Oct. 28, 1941. P. T. FARNSWORTH 2,260,613

ELECTRON MULTIPLIER

Original Filed May 18, 1936 2 Sheets-Sheet 1

Fig. 1.

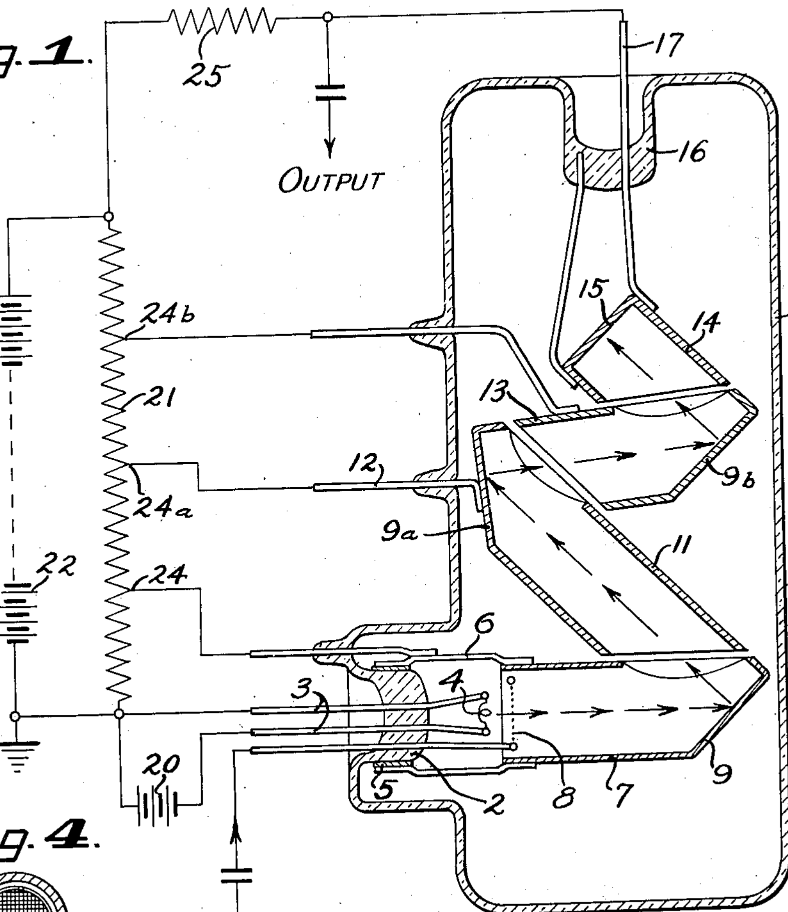

Fig. 4.

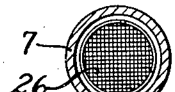

Fig. 2.

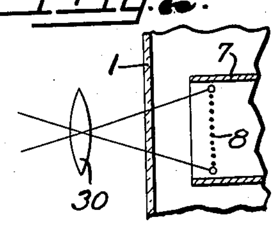

Fig. 3.

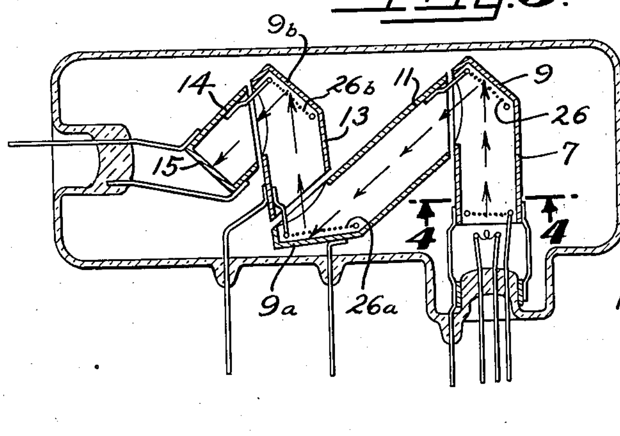

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Fig. 5.

