April 23, 1940. E. W. PIKE ET AL 2,198,227

ELECTRON MULTIPLIER

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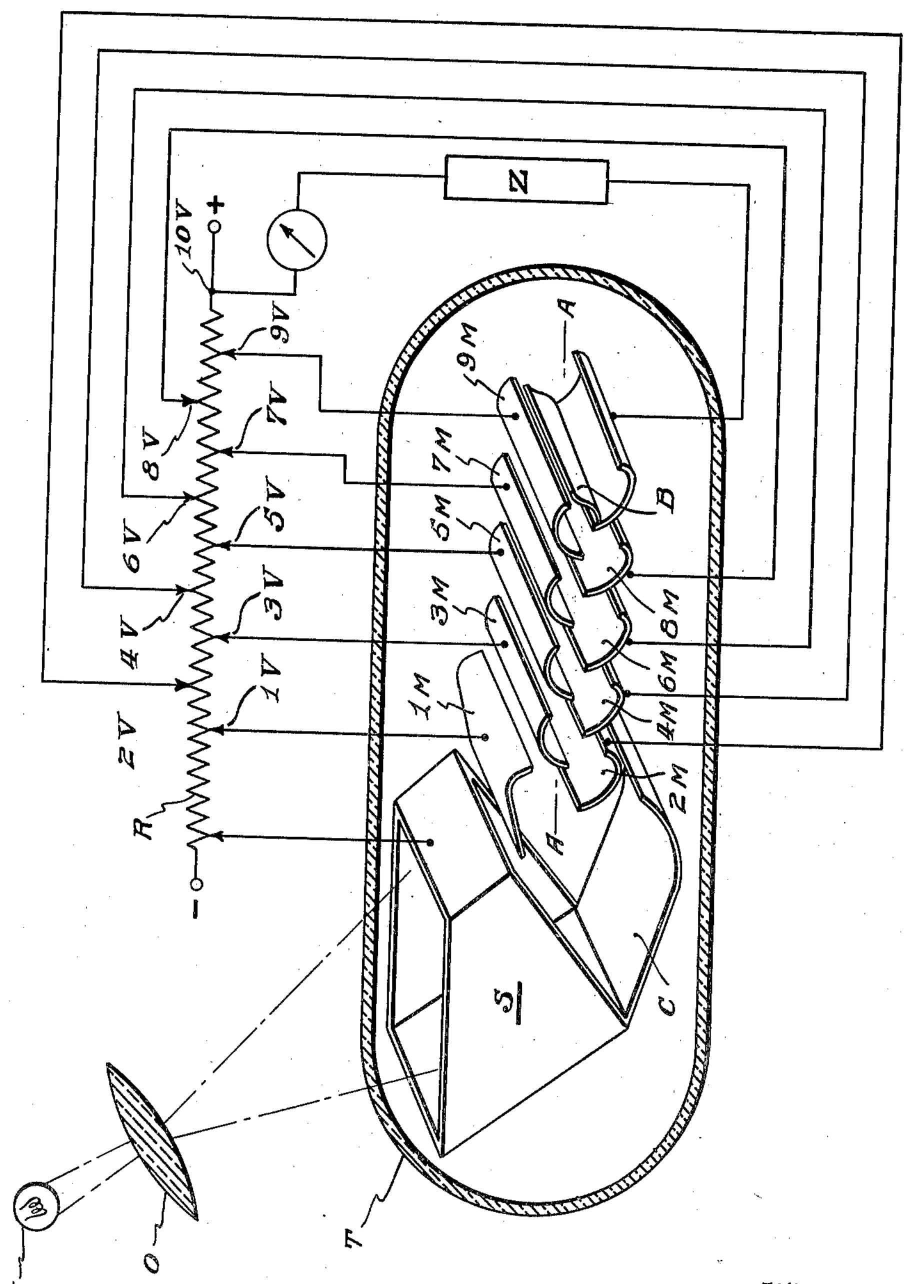

FIG. 1.

