June 17, 1941. G. K. TEAL 2,245,624

ELECTRON DISCHARGE APPARATUS

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FIG. 1

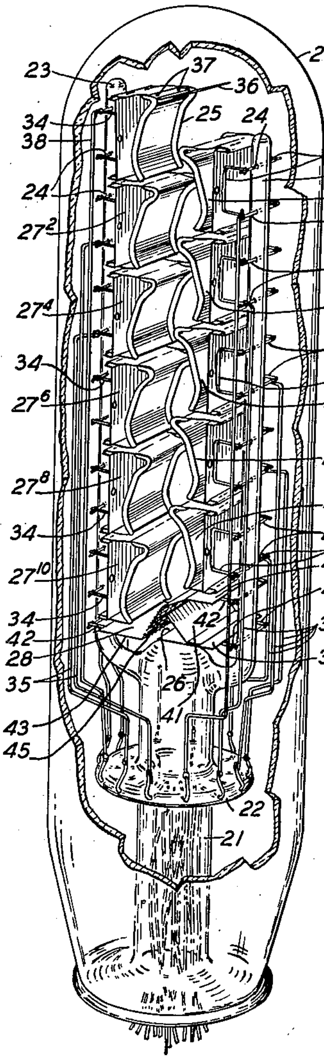


FIG. 2

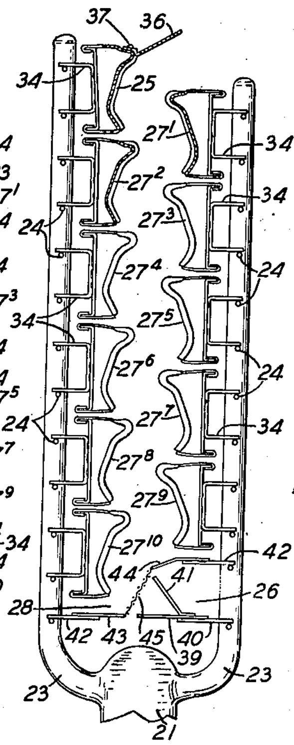
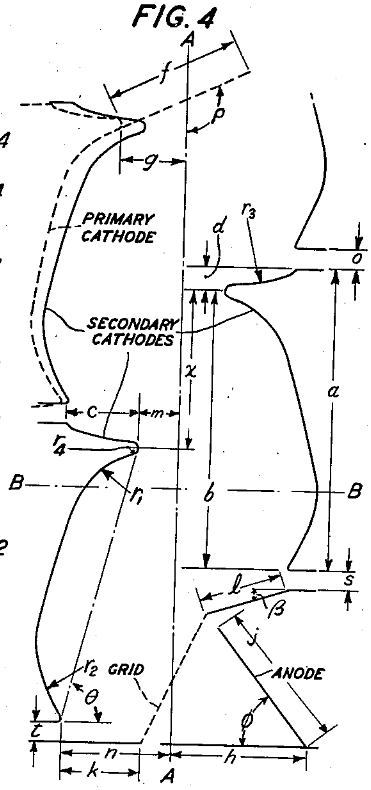


