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J. R. PIERCE ET AL

2,245,605

ELECTRON MULTIPLIER

Filed Nov. 26, 1937

FIG. 1

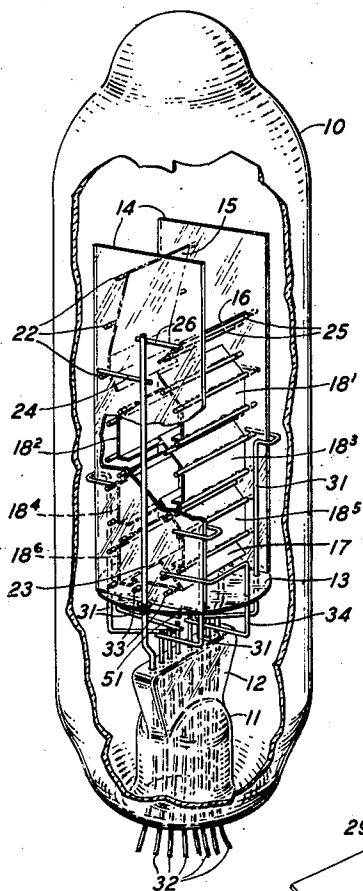


FIG. 2

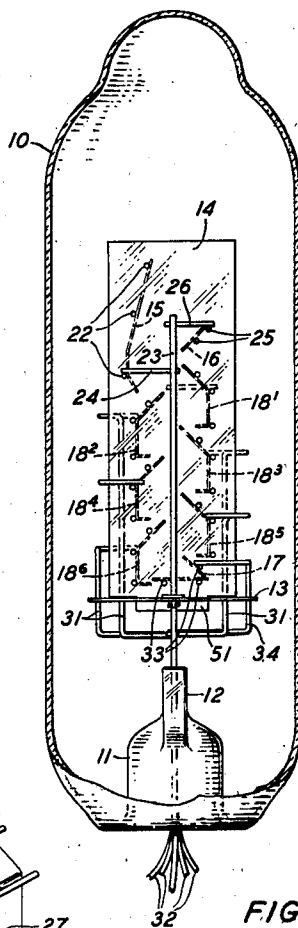


FIG. 3

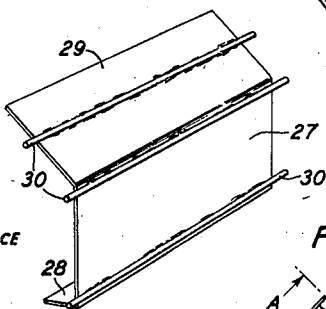


FIG. 4

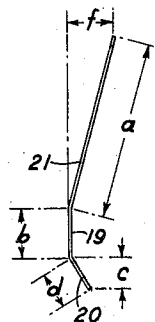


FIG. 5

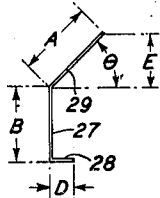
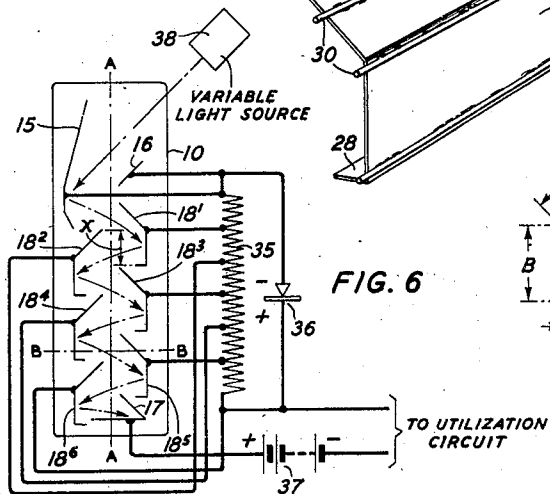


FIG. 6



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## UNITED STATES PATENT OFFICE

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## ELECTRON MULTIPLIER

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Application November 26, 1937, Serial No. 176,566

14 Claims. (Cl. 250—175)

This invention relates to electron multipliers and more particularly to electron multipliers of the multistage type.

