

May 14, 1940.

J. R. PIERCE ET AL

2,200,722

ELECTRON DISCHARGE DEVICE

Filed May 4, 1938

2 Sheets-Sheet 1

FIG. 1

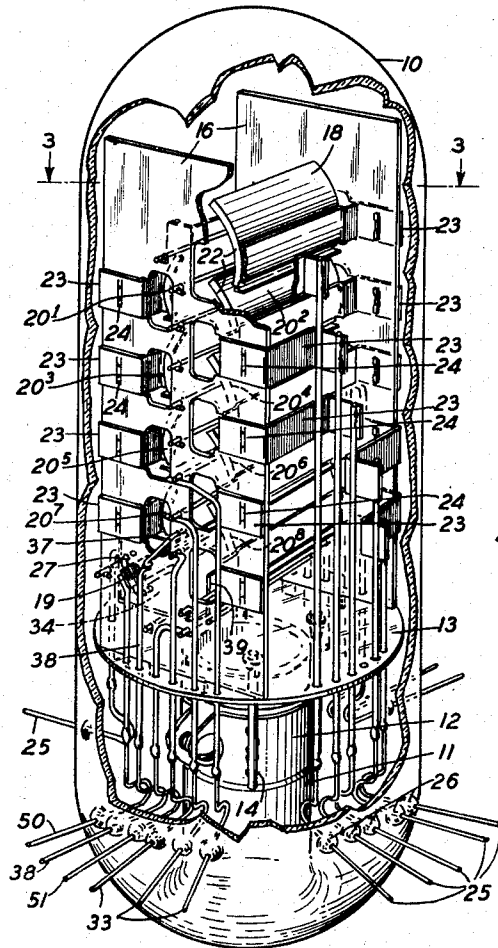


FIG. 2

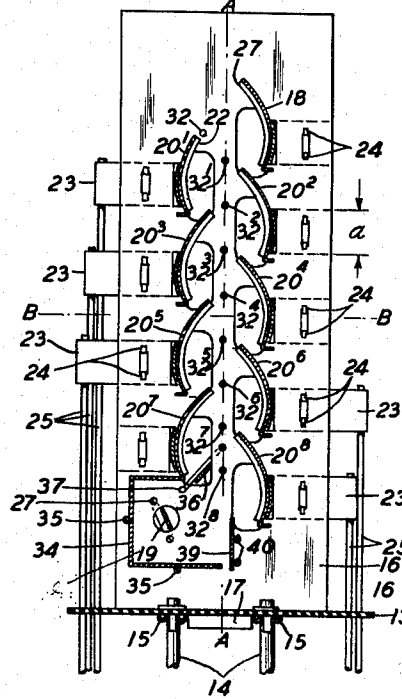


FIG. 3

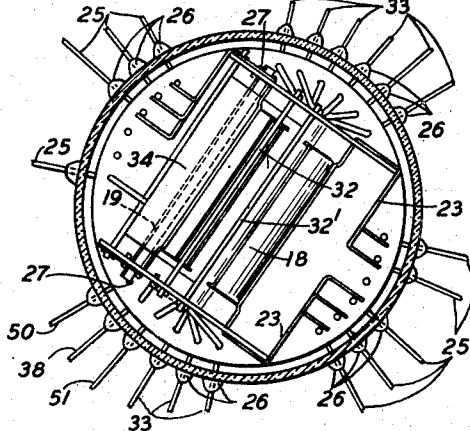
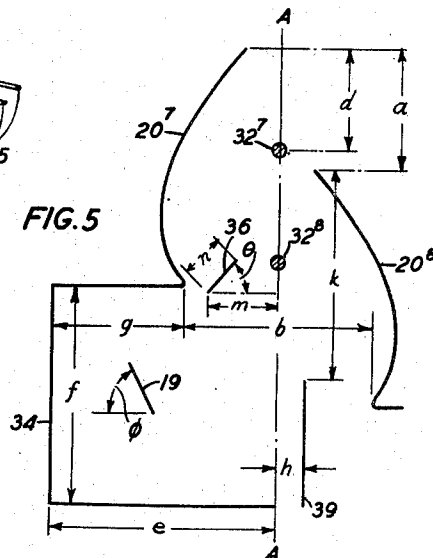