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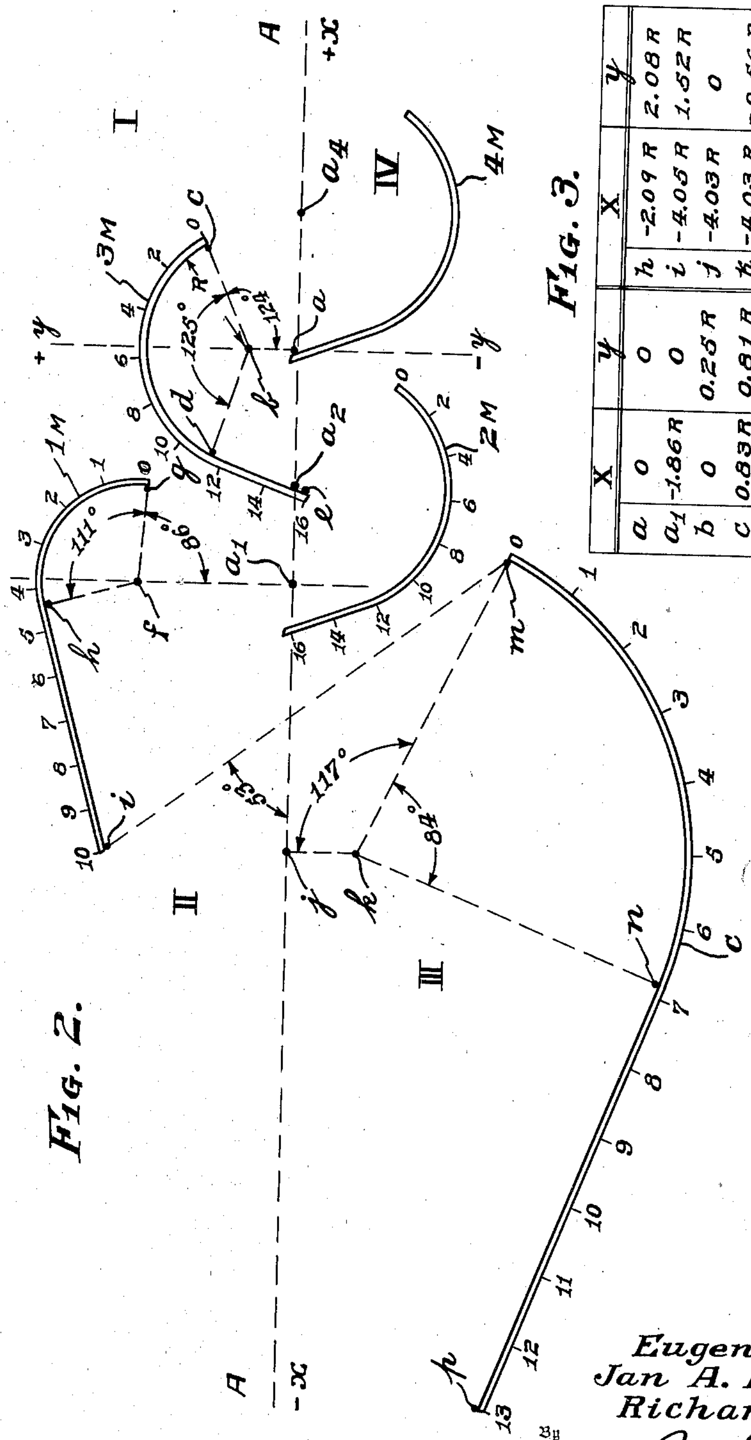

FIG. 2.

FIG. 3.

