

July 9, 1940.

W. SHOCKLEY

2,207,355

ELECTRON DISCHARGE DEVICE

Filed Aug. 31, 1938

2 Sheets-Sheet 1

FIG. 1

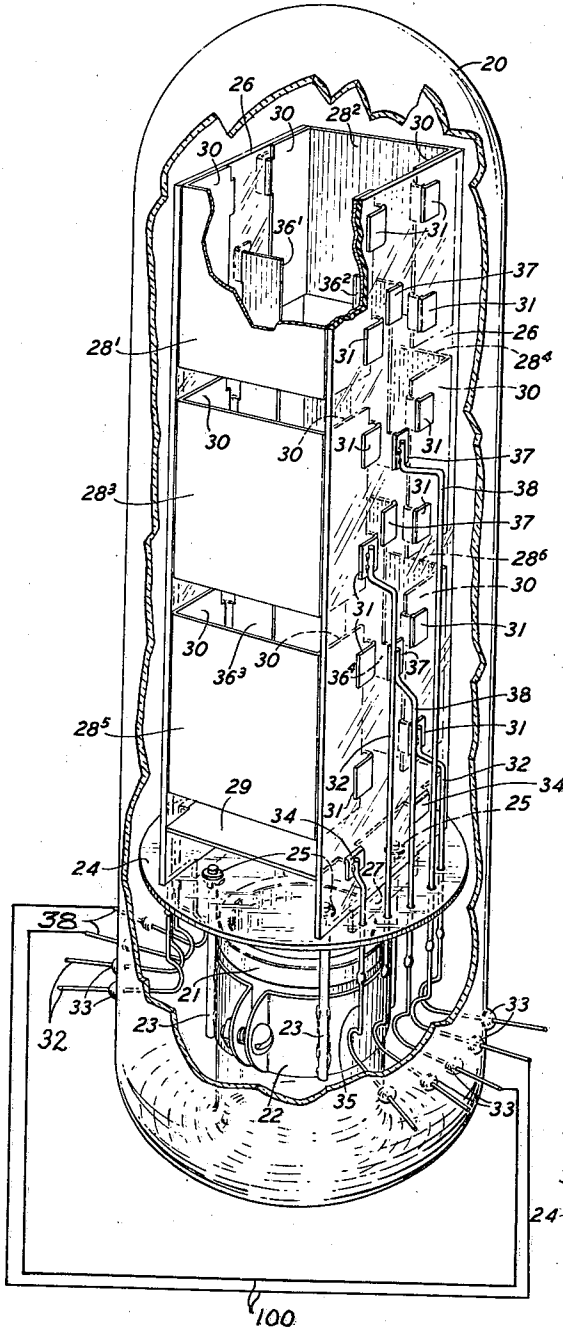


FIG. 2

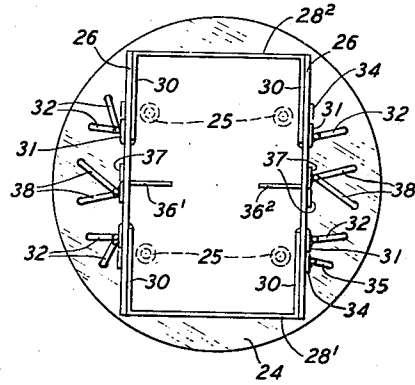
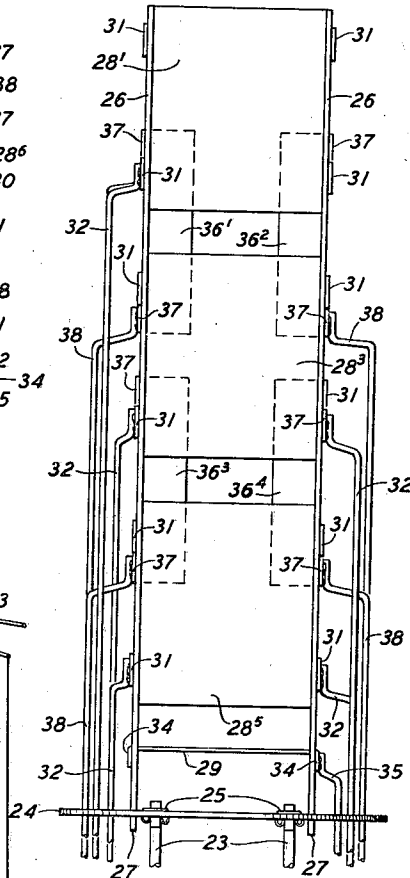