FIG. 4



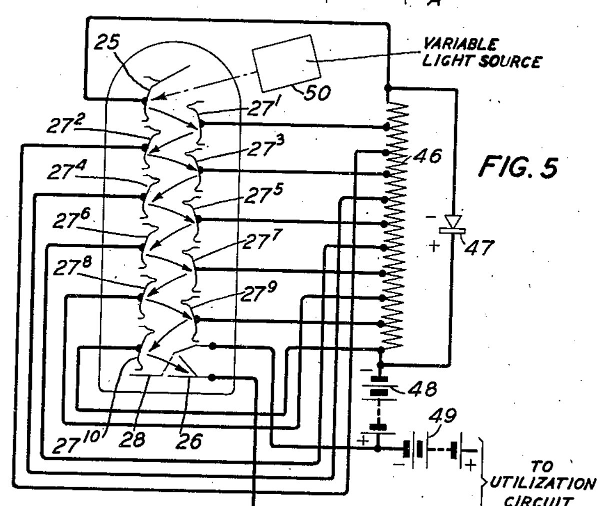


FIG. 5

FIG. 3

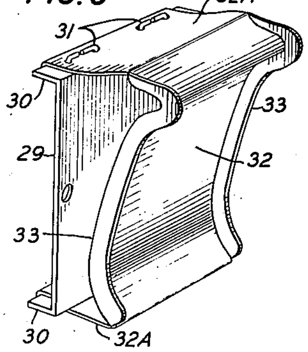


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FIG. 6

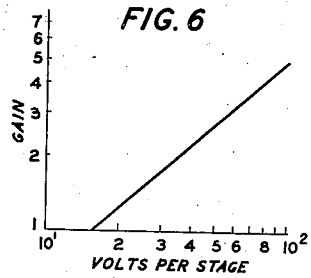


FIG. 7

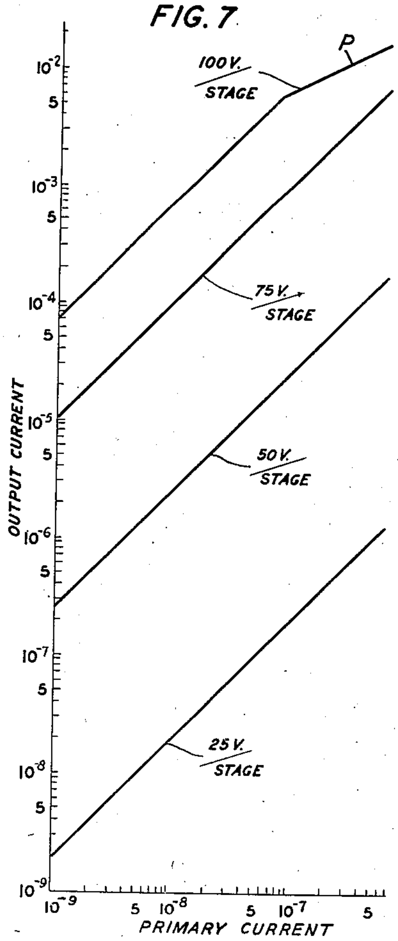


FIG. 8

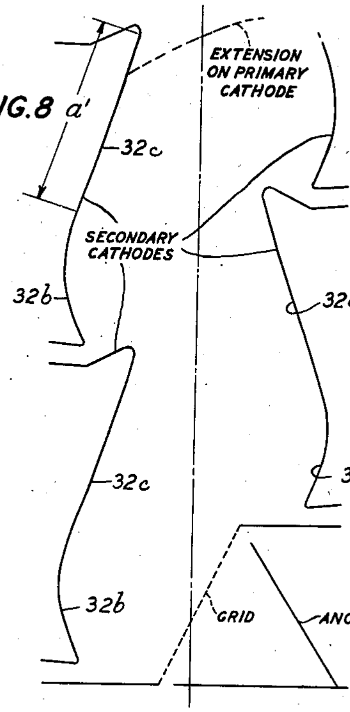
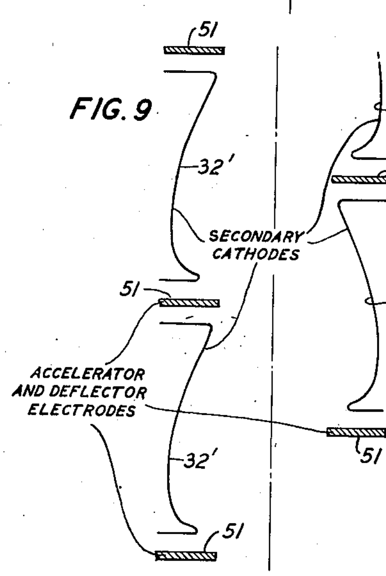


FIG. 9



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ELECTRON DISCHARGE APPARATUS

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FIG. 10

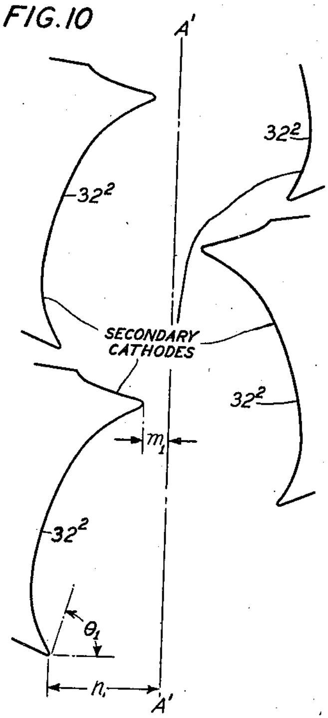


FIG. 16

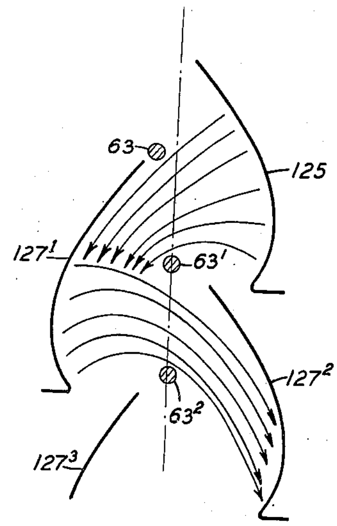
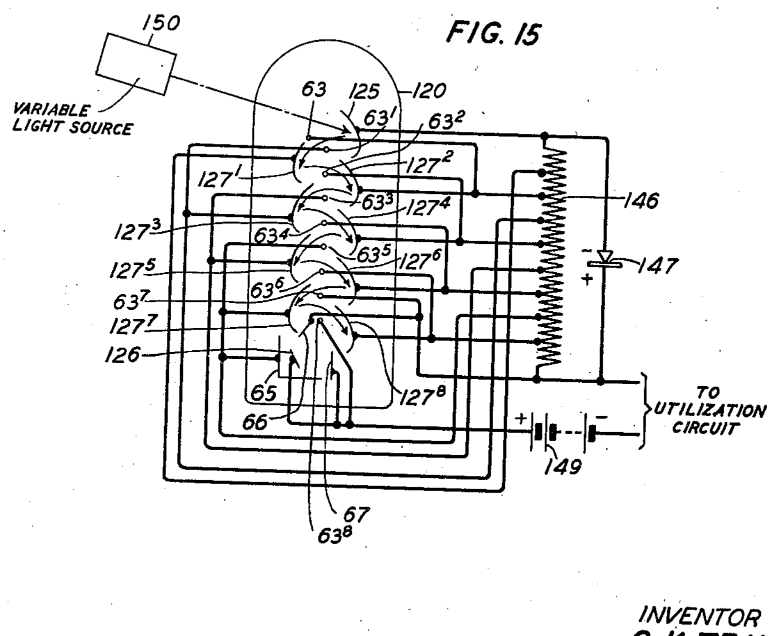


FIG. 15



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ELECTRON DISCHARGE APPARATUS

