CIRCULAR ELECTRON MULTIPLIER AND PERMEABLE ANODE


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3 Claims

ABSTRACT OF THE DISCLOSURE

Electron multiplier dynodes are circularly arranged around and spaced from a permeable anode. Means are provided to accelerate and direct electrons through the anode onto successive dynode surfaces displaced circumferentially from a diametrically opposed position. The present invention relates to an improved electron multiplier and more particularly to a multiplier having circularly arranged dynodes between which electrons make traversals along paths slightly angularly offset from a diameter. Electron multipliers of the direct current type involve the generation of secondary electrons by successive impacts of an electron stream with a series of dynodes energized to successively increasing positive potentials. The prior art is replete with a variety of different multiplier configurations having different performance characteristics leading to different end uses. One use for a multiplier of this type is to amplify current in television camera tubes such as image disectors and the like. Such multipliers should have good sensitivity and high amplification factors. In achieving this performance, electrons must be accelerated toward each dynode with a high enough velocity that they will generate secondary electrons on impact at a ratio greater than unity. The electrons during their passage from one dynode to another must be accelerated so that as many electrons as possible impact the dynode. A further requirement for some applications involves the uniformity in transit time of all of the electrons from one dynode to the next, such that electrons leaving one dynode at any given instant of time will arrive at a succeeding dynode simultaneously. By improving the simultaneity of electron arrival transit time spread is minimized, this resulting in improvement in tube sensitivity at higher frequencies. It is therefore an object of this invention to provide an improved electron multiplier in which transit time spread is minimized, thereby providing an improvement in frequency response. It is another object of this invention to provide an electron multiplier of circular configuration in which the electrons passing between dynodes follow paths substantially orthogonal to the dynode surfaces such that the probability of impact of electrons therewith is maximized. In the accomplishment of the present invention, there is provided an electron multiplier having a series of dynodes arranged circularly in circumferentially spaced relation. These dynodes are provided with surfaces arranged and shaped as discontinuous segments of a cylinder. Disposed within these surfaces is an electron permeable anode or accelerator which develops a coaxial, cylindrically shaped, field-free space through which electrons may travel in moving from one dynode surface to another. In order to assure successive impact of the electron stream with different dynodes, some means, such as a magnetic field, is provided, which deflects the electron streams inside the field-free space along paths slightly angularly removed from a straight, diametral direction. The above-mentioned and other features and objects of this invention and the manner of attaining them will become more apparent and the invention itself will be best understood by reference to the following description of an embodiment of the invention taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a diagrammatic illustration of an embodiment of this invention and is used in explaining the construction and operating principles thereof;

FIG. 2 is a similar diagrammatic illustration used in explaining the formation of the electron streams between dynodes;

FIG. 3 is a cross-sectional view of a working embodiment of this invention;

FIG. 4 is a sectional view taken substantially along section line 4-4 of FIG. 3; and

FIG. 5 is a curve used to further explaining operation. Referring to the drawings, and more particularly to FIGS. 3, 4 and 5, a cylindrical, evacuated envelope 1 encloses a series of circularly arranged dynodes 2, 3, 4, 5, 6 and 7 circumferentially spaced apart as shown, a translucent photocathode 8 circumferentially positioned between the dynodes 4 and 6 and a collector element 9 positioned in like manner between the dynodes 3 and 5. All of these dynodes, the cathode 8 and the collector 9 have inner surfaces shaped as discontinuous segments of a cylinder having a common axis 10. For the dynodes, 2 through 7, surfaces 11 are of a material which is secondary emissive at a ratio greater than unity. The photocathode 8 shown in this embodiment comprises a glass backing of the aforementioned part-cylindrical shape having a photoelectric coating 12 on the inner surface thereof. All of these dynodes, the photocathode 8 and the collector 9 are supported inside the envelope 1 by means of terminal supports or leads 13, 16, etc., conducively connected thereto at the inner ends and projecting through the envelope 1 to serve as connecting pins. Also supported within the envelope 1 by means like terminal supports 14 and 15 is an anode element or mesh 17 which in this case is in the form of a cylindrically shaped wire screen positioned coaxially about the axis within the surfaces 11. Either the same screen material or non-magnetic, metal discs may be used to close the opposite ends 18 and 19 of the anode 17. The anode 17 is positioned as closely as possible to the inner surfaces of the dynode, cathode and collector elements for a purpose which will be explained more fully later on. A solenoid 20 coaxially surrounds the envelope 1 as shown and has a variable source of potential, such as battery 21, connected thereto. Reference may now be had to Figs. 1 and 2 for an explanation of the operation of the multiplier just described. Potentials are connected to the various dynodes, the cathode 8 and the collector 9 as shown. As will be noted, the photocathode 8 is grounded, or in other words is connected to a reference potential, while the dynodes 2 through 7 and the collector 9 have successively higher potentials, respectively, connected thereto. The anode 17 has applied thereto a higher potential than any of the foregoing, typical potential values being shown in FIG. 1. The solenoid 20 is so operated as to provide an axially extending, magnetic field centrally axially positioned as indicated by the numeral 22. Radiation falling on the cathode 8 causes the liberation of electrons which are accelerated toward the periphery of the cylindrical anode 17 along approximately diametral paths leaving at right angles to the cathode surface 12. Since the anode 17 is permeable, the electrons will pass therethrough into the field-free interior thereof. If the magnetic field were not present, these electrons would
travel in straight, diametral paths across the tube with no velocity change within the field-free space. Upon departure, however, from the anode, they experience the decelerating field of the diametrically opposed dynode 5. However, because of the deflecting effect of the magnetic field 22, the electrons follow approximately circular paths indicated by the dotted lines 23 and will approach instead the dynode 2. Because of the difference in potential between the dynode 2 and the cathode 8, these electrons even though decelerating after leaving the anode 17 will impact the dynode surface with sufficient velocity to liberate secondaries. These secondaries are returned along paths orthogonal to the surface 11 of dynode 2 once again into the field-free space of the anode 17, and again because of the deflecting effect of the magnetic field 22 follow the curved path 24. This cycle repeats itself with the electrons successively impacting the remaining dynodes 3, 4, 5, 6, 7, 8 and lastly collector 9, the curved paths as shown in FIG. 1 forming a geometric pattern corresponding approximately to a folded hypocycloid. By varying the potential of the power source 21, the strength of the magnetic field developed by the solenoid 20 may be altered. Proper deflection of the electron streams may thereby be controlled by adjusting this field strength such that substantially all of the electrons emitted by one dynode will impact the next succeeding dynode.