FIG. 3



INVENTOR
W. SHOCKLEY

BY

Walter C. Kiesel
ATTORNEY

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W. SHOCKLEY

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FIG. 4

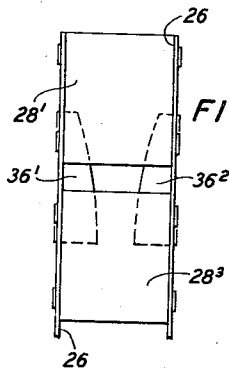
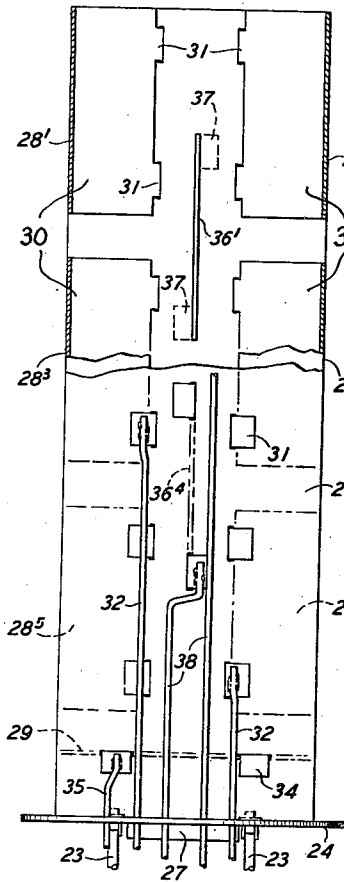