In electron multipliers having a plurality of auxiliary or secondary cathodes successively arranged between a primary cathode and an anode or collector electrode, it has been found that the several electron streams emanating from the primary and secondary cathodes tend to diverge. Because of the divergence some of the electrons constituting the electron streams emanating from each of the cathodes may flow to other than desired portions of the next succeeding electrode or may fail to impinge upon the next succeeding electrode. Consequently, a low efficiency and poor operating characteristics result.

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

More specifically, one object of this invention is to facilitate the attainment of convergence of the electron streams between successive electrodes in multistage electron multipliers.

Another object of this invention is to shield the interelectrode spaces in electron multipliers, and particularly the regions adjacent the emissive surfaces of the cathodes thereof, from extraneous fields.

Still another object of this invention is to effectively segregate the emissive surface of each secondary or auxiliary cathode in multistage electron multipliers from the electrodes thereadjacent whereby the fields of such adjacent electrodes will not produce a component toward the emissive surface.

A further object of this invention is to obviate the use of means separate from the electrodes for focussing the interelectrode electron streams in electron multipliers.

In one illustrative embodiment of this invention, an electron multiplier comprises a primary cathode, an anode or collector electrode and a plurality of auxiliary or secondary cathodes arranged successively and in staggered relation between the primary cathode and the anode or collector electrode.

In accordance with one feature of this invention, each of the auxiliary or secondary cathodes is provided with integral baffle and barrier members which shield the emissive surfaces of these cathodes and guide the electrons emitted from these surfaces in desired paths.

In accordance with another feature of this invention, the electrodes are so constructed and arranged that the electrons emanating from each

of the cathodes are focussed electrostatically upon the next succeeding electrode.

In accordance with still another feature of this invention, the primary cathode is provided with baffle portions which shield the emissive surface thereof from extraneous fields and focus and guide the electron stream emanating therefrom.

In accordance with a further feature of this invention, an auxiliary or barrier member is provided for augmenting the focussing of the electron stream from the primary cathode upon the next succeeding secondary cathode.

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

Fig. 1 is a perspective view of an electron multiplier constructed in accordance with this invention, portions of the enclosing vessel and of the electrode assembly being broken away to show details of the assembly more clearly.

Fig. 2 is a side elevational view of the electron multiplier illustrated in Fig. 1, a portion of the enclosing vessel being broken away;

Fig. 3 is an enlarged detail view in perspective of one of the auxiliary or secondary cathodes of the electron multiplier illustrated in Figs. 1 and 2;

Figs. 4 and 5 are dimensioned end views of the primary cathode and one of the auxiliary cathodes, respectively, embodied in the electron multiplier shown in Figs. 1 and 2; and

Fig. 6 is a circuit diagram illustrating the utilization of an electron multiplier constructed in accordance with the invention in an amplifying system.

Referring now to the drawing, the electron multiplier illustrated therein comprises an enclosing vessel 10 having a stem 11 at one end terminating in a press 12 from which a unitary electrode assembly is supported.

The electrode assembly comprises an insulating frame including a disc 13, which may be of mica or the like, and spaced parallel uprights or arms 14, which also may be of mica. Each of the uprights or arms 14 is provided with an integral extension or tongue 51 which extends through and is fitted in a slot in the disc 13. Supported between the uprights or arms 14 are a primary cathode 15, a baffle or focussing member 16, an anode or collector electrode 17, and a plurality of similar, substantially identical auxiliary or secondary cathodes 18<sup>1</sup> to 18<sup>6</sup>, inclusive. As shown clearly in Figs. 2 and 6, the cathodes 15 and 18

are mounted successively in staggered relation so that the secondary or auxiliary cathode 18<sup>1</sup> is opposite to and obliquely aligned with the primary cathode 15 and each of the secondary or auxiliary cathodes 18<sup>2</sup> to 18<sup>6</sup> is opposite and obliquely aligned with the next preceding one. The anode or collector electrode 17 is opposite and aligned with the auxiliary or secondary cathode 18<sup>6</sup>. The baffle or focussing member 16 is opposite the primary cathode 15 and oblique to the longitudinal axis of the vessel 10.