	X	Y		X	Y
a	0	0	h	-2.09 R	2.08 R
a_1	-1.86 R	0	i	-4.05 R	1.52 R
b	0	0.25 R	j	-4.03 R	0
c	0.83 R	0.81 R	k	-4.03 R	-0.56 R
d	-0.93 R	0.61 R	m	-1.58 R	-1.80 R
e	-1.19 R	-0.06 R	n	-5.01 R	-3.11 R
f	-1.86 R	1.29 R	p	-8.41 R	-1.77 R
g	-1.04	1.23			

	X	Y
a_n	$(n-3)\,1.09R$	0
b_n	$(n-3)\,1.09R$	$0.25(-1)^{(n-1)}$

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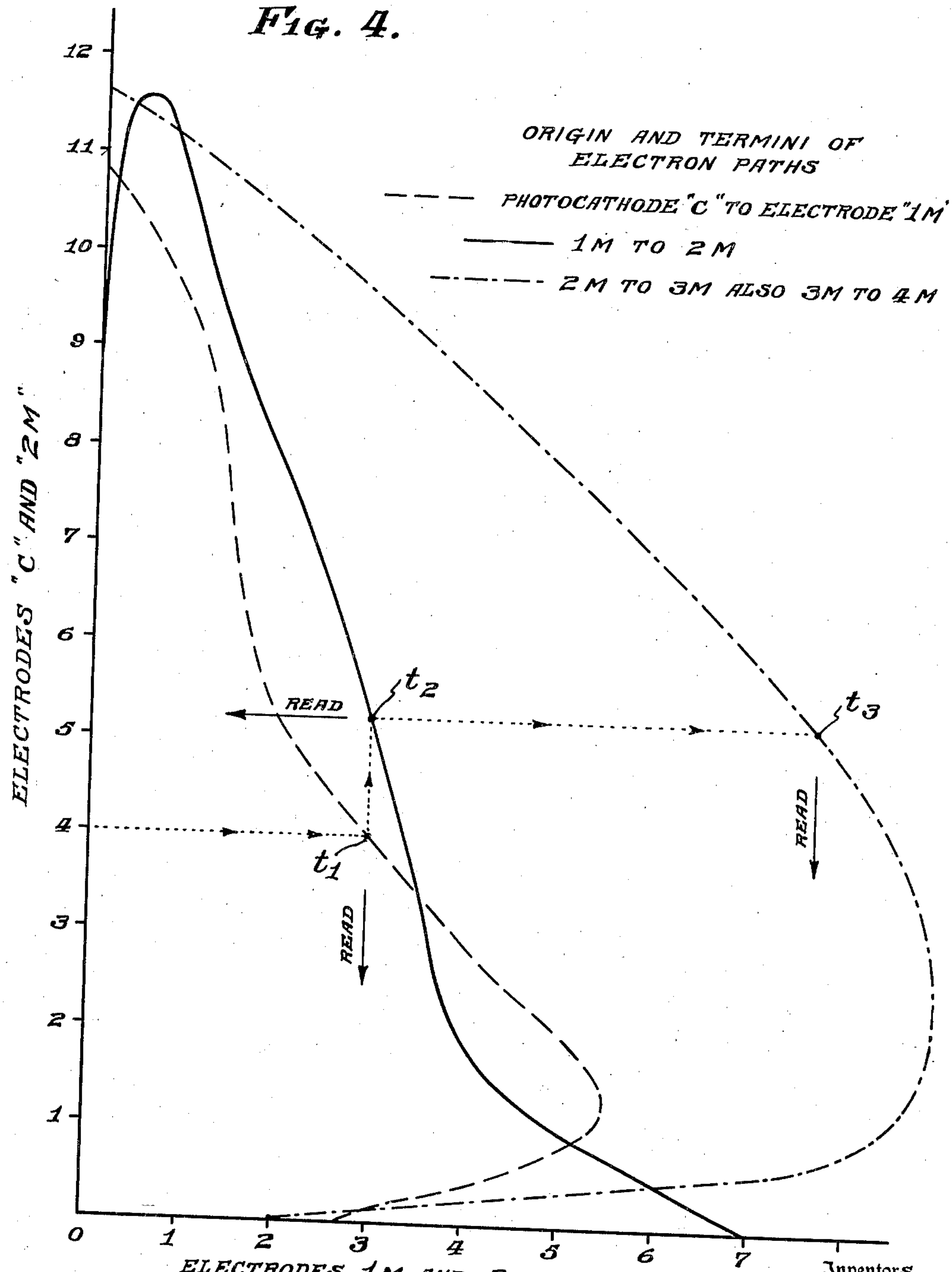
FIG. 4.



