July 20, 1943. R. C. HERGENROTHER 2,324,776

VACUUM TUBE

Filed March 8, 1941

FIG. 1.

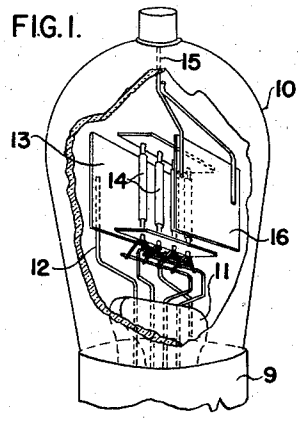


FIG. 2.

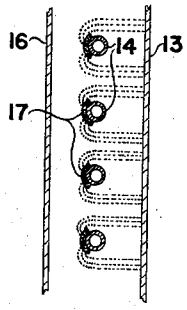


FIG. 3.

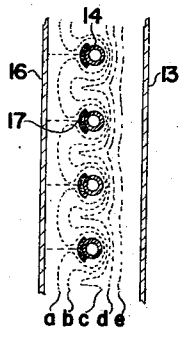


FIG. 4.

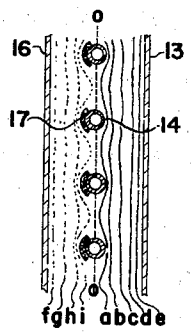


FIG. 5.

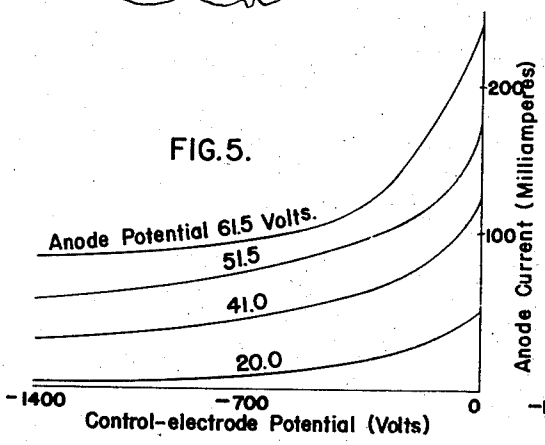


FIG. 6.

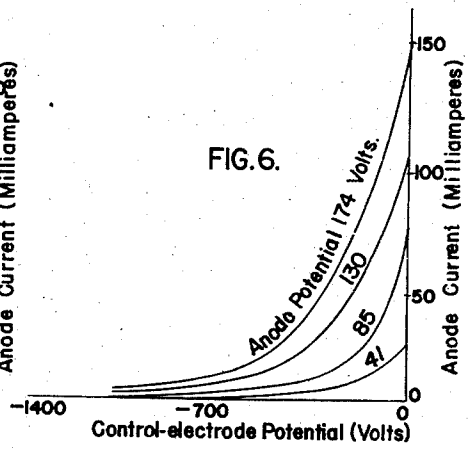


FIG. 7.

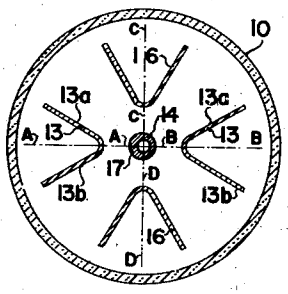


FIG. 8.

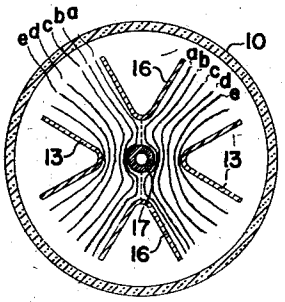


FIG. 9.

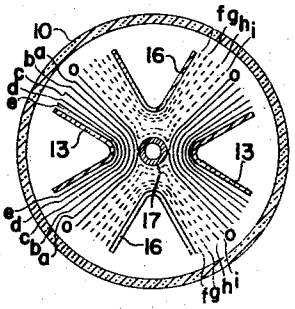
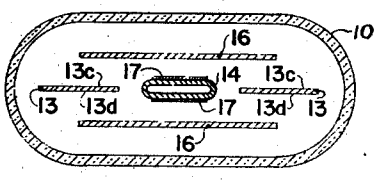


FIG. 10



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VACUUM TUBE

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Application March 8, 1941, Serial No. 382,279

11 Claims. (Cl. 250—27.5)

The present invention relates to vacuum tubes and, particularly, to vacuum tubes having a low amplification factor or mu. In greater particularity, the invention relates to low-mu vacuum tubes adapted to deliver relatively high values of output power.