The primary cathode 15, which may be formed of a metallic sheet or strip, for example a strip of silver, includes a plane rectangular section 19, a rectangular flange or baffle portion 20 extending obliquely from the section 19, and a relatively large area barrier or screen portion 21 also extending obliquely from the section 19. The inner surfaces, that is the surfaces to the right in Figs. 2 and 4, of the cathode 15, and preferably only the surfaces of the section 19 and flange portion 20, are treated or activated so that copious emission of electrons therefrom may be obtained. For example, these surfaces may be treated suitably to form a photoelectrically active coating or matrix including silver, caesium oxide and some free caesium.

The cathode 15 is supported by a plurality of rigid metallic rods or wires 22 which are affixed to the cathode and have their ends fitted in apertures in the arms or uprights 14 of the insulating frame. Preferably, the uprights or arms 14 engage the sides of the cathode 15 to hold the cathode firmly in proper position. Electrical connection to the cathode 15 may be established through a leading-in conductor 23 embedded in the press 12 at one end and connected at the other end to one of the rods or wires 22 by a tie wire 24.

The baffle or focussing member 16, which may be a metal plate or strip, is supported by a pair of wires or rods 25 affixed thereto and having their ends fitted in suitable apertures in the uprights or arms 14. Preferably, the baffle or focussing member 16 is connected electrically to the primary cathode 15, as by a wire 26 secured to the conductor 23 and to one of the rods or wires 25.

Each of the auxiliary or secondary cathodes 18, as shown clearly in Figs. 3 and 5, may be formed of sheet metal and comprises a plane rectangular central section 27, a flange or baffle portion 28 extending at an angle, for example, a right angle, from the section 27, and a barrier or screen portion 29 extending obliquely from the section 27. The inner surfaces, that is the surfaces to the right in Fig. 5, of each of the cathodes 18, and preferably only the surface of the section 27, may be treated or coated to facilitate copious emission of secondary electrons therefrom. For example, these surfaces may be treated to provide a coating or matrix including silver, caesium oxide and some free caesium, which has good secondary electron emitting characteristics.

The cathodes 18 may be supported individually between the uprights or arms 14 by rigid metallic rods or wires 30 which are affixed to the cathodes and are fitted at their ends in apertures in the arms or uprights. Preferably, the sides of the several secondary or auxiliary cathodes 18 are engaged by the arms of the insulating frame. As indicated clearly in Figs. 2 and 6, the intermediate sections 27 of the auxiliary cathodes 18<sup>2</sup>, 18<sup>4</sup>, and 18<sup>6</sup> are substantially co-

planar and the intermediate sections 27 of the auxiliary cathodes 18<sup>1</sup>, 18<sup>3</sup> and 18<sup>5</sup> also are substantially coplanar and parallel to the sections 27 of the opposite cathodes. Electrical connection to the secondary or auxiliary cathodes 18 may be established through conductors 31, extending through the disc 13, each of which is connected at one end to a corresponding one of the cathodes and at the other end to a leading-in conductor 32 embedded in the press 12.

The anode or collector electrode 17, which also may be formed of a sheet or strip of metal, is generally V-shaped in section, one wall thereof, as shown in Figs. 2 and 6, being adjacent and parallel to the baffle or flange 28 of the auxiliary or secondary cathode 18<sup>6</sup> and the other wall thereof being substantially parallel to the barrier or screen portion 29 of the auxiliary or secondary cathode 18<sup>5</sup>. Rigid metallic wires or rods 33 having their ends fitted in apertures in the uprights or arms 14 are affixed to the anode or collector electrode 17 and support this electrode on the insulating frame. One of the wires or rods 33 is connected to a wire 34, in turn connected to one of the leading-in conductors 32 through which desired electrical connection to the anode or collector electrode 17 may be made.