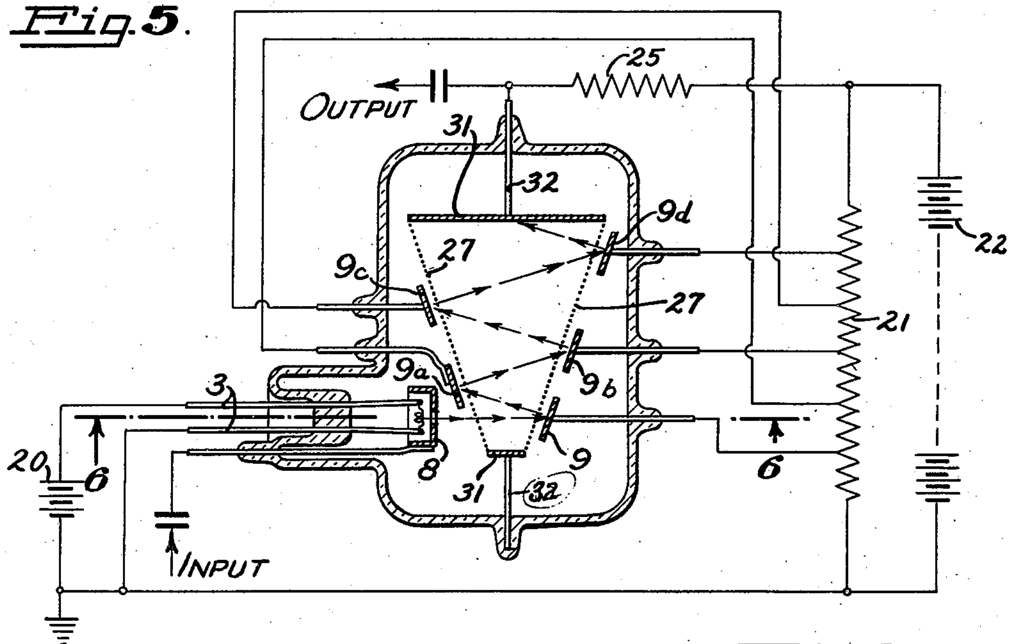


Fig. 7.

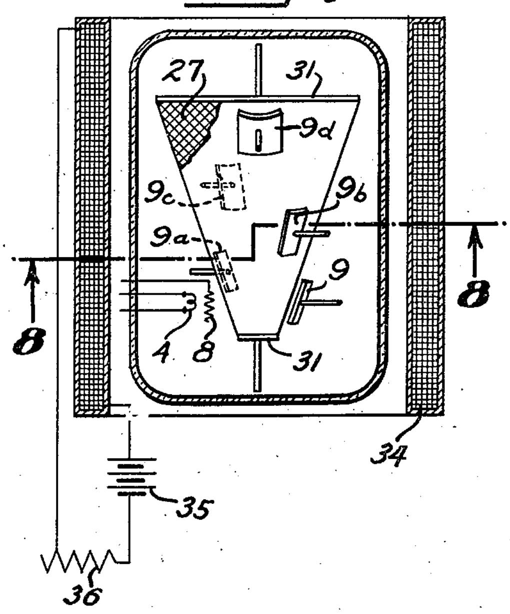


Fig. 6.

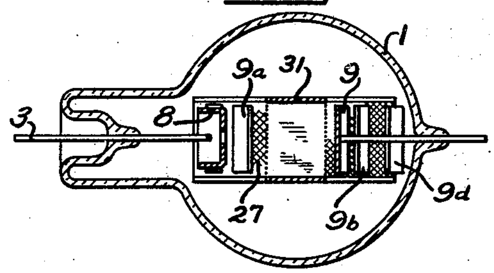
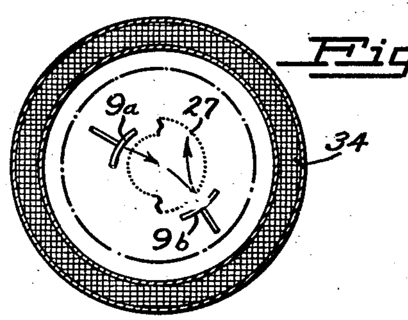


Fig. 8.



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UNITED STATES PATENT OFFICE

2,260,613

ELECTRON MULTIPLIER

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Original application May 18, 1936, Serial No. 80,194. Divided and this application April 25, 1939, Serial No. 269,895

8 Claims. (Cl. 250—175)

My invention relates to electron multipliers, and more particularly to that type of electron multiplier where electrons are directed to successively impact a series of surface elements to produce a current augmented by secondary emission at each impact.