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FIG 11

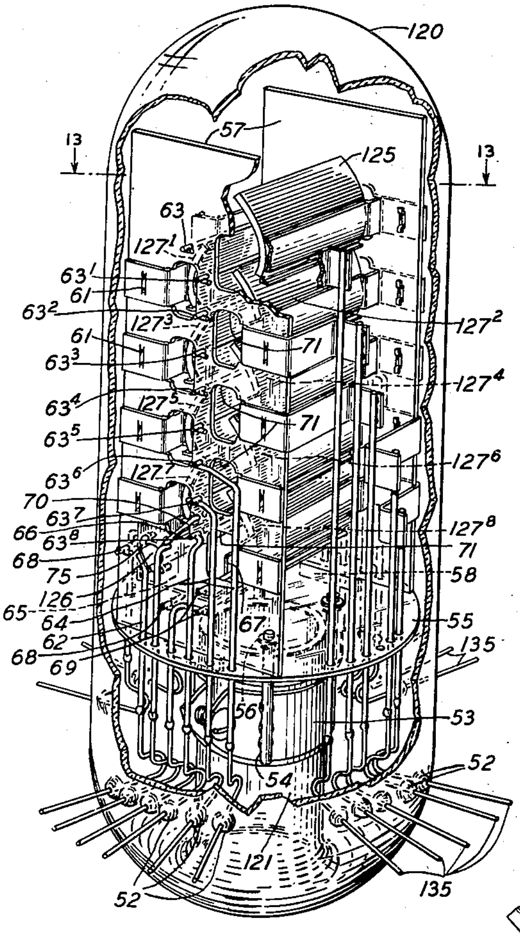


FIG. 12

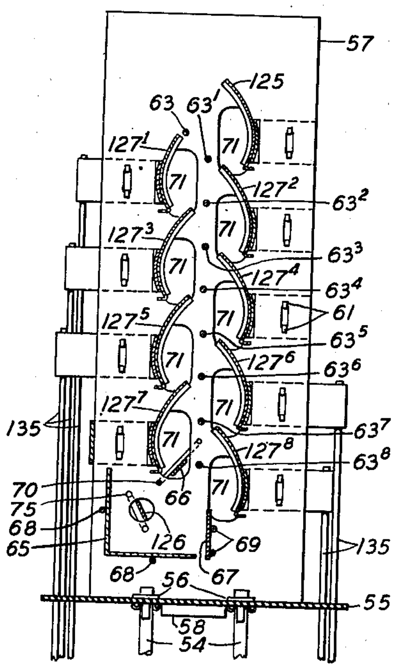


FIG. 14

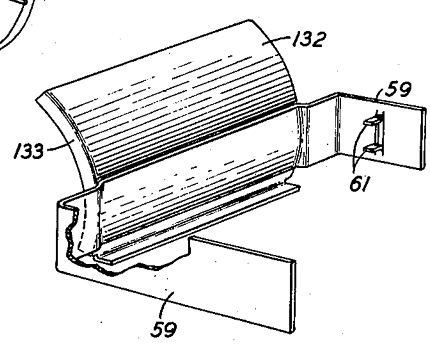
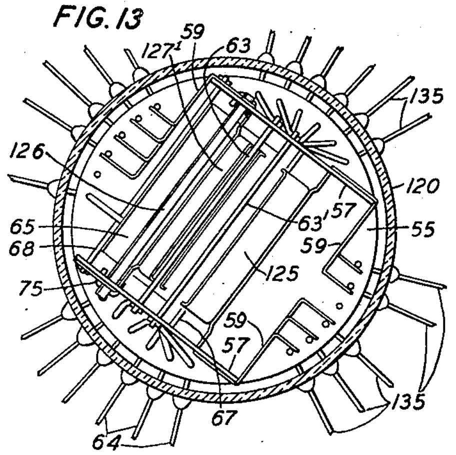


FIG. 13



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Patented June 17, 1941

2,245,624

UNITED STATES PATENT OFFICE

2,245,624

ELECTRON DISCHARGE APPARATUS

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Application May 4, 1938, Serial No. 205,931

15 Claims. (Cl. 250—175)

This invention relates to electron discharge apparatus and more particularly to electron discharge devices having one or more secondary electron emitting electrodes and commonly known as electron multipliers.

Electron multipliers of a type comprehended by this invention comprise a source of primary electrons, such as a photo-electric cathode, an anode or collector electrode spaced from the primary source, and one or a plurality of secondary electron emissive cathodes between the source and the anode or collector electrode. Primary electrons emanating from the source are drawn to and impinge upon the secondary cathode nearest thereto and result in the emission of secondary electrons therefrom. Because of the character of the secondary cathode, among other factors, the secondary current emanating therefrom is greater than the impinging primary current so that in effect an electron multiplication or amplification is obtained. The secondary current is drawn to the anode or collector electrode, or to the next succeeding secondary cathode if a plurality of such cathodes are employed.

The efficiency and other characteristics of such an electron multiplier are dependent to a large extent upon the fields extant between the successive electrodes, and particularly adjacent the emissive surfaces of the various cathodes, and upon the degree of concentration of the electron streams between successive electrodes.

One broad and general object of the invention is to improve the efficiency and operating characteristics of electron multipliers.

More specifically, objects of this invention are:

To obtain a high degree of convergence of the electron streams between successive electrodes in electron multipliers;

To obtain relatively sharp focussing of the electrons emanating from each of the cathodes, upon restricted portions of the next succeeding electrode;

To assure strong fields away from the emissive surfaces of the cathodes whereby copious emission of electrons and voltage saturation may be achieved;

To enable voltage saturation of the secondary electron current or currents at relatively low potential differences between successive electrodes;

To decrease the transit time of electrons between successive electrodes;

To avoid the formation of space charge in the vicinity of the emissive surfaces of the cathodes;

To reduce the effects of initial velocity of the secondary electrons;

To enable control of the trajectories of the electrons flowing to the secondary cathode or cathodes whereby the incidence of such electrons, most conducive to copious emission of secondary electrons may be obtained; and

To facilitate control of the gain of an electron multiplier and modulation of the output current thereof.

In one illustrative embodiment of this invention, an electron multiplier comprises a primary photoelectric cathode, a collector electrode spaced from the primary cathode, and a plurality of secondary cathodes mounted in staggered relation in two rows, between the primary cathode and the collector electrode or anode. The secondary cathodes have their opposing surfaces electron emissive and preferably are of such form and are so disposed that in the aggregate they have glide plane symmetry.

In accordance with one feature of this invention, the secondary cathodes have their opposed surfaces generally concave so that an electron lens effect is obtained and focussing of the electrons emanating from each of the cathodes is effected.

In accordance with another feature of this invention one or more auxiliary electrodes are provided between the rows of secondary cathodes for producing strong fields in such relation to the emissive surfaces that high acceleration of the emanating electrons and a high degree of convergence of the various electron streams are obtained. The auxiliary electrodes may be, for example, small area linear rods or wires, each of which may be parallel and substantially centrally located with respect to a corresponding one of the secondary electron emissive surfaces.