FIG. 5



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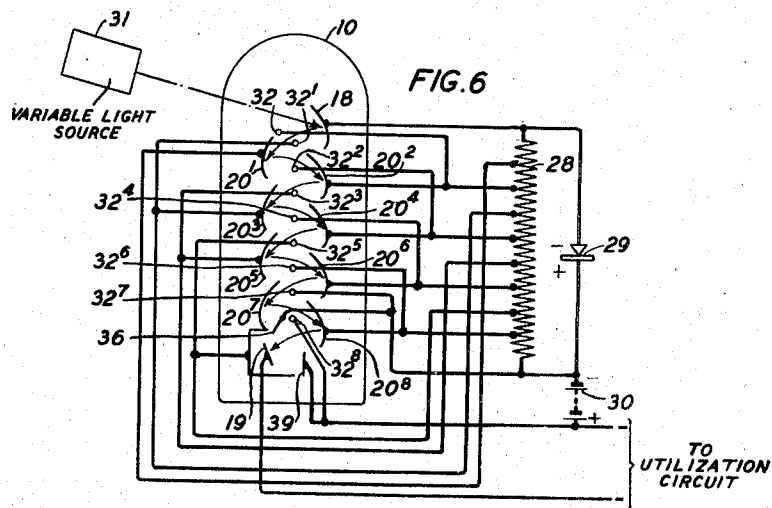
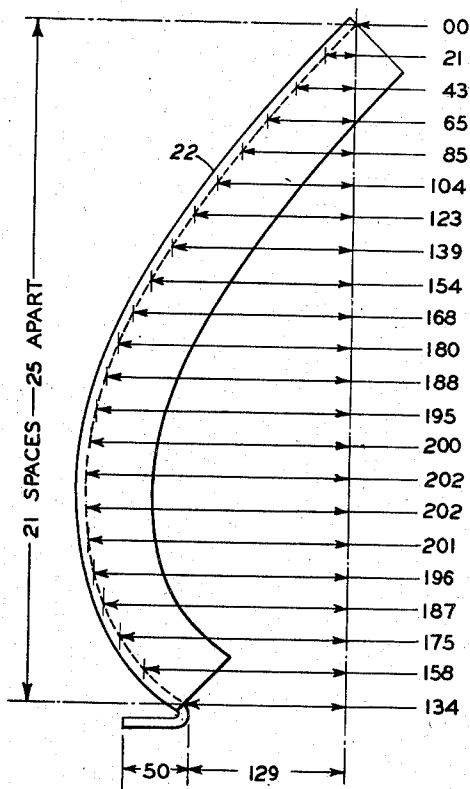
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2 Sheets-Sheet 2

FIG. 4



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2,200,722

ELECTRON DISCHARGE DEVICE

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of New York

Application May 4, 1938, Serial No. 205,929

8 Claims. (Cl. 250-175)

This invention relates to electron discharge devices and more particularly to such devices, such as shown in the applications Serial No. 205,930, filed May 4, 1938, of John R. Pierce, Serial No. 205,931, filed May 4, 1938, of Gordon K. Teal and Serial No. 176,566, filed November 26, 1937, of John R. Pierce and William Shockley, including one or more secondary electron emitting electrodes and generally designated as electron multipliers.

Electron multipliers of a type comprehended by this invention comprise a source of primary electrons, such, for example, as a photoelectric cathode, an anode or collector electrode spaced from the primary electron source, and one or a plurality of secondary electron emissive cathodes between the primary electron source and the anode or collector electrode.

When the primary electron source is energized, electrons are emitted therefrom and these electrons are drawn to and impinge upon the secondary cathode nearest thereto. Because of the character of the surface of the secondary cathode upon which the primary electrons impinge, a secondary electron current several times greater than the impinging primary current emanates from this secondary cathode so that, in effect, an electron multiplication or amplification is obtained. This secondary electron current is drawn to the anode or collector electrode, or to the next succeeding secondary cathode when a plurality of such cathodes are employed.

The operating characteristics of such an electron multiplier are dependent to a large extent upon the direction and intensity of the various fields extant between the various electrodes which fields determine, among other things, the electron trajectories and the character and magnitude of the emission from the various secondary cathodes. The various fields, in turn, are determined primarily by the form of the various electrodes and, more particularly, by the shape of the emissive surfaces of the various cathodes and by the relative disposition of the electrodes.

One general object of this invention is to obtain such fields and distribution thereof in an electron multiplier that efficient and stable operation obtains and uniform characteristics throughout a wide range of interelectrode potentials and input frequencies are achieved.