Electron multipliers may be roughly divided into two general types: first, the so-called "direct-current" multiplier, where the generation of secondary electrons takes place by successive impact of an electron stream with a series of emitting elements energized to successively increasing positive potentials; and second, that type of multiplier where repeated impacts are made between a pair of operatively opposed surface elements, such as has been described by me in my prior United States Patents Nos. 2,071,515 and 2,071,516. The present application deals with the first type of multiplier mentioned above, and is a division of my copending application Serial No. 80,194, filed May 18, 1936, now United States Patent No. 2,204,479, issued June 11, 1940.

When a series of surface elements are energized to successively increasing potentials and placed with relation to each other so that electrons may be drawn from one to another until the entire series has been impacted, a number of factors must be taken into account to produce effective electron multiplication. First, the electrons must be accelerated toward each surface element with such a velocity that they will generate secondary electrons on impact; second, the secondaries generated must be reformed and usually changed in direction so that they may again be directed and accelerated toward a second and similar surface, and so on until a sufficient number of impacts have occurred to produce the desired multiplication; third, electrons, during their passage from one element to another, must be so under control that as many electrons as possible reach the next element; fourth, the surface elements themselves must be so sensitized as to produce secondary electrons with a maximum ratio of secondary electrons to primary electrons; and fifth, space-charge limitations must be avoided.

My present invention has for its main object the provision of a means and method whereby electron multiplication may take place with high efficiency and in which electrons may be made to follow predetermined paths between impacts with minimum collection, and it also provides a means and method of adding to the field produced by the elements themselves an additional field which ensures that electrons strike each element, and with a velocity sufficient to emit secondaries at each impact.

Among other objects are: To provide a means and method of segregating accelerating fields in a multistage secondary emission multiplier; to provide a means and method of insuring that electrons reach the proper target in a multistage secondary emission multiplier; to provide, in a secondary emission multiplier, a means and method of focusing electrons between electrodes therein; to provide a means and method of reducing space-charge limitations in electron multipliers; to provide a means and method of controlling electron paths in a mutistage electron multiplier; to provide a cooperating system of electrical fields in an electron multiplier to insure efficient multiplication; and to provide a means and method of efficient electron multiplication utilizing secondary emission.

My invention possesses numerous other objects and features of advantage, some of which, together with the foregoing, will be set forth in the following description of specific apparatus embodying and utilizing my novel method. It is therefore to be understood that my method is applicable to other apparatus, and that I do not limit myself, in any way, to the apparatus of the present application, as I may adopt various other apparatus embodiments, utilizing the method, within the scope of the appended claims.

Broadly as to method, my invention comprises directing the electrons, in the type of multiplier described, between impacts in such a manner that they reach the next surface, and my method may also provide the step of creating an accelerating field in addition to the fields created by the surface elements themselves, that is, the inter-element field; and in this respect I may prefer to utilize the potential of the next succeeding element to accelerate electrons between a pair of elements lower in potential.

Broadly as to apparatus, my invention comprises a series of surface elements energized to successively increasing positive potentials, and means for directing electrons emitted from one element onto the element of the next higher potential. In order to ensure electrons impacting the surfaces with the proper velocity, I may desire to insert operatively between each pair of elements an accelerating electrode energized to a potential higher than either of that specific pair, and I thus provide an accelerating field graded as the elements themselves are graded, the accelerating field being higher at all points than the element to which the electrons are being accelerated.

Specifically as to directional structure, I find that successive cylinders or tubular conduits may be used to create an electrostatic focusing system, these cylinders enclosing the path of the electrons between respective pairs of surface elements, and I may make use of a Faraday space between surface elements.

My invention may be better understood by specific reference to certain particular embodiments of my invention, these embodiments, however, being used only for purposes of illustration, other structures utilizing the method being deemed full equivalents.

Referring to the drawings:

Figure 1 is a diagrammatic longitudinal sectional view of a tube embodying one preferred form of my invention, together with a schematic circuit showing how it may be utilized.

Figure 2 is a diagram showing how the device of Figure 1 may be built, when used as a multiplier of photoelectrons.

Figure 3 is a diagrammatic sectional view of another embodiment of my invention utilizing accelerating electrodes.

Figure 4 is a sectional view taken as indicated by the line 4—4 in Figure 3.

Figure 5 is a longitudinal sectional view and circuit of an embodiment utilizing a unipotential space.

Figure 6 is a view taken along a sectional plane, as indicated by the line 6—6 in Figure 5.

Figure 7 is a diagrammatic representation, partly in section, of a device utilizing a cone-shaped accelerating electrode, and a magnetic deflecting field.