The invention and the foregoing and other features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawings, in which:

Fig. 1 is a perspective view of an electron multiplier illustrative of one embodiment of this invention, a portion of the enclosing vessel being broken away to show the electrode assembly more clearly;

Fig. 2 is a side view, partly in section, of the electrode assembly of the electron multiplier illustrated in Fig. 1;

Fig. 3 is an enlarged perspective view of one of the secondary cathodes of the electron multiplier illustrated in Fig. 1;

Fig. 4 is a diagrammatic side view of the electrodes in the electron multiplier shown in Fig. 1, illustrating the form and space relation thereof;

Fig. 5 is a circuit diagram showing one manner in which the electron multiplier of Fig. 1 may be operated;

Fig. 6 is a graph illustrating a typical operating characteristic of the multiplier of Fig. 1, operated as illustrated in Fig. 5;

Fig. 7 is a graph showing a family of lines indicative of the operating characteristics of the multiplier of Fig. 1 with various interelectrode potentials;

Figs. 8, 9 and 10 are diagrammatic side views to scale showing modifications of the embodiment illustrated in Fig. 1;

Fig. 11 is a perspective view of an electron multiplier illustrative of another embodiment of this invention, portions of the enclosing vessel and of the electrode structure being broken away;

Fig. 12 is a side view, mainly in section, of the electrode assembly in the multiplier illustrated in Fig. 11;

Fig. 13 is a top view along line 13—13 of Fig. 11 and partly in section, of this multiplier;

Fig. 14 is an enlarged perspective view of one of the secondary cathodes included in the structure shown in Fig. 11;

Fig. 15 is a circuit diagram illustrating one manner of operating the electron multiplier shown in Fig. 11; and

Fig. 16 is an enlarged diagrammatic view indicating the electron trajectories in the electron multiplier shown in Fig. 11.

Referring now to the drawings, the electron multiplier illustrated in Figs. 1 to 4, comprises a highly evacuated vitreous enclosing vessel **20** having an inwardly extending stem **21** at one end provided with an intermediate annular flange **22**. Extending from the stem **21** are a pair of parallel elongated uprights or standards **23**, which may be of vitreous material and fused to the stem, from which the electrodes of the multiplier are supported by rigid metallic cross-pieces or wires **24** sealed in the uprights.

These electrodes include a primary cathode **25**, an anode or collector electrode **26**, a plurality (ten) of secondary cathodes 27^1 to 27^{10}, inclusive, and a screen or shield electrode **28** between the secondary cathode 27^{10} and the anode or collector electrode **26**.

The secondary cathodes are arranged in staggered relation in two parallel rows, are substantially identical in form and construction and preferably are spaced so that in the aggregate they have glide plane symmetry. That is to say, these cathodes are of such form and are so disposed that if one row were displaced a distance x (Fig. 4) parallel to the medial plane between the two rows (as A—A in Fig. 4), each of the secondary cathodes in the one row would be exactly opposite the corresponding secondary cathode in the other row and the two rows would be exactly symmetrical with respect to the medial plane mentioned. The various secondary cathodes, furthermore, preferably have symmetry with respect to a longitudinal plane normal to the medial plane mentioned above, and are non-symmetrical with respect to any plane (such as one passing through B—B, Fig. 4) at right angles to both of the aforementioned planes. Such non-symmetry, it has been found, is of material import inasmuch as it enables the attainment of strong fields away from large portions of each of the secondary cathodes whereby copious emission and convergence of the electron streams may be attained expeditiously.

As indicated in Fig. 4, the secondary cathodes in each row are equally spaced from each other and from the medial plane between the two rows.

As shown clearly in Fig. 3, each of the secondary cathodes **27** comprises a backing member or plate **29**, preferably of sheet metal such as nickel, having opposite edge flanges **30**, and a formed sheet metal member having end portions **32A** affixed to the flanges **30**, as by bent wire fasteners or rivets **31**. The formed metal member includes also a concave or dished portion **32**, the concave surface of which is treated or coated to render it capable of efficient and copious emission of secondary electrons. For example, the formed member may be of sheet silver, the concave surface of the portion **32** being treated to form a matrix or coating including silver, caesium oxide and some free caesium.

As will be noted from Figs. 2 and 3, the concave surface **32** of each secondary cathode comprises a central or intermediate portion and end baffle or barrier portions, the latter extending at unequal angles from the intermediate portion and toward the medial plane between the two rows. These end portions and also the end members **32A** extend between the intermediate parts of the concave surfaces of adjacent or succeeding electrodes in the same row and thereby prevent one secondary electrode from producing a field component near the next adjacent cathode which might tend to retard the electrons emanating from such next adjacent cathode. The upper end portions of each secondary cathode, and particularly the upper end members **32A**, in addition serve to create a strong accelerating field at the lower portion of the next adjacent cathode in the same row, i. e., the second preceding cathode, and also at substantially the entire surface of the next preceding cathode. Furthermore, the end members **32A** aid in providing a closed, substantially completely shielded electrode structure.

Preferably, the dished or concave portion **32** of each of the secondary cathodes is provided with side flanges **33**, which may be integral therewith, to prevent lateral dispersion of the electrons emanating from the coated or treated surfaces.

If desired, the cathodes **27** may be dished or curved somewhat between the side flanges **33** and toward the backing plate **29** to further prevent lateral dispersion of electrons emanating from the surfaces **32**.

Each of the secondary cathodes **27** is supported from two of the cross-wires **24** by a pair of metallic U-shaped wires or brackets **34** affixed to the backing member or plate **29**. Electrical connection to these cathodes may be established through leading in conductors **35** sealed radially in the flange **22** and extending outwardly through the stem **21**.

The primary cathode **25** may be substantially identical in construction to the secondary cathodes **27** with the addition of a metallic overhanging portion or projecting plate element **36** affixed to one of the end portions **32A** by wires or rivets **37**. The overhanging portion **36**, being electrically integral with the cathode, provides field components assisting in focussing the electrons emanating from the concave surface of the dished portion **32** of the primary cathode so that these electrons impinge upon desired portions of the first secondary cathode **27**. This concave surface is photoelectrically active. For example, it may be a coating or matrix including silver, caesium oxide and free caesium.

