made of a suitable material such as Kovar. More specifically, the flange **32** is sealed to the cyindrical portion **30**, and to the ring support **28** as by heliarc welding.

The electrons are accelerated by increasing potentials applied to the support rings **28** associated with the plurality of dynode elements **16**. More specifically, the photoelectrons are accelerated to the first dynode element **16** where transmission secondary electrons are emitted in numbers larger than the number of incident photoelectrons. The resulting secondary electrons are accelerated to the second dynode **16** where further multiplication takes place. This process is repeated until the multiplied electrons reach the last dynode element **16**. An anode element **42** is disposed to receive the multiplied sheets of electrons. A suppressor-grid electrode **38** is disposed between the last dynode element **16** and the anode element **42** to accelerate the electrons to a high velocity and to electrostatically shield the anode element **42** so that the arriving electrons will not induce a charge in the anode circuit prior to the actual entry of the cloud of electrons into the space between the suppressor-grid electrode **38** and the anode element **42**. An electromagnetic wave is formed in the space between the suppressor-grid **38** and the anode element **42**.

The suppressor-grid **38** illustratively takes the form of a mesh made of a suitable electrically conductive material such as nickel and having a mesh size of approximately 20 per inch. The suppressor-grid electrode **38** is mounted upon a ring-shaped flange **37** which in turn is supported upon a support plate **28**. The anode element **42** forms a part of a coaxial output terminal **45**. The anode element **42** is the inner coaxial member of the terminal **45** and a cylindrically shaped flange **40** forms the outer part of the coaxial terminal **45**. The flange **40** is connected as by heliarc welding to the support **28** upon which the suppressor grid **38** is mounted. An interaction region **49** is formed between the suppressor-grid **38** and the anode element **42** for receiving the cloud of electrons which has been successively multiplied by the transmission dynodes **16**. A coaxial transmission line **46** is connected to the coaxial terminal **45** to extract the electromagnetic waves induced in the interaction region **49**. The coaxial transmission line **46** includes an outer conductor **50** which is disposed concentrically about an inner conductor **48**. In order to enclose the envelope **12**, an annularly shaped disc **44** is disposed between and sealed to the flange **40** and the anode element **42**. Further, the disc **44** is hermetically sealed to the inner and outer conductors **48** and **50**. Illustratively, the disc **44** may be made of a suitable insulating material such as ceramic alumina. A pair of electrically conductive layers **47** and **51** are applied to inner and outer peripheral portions of the disc **44** as shown in FIG. 1 in order to electrically connect the members of the coaxial terminal **45** and the coaxial transmission line **46**. The layers **47** and **51** further serve to prevent the attenuation of the electromagnetic energy propagated through the disc **44** by confining the transmitted energy to that portion of the disc **44** disposed between the inner and outer conductors **48** and **50**. The electromagnetic wave induced between the suppressor grid **38** and the anode element **42** is transmitted along the coaxial terminal **45** and the transmission line **46** through the disc **44** without significant change of impedance to the transmission line **46**. In this way, electrical reflections that lead to poor rise characteristics are avoided and full advantage can be taken of the rapid pulse rise time characteristics of this structure.

Referring now to FIG. 2, there is shown an enlarged cross sectional view of the dynode element **16**. The dynode element **16** includes a support layer **62** of about 100 angstroms thickness and made of a stable material such as silicon oxide. The layer **62** is disposed between two metallic rings **56** and **58**, which may be made of nickel. A third ring **60** provides a means of making electrical contact to the annular flange **36** which supports the dynode element **16** upon the rings **28** as shown in FIG. 1. Next, a very thin layer **64** of a suitable electrically conductive material such as aluminum may be deposited to a weight of .01 mg. per $cm.^2$ upon the layer **62**. The electrons strike a layer **66** made of a suitable insulating material such as potassium chloride which is deposited upon the layer **64**. The structure and the method of forming the dynode element **16** is similar to that described in U.S. Pat. No. 2,898,499, issued Aug. 4, 1959, to E. J. Sternglass and W. A. Feibelman The dynode element described in this patent utilizes a coherent oxide such as aluminum or magnesium oxide of the support layer, which supports a conductive layer and a secondary electron emissive layer In addition to transmission dynodes having a continuous surface, the open mesh type dynode, well known as the Weiss multiplier, is also available for use in the present invention. This latter type dynode does not, however, provide the short rise times obtainable with transmissive dynodes and is therefore not as desirable for use in some applications.