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

To reduce the over-all voltages required for operation of a multistage electron multiplier;

To assure sharp focussing of the electrons emanating from the last secondary cathode whereby a small area anode or collector electrode may be utilized and hence a low capacity output achieved;

To suppress secondary emission from the anode or collector electrode;

To prevent diffusion of electrons in the vicinity of the anode or collector electrode; and

To effectively segregate the anode or collector electrode from the secondary cathodes whereby the secondary electron current emanating from the last secondary cathode will be substantially unaffected by potential variations occasioned by changes in the current in the output circuit of the multiplier.

In accordance with one feature of this invention, the primary and secondary cathodes in an electron multiplier are so shaped and spatially related that strong fields away from the emissive surfaces thereof obtain and the electrons emanating from each cathode are converged and focussed upon a restricted portion of the next succeeding electrode.

In accordance with another feature of this invention, means are provided in cooperative relation with the anode or collector electrode for producing a "saddle back" in the field adjacent the face of the anode or collector electrode directed toward the last secondary cathode, and a retarding field around the anode or collector electrode.

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, portions of the enclosing vessel and of the electrode structure being broken away to show details more clearly;

Fig. 2 is a side view, mainly in section, of the electrode assembly incorporated in the electron multiplier shown in Fig. 1;

Fig. 3 is a top view along line 3-3 of Fig. 1;

Fig. 4 is an enlarged diagrammatic dimensioned side view of one of the secondary cathodes in the electron multiplier shown in Fig. 1;

Fig. 5 is a diagrammatic detail side view of the collector electrode or anode end of the electrode assembly illustrated in Fig. 2 and incorporated in the multiplier shown in Fig. 1; and

Fig. 6 is a circuit diagram illustrating one manner in which an electron multiplier constructed in accordance with this invention may be operated.

Referring now to the drawings, the electron multiplier there shown comprises a highly evacuated enclosing vessel 10 having at one end thereof an inwardly extending, generally cylindrical

stem 11. Clamped about the stem 11 are a pair of semicircular bands or collars 12 from which the electrodes, fabricated in a unitary assembly, are supported. This assembly comprises an insulating spacer member 13, for example, a mica disc, which is mounted upon a plurality (four) of rigid uprights or posts 14 extending from the bands or collars 12 and affixed to these uprights, as by eyelets 15. Mounted upon the insulating spacer or disc 13 are a pair of parallel insulating uprights 16, such as mica plates, having tongues or projections 17 fitted in parallel slots in the insulating spacer or disc 13.

Mounted between and supported by the insulating uprights 16 are a primary cathode 18, an anode or collector electrode 19 and a plurality of secondary cathodes 20¹ to 20⁸, inclusive, the cathodes being mounted in two parallel rows and in staggered relation. The primary and secondary cathodes are identical in form and dimensions except that the first secondary cathode 20¹ is slightly shorter than the other cathodes, the decrease in length being due to the lesser extension of the upper end thereof.

The various secondary cathodes 20¹ to 20⁸ are so mounted and arranged that they have glide plane symmetry; that is, they are so arranged and mounted that if one row of secondary cathodes were displaced longitudinally a distance a , as indicated in Fig. 2, parallel to the medial plane (see A—A, Fig. 2) between the two rows of cathodes, each cathode in one row would be exactly opposite a corresponding cathode in the other row. Preferably, these cathodes are so mounted and arranged that they are symmetrical with respect to a longitudinal plane normal to the medial plane mentioned above. However, the electrodes do not have symmetry with respect to any plane, such as one passing through the line B—B in Fig. 2, normal to both the medial plane and the longitudinal plane previously mentioned.

Each of the primary and secondary cathodes 18 and 20, respectively, may be formed of a strip of metal, for example, silver, and has a continuously curved portion, the concave surface of which is treated or coated so that the concave surface of the primary cathode 18 is photoelectrically active and the concave surface of each of the secondary cathodes 20 is secondary electron emissive. For example, the concave surface of each of the primary and secondary cathodes may be treated to form thereon a coating or matrix including silver, caesium oxide and some free caesium.

The cathodes 18 and 20 preferably have side flanges 22 which assist in preventing lateral dispersion of the electrons emanating from the emissive surfaces thereof.

Affixed to the outer face of the formed metal cathode strips, as by welding, are support members or brackets which may be, for example, of nickel and have arms 23 bent around the insulating uprights 16. The support or bracket members extend through apertures in the uprights 16 and may be locked to the uprights by integral bent-over tabs 24. Electrical connection to the cathodes 18 and 20 may be established through leading-in conductors 25, each of which is secured to a corresponding one of the arms 23, extends through a suitable aperture in the spacer disc 13 and is sealed in the wall of the enclosing vessel, as indicated at 26.