As each electron impacts a dynode surface, the plurality of ejected secondaries travel across the tube and impact the next succeeding dynode. Each of these electrons ejects secondaries which repeat the cycle to the next dynode. Thus, the number of electrons finally reaching the collector 9 is multiplied many times over the original emission from the cathode 8.

Of primary importance in this invention is the path length of the individual electron in its transit from one dynode to that next succeeding. As shown in FIG. 2, all of these electrons travel paths such as 27, 28, 29, etc. of identical lengths through identical electric and magnetic fields regardless of their point of origin on the emitting dynode, such that the transit time of the electrons is the same. This phenomenon is best explained by considering two identical dynodes which are precisely diametrically opposed from each other. If the magnetic field 22 were omitted for the moment, an electron leaving the right-hand edge of the dynode 2 would cross through the exact center 10 of the tube and impact the left-hand edge of the dynode 6. Similarly, an electron emitted from the left-hand edge of the dynode 2 would also follow a diametral path similar to the center 10 as well as the right-hand edge of the dynode 6. The path thus described by these two electrons reveals a cross-over at the tube center. These paths are of identical lengths inasmuch as they are diameters of the same circle. Thus, the time of transit of all electrons from the dynode 2 to the dynode 6 must be equal. This is a highly desirable condition inasmuch as by maintaining path lengths and transit times of all electrons equal, transit times spread is held to a minimum, thereby leading to the intended result of improved sensitivity and frequency response.

In this hypothetical example just given, it will be quite obvious that further stages cannot be cascaded inasmuch as secondary electrons from the dynode 6 cannot be returned with sufficient energy to dynode 2. By inserting the magnetic field 22, however, electrons emitted by one dynode can be deflected slightly to one side of a diameter to impact a dynode next adjacent to the diametrically opposite dynode. The configuration of the electron stream would thus resemble that shown in FIG. 2, wherein the hatched portions depict the envelope of the electron paths and 27–29 represent typical paths. It will be noted that these paths from one dynode to another for each electron are substantially identical in length, thereby achieving equalization of transit times as previously explained. The stream of electrons initially emitted by the cathode 8 flow within the crossed pattern envelope indicated by numeral 25 to the dynode 2. Similarly, the secondaries emitted by the dynode 2 flow in a stream indicated by the crossed pattern 26, which terminates on the dynode 3. This pattern is repeated with the secondaries in each instance flowing in the same general pattern to the next succeeding dynode until eventually the collector 9 is reached.

While it has been stated in the preceding that all electron trajectories have identical transit times, this, of course, ignores the phenomenon of variable emission energy which is present in all cases in all electron multipliers. The present invention minimizes the effect of this variable emission energy by accelerating all electron streams to high velocity prior to the approach of successively higher potential (2000 v. as an example) on anode 17, in combination with the close proximity of anode 17 to the emitting surfaces.