If the cathode 25 is to be energized other than by light focussed thereon, the concave or emissive surface thereof may be treated or coated in other ways. For example, if it is to be energized by an electron stream, produced by an electron gun, thermionic cathode or otherwise, the concave surface of the primary cathode may be coated or treated to have thereon a secondary electron emissive surface. The active material may be, for example, nickel, aluminum or any oxidized material exhibiting a high work function.

The primary cathode 25, similarly to the secondary cathodes, may be supported from two of the cross-members 24 by two U-shaped brackets 34 to one of which a leading-in conductor 38 is connected. As illustrated in Fig. 4, the primary cathode is set back somewhat, as compared with the secondary cathodes in line therewith, to allow energization, as by a beam of light, of substantially all of the photoelectrically active surface thereof.

The collector electrode or anode 26 comprises a metallic base plate 39 supported from one of the cross-wires 24 by a pair of rigid rods or wires 40, and a metallic plate 41, affixed to the base plate 39 as by welding, and extending at an acute angle thereto and toward the secondary cathode 27^{10}. Electrical connection to the anode or collector electrode may be established through a leading-in conductor (not shown) sealed in the side wall of the vessel 20 to reduce leakage and capacitance to ground.

The shield or screen electrode 28 is supported by wires 42, only one of which is shown, and comprises two metallic plates 43 and 44, one (43) of which is substantially parallel to the lower end portion of the secondary cathode 27^{10} and coplanar with the base plate 39 of the anode or collector electrode and the other (44) of which extends between the secondary cathode 27^{9} and the anode or collector electrode. The shield or screen electrode 28 includes also a reticulated or grid portion 45 extending diagonally between the plates 43 and 44 and affixed thereto. This electrode 28 serves to shield the cathodes 27^{9} and 27^{10} from the anode or collector electrode 26 so that voltage fluctuations upon the latter do not deleteriously affect the fields adjacent these secondary cathodes, and also to assure flow of substantially all the secondary electrons emanating from the cathode 27^{9} to the cathode 27^{10}. Electrical connection to the electrode 28 may be established through a leading-in conductor, not shown, sealed in the flange 22.

During operation of the electron multiplier, as shown in Fig. 5, the secondary cathodes are maintained at successively equally higher positive potentials with resect to the next preceding cathode. For example, the first secondary cathode 27^{1} may be maintained at a positive potential of the order of 25 to 100 volts with respect to the primary cathode, the next secondary cathode 27^{2} may be maintained of the order of 25 to 100 volts positive with respect to the cathode 27^{1} and each succeeding secondary cathode may be maintained of the order of 25 to 100 volts positive with respect to the next preceding one. The desired potentials may be obtained from a potentiometer arrangement including a resistance 46 in shunt with a source 47, such as a rectifier. The shield or screen electrode 28 may be maintained at a similar voltage, e. g. 25 to 100 volts, positive with respect to the secondary cathode 27^{10}, as by a battery 48, and the anode 26 likewise maintained of the order of 25 to 100 volts positive with respect to the shield or screen electrode 28, as by a battery 49. An output or utilization circuit may be connected between the cathode 27^{10} and the anode or collector electrode 26 through the batteries 48 and 49 as shown in Fig. 5.

When the primary cathode 25 is energized, as by a beam of light, corresponding to a signal to be translated, emanating from a source 50 of variable light, photo or primary electrons are emitted from the activated concave surface 32 of this cathode. Under the influence of the higher potential upon the secondary cathode 27^{1}, and the fields extant between the cathodes 25, 27^{1}, 27^{2} and 27^{3} the primary electrons flow to and impinge upon the activated concave surface of the secondary cathode 27^{1} and cause the emission of secondary electrons therefrom. Because of the treatment or coating of the concave surface of the secondary cathode, as described heretofore, the secondary electron current will be greater, for example 4 to 8 times greater, than the impinging primary electron current. Hence, in effect, an electron multiplication and, therefore, amplification of the signal corresponding to the light beam will result.

The secondary electrons emanating from the cathode 27^{1} will be drawn toward and impinge upon the concave surface of the cathode 27^{2} and cause the emission of a still greater number of secondary electrons with a corresponding further amplification of the signal being translated. This phenomenon of electron multiplication and amplification is repeated a each of the succeeding secondary cathodes 27^{3} to 27^{10} inclusive. The electrons emanating from the last cathode 27^{10} flow to the anode or collector electrode 26 and constitute the output current of the multiplier.

The paths traversed by the several electron streams are indicated generally by the arrows between electrodes in Fig. 5.

One of the principal factors determinative of high efficiency and stable and satisfactory operating characteristics of electron multipliers of the type comprehended by this invention and exemplified by the device illustrated in Fig. 1 is the degree of convergence of the several electron streams emanating from the various cathodes. It is necessary for the attainment of high efficiency and satisfactory characteristics that substantially all of the secondary electrons emanating from each secondary cathode be drawn away therefrom and caused to impinge upon the next succeeding electrode. Preferably the impingement should occur over a restricted area of the emissive surface of the receiving electrode.

In accordance with one feature of this invention, the various cathodes are so shaped and disposed that a strong field away from a large portion of the emissive surface of each cathode obtains so that substantially all of the emitted electrons are accelerated away from this surface. The shaping and space relation are such, furthermore, that the electrons emitted from each surface are focussed upon a restricted portion of the emissive surface of the next succeeding electrode.

Generally, as noted heretofore, the emissive surfaces of the secondary cathodes are concave. The degree of convergence of the electron streams and the intensity and direction of the fields in the vicinity thereof have been found to be fairly critically dependent upon the relative parameters of these surfaces. Specific relative parameters for one embodiment of this invention expressed in units are indicated in Fig. 4, wherein

$a=11.62$	$o=0.78$
$b=10.78$	$x=6.20$
$c=2.90$	$r_1\cong4.20$
$d=0.84$	$r_2\cong4.43$
$m=1.63$	$r_3>>r_1$, r_2, and r_4
$n=4.53$	$r_4\cong0.23$

and $\theta=75$ degrees.