Figure 8 is a sectional view of the structure shown in Figure 7, taken as indicated by the line 8—8 in Figure 7.

Referring directly to the embodiment shown in Figure 1, an envelope 1 is provided at one end with an input stem 2 through which cathode leads 3 are sealed, supporting a filamentary cathode 4. A band 5 is placed around the stem, and supports by means of risers 6, an input cylinder 7. A control grid 8 is placed in the opening to the cylinder 7. The cylinder 7 extends away from filament 4 and terminates at the opposite end in a surface element 9 which is sensitized to readily emit secondary electrons at a ratio greater than unity when impacted by primary electrons traveling at the proper velocity.

One side of the cylinder is cut away to provide an opening toward which is directed the open end of a second cylinder 11, also terminating in a secondarily emissive surface 9*a*. The second cylinder is supported by a lead 12 through the wall of the tube 1. Cylinder 11 is also cut away adjacent the emissive surface 9*a*, and a third cylinder 13 has its open end opposed to the opening, cylinder 13 also terminating in an emissive surface 9*b*. Cylinder 13 is provided with an opening exactly as before, and an output cylinder 14 has its open end presented thereto so that electrons emitted from surface element 9*b* may pass to the cylinder 14, there to be collected by an anode surface 15. Anode cylinder 14 is mounted on an output stem 16, a lead 17 passing through the stem to provide exterior connection.

It is of course to be understood that while I have shown, for purposes of illustration, only three surfaces sensitized for secondary emission, namely, 9, 9*a* and 9*b*, the construction may be repeated as often as is desired, the number of successive surface elements being limited only by the number of secondary-electron generating impacts desired.

I have found that the surface elements 9, 9*a* and 9*b* may be sensitized for secondary emission by the deposit thereon in any well known manner of a thin film of thorium, barium, potassium, caesium or other metals in the alkali and alkaline earth groups, and I have obtained a sensitivity with such surfaces so that a primary-to-secondary emission ratio of 1:1 can be obtained with an electron velocity of 20 volts, maximum emission of a ratio of 1:7 being obtained with caesium surfaces. However, any material capable of emitting secondary electrons on impact is satisfactory.

The setup can be made operative by energizing the filament 4 from a filament source 20 and attaching a resistor 21 across a potential source 22, taps 24, 24*a* and 24*b* being taken off and leading respectively to cylinders 7, 11 and 13, to produce progressively increasing positive potentials thereon, the end of the resistor 21 being connected directly to anode cylinder 14 through lead 17 and output impedance 25, the latter being so connected that variations in current therethrough may be utilized.

Energized as described immediately above, electrons leaving the filament 4 enter the interior of cylinder 7. Cylinder 7, being energized at a positive potential higher than that of the filament from which the electrons were emitted, tends to focus the electrons onto the central portion of the first element 9 in the series of surface elements, and secondary electrons will be emitted therefrom. These secondary electrons, having random velocities, are acted upon by the field of cylinder 11 and are drawn into that cylinder and accelerated toward surface 9*a* where more secondary electrons are emitted, these latter secondary electrons being drawn into cylinder 13 to impact surface element 9*b* where still further secondary emission takes place, the final multiplied current then being drawn into cylinder 14 and collected therein. Each cylinder is therefore a part of each emissive surface and is at the same potential as that surface.

The focusing is enhanced by the fact that the exits from the cylinders are close to the surface elements and the length of the cylinders toward the lower potential surface is such that electrons entering each cylinder are deflected a minimum amount by the field from the succeeding cylinder.

However, while my device is entirely operative to produce electron multiplication as described, space-charge effects occur which limit rather definitely the amplification which can be drawn from a device of this sort, and it is desirable, when cylinders alone are used, that a fairly high voltage per stage be used, perhaps from 200 to 500 volts.

I have also found that the multiplication effect may be greatly increased by the use of an accelerating field in addition to the field produced by the surface elements themselves, or their connected cylinders, and I produce this field in one manner as shown in Figure 3, where fine wire grids 26, 26*a* and 26*b* are positioned immediately in front of surface elements 9, 9*a* and 9*b*, respectively, so that electrons entering the cylinders are subjected to the fields of these electrodes.