It is an important aspect of this invention that the leading edge (or surface) of a radiation pulse **68** be converted into a sheet **72** of electrons which is of an approximately conical configuration as shown in FIG. 1. More specifically, there is provided a radiation delay means **98** which acts to delay the peripheral portions of the incident radiation sheet **68** with respect to the central portions thereof. Illustratively, the radiation delay means **98** may take the form of a lens having conically shaped surfaces **99** and **100** disposed on either side as shown in FIG. 1. Alternatively, the lens may have one surface shaped conically, whereas the other surface is substantially planar. It is noted that the delay means may be incorporated as the faceplate **14** without departing from the teachings of this invention. The resulting delay means is thin at the central portions and its thickness increases in proportion to the radius from the center. The substantially planar leading edge of the radiation pulse **68** is directed through the delay means **98** with the result that the peripheral portions will be delayed by the thicker part of the delay means **98** presented to the radiation pulse **68**. The pulse radiation transmitted from the delay means **98** has a leading surface **70** wherein the central portions precede the peripheral portions. The leading surface **70** of the radiation takes the approximate configuration of a cone and will strike the photocathode element **18** first in the center and then in an annulus of increasing radius as a function of time. In response to the incident radiation sheet **70**, the substantially planar photocathode element **18** emits the cloud of electrons having the leading surface **72** of an approximately conical configuration. The leading surface **72** of electrons will pass down the length of the device **10** being successively multiplied by the plurality of transmissive dynode elements **16**.

The impulse of radiation has been described in terms of its leading edge or surface. Similarly, the cloud of electrons emitted from the photocathode element **18** has been described in terms of its leading surface. It is difficult to describe with preciseness or accuracy the configuration of a pulse of radiation or a cloud of electrons. An impulse of radiation takes its form within a time period of more than 10^{-14} seconds. During this period the leading surface may not be planar. Further, the leading surface of the radiation impulse may be planar to a degree within a tolerance of a wavelength of the radiation. Similarly, the shape of the cloud of electrons is difficult to describe due to the irregularities in the leading surface of the radiation impulse and the means used to shape the leading surface of the electron cloud. Therefore, the terms used to describe the configuration of the leading surfaces are precise to the degree with which an impulse of radiation can be observed by a resolving instrument, i.e., in the order of less than 10^{-9} seconds.

Referring now to FIG. 4, a leading surface **90** of the multiplied cloud of electrons will arrive at the suppressor-grid electrode **38** and will be inserted into the interaction region **49** between the suppressor-grid electrode **38** and the anode element **42**. The leading surface **90** of the electron cloud intercepts the anode element **42** first in the center and then in an annulus of increasing diameter as a function of time. The intersection of this conical surface of electrons with the suppressor-grid **38** is a circle or more particularly an annulus of increasing diameter with time. The leading surface **90** of electrons will excite an electro-magnetic wave **94** in the gap between the suppressor-grid **38** and the anode element **42** which will travel away from the central axis of the anode element **42** with approximately the speed of light. In order that the electron cloud be inserted in synchronism with the resulting electromagnetic wave **94** the intersecting annulus of the conical surface **90** of electrons should grow in radius with approximately the speed of light. This condition is satisfied if the resulting surface **90** of electrons is of an approximate conical configuration with the central portions thereof preceding the peripheral portions. As shown in FIG. 4, the leading surface **90** is timed to enter the interaction space in such a way as to reinforce the electromagnetic wave **94** established between the suppressor-grid electrode **38** and the surface of the anode element **42**. The surface **90** of electrons reinforces the movement of the electromagnetic energy in a radial direction from the axis of the anode element **42** and propagates the electromagnetic wave **94** through a junction **96** and into the annular space between the conductor and the anode element **42**.

An approximate calculation for electrons which have a speed corresponding to an accelerating field of 3600 volts shows that a cloud of electrons striking the surface of the anode element **42** with a cone apex angle of approximately 168° would require a delay means **98** having a .050 inch greater thickness at the peripheral portion than in the center if the refractive index of the glass of which the means **98** is made is 1.6.