It has heretofore been proposed that a low-mu vacuum tube be provided by inverting a conventional type of triode or pentode vacuum tube, inversion being accomplished by connecting the anode to serve as the control electrode of the tube and one of the grids to serve as the anode. When this is done, the mu of the tube is approximately the reciprocal of the mu which the tube would have if connected in conventional manner. This connection of a conventional tube is subject to the limitations that any grid element which may be chosen for use as the anode of the inverted tube has a heat dissipation less than that of the conventional anode and consequently places a limitation on the maximum power which may be obtained from the tube when used in this inverted manner.

It has also been proposed that the limitation on the power output which results from inverting a conventional vacuum tube be avoided by a rather special tube construction wherein a planar anode and planar control electrode are positioned on opposite sides of a cathode. The cathode of such a tube has heretofore been provided with an electron-emissive surface which is directly exposed to substantially one entire surface of both the anode and the control electrode. While this construction provides a low-mu vacuum tube, it is subject to the limitation that a large portion of the cathode current, that is, the portion which is due to the electron emission on the side of the cathode facing the anode, is not controlled by the control electrode and consequently produces considerable anode dissipation without contributing to the power output of the tube. Additionally, the grid voltage—anode current characteristic of the tube exhibits a substantial tailing-off in the region of large values of negative grid bias and the tube consequently does not cut off at any practicable value of control-electrode bias.

It is an object of the invention, therefore, to provide a new and improved vacuum tube of the low-mu type and one which avoids one or more of the above-mentioned disadvantages and limitations of the prior art devices.

It is a further object of the invention to provide a low-mu vacuum tube adapted to provide large power outputs and one having a relatively sharp-cutoff operating characteristic.

In accordance with one form of the invention, a vacuum tube comprises a cathode having an electron-emissive surface over only a portion of the area thereof, an anode supported in spaced opposing relation to the cathode with substantially only the nonemissive surface of the cathode facing toward the anode, and a control electrode supported in spaced opposing relation to both the anode and cathode and outside of the space current path therebetween.

In a particular form of the invention, a vacuum tube of the type described comprises a control electrode positioned on the opposite side of the cathode from the anode, and the cathode has an electron-emissive surface only on the side thereof away from the anode.

In a preferred form of the invention, a vacuum tube of the type described comprises a cathode, a pair of anodes, each of generally hyperbolic configuration and each consisting of anode surface portions which are substantially unexposed to the cathode-emissive surface, and means supporting the anodes in spaced relation to the cathode and on opposite sides thereof with the planes of symmetry of the anode surfaces substantially coincident with each other and including the axis of the cathode. The tube includes a pair of control electrodes, each having a surface also of generally hyperbolic configuration, and means supporting the control electrodes in spaced relation to the cathode and on opposite sides thereof with the planes of symmetry of the control-electrode surfaces substantially coincident with each other, substantially normal to those of the anodes and including the axis of the cathode.

In another form of the invention, a vacuum tube of the type described comprises a cathode having an electron-emissive surface over only a portion of the area thereof, a pair of planar anodes supported in spaced relation to the cathode and on opposite sides thereof with the planes of the anodes substantially coincident with each other and including the axis of the cathode, and a pair of planar control electrodes supported in spaced opposing relation to the cathode and on opposite sides thereof with the planes of the control electrodes substantially parallel with each other and with the plane of the anodes.

For a better understanding of the invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawing, and its scope will be pointed out in the appended claims.

Referring now to the drawing, Fig. 1 is a view in elevation, with the envelope partly broken away, of a vacuum tube embodying the invention; Fig. 2 is a schematic cross-sectional diagram of the Fig. 1 tube and shows the arrangement of the tube electrodes thereof; Figs. 3 and 4 represent plots of the equipotential fields which are established between the electrodes of the tube of Fig. 1; Fig. 5 is a graph representing the operating characteristics of a tube of the prior art similar in construction to that of Fig. 1, while

Fig. 6 is a graph representing the corresponding operating characteristics of the Fig. 1 tube; Fig. 7 is a cross-sectional view of a tube embodying a modified form of the invention; Figs. 8 and 9 represent equipotential field plots for a tube embodying the Fig. 7 modification of the invention; and Fig. 10 is a cross-sectional view of a vacuum tube embodying an additional modified form of the invention.

Referring now more particularly to Fig. 1 of the drawing, there is shown a view in elevation of a tube embodying one form of the invention. In general, the tube comprises an envelope 10, partly broken away, having a reentrant stem or press 11 through which are sealed lead-in conductors 12. The lead-in conductors 12 are connected to individual prongs, not shown, of the tube base 9, and are individually connected to and support a planar anode 13, a plurality of cylindrical cathode members 14, more fully described hereinafter, which are aligned in a plane substantially parallel to that of the anode 13, and individual heaters, not shown, provided internally of the cathode members 14. A lead-in conductor 15 is sealed through the top of the tube envelope 10 and supports a planar control electrode 16 in spaced opposing relation to both the anode 13 and the cathode members 14 and on the opposite side of the cathode members from the anode.