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2,198,227

ELECTRON MULTIPLIER

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Application May 3, 1938, Serial No. 205,672

6 Claims. (Cl. 250—166)

Our invention relates to electron discharge devices, particularly to photosensitive electron-multipliers and has special reference to the provision of improvements in the photo and first secondary-electron emissive stages of such devices.

The sensitivity of the ordinary photo cathode is usually not perfectly uniform. It is therefore frequently desirable to employ a photo cathode of large area and to diffuse the light rays impinging thereon so that changes in the light which would otherwise change the point of incidence will not result in disproportionate changes in electrical sensitivity as manifest in the output current of the device. An increase in the area of the cathode has heretofore required an increase in the area of the electron multiplying and target electrodes or has required the use of auxiliary electron lens systems for focusing the electrons from the cathode to the succeeding multiplying electrodes. The resulting assembly in either case has been far more cumbersome, more difficult to operate, and is less efficient than is desirable.

Accordingly, the principal object of our present invention is to obviate the above described and other disadvantages inherent in photosensitive electron-multiplier devices.

Another object of our invention is to provide an electrostatic (as distinguished from electromagnetic) type multiplier having an "over-size" cathode and to determine the particular contour and relative position and arrangement of the electrodes required to achieve optimum performance in an electron multiplier which has been thus modified.

Another and important object of our invention is to provide improvements in electron multipliers of the type described in copending application Serial No. 171,916, to Rajchman and Pike, filed October 30, 1937.

Certain important details of construction, together with other objects and advantages, will be apparent and our invention itself will be best understood by referring to the following description and to the accompanying drawings wherein

Figure 1 is a partly diagrammatic perspective view of a multistage electron multiplier provided, in accordance with the principle of our invention, with an "over-size" photosensitive cathode;

Figure 2 shows diagrammatically so much of the device of Fig. 1 as is necessary to explain the contour and the relative arrangement of the electrodes required to achieve optimum performance;

Figure 3 is an explanatory tabulation; and

Figure 4 is a diagram which will be referred to in explaining the trajectories of the electrons in a device utilizing the electrode arrangement of Fig. 2.

The electron multiplier shown in Fig. 1 comprises an evacuated envelope T which, for purposes of this description, may be considered to contain a reference axis A—A adjacent the opposite ends of which an anode B and an "over-size" photosensitive cathode C are mounted. A pair of sets of curved substantially L-shape multiplying (i. e., secondary-electron emissive) electrodes are mounted on opposite sides of the reference axis between the cathode and anode. The electrodes of the "upper" set are odd-numbered 1M, 3M, 5M, 7M and 9M, and those of the "lower" set are even-numbered 2M, 4M, 6M and 8M.

The long leg of each L-shape multiplying electrode, except electrode 1M, extends across the axis A—A with its free end inclined toward the cathode. The short leg of each of the said L's extends in the direction of the anode and each terminates at a point substantially equally distant from the said reference axis.

As will hereinafter more fully appear, the contour of the cathode C differs from that of the first multiplying electrode 1M and the contour of electrode 1M preferably, but not necessarily, differs from the contour of the other multiplying electrodes. However, all of the electron emissive electrodes are of cylindrical curved construction and are mounted with the generatrices of their surfaces normal to a plane containing the reference axis A—A. The hollow box-like metal member S which forms a continuation of the surface of the cathode is designed to prevent wall charges (on the glass) from affecting the motion of the photoelectrons in the region where their velocities are low, but may be omitted if desired.

The potential distribution preferably employed in operating the device of Fig. 1 may be expressed by the mathematical series 1V, 2V, 3V, 4V, 5V, 6V, etc., where 1V is the potential drop between the photosensitive cathode C and the first target or multiplying electrode, and 2V, 3V, 4V, etc., represent the potential drop between the respective succeeding electrodes in point of electron travel, and said cathode.