It is preferable that the potential on these accelerating electrodes will be greater than that of the surface element to which the electrodes are being accelerated thereby, and in order that the various accelerating electrodes be conveniently energized, I may prefer to attach, for example, accelerating electrode **26** to cylinder **11**, thereby maintaining it at the same potential as surface element *9a*. In like manner accelerating electrode **26***a* is attached to cylinder **13** and at the potential of surface element *9b*. Accelerating electrode **26***b* is attached to output cylinder **14** and therefore is at the same potential as anode **15**. Of course these grids may be separately and independently energized directly from a potential source if desired.

It is relatively immaterial as to the direction in which electrons approach the surface elements, as they will pass through the accelerating screens to reach the emissive surface. They will, however, leave the emissive surface perpendicular thereto and therefore will be directed into the next succeeding cylinder to repeat the cycle.

In this manner I have also provided, in addition to the successively energized surface elements, successively energized accelerating electrodes, and the potential of the accelerating electrodes is always higher than the surface to which the electrons are being accelerated thereby. I prefer to make the accelerating electrodes either of extremely fine wire so that few electrons will be picked up thereby, either approaching or leaving the surface elements, or to form the accelerating electrodes in any other well known manner so that the electrons approaching each surface will receive the benefit of the increased positive potentials thereon, with minimum pickup or collection.

In the manner described, I have been able to obtain extremely high multiplication per stage. First, due to the focusing, a majority of electrons leaving one surface element reach the next without collection; second, by the use of accelerating electrodes I ensure that the electrons will impact the surfaces with a sufficient velocity to create secondary electrons and prevent formation of limiting space charges; and third, by continual focusing of the entire path from one end of the device to the other, I prevent gradual dispersion.

As the device is capable of extreme amplification, it is of course adapted to be used either as a straight amplifying device, as indicated in Figure 1, where a grid is used to control the emission from the filament; or as a photoelectric device, as shown in Figure 2, where the grid **8** has been coated with a photosensitive material and connected to the first cylinder **7**. Light projected against this grid by optical system **30** causes the emission of electrons which are then accelerated toward the first surface **9**. The output in this case will then be proportional to the light falling upon the grid **8**.

It should also be pointed out that the device may be used in conjunction with any other apparatus where electrons from any source whatsoever may be passed into the input end of cylinder **7**. It may be seen, therefore, from the foregoing description of this particular embodiment that I have completely surrounded the entire path of the electrons between successive surface elements, thus obtaining electron focusing to ensure impact at each stage. In addition, I have provided a means and method for reducing space-charge limitations within the device.

It should also be pointed out that while I have shown the device in the form of cylinders, it is also operative with conduits of other cross-sectional contours, and tubular in this application is deemed to mean a conductive surrounding of the path to produce an electrostatic focusing field.

It will also be apparent that the device is a self oscillator if feedback from the output to input be used.

In the embodiment of my invention shown in Figures 5 and 6, surface elements **9**, *9a*, *9b*, *9c* and *9d*, capable of secondary emission, are arranged opposite an accelerating electrode **27** which in this case takes the form of a wire screen extending parallel to each set of opposed surfaces, the wire screen being arranged to form side walls and end walls **31** also being provided, the entire accelerating electrode structure being supported on leads **32**, one of which is brought through the envelope wall for potential connection. The surface elements are connected to resistor **21** in exactly the same manner as in the device shown in Figure 1, so that there is a progressive increase in positive potential on each element.

As the electrons leave each element at right angles thereto, the opposite element is positioned in the path of the outgoing electrodes, this giving rise to the divergence of the accelerating screens and the increasing distance between the elements on each side of the device. This arrangement provides certain advantages. The electrons, after they leave the accelerating screen on one side and until they pass through the accelerating screen on the other side, travel in a Faraday or equipotential space, and the electrons in one inter-element path are shielded, during their traversal of that path, from the voltages on the other surface elements, the voltage on the accelerating screens being, of course, at all times greater than any potential on any surface element. Furthermore, the arrangement provides a continually lengthening path between surface elements, the electrons, therefore, being given more space as they increase in number. This has the effect of limiting the development of space charges in the device, and it may be seen that by proper coordination of path lengths the space-charge effects may be minimized. Electrons leaving the last surface element *9d* will be collected either by the end wall **31** or by the ends of the side walls **27**. In this embodiment also it is obvious that the entering electrons may be photoelectrons or those emanating from any source to be amplified.