It will be understood that the vacuum tube thus far described involves, with the exception of the cathode members 14, a construction heretofore proposed. Referring particularly to Fig. 2, which is a schematic cross-sectional view of the electrode arrangement of the Fig. 1 tube, each of the cathode members 14 is provided with an electron-emissive coating or surface 17 over only a portion of the area thereof and specifically on the side thereof which is exposed to the control electrode 16. In practice, the electron-emissive coating 17 is provided only over one-half, or slightly less, of the peripheral surface of the cathode members 14 and on the side of the cathode members opposite to the anode 13. As a result of this construction, substantially all of the surface of the anode 13 is unexposed to the cathode-emissive surface 17 while the maximum surface of the control electrode 16 faces toward or is exposed to the cathode-emissive surface. Expressed somewhat differently, it is also true that the anode 13 is supported in spaced opposing relationship to the cathode 14 and that substantially only the nonemissive surface of the cathode faces toward the anode. The trajectories of the electrons emitted by the electron-emissive surface 17 to the anode 13 are indicated in Fig. 2 by the dotted lines. Since the electron trajectories define the space current path between the cathode members 14 and the anode 13, it will be evident that the control electrode 16 is supported outside of the space current path between these elements. Consequently, the control electrode may have a surface which is nonpermeable to electrons and is preferably a continuous conductive surface, as that formed by a conductive plate member.

Fig. 3 represents a plot of the equipotential field which is established between the several tube elements of the Fig. 1 construction when the control electrode 16 is at the potential of the cathode members 14 so that there is no electrostatic field therebetween. If the anode 13 is energized to some positive potential, there is produced between the anode and cathode an equipotential field, represented by the equipotential lines *a*—*c*, inclusive, which extends into close proximity to substantially the entire area of the electron-emissive surfaces 17 so that the anode current is a maximum.

Fig. 4 represents the corresponding plot of the equipotential field when the control electrode 16 is energized to a predetermined negative potential sufficient to bias the tube to cutoff. In this event, the equipotential field of the control electrode 16, which is represented by the dashed lines *f*—*i*, inclusive, extends into close proximity to substantially the entire area of the electron-emissive surfaces 17, thereby to reduce substantially to zero the area of the electron-emissive surfaces over which any of the equipotential field of the anode 13 extends into close proximity. Thus, since the electrostatic field in close proximity to the entire area of the electron-emissive surfaces 17 is negative, all of the electrons emitted by the electron-emissive surfaces 17 are returned thereto and none flow to the anode 13 so that the anode current is cut off. It will be evident from the representation of Fig. 4 that the electron emission to the anode portions is, therefore, substantially terminated by an equipotential field which is produced by the control-electrode means 16 and which extends around the cathode through a total angle not substantially exceeding 180 degrees.

Fig. 5 is a graph representing typical control-electrode bias-anode current operating characteristics of a prior art vacuum tube of similar construction but not embodying the present invention. It will be evident that such prior art tubes are distinguished by a long tailing-off of the characteristic in the region of large values of control-electrode bias and are not subject to cutoff with any practicable values thereof.

Fig. 6 is a graph representing corresponding typical operating characteristics of the Fig. 1 vacuum tube. It will be seen from this figure that the tube of Fig. 1 has a definite cutoff characteristic and is quite free from the tailing-off which is inherent in the characteristics of the prior art tubes of this type.

As illustrative of a specific embodiment of the invention, the following specifications are given for an embodiment of the invention of the type shown in Fig. 1:

Anode 13 ____ inch__	15/16 x 15/16
Control electrode 16 ___do____	15/16 x 15/16
Cathode members 14 ___do____	0.041 outside diameter, 1 long, 4 in number
Anode-cathode spacing ____ do____	0.060
Control-electrode cathode spacing ____ do____	0.120
Amplification factor mu____	0.56 to 0.39
Anode potential ___ volts__	152 to 107
Anode current ____ milliamperes__	100 to 50
Mutual conductance factor (g_m) ____ micromhos__	580 to 130
Anode potential ___ volts__	174 to 85
Grid potential ____ do____	—25 to —200