During operation of the electron multiplier, each of the secondary or auxiliary cathodes 18 is maintained at a positive potential above that of the next preceding cathode. For example, the auxiliary or secondary cathode 18<sup>1</sup> may have applied thereto a potential of the order of 100 to 150 volts positive with respect to the primary cathode 15 and each of the other auxiliary or secondary cathodes 18<sup>2</sup> to 18<sup>6</sup> may be operated at a potential of the order of 100 to 150 volts positive with respect to the next preceding one. The anode or collector electrode 17 may be maintained of the order of 100 to 150 volts positive with respect to the auxiliary or secondary cathode 18<sup>6</sup>. The potentials for the cathodes may be obtained, as shown in Fig. 6, from a potentiometer or voltage divider including a resistance 35 and a suitable source, such as a rectifier 36, the cathodes being connected to equally spaced taps on the resistance 35. The anode or collector electrode potential may be obtained from a source such as a battery 37.

When the primary cathode 15 is energized or activated, as by a light beam emanating from a source 38 of light of variable intensity and focussed upon the treated or coated surfaces of the cathode 15, a stream of electrons will be emitted from these surfaces. Under the influence of the potential upon the secondary or auxiliary cathode 18<sup>1</sup>, these electrons will flow toward and impinge upon the inner surfaces of this secondary or auxiliary cathode as indicated by the arrow in Fig. 6. The baffle or focussing member 16 and the portions 20 and 21 of the cathode 15 provide field components which assist in focussing the electrons emanating from the cathode 15, upon the auxiliary or secondary cathode 18<sup>1</sup> and also shield this electron stream from the influence of fields external to the vessel 10 and from charges upon the walls of the vessel.

The primary electrons impinging upon the auxiliary or secondary cathode 18<sup>1</sup> cause the copious emission of secondary electrons from the treated or coated inner surfaces of the latter. Because of the treatment or coating of the inner surfaces of the cathode 18<sup>1</sup> as described heretofore, the secondary electron current emanating from this cathode will be several times greater than the

impinging electron stream so that, in effect, an electron multiplication and hence an amplification of the primary current is obtained.

The secondary electrons emanating from the cathode 18<sup>1</sup>, under the influence of the electrostatic fields extant between the cathodes 18<sup>1</sup> and 18<sup>2</sup> traverse paths as indicated by the arrow in Fig. 6 and impinge upon the treated or coated surfaces of the cathode 18<sup>2</sup>. The impinging electrons cause the emission of other and a greater number of secondary electrons from the cathode 18<sup>2</sup> so that a further multiplication and amplification occurs.

The phenomenon above described is repeated at each of the subsequent secondary or auxiliary cathodes 18. The secondary current emanating from the last cathode 18<sup>6</sup>, which current is many times greater than the primary electron current from the primary cathode 15, flows to the anode or collector electrode 17 and constitutes the output current of the multiplier. The magnitude of the output current is proportional to the intensity of the light beam from the source 38 and will vary in accordance with variations in the intensity of this beam. The variations in intensity may be in accordance with a signal of audio or radio frequencies it is desired to amplify.

In electron multipliers having successive electrodes arranged in staggered relation, it has been observed that the various electron streams exhibit a marked tendency to diverge. This tendency is due to a number of factors, among which may be the variations in the initial velocities of the secondary electrons and the complexity of the fields adjacent the emissive surfaces of the cathodes. When such divergence occurs, all of the electrons do not flow to and impinge upon such portions of the next succeeding cathode as will result in utilization thereof. Some of the electrons may impinge upon portions of the next succeeding cathode adjacent which the field has material components in directions other than away from the emissive surface of this succeeding cathode so that secondary emission is retarded or suppressed. Other of the electrons may traverse such paths that they do not impinge upon the next succeeding electrode and, hence, do not contribute to the ultimate output current.