FIG. 5

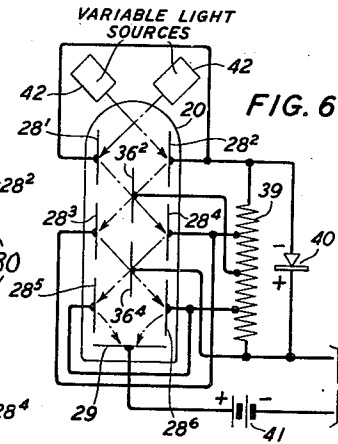


FIG. 6

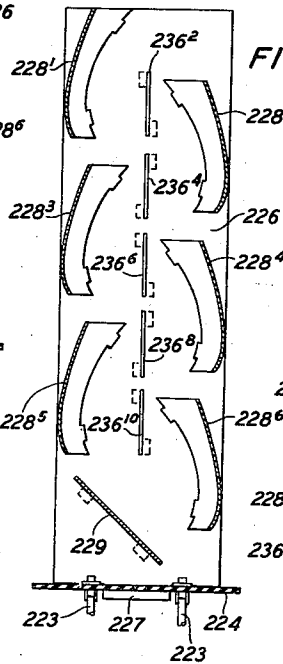


FIG. 9

FIG. 7

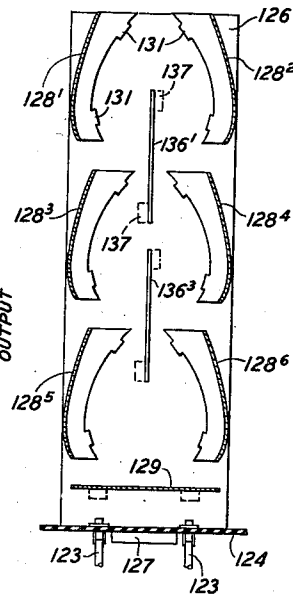


FIG. 10

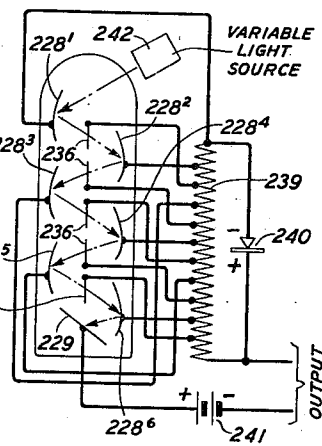
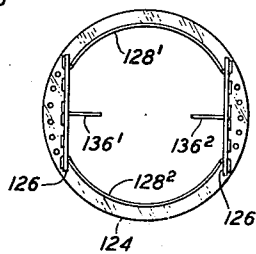


FIG. 8



INVENTOR
W. SHOCKLEY
BY
Walter C. Kiesel
ATTORNEY

UNITED STATES PATENT OFFICE

2,207,355

ELECTRON DISCHARGE DEVICE

William Shockley, New York, N. Y., assignor to
Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Application August 31, 1938, Serial No. 227,649

20 Claims. (Cl. 250-175)

This invention relates to electron discharge devices and more particularly to such devices having a plurality of cooperatively associated secondary electron emitting electrodes and generally known as electron multipliers.

One object of this invention is to facilitate the attainment of manifold amplification of electrical or optical impulses.

Another object of this invention is to obtain a high degree of lateral convergence of the electron streams in an electron multiplier.

A further object of this invention is to attain focussing of the electron streams emanating from the emitting electrodes in a multi-stage electron multiplier, upon the next succeeding electrode.

Still another object of this invention is to produce strong accelerating fields away from the emissive surfaces of the cathodes in a multi-stage electron multiplier whereby space charge effects are avoided and efficient and stable operation are achieved.

In one illustrative embodiment of this invention, an electron multiplier comprises a plurality of electron emitting members or cathodes mounted in two rows and having opposed electron emissive surfaces, and an anode or collector electrode at one end of these rows. Corresponding electron emitting members in the two rows may be directly opposite one another or the several emitting members may be mounted in staggered relation.

In accordance with one feature of this invention, auxiliary electrodes are provided between the emissive surfaces of certain of the electron emitting members for laterally confining the electrons emanating from each surface and focussing the electron streams from each emitting member upon the next succeeding electrode. In one form, the auxiliary electrodes may be plate members projecting inwardly from between opposite edges of the secondary electron emitting members.

In accordance with another feature of this invention, the electron emissive members or cathodes are provided with laterally and longitudinally concave emissive surfaces whereby concentration and focussing of the various electron streams is effected.

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 wherein;

Fig. 1 is a perspective view of an electron mul-

tiplier illustrative of one embodiment of this invention, portions of the enclosing vessel and of one of the electrodes being broken away to show details of the electrode structure more clearly;

Figs. 2 and 3 are top and front elevational views respectively of the electrode structure embodied in the electron multiplier shown in Fig. 1;

Fig. 4 is a side elevational view of this electrode structure, portions being broken away to show details more clearly;

Fig. 5 is a detail view showing a modification of the embodiment of this invention illustrated in Figs. 1 to 4;

Fig. 6 is a circuit diagram illustrating one manner in which the electron multiplier shown in Fig. 1 may be operated;

Fig. 7 is a side view in section of the electrode structure for an electron multiplier illustrative of another embodiment of this invention;

Fig. 8 is a top view of the electrode structure illustrated in Fig. 7;

Fig. 9 is a side view in section of a modification of the electrode structure illustrated in Figs. 7 and 8; and

Fig. 10 is a circuit diagram illustrating one manner of operating an electron multiplier having an electrode structure of the construction illustrated in Fig. 9.