The values given for r_1, r_2 and r_4, it may be noted, are but approximate inasmuch as the curves indicated thereby are not continuous single circular arcs.

In a specific and illustrative embodiment, the unit may be 0.0666 inch.

As to the collector or anode **26** and the shield or screen electrode **28**, the parameters indicated in Fig. 4 and expressed in units, a specific unit being 0.0666 inch, may be

$h=5.48$	$l=3.375$
$j=5.875$	$s=0.78$
$k=3.30$	$t=0.78$

and $\varphi=51.2$ degrees and $\beta=17$ degrees.

The grid portion **45**, it will be noted, subtends the angle bounded by the members **39** and **41** of the anode or collector electrode.

As indicated in Fig. 4, with respect to the primary cathode, f may be 5.625 units, g may be 2.51 units and ρ may be 115 degrees, a unit in a specific embodiment being 0.0666 inch, as noted above.

In an electron multiplier of the construction illustrated in Fig. 1 and having the relative parameters as noted above with respect to Fig. 4, the operating characteristics are illustrated in Figs. 6 and 7. Fig. 6 illustrates the relationship for a single stage, activated by secondary electrons, between the electron multiplication or gain and the voltage, both the abscissae and ordinates being logarithmic. From this figure it will be seen that this relationship is linear over a wide range of voltages, which of source is highly desirable and advantageous inasmuch as it enables satisfactory utilization of the electron multiplier under a variety of conditions.

In Fig. 7, the output current of the electron multiplier is indicated with respect to the energization of the primary cathode, i. e., intensity of the light beam focussed upon the primary cathode indicated by the primary current therefrom, both the abscissae and ordinates being logarithmic. As clearly indicated by the family of characteristics in Fig. 7, each characteristic having a substantially 45 degree slope, this relationship is linear over a wide range of interstage voltages, which also is highly desirable and advantageous inasmuch as it assures uniform operation and amplification for a range of light intensities throughout a wide voltage range.

The departure from linearity indicated by the portion P in the 100-volt per stage characteristic is attributable to space charge effects.

In modifications of the embodiment of this invention, illustrated diagrammatically and to scale in Figs. 1 to 4, the electrodes may be of the forms illustrated in Figs. 8, 9 and 10. In the modifications shown in these figures, the secondary cathodes differ from those in the specific embodiment shown in Figs. 1 to 4, principally in the form of the emissive surfaces. In other respects, the secondary cathodes may be substantially identical with those shown in Figs. 1 to 4.

In the modification illustrated in Fig. 8, the emissive surface includes a curved portion **32b** and a generally plane portion **32c**, the radius of the curved portion being approximately 6 units and the dimension a of the plane portion being substantially 4.5 units. The other parameters of the electrode structure may be substantially the same as those indicated hereinabove with respect to Fig. 4.

In the modification illustrated in Fig. 9, the concave emissive surfaces **32'** of the secondary cathodes are substantially continuously curved, the relative dimensions thereof and the space relation of the various electrodes being substantially the same as those indicated heretofore with reference to Fig. 4.

As shown in Fig. 9, auxiliary electrodes **51**, for example flat metallic plates or strips, may be provided between adjacent ends of the electrodes for assisting in the formation of fields of the requisite and optimum direction adjacent the emissive surfaces of the cathodes so that acceleration and convergence of electron streams are augmented and flow of electrons between successive electrodes in the same row is prevented. The auxiliary electrodes **51** may be maintained at a positive potential, preferably somewhat higher than that of the preceding cathode in the same row, i. e., the next above cathode in Fig. 9, and also higher than the potential of the opposite cathode. It may be positive with respect to the succeeding electrode or equipotential and integral with it.

In the modification illustrated in Fig. 10, the opposed surfaces **32²** of the secondary cathodes are continuously curved and are inclined toward the medial plane passing through the line A′—A′. The surface and spacing parameters may be substantially the same, except for the distances m_1 and n_1 and the angle θ_1, as given in connection with Fig. 4. The distances m_1 and n_1 may be 1.03 and 4.52 units, respectively, a typical unit being 0.0416 inch. The angle θ_1, may be 71.8 degrees.

In Figs. 8, 9 and 10, the surfaces are drawn and spaced to scale and thereby indicate specific relationships of parameters whereby the desired field and convergence effects, among others, in accordance with the invention may be obtained.

In the embodiment of this invention illustrated in Figs. 11 to 14, the enclosing vessel **120** is provided near one end thereof with a plurality of seals **52**. The electrodes are fabricated in a unitary structure supported from the stem **121** by a pair of semi-circular bands or collars **53** clamped about the stem and having rigid posts or uprights **54** arising therefrom. The unitary electrode assembly includes an insulating spacer **55**, such as a mica disc, supported by the posts or uprights **54** and securely affixed thereto, as by eyelets **56**, and a pair of parallel insulating uprights **57**, for example mica strips, having projections or tongues **58** extending through and fitted in slots in the disc **55**.

Supported by and between the insulating uprights **57** are a primary cathode **125**, an anode or collector electrode **126** and a plurality of secondary cathodes **127¹** to **127⁸** inclusive, the cathodes being mounted in two parallel rows and in staggered relation. The several secondary cathodes **127²** to **127⁸** are identical in form and are arranged so that they have glide plane symmetry, have symmetry with respect to a longitudinal plane parallel to the insulating uprights 57 and are non-symmetrical with respect to any plane normal to the longitudinal plane and the medial plane, as described more fully in connection with Fig. 1.

The secondary cathode 127^1 is substantially identical with the other cathodes except that it is somewhat shorter, the decrease in length being due to the lesser extension of the upper end.