The anode or collector electrode may be a relatively small area metallic plate disposed oblique-

ly to the medial plane between the rows of secondary cathodes 20 and supported by a pair of bent wires 27 extending through and fitted in suitable apertures in the insulating uprights 16. Leading-in connection to the anode or collector electrode may be made through a conductor 50.

During operation of the electron multiplier, as illustrated in Fig. 6, the cathodes may be maintained at successively equally higher potentials. That is to say, for example, the first secondary cathode 20¹ may be maintained of the order of twenty-five to one hundred volts positive with respect to the primary cathode 18, the next secondary cathode 20² may be maintained of the order of twenty-five to one hundred volts positive with respect to the secondary cathode 20¹, and each succeeding secondary cathode may be maintained similarly positive with respect to the next preceding secondary cathode. The potentials for the various cathodes may be obtained from a potentiometer arrangement including a resistance 28 having equally spaced taps to which the cathodes are connected, the resistance 28 being shunted by a suitable source such as rectifier 29.

The anode or collector electrode 19 may be maintained of the order of twenty-five to one hundred volts positive with respect to the last secondary cathode 20⁸ as by a source such as a battery 30.

When the primary cathode 18 is energized, as by a beam of light emanating from a variable light source 31 focussed thereon, primary or photoelectrons will be emitted from the concave surface thereof. These electrons, under the influence of the fields extant between the primary cathode 18 and the secondary cathode 20¹ will be attracted toward and impinge upon this secondary cathode, thereby causing the emission of secondary electrons from the latter. Inasmuch as the concave surface of a secondary cathode 20¹ is treated or coated as described hereinabove, each impinging primary electron will cause the release of a plurality of secondary electrons so that the secondary electron current emitted from the cathode 20¹ will be greater, for example, four to eight times, than the primary electron current thereto. Consequently, in effect, an electron multiplication and a corresponding amplification of the signal corresponding to the light beam played upon the primary cathode will result.

The secondary electrons emanating from the cathode 20¹, under the influence of the fields between this cathode and the secondary cathode 20², will be drawn toward and impinge upon the latter cathode and cause the release of a still greater number of secondary electrons therefrom. This phenomenon is repeated at each of the secondary cathodes 20 so that the secondary electron current emanating from the secondary cathode 20⁸ will represent a very large amplification of the signal corresponding to the light beam focussed upon the primary cathode 18. The secondary electrons emanating from the cathode 20⁸ are attracted toward and impinge upon the anode or collector electrode 19 and constitute the output current of the electron multiplier.

In order that substantially all of the secondary electrons produced at each of the secondary cathodes 20 will flow away from this surface and travel to the next succeeding electrode, it is necessary that the fields adjacent the concave surface of each of the cathodes be such that the

emanating electrons are accelerated away from these surfaces and, in addition, that the fields be such that the electrons emanating from each concave surface are concentrated and fairly sharply focussed upon a concave surface of the next succeeding electrode. The fields between the various successive electrodes, it has been found, are primarily dependent upon the shape of the electrode surfaces. The proper direction of these fields resulting in copious emission and concentration or focussing of the electrons may be obtained in accordance with this invention by shaping the secondary cathodes so that the concave surfaces are of the form and have the relative dimensions indicated in Fig. 4.

In this figure, the relative dimensions are expressed in units, a typical unit being, for example, one-thousandth of an inch.

The fields adjacent the emitting surfaces of the various cathodes are dependent also upon the relative spacings of these electrodes. The critical spacings are indicated in Fig. 5 wherein a equals 250 units and b equals 418 units, a typical unit being one-thousandth of an inch, as above.

The attainment of optimum fields adjacent the emissive surfaces of the several electrodes may be facilitated by the provision of a plurality of auxiliary or field electrodes 32¹ to 32⁸, inclusive, mounted between the two rows of secondary cathodes 20. In one form, these auxiliary electrodes may be linear small area rods or wires extending between the insulating uprights 16 and fitted in apertures therein. As shown clearly in Fig. 2, the auxiliary electrode 32 may be mounted opposite the concave surface of the primary cathode 18 and immediately adjacent and parallel to the upper edge of the first secondary cathode 20¹. Each of the auxiliary electrodes 32¹ to 32⁷, inclusive, may be mounted opposite the secondary cathode having the same superscript and immediately adjacent and parallel to the upper edge of the secondary cathode having the next higher superscript. The auxiliary electrode 32⁸ may be mounted opposite the concave surface of the last secondary cathode 20⁸. Preferably, as shown in Fig. 2, the auxiliary electrodes 32¹ to 32⁸ are equally spaced and are mounted parallel to one another and in the medial plane extending between the two rows of cathodes.