At the present, it is believed that the discontinuity or junction **96** may present an impedance to the electromagnetic wave **94** traveling radially from the axis of the anode element **42**. As a result, the discontinuity **96** may cause reflections of the radially traveling electromagnetic wave which would be reflected toward the center of the anode element **42** and which would tend to spread out again to degrade the response of this device. Thus, it may be necessary to place at the center of the anode element **42** a termination impedance **92**. More specifically, the termination impedance **92** may be disposed between the anode element **42** and the suppressor-grid **38** in order to absorb the reflected electromagnetic waves. Illustratively, the termination resistance **92** may take the form of a uniform mixture of aluminum oxide and carbon to provide an impedance of approximately 50 ohms between the suppressor-grid **38** and the anode element **42**.

Referring now to FIG. 3, there is shown another illustrative means for converting a substantially planar pulse **85** of radiation into an electron cloud having a surface **86** with a substantially conical configuration. More specifically, the photocathode element of FIG. 1 may be replaced by a photocathode element **78** having a substantially conical configuration as shown in FIG. 3. The device of FIG. 3 includes a cylindrical portion **74** having a faceplate **76** of substantially conical configuration. The photocathode element **78** is disposed upon the faceplate **76** and includes an annular electrode **80** and a layer **82** of a suitable photoemissive material disposed thereon. The incident pulse **85** of radiation causes the photoemissive layer **82** to emit a cloud of electrons which in turn is accelerated by an electrode **84**. In operation, the peripheral portions of the pulse **85** of radiation strike the photocathode element **78** to thereby emit electrons at a first point in time. At a second point in time, the central portions of the pulse **85** of radiation will strike the photocathode element **78** to emit electrons. Since, the photons of the impulse **85** of radiation travel at a faster velocity than the photoelectrons emitted from the photocathode element **78**, the central portion of the cloud of photoelectrons will be farther advanced in space and will precede the peripheral portions of the surface **86**.

Although it has been a common practice to provide "focusing lens" for such imaging devices as television camera tubes and image intensifying devices, the use of an optical delaying means such as the lens structure **98** substantially differs from such lenses. It is the object of the focusing lens to direct the radiation so that it falls simultaneously upon the photocathode element of the imaging device. In contradistinction, it is the principal object of this invention to provide means for delaying the peripheral portions of the radiation image with respect to the central portions thereof so as to produce a conically shaped sheet of electrons. As explained above, the conically shaped sheet of electrons induces and reinforces an electromagnetic wave in the coaxial terminal structure at approximaetly the speed of light to thereby improve the rise time response of this device.

Since numerous changes may be made in the above described apparatus and different embodiments of the invention may be made without departing from the spirit thereof, it is intended that all matter contained in the foregoing description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

I claim:

1. A radiation sensitive device including first means for converting a substantially planar pulse of radiation into a cloud of electrons having a leading surface whose central portions precede the peripheral portions thereof, and second means for rapidly providing electromagnetic energy in response to said cloud of electrons.

2. A radiation sensitive device as claimed in claim **1**, wherein said second means includes a coaxial terminal into which said electromagnetic energy is induced.

3. A radiation sensitive device as claimed in claim **1**, wherein said second means includes an anode element presenting a surface transverse to said leading surface and an electrically conductive member disposed about said anode element and forming a coaxial terminal.

4. A radiation sensitive device as claimed in claim **1**, wherein third means for multiplying said cloud of electrons is disposed between said first and second means.

5. A radiation sensitive device as claimed in claim **4**, wherein said third means includes a plurality of transmissive dynodes.

6. A radiation sensitive device as claimed in claim **1**, wherein said first means includes a substantially planar photocathode element, and said first means disposed to

intercept said pulse of radiation for imparting a dela: to the peripheral portion of said pulse of radiation with respect to the central portion thereof.

7. A radiation sensitive device as claimed in claim 6, wherein said first means includes a lens structure whose peripheral portions are of greater thickness than the central portions thereof.

8. A radiation sensitive device as claimed in claim 7, wherein said lens structure has first and second surfaces disposed transverse to said pulse of radiation and being of substantially conical configuration.

9. A radiation sensitive device as claimed in claim 1, wherein said first means takes the form of a photocathode element whose central portions are disposed closer to said second means than the peripheral portions thereof.

10. A radiation sensitive device as claimed in claim 9,

wherein said photocathode element has an approximately conical configuration.

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250—199; 313—104