Referring now to the drawings, the electron multiplier illustrated in Figs. 1 to 4 comprises an elongated, evacuated enclosing vessel 20 having at one end an inwardly extending stem 21. Clamped about the stem 21 is a split metallic collar or band 22 having extending therefrom a plurality of rigid supports or rods 23 which support an electrode assembly from the band or collar 22.

The electrode assembly comprises an insulating member 24, such as a disc of mica, securely affixed to the supports or rods 23, as by eyelets 25, and a pair of parallel insulating uprights or arms 26, which also may be of mica, having extensions or tongues 27 fitted in parallel slots in the disc 24.

Mounted between the uprights or arms 26 and supported thereon are a plurality of similar cathodes 28¹ to 28⁶ inclusive arranged in two parallel rows, and an anode or collector electrode 29 disposed adjacent the disc 24. The cathodes 28 may be formed of sheet metal, for example, silver, and each cathode includes an intermediate plane portion, side flanges 30 abutting the uprights or arms 26, and integral tabs or fingers 31 extending through apertures in the uprights or arms and bent thereagainst to lock the cathodes in posi-

tion. The inner surface of the intermediate plane portion of one or both of the cathodes 28¹ and 28² is treated or coated to render it photoelectrically active and the inner surface of the intermediate portion of each of the cathodes 28³ to 28⁶, inclusive, is treated or coated to render it capable of copious emission of secondary electrons. For example, the inner surface of the intermediate portion of each of the cathodes may be treated to form thereon a matrix or coating including silver, caesium oxide and some free caesium.

As shown in Figs. 2 and 4, the emissive surfaces of the cathodes 28¹, 28³ and 28⁵ may be coplanar and parallel to the emissive surfaces of the cathodes 28², 28⁴ and 28⁶, which also may be coplanar. Each of the cathodes in one row is directly opposite a corresponding cathode in the other row. As shown in Figs. 3 and 4, the cathodes in each row are equally spaced, although in some cases it may be desirable to have unequal spacings between successive cathodes in the same row.

Suitable connection between the cathodes 28 and external circuits may be established through leading-in conductors 32 sealed in the wall of the vessel 20 as indicated at 33 and each connected to one of the fingers or tabs 31 on one of the cathodes.

The anode or collector electrode 29 may be a metallic plate having a number of integral tabs or flanges 34 extending through slots in the arms 26 and bent against these arms to lock the anode or collector electrode in position. Electrical connection to the anode or collector electrode may be established through a leading-in conductor 35 affixed to one of the tabs or flanges 34.

Extending between the opposed surfaces of the cathodes 28 are a plurality of similar auxiliary electrodes 36¹ to 36⁴, inclusive, which may be flat metallic plates having tabs or flanges 37 extending through the arms 26 and bent thereagainst to lock the plates in position. As shown clearly in Fig. 2, opposite auxiliary electrodes are substantially coplanar and are located midway between the emissive surfaces of the cathodes 28. As shown clearly in Fig. 3, each of the auxiliary electrodes 36 extends between two pairs of the cathodes 28. For example, the auxiliary electrode 36¹ extends between the emissive surfaces of the cathodes 28¹ and 28² and also between the emissive surfaces of the cathodes 28³ and 28⁴. Preferably, the auxiliary electrodes extend opposite equal portions of adjacent cathodes in the same row.

Electrical connection to the auxiliary electrodes 36 may be established through leading-in conductors 38 each affixed to one of the tabs or flanges 37 and sealed in the vessel 20 as indicated at 33.

The relative dimensions of the cathodes and the auxiliary electrodes and the spacing thereof affect the operating characteristics of the electron multiplier. In one specific embodiment, the width of the cathodes, as measured between the flanges 30, may be twice the width of the flanges and the distance between the opposed emissive surfaces of the cathodes may be 1½ times the width of the cathodes. Each of the auxiliary electrodes 36 may extend inwardly a distance one-quarter that between the arms or uprights 26.