It has been found that this tendency of electron streams to diverge is dependent upon the form of the electrodes, the relative dimensions and spacing thereof and the relative potential differences between the electrodes. In accordance with this invention, the electrode parameters and spacings are so correlated that a high degree of convergence of the several electron streams is obtained and the electron stream emanating from each of the cathodes is focussed upon a restricted portion of the next succeeding electrode.

More specifically, in accordance with one feature of this invention, the auxiliary or secondary cathodes 18 are so constructed and arranged that the two rows thereof have glide plane symmetry with respect to a medial plane passing between the two rows, have symmetry with respect to a longitudinal plane at right angles to the first plane, and have non-symmetry with respect to any plane at right angles to the first two planes. That is to say, with reference to glide plane symmetry, as indicated in Fig. 6, the secondary cathodes 18, which as heretofore noted are substantially identical, are so arranged that if one row, for example the row including the cathodes 18<sup>2</sup>, 18<sup>4</sup> and 18<sup>6</sup>, were displaced a distance  $x$  parallel

to the medial plane passing through the line A—A, each of the cathodes 18<sup>2</sup>, 18<sup>4</sup> and 18<sup>6</sup> would be exactly opposite the corresponding one of the cathodes 18<sup>1</sup>, 18<sup>3</sup> and 18<sup>5</sup> and the two rows would be exactly symmetrical with respect to this medial plane. When the potentials applied to the secondary cathodes 18 increase successively by equal increments, as heretofore described, the electrostatic fields adjacent the electrodes, in devices constructed in accordance with this invention also will possess glide plane symmetry.

However, it has been found important that the two rows of auxiliary or secondary cathodes be non-symmetrical with respect to any plane, such as one passing through the line B—B in Fig. 6, normal to the medial plane mentioned heretofore and to the rows of secondary or auxiliary cathodes. This non-symmetry, it has been found, enables the attainment of a strong field away from a very large portion, e. g. greater than half, of the inner surface of each of the secondary or auxiliary cathode 18 with a consequent copious, efficient and substantially uniform emission of secondary electrons from large portions of the inner surfaces of each of these cathodes.

Also it has been found important that the several auxiliary or secondary cathodes be symmetrical with respect to a medial plane at right angles to both the planes mentioned above, that is at right angles to the medial plane passing through the line A—A and a lateral plane such as one passing through the line B—B.

In electron multipliers having electrodes arranged as above described and dimensioned as noted hereinafter, substantially all of the secondary electrons emanating from the auxiliary or secondary cathodes 18<sup>1</sup> to 18<sup>6</sup>, inclusive, will impinge upon a region of the next succeeding cathode at which the field is away from the surface thereof.

As shown clearly in Figs. 2 and 6, the screen or barrier portions 29 of each of the auxiliary or secondary cathodes 18 projects toward the next preceding opposite cathode and preferably laterally beyond the flange or baffle portion 28 of the adjacent preceding cathode so that electron flow between adjacent electrodes is prevented and the electrons are guided or focussed into such paths that they impinge upon restricted portions of the next succeeding electrode. The flange or baffle portions 28 assist in or augment this guiding or electron focussing action. Each barrier or screen portion 29, furthermore, shields the emissive surfaces of the cathode 18 of which it forms a part from external fields and also from the adjacent preceding cathode so that the field of the latter will not produce a component toward the emissive surfaces and thereby retard or interfere with the secondary emission therefrom.

Typical values illustrative of the ratios of dimensions which will result in the desired convergence of the various electron streams are the following, reference being had to the characters in Figs. 4 and 5.

| Primary cathode | Secondary cathodes  |
|-----------------|---------------------|
| $a=0.7$ inch    | $A=0.283$ inch      |
| $b=0.2$ inch    | $B=0.3$ inch        |
| $c=0.125$ inch  | $D=0.1$ inch        |
| $d=0.15$ inch   | $E=0.2$ inch        |
| $f=0.25$ inch   | $\theta=45$ degrees |