For the purpose of providing such a potential distribution, the cathode C may be connected to the negative terminal of a direct current source exemplified in the drawings by resistor R, and the first multiplying electrode, i. e., electrode 1 connected to a point 1V somewhat more positive. The other electrodes 2 to 9, inclusive, in the order of their numbers, are shown connected to successively more positive points 2V to 9V on the resistor. The reference characters 1V, 2V, 3V, etc., given to the several points on resistor R will be understood to indicate that the voltage drop between the given electrode and the cathode is the designated whole number multiple of the drop existing between the cathode C and the first multiplying electrode 1M. Thus, where the potential drop between the first multiplying electrode 1M and the cathode C is 100 volts, the drop between electrodes 2M and C should preferably be 200 volts, that between the electrodes 3M and C, 300 volts. In accordance with the invention, a beam of light, say of varying intensity, from a source exemplified by a lamp L is diffused by a lens O over substantially the entire surface of the "over-size" cathode C. The quantity of photoelectrons released by the impress of the diffused light beam upon the cathode will be, of course, determined by the instantaneous intensity of the light beam. These photo-electrons will be accelerated toward the first "upper" electrode 1M and, because of the described design, relative arrangement and voltage distribution will impinge upon this first multiplying electrode. The photo-electrons striking electron 1M will cause the emission of secondary electrons, the number of secondary electrons emitted being dependent, in part at least, upon the magnitude of the potential between it and the cathode.

The next electrode in point of electron travel is the second "lower" electrode 2M. The trajectory of secondary electrons from the first multiplying electrode 1M is such that they impinge upon the cupped surface of the second multiplying electrode 2M. Here again, a multiplication, by reason of secondary emission, is secured, and this is repeated in any number of stages until the amplified stream of secondary electrons is collected upon the inclined surface of the anode B and caused to flow in a utilization circuit exemplified in the drawings by the impedance Z which is included between the output electrode B and the positive terminal 10V of the potential divider R.

The principal difficulty encountered in applying our inventive concept to multistage electron-multipliers of the type disclosed in the above identified Raichman and Pike application was in the design of an electrode assembly capable of directing all of the electrons from an "over-size" cathode to the smaller target electrodes without substantial numerical diminution. By the words "over-size cathode" we mean a cathode having an emissive area at least twice that of the first multiplying electrode. Many arrangements capable of focusing a substantial percent of the electrons from an oversize cathode upon the input multiplying electrode are possible. However, after a great many experiments, we have succeeded in designing and constructing an electrode assembly capable of utilizing substantially all of the electrons from an oversize cathode and have formulated the following mode of procedure to enable others skilled in the art to duplicate this desired result.

Referring now to Fig. 2 and to the chart of Fig. 3: It is first necessary to select a unit of length (R) which determines the scale of the multiplier. By way of example, a unit wherein R = 0.25″ will ensure a device of a convenient size. Now, having drawn the axis A—A and determined the positive (anode) and negative (cathode) sense of the axis, a point a on the axis is selected and a perpendicular of a length equal to 0.25R is erected. Around point b at the end of the perpendicular, describe an arc of a radius equal to R, terminate this arc on the positive (anode) side at a point c, at a distance equal to 0.81R from the axis A—A, and terminate the other end of the arc at a point d which lies 125° in the counter-clockwise direction with respect to c. Now draw a tangent to the arc at point d and extend it a distance equal to 0.73R to point e, crossing the axis A—A.

The electrode plotted in the manner above described, and whose position is determined by the point a, should be considered as the third electrode, in point of electron travel, from the cathode. To locate the second, the fourth and succeeding multiplying electrodes, a distance equal to 1.09R is measured in each direction from a along the axis A—A and from these points, a^2, a^4, respectively, duplicate electrodes are plotted on the side of the axis opposite to electrode 3. Obviously, as many multiplying electrodes may be provided as are necessary or desirable to achieve a desired degree of amplification.