During operation of the multiplier in one way illustrated in Fig. 6, directly opposite cathodes may be tied together electrically and maintained

at the same potential. The cathodes 28³ and 28⁴, tied together, may be maintained at a positive potential, for example, of the order of 100 volts, with respect to the cathodes 28¹ and 28², and the cathodes 28⁵ and 28⁶, tied together, may be maintained positive, for example of the order of 100 volts, with respect to the cathodes 28³ and 28⁴. The requisite potentials may be obtained from a voltage divider including a resistance 39 and a suitable direct current source such as a rectifier 40. The auxiliary electrodes 36¹ and 36² may be connected together, for example through their respective leading-in conductors 38 and wires 100 as illustrated in Fig. 1, and maintained at a positive potential, for example, of the order of 150 volts, higher than that of the cathodes 28³ and 28⁴. Similarly, the auxiliary electrodes 36³ and 36⁴ may be connected together and maintained at a potential, for example, of the order of 150 volts, higher than that of the cathodes 28⁵ and 28⁶. The anode or collector electrode 29 may be maintained at a positive potential, for example, of the order of 100 volts, with respect to the auxiliary electrodes 36³ and 36⁴, by a suitable source such as a battery 41.

When the cathodes 28¹ and 28² are energized, as by beams of light emanating from variable light sources 42, primary or photoelectrons are emitted therefrom. These electrons, under the influence of the fields produced by the cathodes 28³ and 28⁴ and the auxiliary electrodes 36¹ and 36², flow to the cathodes 28³ and 28⁴, as indicated by the arrows in Fig. 6, and impinge thereon. The impinging electrons cause the emanation of secondary electrons from the cathodes 28³ and 28⁴. These secondary electrons flow to and impinge upon the cathodes 28⁵ and 28⁶ and cause the release of other secondary electrons which flow to the anode or collector electrode 29 and constitute the output current.

Inasmuch as, as described heretofore, the opposed surfaces of the cathodes 28³ to 28⁶ are treated or coated, the secondary emission therefrom will be greater than the electron current thereto. Hence, an electron multiplication and, therefore, an amplification of the signal corresponding to the energizing light beams occurs at each of the cathodes 28³ to 28⁶ so that the output current represents a manifold amplification of the signal.

The auxiliary electrodes 36, it will be noted, being at a higher potential than the cathodes between which they extend, produce strong fields away from the emissive surfaces of the cathodes so that substantially all of the electrons emitted by each cathode are drawn away therefrom and accelerated toward the electrode upon which they are intended to impinge. Consequently, undesirable space charge effects are avoided and efficient and stable operation is attained.

The auxiliary electrodes serve also to confine or converge laterally the electron streams flowing between the electrodes and this lateral confinement or convergence is augmented by the effect of the flanges 30 on the cathodes. Hence, concentration of the electron streams and focusing thereof upon the proper succeeding electrode are obtained.

Although in the embodiment illustrated in Figs. 1 to 4, the opposed edges of the auxiliary electrodes 36 are shown as straight, parallel and uniformly spaced, they may be of other shapes, for example, curved as illustrated in Fig. 5, so that the spacing thereof decreases toward the anode

or collector electrode 29 and the fields produced thereby vary along the length thereof. These edges may be made of various forms and spaced in different ways to control the trajectories of the electrons and produce focusing of the electron streams upon restricted portions of the electrodes upon which the streams impinge.

Although in Fig. 6 the two sources 42 are poled alike and a single anode is shown, two anodes may be provided and the sources 42 so poled and energized that as the current to one anode increases, that to the other anode decreases by a like amount. There are provided, then, two electrode groups operable in push-pull, one group including the cathodes 28¹, 28⁴ and 28⁵ and the other including the cathodes 28², 28³ and 28⁶.

In another embodiment of this invention, illustrated in Figs. 7 and 8, wherein elements corresponding to those shown in Figs. 1 to 4 are identified by the same numeral increased by 100, the cathodes 128¹ to 128⁶, inclusive, may be curved longitudinally, or both longitudinally and laterally, so that the directions of the fields away therefrom are such as to produce a convergence of the electron streams and focussing thereof upon the proper succeeding electrode obtains.