With electrodes of the dimensions set forth above, the plane of the inner surfaces of the sections 19 of the cathodes 18<sup>2</sup>, 18<sup>4</sup> and 18<sup>6</sup> should be spaced from the plane of the inner surfaces of

the cathodes 18<sup>1</sup>, 18<sup>3</sup> and 18<sup>5</sup> 0.55 inch, the upper edge of each section 27 spaced 0.2 inch from the flange 28 of the cathode immediately above and 0.25 inch from the upper edge of the inner surface of the opposite preceding section 27. Each of the electrodes may be 1.0 inch in width. The focussing electrode 13 may be 1.0 inch by 0.3 inch, spaced 0.081 inch from the upper edge of the portion 29 of the auxiliary or secondary cathode 18<sup>1</sup> and at approximately right angles thereto. The base of the anode or collector electrode may be 1.0 inch by 0.425 inch and spaced 0.2 inch from the flange 28 of the cathode 18<sup>5</sup>.

Inasmuch as the potentials for the several cathodes are obtained from a voltage divider as described heretofore, variations in the potential of the source 36 will not affect the relative potential differences between the cathodes. Furthermore, it will be seen that each secondary cathode 18 has thereadjacent a portion 29 of the second succeeding cathode, which is at a potential twice that of the potential of the next succeeding cathode so that a strong field away from the surface of each cathode is obtained.

It will be noted that in the electron multiplier shown and described, the focussing of the several electron streams is accomplished without the use of additional means, such as magnetic fields, separate from the multiplier.

It may be desirable in some instances to remove the portions of the insulating arms 14 between the opposed surfaces of the electrodes in order to reduce edge effects and thereby reduce lateral concentration of the various electron streams.

Reference is made of the application Serial No. 205,930, filed May 4, 1933, of John R. Pierce wherein a related invention is disclosed and claimed.

Although a specific embodiment of this invention has been shown and described and specific values for dimensions given, it will be understood that this embodiment and these values are but illustrative and that various modifications in the structure and changes in the dimensions may be made 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 primary cathode, a collector electrode spaced from said primary cathode, a plurality of auxiliary electrodes successively mounted in staggered relation between said cathode and said collector electrode, each of said auxiliary electrodes having a portion adapted to emit secondary electrons, said portions of successive auxiliary electrodes being substantially parallel, a barrier member extending obliquely from an edge of each of said portions toward the next preceding electrode, and a baffle member adjacent the opposite edge of each of said portions and extending at substantially right angles thereto and toward the next succeeding electrode.

2. An electron multiplier comprising a primary cathode, a collector electrode spaced from said primary cathode, a row of spaced auxiliary electrodes between said cathode and said collector electrode, and a second row of spaced auxiliary electrodes opposite said first row, the auxiliary electrodes in said rows having opposed transversely dishd secondary electron emissive surfaces and being mounted in staggered relation, and the end of each of said auxiliary electrodes toward said collector electrode being spaced from the other row a distance greater than the spac-

ing between the other end of the auxiliary electrode and the other row.

3. An electron multiplier comprising a primary cathode, a collector electrode, a secondary cathode between said primary cathode and said collector electrode having a secondary electron emitting portion parallel to said primary cathode and displaced therefrom toward said collector electrode, and means including members integral with said primary and secondary cathodes respectively and inclined toward each other and including also an auxiliary electrode separate from said cathodes for screening the emissive portions of said primary and secondary cathodes from extraneous fields.

4. An electron multiplier comprising a primary cathode, a collector electrode, a secondary cathode between said primary cathode and said collector electrode, having an emissive surface substantially parallel to and facing toward said primary cathode, said primary and secondary cathodes having barrier portions inclined toward each other, and an electron focussing member opposite said primary cathode.

5. An electron multiplier comprising a primary cathode having an electron emissive surface and an integral barrier portion extending obliquely from said surface, a collector electrode spaced from said cathode, an auxiliary electrode having a secondary electron emissive section and an integral barrier portion extending toward said first barrier portion, and a guiding electrode opposite said emissive surface and mounted adjacent and at an angle to said second barrier portion.