Each of the secondary cathodes, as shown clearly in Fig. 14, may be formed of a strip of metal, for example silver, and has a continuously curved portion 132, the concave surface of which is secondary electron emissive. This surface may be, for example of silver, caesium oxide and some free caesium. The cathodes preferably have side flanges 133 which assist in preventing lateral dispersion of the electrons emanating from the emissive surfaces. Affixed to the outer face of the formed metal strips, as by welding, are substantially rectangular metallic, e. g. nickel, support or bracket members having arms 59 bent around and engaging the insulating uprights 57. The arms 59 extend through apertures in the uprights 57 and may be locked to the latter by integral bent-over tabs 61 extending through suitable slots in the uprights. Electrical connection to the secondary cathodes may be established through leading-in conductors 135 each secured at one end to a corresponding one of the arms 59, extending through a suitable aperture in the disc 55 and sealed adjacent the other end in one of the seals 52.

The primary cathode 125 may be substantially identical with the secondary cathodes 127^2 to 127^8 inclusive, and supported in the same manner as the secondary cathodes. The concave surface thereof is photoelectrically active. For example, it may be treated to have thereon a coating or matrix including silver, caesium oxide and some free caesium.

As will be noted clearly in Fig. 12, the concave portion 132 of each of the secondary cathodes 127^2 to 127^8 inclusive extends between the corresponding emissive surface and the next adjacent and preceding cathode in the same row so that the production of a retarding field effect, by such next adjacent preceding cathode, upon the electrons emanating from such corresponding surface is prevented.

The anode or collector electrode 126 comprises a plane metallic plate section supported by a pair of bent wires 75 extending into the uprights 57 and fitted in apertures therein. Electrical connection to the anode or collector electrode may be established through a leading-in conductor 62 extending through the disc 55 and sealed in one of the seals 52.

During operation of the electron multiplier shown in Fig. 10, the cathodes may be maintained at successively equally higher potentials, as indicated in Fig. 15, wherein elements corresponding to those of Fig. 5 are designated by the same identifying numeral increased by 100. The electron trajectories are indicated by the arrows in Figs. 15 and 16. In view of the detailed description of Fig. 5 given hereinabove, the connections to the cathodes and anode in Fig. 15 will be clear without further discussion.

As pointed out heretofore, high efficiency and fully satisfactory operating characteristics require that strong fields away from the emissive surfaces and a high degree of convergence of the electron streams between the electrodes obtain. In addition, it is desirable in some instances that the maximum current obtainable with a given structure be available and utilized.

In accordance with a feature of this invention, the attainment of these and other desiderata is facilitated by the provision of auxiliary electrodes 63 to 63^8 inclusive, in cooperative relation with the several cathodes for producing such fields that the electrons are subjected to strong accelerating and directive or focussing forces.

In one illustrative form, these auxiliary accelerating and focussing electrodes may be linear, small diameter metallic rods or wires extending between the insulating uprights 57 and fitted in apertures therein. The auxiliary electrodes 63^1 to 63^8 inclusive, are located in the medial plane between the rows of cathodes and the electrode 63 is arranged adjacent the upper end of the secondary cathode 127^1. As shown clearly in Fig. 12, each of the auxiliary electrodes 63 is opposite the concave surface of a corresponding one of the cathodes and each of the electrodes 63^1 to 63^7 inclusive is in alignment with and adjacent the upper edge of the secondary cathodes 127^2 to 127^8 inclusive, respectively. That is to say, for example, the accelerating or focussing electrode 63^1 is opposite the concave surface of the first secondary cathode 127^1 and in alignment with and adjacent the upper edge of the secondary cathode 127^2.

Electrical connection to the auxiliary electrodes 63 may be made individually through leading-in conductors 64 extending through the disc 55 and sealed in the wall of the vessel 120 at 52.

During operation of the electron multiplier, each of the auxiliary electrodes 63 is maintained at a higher positive potential than both the corresponding opposite cathode and the next succeeding cathode. For example, as shown in Fig. 15, each auxiliary electrode may be maintained at the same potential as the second succeeding cathode, that is, the one having the second greater superscript. That is to say, the auxiliary electrode 63 may be operated at the same potential as the secondary cathode 127^2, the electrode 63^1 may be maintained at the same potential as the secondary cathode 127^3 and so on.

Each of the auxiliary electrodes 63 thus operated will produce a strong field component away from the opposite emissive surface. Thus, the auxiliary electrode 63 will produce a strong field away from the concave surface of the primary cathode 125 and each of the electrodes 63^1 to 63^8 will produce a strong field away from the concave surface of the secondary cathode 127 having the same superscript. Consequently, all of the electrons emanating from these surfaces will be drawn away therefrom and accelerated toward the next succeeding electrode so that the formation of space charge is prevented and, in addition, the secondary electron current may be voltage saturated even at relatively low interstage voltages.

Furthermore, the strong fields produced by these auxiliary electrodes result in a decrease in the transit time of electrons between successive electrodes and reduce the effect of initial velocity of the secondary electrons so that uniform characteristics for a wide range of potentials and frequencies may be attained.

Finally, it will be appreciated that the auxiliary electrodes 63 produce fields which exercise a focussing effect upon the several electron streams and aid in the attainment of convergence thereof. Specifically, it may be noted that these electrodes cause a turning or bending of the electron streams, as indicated by the arrows in Fig. 15, so that electrons emanating from the cathodes are caused to impinge upon a restricted area of the next succeeding electrode.

This turning or bending action is dependent upon the potential of the several auxiliary electrodes and various desirable effects may be achieved by adjustment of these potentials. For example, the potentials may be made such that the electrons arrive at each secondary cathode with a grazing incidence whereby more secondary electrons are produced than by electrons impinging at normal incidence.

Furthermore, the potentials of one or more of the auxiliary electrodes **63** may be made such as to cause a very large bending or turning of the electron trajectories, sufficient to cause some of the electrons emanating from one or more cathodes to miss or pass by the next succeeding cathode. Thus, the gain of the electron multiplier may be varied and its output may be modulated.

The auxiliary electrodes **63**, as previously noted, have a small area so that the current thereto is very small.