Individual connection may be established to the auxiliary electrodes 32 by leading-in conductors 33 extending through suitable apertures in the spacer disc 13 and sealed in the wall of the enclosing vessel 10, as indicated at 25.

During operation of the electron multiplier, each of the auxiliary electrodes 32 may be maintained at a higher positive potential than the corresponding opposite cathode and the next succeeding cathode. For example, as shown in Fig. 6, each auxiliary electrode may be maintained at the same potential as the one having the second greater superscript. That is to say, for example, the auxiliary electrode 32 may be maintained at the same potential as the secondary cathode 20², the auxiliary electrode 32¹ may be maintained at the same potential as the secondary cathode 20³, and so on.

Each of the auxiliary electrodes 32 thus operated will produce a strong field component away from the opposite emissive surface. That is, for example, the auxiliary electrode 32 will produce a strong field component away from the concave surface of the primary cathode 18 and each of the auxiliary electrodes 32¹ to 32⁸ will produce a strong field component away from the concave

surface of the secondary cathode 20 having the same superscript. Hence, all of the electrons emanating from the surfaces may be drawn away therefrom and accelerated toward the next succeeding electrode so that the secondary electron current may be voltage saturated even at relatively low interstage voltages and the formation of space charge may be prevented. In addition, these auxiliary electrodes 32 assist in producing convergence of the electron streams and the focussing thereof upon restricted portions of the next succeeding electrodes.

The trajectories of the electron streams between electrodes are indicated by the arrows in Fig. 6 from which it will be noted that the auxiliary electrodes 32 cause a turning or bending of the electron streams. This turning or bending effect is dependent upon the potential of the several auxiliary electrodes 32 and control of the electron streams, therefore, may be effected by varying the potentials of these electrodes. For example, these potentials may be made such that the electrons arrive at each secondary cathode with a substantially grazing incidence, which condition is most favorable to the production of copious secondary emission.

Similarly, by adjustment of the potentials upon the auxiliary electrodes 32, the gain of the multiplier may be varied and its output may be modulated through the controlling of the bending or turning of the electron streams. That is to say, for example, the potentials may be such that the electrons emanating from one or more of the secondary cathodes do not impinge upon the emissive surface of the next succeeding cathode, or impinge upon a portion thereof which does not contribute substantially to electron multiplication.

A particularly desirable location of the auxiliary electrodes is indicated in Fig. 5 wherein d equals 231 units, a typical unit being as given heretofore.

The collector electrode or anode 19 may be substantially enclosed on three sides by an auxiliary or screen electrode 34 which, as shown clearly in Fig. 2, has three walls at right angles to each other and is supported by and between the insulating uprights 16 by a plurality of wires 35 fitted in apertures in the uprights 16. Preferably, this auxiliary or screen electrode is electrically integral with the secondary electrode 20⁷. It may be formed integral with this cathode or fabricated separately and joined to this cathode.

Mounted in cooperative relation with the secondary cathodes 20⁷ and 20⁸ and the anode or collector electrode 19 is a baffle or field plate 36 which is supported by bent wires 37 fitted in apertures in the insulating upright 16 and extends obliquely toward the medial plane between the rows of secondary cathodes. Leading-in connection to the baffle or field plate 36 may be established through a conductor 38.

A second baffle or field plate 39, having a leading-in conductor 51, is provided adjacent the lower end of the last secondary cathode 20⁸ and may be supported by wires 40 extending between and fitted in suitable apertures in the insulating uprights 16. As shown clearly in Fig. 5, the baffle or field plate 39 is slightly offset with respect to the medial plane passing between the rows of secondary cathodes and is parallel thereto.

Specific dimensions and spacings for the auxiliary or screen electrode 34, baffle or field electrodes

36 and 39 and anode or collector electrode 19 are indicated in Fig. 5 wherein

$e=531$	$k=475$
$f=469$	$m=165$
$g=322$	$n=100$
$h=72$	$\theta=45$ degrees,
and $\phi=63$ degrees	

In the above table the dimensions are expressed in units, a typical unit being the same as given hereinbefore.