An electron multiplier including an electrode assembly of the construction illustrated in Figs. 7 and 8 may be operated in the same manner as described with reference to Fig. 6.

In the embodiment of this invention, illustrated in Figs. 9 and 10, wherein elements corresponding to those of Figs. 1 to 4 are identified by the same reference numeral increased by 200, the cathodes 228 may be of the same form as in Figs. 7 and 8 and are mounted in two similar rows and in staggered relation and two rows of auxiliary electrodes 236, only one row of which is shown, are provided. The auxiliary electrodes 236 may extend inwardly from between adjacent edges of successive cathodes in the manner shown in Fig. 8, each auxiliary electrode being directly opposite to another extending from the opposite side of the structure. Each laterally opposite pair of auxiliary electrodes is mounted between the lower portion, that is, the portion toward the anode or collector electrode, of one cathode, and the upper portion of the next succeeding cathode. For example, the auxiliary electrode 236² and the one (not shown) laterally opposite thereto are mounted between the lower portion of the cathode 228¹, which serves as the primary cathode, and the upper portion of the first secondary cathode 228².

As illustrated in Fig. 10, the secondary cathodes 228² to 228⁶ may be operated at successively higher equal positive potentials, the potentials being obtained from a voltage divider including the resistance 239 and a source, such as rectifier 240. For example, each secondary cathode may be maintained at a potential of the order of 100 volts positive with respect to the cathode having the next lower superscript. The laterally opposite auxiliary electrodes 236 may be tied together electrically and each pair operated at a positive potential higher than that of the cathodes between which they extend. For example, the auxiliary electrode 236² and the one laterally opposite thereto may be operated at a positive potential of the order of 50 or 100 volts higher than that of the cathode 228². The other pairs of auxiliary electrodes may be operated at similar higher potentials with respect to the cathodes corresponding thereto. The anode or collector electrode may be maintained of the order of 100

volts positive with respect to the auxiliary electrodes nearest thereto, as by a battery 241.

When the primary cathode 228¹ is energized, as by a beam of light emanating from a source 242, primary or photoelectrons are emitted therefrom and, as described heretofore in connection with Fig. 6, secondary electrons are emitted by each of the cathodes 228² to 228⁶, inclusive, the trajectories of the electron streams being indicated generally by the arrows in Fig. 10.

It will be noted that in multipliers constructed in accordance with this invention, a high degree of convergence of the electron streams and sharp focussing thereof may be obtained without the use of magnetic fields or other media separate from the electrodes of the multiplier.

Although various embodiments of this invention have been shown and described, it will be understood that they are but illustrative and that various modifications may be made therein without departing from the scope and spirit of the invention as defined in the appended claims. For example, although photoelectric primary cathodes have been shown, thermionic primary cathodes may be used and the primary current controlled or modulated by a grid in cooperative relation with the primary cathode.

What is claimed is:

1. An electron multiplier comprising a pair of cathodes having longitudinal edges and opposed electron emissive surfaces, a collector electrode opposite one end of said surfaces, and an auxiliary electrode mounted between said surfaces and extending adjacent and in the same direction as corresponding longitudinal edges of said surfaces.
2. An electron multiplier comprising a plurality of electron emissive members mounted in two rows with the emissive surfaces thereof facing one another, a collector electrode at one end of said rows, and a plurality of auxiliary electrodes substantially parallel to said rows and extending inwardly from points adjacent opposite sides of said emissive surfaces.
3. An electron multiplier comprising a row of cathodes, a second row of cathodes each having its emissive surface opposite the emissive surface of a corresponding one of said first cathodes, a collector electrode at one end of said rows, and a row of auxiliary electrodes each extending inwardly from one side of said rows and between directly opposite portions of the emissive surfaces of corresponding cathodes.
4. An electron multiplier comprising a pair of cathodes mounted in spaced relation and having juxtaposed edges and facing emissive surfaces, a collector electrode, and a pair of plate auxiliary electrodes each extending inwardly between said cathodes from adjacent the juxtaposed edges thereof and overlying portions of said surfaces.
5. An electron multiplier in accordance with claim 4, wherein said auxiliary electrodes are substantially coplanar plate members.
6. An electron multiplier comprising a row of cathodes, a second row of cathodes each opposite a corresponding one of said first cathodes, the cathodes in said rows having opposed emissive surfaces, a collector electrode at one end of said rows, and a plurality of auxiliary electrodes extending inwardly from the sides of said rows, each of said auxiliary electrodes overlying portions of the emissive surfaces of two successive pairs of corresponding cathodes.
7. An electron multiplier in accordance with claim 6, wherein the emissive surfaces of the