To locate the first multiplying electrode (1M), measure from a a distance equal to 1.86R along A—A, in the cathode direction, and from this point a_1 erect a perpendicular (on the same side of the axis as b) and terminate it at a point f removed 1.293R from the axis. To form the first multiplying electrode, describe an arc of a radius equal to .824R about f. Terminate this arc on the anode side at a point g such that the angle between gf and a_1f is 86°. This arc is extended in a counter-clockwise direction 111° from g to point h, and from h the tangent to the arc at h is extended in the cathode direction a distance equal to 2.045R to the point i. Point i thus constitutes one terminal edge and point g the other terminal edge of electrode 1M.

The contour and relative arrangement of the multiplying electrodes having been determined, the cathode (C) is finally located by drawing a point j on axis A—A spaced 4.03R in the negative direction from a, erecting a perpendicular (on the side of the axis opposite to points b and f) to point k which is removed 0.564R from the axis A—A. The contour of the cathode is determined by describing an arc of a radius equal to 2.73R about point k; terminating the arc, on the positive side, at a point m distance 1.58R from the axis A—A and on the negative side at a point n 84° removed from point m. From point n the tangent to the arc at n is drawn in the negative direction to a point p which is removed from n a distance equal to or greater than 3.74R. To check the position of the cathode C with respect to electrode 1M, a line drawn between points i and m should make an angle of 53° with axis x—x.

From the foregoing, it will be apparent that the relative size and the contour and relative arrangement of the cathode and multiplying electrodes, as viewed in a plane normal to the generatrices of the cylindrical (curved) electrodes (as in Fig. 2) may also be defined by giving the coordinates of a, b, c, etc. of Fig. 2 in a Cartesian coordinate system imposed on that figure. If the x axis of the Cartesian coordinate system is laid on the axis A—A with its origin at the point a (as indicated by the symbols x—x and y—y, Fig. 2), then the coordinates are those given in the table of Fig. 3. It will be seen, from an inspection of Fig. 2, that the cathode is in quadrant III and is defined by a straight line from n through p, and by a circular arc drawn between n and m about k as a center.

The first multiplying electrode 1M is defined by a straight line connecting i and h, and by a circular arc drawn between h and g about f as a center. The third multiplying electrode 3M is defined by a straight line connecting e and d, and by a circular arc drawn between d and c about b as a center. Any of the other multiplying electrodes (which, for the sake of convenience, may be designated as the nth multiplying electrode) is described about the point b_n congruent to the said third multiplying electrode 3M, and has the same aspect with respect to the Cartesian x axis.

Referring again to Fig. 2. It will be observed that the surfaces of the cathode C and the surfaces of the multiplying electrodes 1M, 2M and 3M each carries a numbered scale. Thus, the scale on the cathode is numbered 0 to 13; the scale on the electrode 1M from 0 to 10; and the scales on electrodes 2M and 3M from 0 to 16, respectively. The vertical and horizontal numbered scales on the chart of Fig. 4 correspond, as indicated in the legend adjacent respectively thereto, to the scales on the several electrodes of Fig. 2.

How well the objects of the invention are achieved in an electrode assembly constructed in the manner shown in Fig. 2 is illustrated by the chart of Fig. 4 which shows the relation between the origin and termini of the electron paths between successive electrodes.

By way of example, the path of a photo-electron released from a point (say point 4) on the cathode, will be traced. Referring to the vertical scale of Fig. 4 and projecting a line at right angles from point 4 on the said scale to the point t_1 on the broken line curve and reading this point (t_1) on the horizontal scale, it will be seen that the said electron will strike electrode 1M near point 3 on that electrode.

Assume now that a secondary electron is released at the point of impact, i. e., point 3; then to ascertain where on electrode 2M this secondary-electron will strike it is merely necessary to move vertically from point t_1 to point t_2 on the solid-line curve and to read the point t_2 on the vertical scale. In this case the reading is about 5.2, which means that the said secondary electron will strike electrode 2M about point 5.2.