By the use of elementary electron ballistic relationships, it can be shown that the transit time spread pertaining to two electrons emitted with slightly different energies from a dynode is reduced by the ratio, $L_{DA}/V/L_{VA}$, where $L_{DA}$ is the path length in the comparatively small gap between the emitting dynode or cathode and the anode 17, $L_{DA}$ is the total path length to the next dynode or collector, $V$ is the potential difference between the emitting and collecting dynodes, and $V_{DA}$ is the potential difference between the emitting dynode and the anode 17. It can therefore be seen that the proposed geometry is capable of a substantial reduction in transit time spread and a resultant increase in the upper frequency response limit by at least a factor of 10 and probably by as much as 100 or more.

An important factor involves the coaxial relationship between the various dynodes, the photocathode 8 and the collector 9 with respect to the anode mesh 17. By reason of this coaxial relationship, equipotential surfaces developed between each dynode and the cylindrical surface of the anode mesh 17 will be concentric. Thus, all electrons departing from the dynodes will follow orthogonal paths with respect to the surface thereof. By the same token, electrons approaching a given dynode will do so along paths orthogonal to the surface thereof. The paths thereby being mainly orthogonal to the dynode surfaces enhances correspondingly the probability of electron impact with the dynode being approached. This is to be contrasted with the trajectory of an electron approaching a dynode surface at an angle other than at right angles which inescapably results in some of the electrons being deflected away from the surface instead of impacting the same. By controlling these paths such that they will normally be orthogonal to the surface thereof, the probability of being deflected and not impacting the surface will be measurably reduced, thereby contributing correspondingly to the generation of a greater number of secondaries.

A further consequence of the coaxial cylindrical geometry is the fact that all electrons travel through essentially identical electric and magnetic fields, regardless of their point of origin on the emitting dynode. This advantageous property helps maintain the desired equal transit time of the electrons traveling to the subsequent dynode. As a consequence, higher currents with reduced transit time spread are achieved. This is partially illustrated by the graph in FIG. 5, in which the solid line curve is used to indicate the frequency response of a typical prior art tube and the dashed line curve the response of the present invention. Notably, the present invention enables efficient tube operation at higher frequencies than has heretofore been possible.

While the photocathode 8 has been disclosed as the initial electron emitter, it will be obvious to a person skilled in the art that other sources of electrons may be used. Also, initiating electrons need not originate at the circumference of the tube geometry, but instead can be directed inwardly from an electron gun axially of the tube to a point near the tube center at which an inclined dyno-
node or deflecting electrode may be positioned from which the electrons may be directed radially outwardly against the first dynode 2. A further modification would be the replacement of the coaxial cylindrical geometry specifically shown in FIG. 4 with concentric spherical geometry, in which all electrodes are segments of spheres instead of cylinders. The geometrical relationship shown in FIGS. 1–3 would be unaffected by this change. Other obvious alternatives will appear to persons skilled in the art.

While there have been described above the principles of this invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of the invention.

What is claimed is:

1. An electron multiplier comprising a series of dynodes having electron-multiplying surfaces circularly arranged in spaced relation about a common central axis, said dynode surfaces facing radially inwardly and being intersected by a plane including said axis, means for accelerating and directing electrons between facing said surfaces in a pattern of succession to cause electrons emitted from one said surface to flow to a successive surface displaced circumferentially from a diametrically opposed position, said means including a circular electron permeable anode coaxially disposed within said dynodes in the path of electrons passing therethrough between said successive surfaces and means for applying successively higher potential to said successive surfaces, respectively, and means for collecting electrons leaving the surface of highest potential.

2. The multiplier of claim 1 in which successive dynodes in said pattern have other of said dynodes positioned circumferentially therebetween.

3. The multiplier of claim 2 in which said anode encloses a cylindrically shaped field-free space in radially spaced relation with respect to said surfaces, and means for applying a potential to said anode which is higher than the highest potential aforesaid to cause electrons from an adjacent said surface to enter said field-free space and to exit therefrom adjacent said successive surface.

4. The multiplier of claim 3 in which said surfaces are curved corresponding to parts of a cylinder coaxial with respect to said axis, said anode including a hollow cylindrically shaped member having a multiplicity of openings therein, said member being insulated from but disposed immediately adjacent to said surfaces and establishing coaxial equipotential surfaces between said surfaces and said member.

5. The multiplier of claim 4 in which said member is a conductive screen, said accelerating and directing means further including means for providing a magnetic field coaxially of said member to deflect the electrons into following curved paths within said field-free space toward said circumferentially displaced surfaces, the electron paths between said dynodes describing a pattern resembling a hypocycloid.

6. The multiplier of claim 5 wherein said magnetic field means includes a solenoid coaxially surrounding said dynodes, said dynodes and said member being contained within an evacuated envelope.

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JAMES W. LAWRENCE, Primary Examiner.

DAVID O'Reilly, Assistant Examiner.

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