During the operation of the device, as indicated in Fig. 6, the baffle or field plate 36 may be maintained at the same potential as the auxiliary electrode 32' and the baffle or field electrode 39 may be operated at the same potential as the auxiliary electrode 32⁸.

During the operation of the electron multiplier, the secondary electrons emanating from the last secondary cathode 20⁸ are subjected to strong fields accelerating them toward the medial or symmetry plane and they finally arrive at the anode or collector electrode 19, the fields being produced by the baffle or field electrodes 36 and 39 and by the auxiliary electrode 32⁸. In passing from the symmetry plane to the anode or collector electrode, these secondary electrodes cross a saddle back in the potential field due to the potentials of the secondary cathode 20', the field electrodes 36 and 39, and the screen or shield electrode 34. They are accelerated toward the anode or collector electrode and focused upon it.

The screen electrode 34 and the baffle or field electrode 36 or 39, as previously noted, produce a saddle back in the potential field in front of the anode or collector electrode 19, that is, the face thereof toward the secondary electrode 20⁸, and produce also a retarding field around the anode or collector electrode 19. Hence, secondary electrons are prevented from passing from the anode or collector electrode to the baffle or plate electrodes 36 and 39 and the use of an additional or higher collector electrode potential is rendered unnecessary. In addition, this arrangement of the electrodes assures that the electron current arriving at the anode or collector electrode 19 is substantially unaffected by potential changes arising from or attributable to changes in the current of the output circuit.

It may be noted, also, that the electrons emanating from the last secondary cathode 20⁸ are concentrated and sharply focused so that a small area collector electrode or anode may be utilized and, hence, a low capacity output achieved.

Furthermore, because of this construction, electron diffusion in the vicinity of and around the anode or collector electrode is prevented so that the building up of charges on the adjacent portion of the enclosing vessel or the production of fluorescence thereat is prevented.

Although a specific embodiment of this invention has been shown and described, it will be understood that this embodiment and also the specific parameters given are but illustrative and that various modifications may be made therein without departing from the scope of this invention as defined in the appended claims.

What is claimed is:

1. An electron multiplier comprising a pair of electron emissive members and an anode mounted successively in staggered relation; and a shield member enclosing said anode on three sides and

having an open side toward the emissive member opposite said anode, said shield member being electrically integral with the other electron emissive member.

2. An electron multiplier comprising a primary cathode, a collector electrode, a secondary cathode between said primary cathode and said collector electrode and having an electron emissive surface facing said collector electrode, and a pair of field electrodes between said surface and said collector electrode and mounted obliquely to said collector electrode.

3. An electron multiplier comprising a primary cathode, a collector electrode, a secondary cathode between said primary cathode and said collector electrode and having an electron emissive surface toward said collector electrode, and a pair of auxiliary electrodes opposite spaced portions of said surface for focussing electrons emanating therefrom upon said collector electrode said auxiliary electrodes being mounted at different angles with respect to said collector electrode.

4. An electron multiplier in accordance with claim 3 comprising means having portions opposite the surface of said collector electrode remote from said first surface for preventing diffusion of electrons about said collector electrode.

5. An electron multiplier comprising a primary cathode, a collector electrode, a secondary cathode between said primary cathode and said collector electrode and having an emissive surface facing said collector electrode, and means for shaping the field between said surface and said collector electrode including electrodes between said surface and said collector electrode and an electrode partially encompassing said collector electrode.

6. An electron multiplier comprising a primary cathode, a collector electrode, a secondary cathode having an electron emissive surface opposite and facing said collector electrode, and a second secondary cathode between said primary and first secondary cathodes, and having an emissive surface facing and opposite said first surface, said second secondary cathode having an integral shield portion extending about said collector electrode.

7. An electron multiplier comprising a primary cathode, a collector electrode, a secondary cathode having a dished emissive surface facing said collector electrode, a second secondary cathode having a dished emissive surface facing said first surface, a field electrode between said first surface and said collector electrode, and a second field electrode between said dished surfaces, said field electrodes being disposed on opposite sides of a medial plane passing between said dished surfaces.

8. An electron multiplier comprising a pair of parallel rows of secondary cathodes having opposed surfaces dished transverse to the longitudinal axis of said rows, the cathodes in one row being in staggered relation with those in the other, a primary cathode at one end of said rows, a collector electrode at the other end of said rows, a plurality of accelerating electrodes between said rows, and a plurality of field shaping electrodes mounted in the vicinity of said anode and on opposite sides of a medial plane normal thereto.

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