cathodes in each row are substantially parallel to the emissive surfaces of the cathodes in the other row, and said auxiliary electrodes include plate portions substantially parallel to said emissive surfaces.

8. An electron multiplier comprising a plurality of cathodes mounted in staggered relation and having facing emissive surfaces, a collector electrode, and a plurality of auxiliary electrodes spaced from and extending inwardly with respect to the sides of said cathodes, each auxiliary electrode overlying portions of the emissive surfaces of two successive cathodes.

9. An electron multiplier comprising a plurality of electron emissive members having their emissive surfaces facing one another, a collector electrode, and a plurality of pairs of auxiliary electrodes extending inwardly from points spaced from and adjacent opposite sides of said emissive members and overlying portions of said surfaces.

10. An electron multiplier in accordance with claim 9, wherein the auxiliary electrodes of each pair include substantially coplanar plate portions.

11. An electron multiplier comprising a row of cathodes, a second row of cathodes, the cathodes in said rows having facing electron emissive surfaces, a collector electrode at one end of said rows, and a plurality of pairs of auxiliary electrodes spaced from said cathodes and extending inwardly with respect to opposite sides of said cathodes, the auxiliary electrodes of each pair having portions opposite one of said cathodes in one row and opposite the nearest cathode in the other row.

12. An electron multiplier in accordance with claim 11, wherein each cathode in one row is opposite a corresponding cathode in the other row and each auxiliary electrode extends between two successive pairs of corresponding cathodes.

13. An electron multiplier in accordance with claim 11, wherein the auxiliary electrodes of each pair include substantially coplanar portions.

14. An electron multiplier in accordance with

claim 11, wherein the cathodes in each row have substantially coplanar emissive surfaces, the emissive surfaces of the cathodes in the two rows are substantially parallel, and said auxiliary electrodes include planar portions substantially parallel to said surfaces.

15. An electron multiplier comprising a plurality of electron emissive members having electron emissive surfaces facing each other, and a collector electrode, said surfaces being laterally and longitudinally concave, and the longitudinal curvature thereof being of varying radius.

16. An electron multiplier in accordance with claim 15, comprising a plurality of auxiliary electrodes extending inwardly with respect to the sides of said electron emissive members.

17. An electron multiplier comprising a pair of rows of cathodes having opposed electron emissive surfaces, said surfaces being laterally and longitudinally concave and of unsymmetrical longitudinal curvature, and a collector electrode adjacent one end of said rows.

18. An electron multiplier in accordance with claim 17, comprising a plurality of pairs of auxiliary electrodes extending inwardly from points adjacent opposite sides of said cathodes, each auxiliary electrode having a portion opposite one of the cathodes in one row and the nearest cathode in the other row.

19. An electron multiplier comprising a collector electrode, and a plurality of electron emissive members mounted in staggered relation in two opposite rows and having their inner surfaces laterally and longitudinally concave, and the longitudinal curvature of said surfaces being of varying radius.

20. An electron multiplier in accordance with claim 19, comprising a plurality of auxiliary electrodes spaced from and extending inwardly from adjacent the longitudinal edges of said members, each auxiliary electrode being opposite portions of two successive cathodes.

WILLIAM SHOCKLEY.