The device shown in Figures 7 and 8 has the accelerating electrode **27** in the form of a truncated cone, all portions of which are preferably meshed. Here, the surface elements **9**, *9a*, *9b*, *9c*, and *9d* are arranged in spiral formation around the accelerating electrode, and a longitudinal magnetic field is provided to cause the electrons to take a curved path between one surface element and the next, being deflected thereto by the field. This field may be produced in any well known manner, such as by a solenoid **34** energized by a deflecting source **35** under the control of a variable resistor **36**. Variation of the magnetic field, in combination with the placing of proper potentials upon each electrode, will ensure that the electrons between elements arrive on the next succeeding element, and if it is desired the multiplication may be controlled by varying the deflecting field so that more or less of the electron stream will impact the surface elements. In this way a steady electron source may be used and the output modulated by a variation of the magnetic field, or several frequencies may be imposed upon the device, one through the input end and the other through the magnetic field. The device, therefore, is adapted to wide use.

All of the devices described may be provided, therefore, in addition to their normal inter-element field, with additional fields which direct electrons leaving one surface element against the next; and in addition, the electron velocity may be added to by a separate accelerating field. Focusing the electrons from one surface onto the next may be accomplished in two manners: first, by the use of an electrostatic focusing system, as described with the tube of Figure 1; or, second, by means of an electromagnetic deflecting system which is the full equivalent of a focusing system, inasmuch as it regulates the path through which the electrons must travel, as shown in Figures 7 and 8.

In all of the devices utilizing additional fields there is the common attribute that space-charge limitations are materially reduced, thus allowing greatly increased power outputs with a given number of impacts, and also reducing collection en route.

I claim:

1. In combination, a series of surfaces arranged in the formation of a conical helix and adapted to be progressively energized to increasing positive potentials, an electron source for supplying electrons to the surface of lowest potential, and means for collecting electrons leaving the surface of highest potential.

2. In combination, a series of surfaces arranged in the formation of a conical helix and adapted to be progressively energized to increasing positive potentials, an electron source for supplying electrons to one end of said series, means for collecting electrons at the other end of said series, and means for causing electrons to impact said surfaces successively.

3. An envelope containing means for producing electrons, an anode, a series of surface elements capable of producing electrons by secondary emission and adapted to be progressively energized to increasing positive potentials, and tubular conductive electrodes enclosing substantially the entire path of the electrons between the various elements of said series, said conductive electrodes being connected to an element of higher potential and extending toward an element of lower potential.

4. An envelope containing means for producing electrons, an anode, a series of surface elements capable of producing electrons by secondary emission and adapted to be progressively energized to increasing positive potentials, and tubular conductive electrodes enclosing substantially the entire path of the electrons between the various elements of said series, said conductive electrodes being connected to an element of higher positive potential and extending toward an element of lower positive potential, and the axes of adjacent pairs of said conductive electrodes forming an acute angle.

5. An envelope containing means for producing electrons, an anode, a series of surface elements capable of producing electrons by secondary emission and adapted to be progressively energized to increasing positive potentials, and tubular conductive electrodes enclosing substantially the entire path of the electrons between the various elements of said series, said conductive electrodes being connected to an element of higher positive potential and extending toward an element of lower positive potential, and said surface elements respectively comprising integral parts of said conductive electrodes.

6. An electron multiplying system comprising a cathode, an anode, and a series of surface elements adapted to be progressively energized to increasing positive potentials and capable of emitting secondary electrons on impact, and means for directing electrons leaving one element onto the next element in said series, said means influencing the electron stream throughout substantially its entire path between said cathode and said anode.

7. A series of opposed surfaces adapted to be energized to increasingly positive potentials to cause electrons contacting one surface to emit secondary electrons which impact the opposing surface at the next higher positive potential and thence impact the following surface at still higher positive potential to repeat the cycle, means for supplying electrons to the first surface in said series, and means for collecting electrons emitted from the last surface in said series, said surfaces being spaced apart from each other at distances progressively increasing in the direction of the electron flow.

8. A series of spaced opposed surfaces adapted to be energized to increasingly positive potentials to cause electrons contacting one surface to emit secondary electrons which impact the opposing surface at the next higher positive potential and thence impact the following surface at still higher positive potential to repeat the cycle, means for supplying electrons to the first surface in said series, means for collecting electrons emitted from the last surface in said series, said surfaces being spaced apart from each other at distances progressively increasing in the direction of the electron flow, and an accelerating anode spaced an equal distance from each surface.

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