Proceeding similarly from point t_2 to point t_3 on the dot and dash curve and projecting point t_3 on the horizontal scale, it will be seen that an electron released from point t_2 on electrode 2M will strike electrode 3M at about point 7.7 on that electrode.

The curves of Fig. 4 show that electrons released from any point on the photocathode between points 0 and 11 will strike electrode 1M between the points 0 and 5.5. Secondary electrons leaving electrode 1M from any point within this region will strike electrode 2M between points 1 and 11.5. Secondary electrons leaving electrode 2M from any point within this region will strike electrode 3M between points 0 and 9. Thus, a photoelectron released from any point on the photocathode will give rise to a group of secondary electrons which will be focused without any numerical diminution upon the next succeeding electrode and thereby give rise to a new and augmented group of secondary-electrons which are, in turn, focused without loss upon the next succeeding multiplying electrode.

So far in this description we have made no reference to the lateral dimensions of the cathode and multiplying electrodes. In practice, this dimension (i. e. dimension across the long axis A—A of the device) is relatively unimportant, the only requirement is that the width of these electrodes be sufficient to minimize so called "end effects". As a matter of practice, the width of the several electrodes is preferably ten times the "R" of Fig. 2 thus if R=0.25'' the width of the cathode and multiplying electrodes will preferably be substantially no less than 2.5 inches.

It will be understood that the foregoing is to be interpreted as illustrative and not in a limiting sense except as required by the prior art and by the spirit of the appended claims.

What is claimed is:

1. An electron-multiplier comprising a cathode, an anode and at least three multiplying-electrodes, said cathode and multiplying electrodes having curved emissive surfaces the generatrices of which are parallel to each other, said cathode surface having a substantially greater emissive area than the first multiplying electrode and said first multiplying electrode having a substantially greater emissive area than the multiplying electrode next adjacent thereto.

2. The invention as set forth in claim 1 and wherein each of the multiplying electrodes following the second multiplying electrode has substantially the same emissive area as said second multiplying electrode.

3. An electron multiplier comprising a cylindrical photosensitive cathode, an anode and at least three cylindrical multiplying electrodes mounted on opposite sides of a reference axis which extends between said cathode and anode, the relative size and the contour and relative arrangement of said cathode and multiplying electrodes, as viewed in a plane normal to the generatrices of said cylindrical electrodes, being defined substantially by the points a, b, c, etc., whose Cartesian coordinates are given in the following table in which the axis of x coincides with said reference axis and said cathode lies in quadrant III,

	x	y		x	y
a	0	0	g	−1.04R	1.23R
a_1	−1.86R	0	h	−2.09R	2.08R
a_n	$(n-3)$1.09R	0	i	−4.03R	1.52R
b	0	0.25R	j	−4.03R	0
b_n	$(n-2)$1.09R	$(-1)^{n-1}\times$0.25R	k	−4.03R	−0.56R
c	0.83R	0.81R	m	−1.58R	−1.80R
d	−0.93R	0.61R	n	−5.01R	−3.11R
e	−1.19R	0.06R	p	−8.41R	−1.77R
f	−1.86R	1.29R			

said cathode being defined by a straight line from n through p and by a circular arc drawn between n and m about k as a center, the first multiplying electrode being defined by a straight line connecting i and h and by a circular arc drawn between h and g about f as a center, the third multiplying electrode being defined by a straight line connecting e and d and by a circular arc connecting d and c about b as a center, the nth multiplying electrode being described about the point b_n congruent to the said third multiplying electrode and having the same aspect with respect to the said reference axis.

4. The invention as set forth in claim 3 wherein R is equal to substantially one-quarter of an inch.

5. The invention as set forth in claim 3 wherein the angle *abc* is substantially 124°, the angle *cbd* is substantially 125°, the angle gfa_1 is substantially 86°, the angle *gfh* is substantially 111°, the angle *mkj* is substantially 117° and the angle *mkn* is substantially 84°.

6. The invention as set forth in claim 3 wherein the width of said electrodes as measured across said references axis is substantially no less than 10R.

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