6. An electron multiplier comprising a primary cathode, a collector electrode, a secondary cathode facing toward said primary cathode, an auxiliary cathode facing toward said secondary cathode, said primary, secondary, and auxiliary cathodes having integral flange means for guiding the electrons emanating therefrom, and a plate focussing electrode opposite and inclined with respect to said primary cathode.

7. An electron multiplier comprising a primary cathode, a collector electrode, and a plurality of auxiliary cathodes successively mounted in staggered relation between said primary cathode and said collector electrode, each of said auxiliary electrodes having a plane secondary electron emissive surface, said surfaces of successive auxiliary electrodes being substantially parallel, a barrier member extending from one extremity of said surface and a baffle member extending from the opposite extremity of said surface, said barrier and baffle members being of different areas and extending at unequal angles with respect to the corresponding emissive surface.

8. An electron multiplier comprising a primary cathode, a collector electrode spaced from said cathode, a row of auxiliary electrodes between said cathode and collector electrode, having substantially coplanar secondary electron emissive surfaces, and a second row of auxiliary electrodes having substantially coplanar secondary electron emissive surfaces parallel to said first surfaces and in staggered relation therewith, each of said auxiliary electrodes having a baffle portion extending from the edge of the electron emissive surface thereof adjacent the next electrode in the same row and at right angles thereto, and having also a barrier portion extending from the opposite edge of the electron emissive portion thereof and at an angle of substantially 45 degrees thereto.

9. An electron multiplier comprising an evac-

uated envelope containing a cathode, an anode and a plurality of secondary electron emissive surfaces mounted intermediate said cathode and anode, said secondary electron emissive surfaces being substantially L-shaped and mounted in staggered relation on opposite sides of a median line drawn through the electron path which extends between said cathode and anode, the long legs of said L-shaped surfaces being inclined inwardly toward the cathode terminal of said median line and the short legs of said L-shaped surfaces extending in the direction of said anode and terminating at points substantially equally distant, respectively, from said median line.

10. The invention as set forth in claim 9 and wherein the long leg of each of said L-shaped surfaces intersects a line drawn between the terminals of the short legs of the next two preceding secondary electron emissive surfaces.

11. An electron multiplier comprising a primary cathode, a collector electrode spaced from said primary cathode, and a pair of rows of secondary cathodes between said primary cathode and said collector electrode, each secondary cathode having field shaping portions at opposite ends and extending toward the other row, the secondary cathodes having glide plane symmetry with respect to a medial plane passing between said rows, and each secondary cathode being non-symmetrical with respect to any plane normal to said medial plane and to the longitudinal axes of said rows.

12. An electron multiplier comprising a primary cathode, a collector electrode, and a pair of parallel rows of opposed substantially identical secondary cathodes between said primary cathode and said collector electrode, each of said secondary cathodes having an intermediate electron emissive portion, a baffle portion extending from

one edge of said emissive portion and a second baffle portion extending from the opposite edge of said emissive portion, said first and second baffle portions being of different areas and extending at different angles with respect to said emissive portion, and the secondary cathodes having glide plane symmetry with respect to a medial plane passing between said rows.

13. An electron multiplier comprising a primary cathode, a collector electrode spaced from said primary cathode, and a pair of rows of secondary cathodes extending between said primary cathode and said collector electrode, the secondary cathodes in one row being in staggered face to face relation with those in the other and each of said secondary cathodes having field shaping portions at opposite ends and extending toward the other row, and the field shaping portion at one end being inclined toward the medial plane between said rows at a different angle than the field shaping portion at the other end.

14. An electron multiplier comprising a primary cathode, a collector electrode, and a pair of substantially parallel rows of identical secondary cathodes between said primary cathode and said collector electrode, said secondary cathodes having opposed surfaces dished and the secondary cathodes in one row being in staggered relation with those in the other row, said secondary cathodes having glide plane symmetry with respect to a medial plane extending between said rows and having symmetry with respect to a longitudinal plane normal to said medial plane, and each secondary cathode being unsymmetrical with respect to any plane normal to said longitudinal and medial planes.

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