The anode or collector electrode **126** may be partially surrounded by a plurality of shields or screens **65**, **66** and **67**. The shield or screen **65** comprises two plate members at right angles to each other and supported by a pair of cross-wires **68** extending between the insulating uprights **57** and fitted in apertures therein. The shields or screens **66** and **67** may be metallic plates supported by wires **69** and **70**, respectively fitted in apertures in the insulating uprights **57**.

The shield **65** may be operated at the same potential as the secondary cathode **127**[7], the shield **66** may be operated at the same potential as the auxiliary electrode **63**[7] and the shield **67** may be operated at the same potential as the anode or collector electrode **126**. Together with the anode, the several shields produce such fields between the secondary cathode **127**[8] and collector electrode **126** that secondary electrons emanating from the latter are highly converged and focussed upon the collector electrode or anode **126** or a restricted portion thereof.

As illustrated in Figs. 11 and 12, the insulating uprights **57** may be provided with apertures **71** adjacent the ends of the cathodes and the anode to reduce end effects.

Reference is made of the applications Serial No. 176,566, filed November 26, 1937, of John R. Pierce and William Shockley and Serial No. 205,930, filed May 4, 1938, of John R. Pierce wherein related inventions are disclosed and claimed.

Although specific embodiments of this invention have been shown and described and specific parameters and potentials given, it will be understood that these embodiments and values are but illustrative and that various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. An electron multiplier comprising a pair of rows of secondary electron emissive members having opposed longitudinally concave surfaces of varying curvature and mounted in staggered relation, a primary cathode at one end of said rows, and a collector electrode at the other end of said rows.

2. An electron multiplier comprising a primary cathode, a collector electrode spaced from said primary cathode, a pair of rows of secondary cathodes between said primary cathode and said collector electrode and having opposed electron emissive surfaces, each of said secondary cathodes having curved end portions of unequal radii extending toward the opposite row of cathodes.

3. An electron multiplier comprising a primary cathode, a collector electrode, and a plurality of secondary cathodes mounted in staggered relation between said primary cathode and said collector electrode, each of said secondary cathodes having a continuously curved portion of varying radius of curvature the concave surface of which is toward the next preceding and next succeeding electrodes.

4. An electron multiplier comprising a primary cathode, a collector electrode, and a plurality of secondary cathodes mounted in staggered relation between said primary cathode and said collector electrode, each of said secondary cathodes being inclined toward the next preceding electrode and having its ends spaced unequal distances from the medial plane extending between said secondary cathodes, and said secondary cathodes having opposed surfaces concave.

5. An electron multiplier comprising a primary cathode, a collector electrode spaced from said primary cathode, a first row of closely adjacent secondary cathodes, a second row of secondary cathodes opposite said first row, the secondary cathodes in said second row being in staggered relation with the secondary cathodes in said first row and each having portions laterally opposite two secondary cathodes in said first row, the secondary cathodes in said rows having their opposed faces longitudinally concave, and each secondary cathode being inclined toward the other row of cathodes with the end thereof remote from said primary cathode spaced from the medial plane between said rows a distance greater than the spacing between the other end thereof and said medial plane.

6. An electron multiplier comprising a primary cathode, a collector electrode spaced from said primary cathode, a row of aligned secondary cathodes one surface of each of which is concave in the direction of alignment of said secondary cathodes, and a second row of secondary cathodes each having a concave surface of varying radius of curvature facing and inclined toward said first row of secondary cathodes.

7. An electron multiplier comprising a primary cathode, a collector electrode spaced from said primary cathode, a plurality of successively arranged secondary cathodes between said primary cathode and said collector electrode, and linear rod auxiliary electrodes opposite and substantially uniformly spaced from the emissive surfaces of certain of said secondary cathodes.

8. An electron multiplier comprising a primary cathode, a collector electrode spaced from said primary cathode, a pair of rows of secondary cathodes between said primary cathode and said collector electrode, said secondary cathodes having opposed emissive surfaces, and a plurality of auxiliary electrodes mounted in a common boundary extending between said two rows, each auxiliary electrode being between two corresponding facing electrodes in said rows.

9. An electron multiplier comprising a primary cathode, a collector electrode spaced from said primary cathode, a plurality of successively ar-

ranged secondary cathodes between said primary cathode and said collector electrode, said secondary cathodes having opposed emissive surfaces, an accelerating electrode opposite said primary cathode, and a plurality of field electrodes each opposite a corresponding one of said emissive surfaces.

10. An electron multiplier comprising a pair of rows of secondary cathodes having opposed emissive surfaces, a primary cathode adjacent one end of said rows, a collector electrode adjacent the other end of said rows, and a plurality of small area field electrodes between said rows, each field electrode being opposite and substantially parallel to a corresponding one of said emissive surfaces.

11. An electron multiplier comprising a pair of rows of secondary cathodes having opposed dished emissive surfaces, a primary cathode adjacent one end of said rows, a collector electrode adjacent the other end of said rows, and a linear auxiliary electrode opposite each of said surfaces.

12. An electron multiplier comprising a pair of rows of electrodes having opposed electron emissive surfaces, and a plurality of rod auxiliary electrodes between said rows, each of said rod electrodes being opposite a corresponding one of said emissive surfaces and parallel thereto.

13. An electron multiplier comprising a pair of rows of secondary cathodes having opposed concave emissive surfaces, the cathodes in one row being in staggered relation with those in the other, and a plurality of auxiliary electrodes between said rows, each of said auxiliary electrodes being opposite a corresponding one of said cathodes and substantially parallel thereto and adjacent the nearest edge of the next succeeding cathode.

14. An electron multiplier in accordance with claim 13 wherein said surfaces are uniformly spaced on opposite sides of the medial plane between said rows and said auxiliary electrodes are mounted substantially in said plane.

15. An electron multiplier comprising a plurality of secondary cathodes mounted in staggered relation in two parallel rows, opposed surfaces of said cathodes being curved toward one another, a primary cathode having a concave surface facing one end secondary cathode in one of said rows, a collector electrode opposite the other end secondary cathode in the other of said rows, a linear rod auxiliary electrode opposite said concave surface, and a plurality of parallel linear rod electrodes between said rows, each opposite a corresponding one of said secondary cathodes.

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