Since the cathode members 14 have electron-emissive coatings 17 only on one side in the Fig. 1 tube construction, the efficiency of the cathode, i. e., the ratio of the cathode-emission current to the cathode heater voltage, is somewhat lowered. The efficiency may be improved by the modification of the invention represented by the cross-

sectional view of Fig. 7 which is functionally essentially similar to that of Fig. 1, similar tube elements being designated by similar reference numerals. The tube of Fig. 7 is provided with a pair of anodes 13, or what may be considered portions of a single anode, of generally hyperbolic configuration which are positioned in spaced relation to, and on opposite sides of, the cathode 14 which is of circular cross-section and is coated over its entire surface with an electron-emissive material. Each of the anodes 13 has surface portions 13*a*, 13*b* which are disposed substantially edge-wise toward the cathode 14 whereby the anode surface portions are substantially unexposed to the cathode-emissive surface 17. The tube also includes a pair of control electrodes 16, or what may be considered portions of a single control electrode, which have surfaces generally of hyperbolic configuration and are positioned in spaced relation to and on opposite sides of the cathode 14. It will be understood that the several tube elements of Fig. 7 are supported by lead-in conductors, not shown, from the tube envelope 10 in a manner essentially similar to that of the Fig. 1 arrangement. It will further be evident that the planes of symmetry of the anode surface portions represented by the traces A, A and B, B are substantially coincident and are normal to the planes of symmetry C, C and D, D of the control-electrode surfaces which are also substantially coincident with each other and that all of such planes include the axis of the cathode 14.

Fig. 8 represents an equipotential field plot of the field which is established between the anodes 13 and control electrodes 16 when the control electrodes 16 have the same potential as the cathode 14. It will be evident from this figure that the energization of the anodes 16 to a predetermined positive potential produces between the anodes and cathode an equipotential field represented by the solid-line curves *a*—*e*, inclusive, which extends into close proximity to substantially the entire area of the cathode-emissive surface 17 so that the anode current is a maximum.

Fig. 9 represents a similar equipotential field plot under the condition that the control electrodes 16 are biased to a negative potential sufficiently large that the tube is cut off. The equipotential field existing between the control electrodes 16 and the cathode 14 is represented by the broken-line curves *f*—*i*, inclusive, of this figure. It will be seen from this figure that the energization of the control electrodes to a predetermined negative potential reduces substantially to zero the area of the cathode-emissive surface 17 over which any of the equipotential field of the anodes 13 extends into close proximity so that the space current of the tube is substantially cut off.

If desired, a conventional space-charge grid may surround the cathode 14 and a screen grid may be positioned between the cathode 14 and each of the anodes 13, a conventional suppressor grid being preferably provided in this case between each of such screen grids and the anode individual thereto. The screen grid should have a cross-section generally of hyperbolic configuration and the anodes may be simply elongated planar conductive members.

The modification of the invention represented by the cross-sectional view of Fig. 10 is functionally essentially similar to that of Fig. 7, similar tube elements being designated by similar reference numerals. In this case, the anodes 13 in this modification are a pair of elongated planar members having anode surface portions 13*c*, 13*d* disposed edgewise to the cathode 14, whereby the anode surface portions 13*c*, 13*d* are substantially unexposed to the cathode-emissive surfaces 17. The planes of the anodes 13 are substantially coincident with each other and include the axis of the cathode 14. The control electrodes 16 also are planar members and are supported in spaced opposing relation to both the anodes 13 and the cathode 14 with the planes of the control electrodes substantially parallel with each other and with the plane of the anodes. The cathode 14 is here shown as having a generally elliptical cross-sectional configuration and the electron-emissive coatings 17 are provided only on the portions of the cathode which are exposed to the control electrodes 16. It will be understood that the anodes 13, control electrodes 16, and cathode 14 are supported from the tube envelope 10 by lead-in conductors, not shown, in a manner similar to that of Fig. 1.

The following specifications are illustrative of a specific embodiment of the invention generally of the type shown in Fig. 10 but with somewhat different relative dimensions:

Anodes 13 ——— inches	1 x $\frac{9}{16}$ x 0.005 (carbonized nickel)
Control electrodes 16 ——— do	1 x ¼ x 0.005 (carbonized nickel)
Cathode 14 ——— do	1¼ long, 0.060 outside diameter
Anode-cathode spacing ——— inches	0.032
Anode—control-electrode spacing ——— inches	0.25
Amplification factor mu ———	0.40 to 0.45
Anode potential ——— volts	145 to 102
Anode current ——— milliamperes	25 to 40
Mutual conductance (g_m) micromhos	110 to 340
Anode potential ——— volts	81 to 167
Control-electrode potential volts	−100 to −25

In the foregoing description of the invention, frequent reference has been made to the "unexposed" surface of the anode. By the term "unexposed surface" as applied to an anode surface in this specification and appended claims is meant either a surface as to which there is substantially no direct unobstructed path to the electron-emissive surface of the cathode, as in the Fig. 1 construction, or a surface that is disposed substantially edgewise to the cathode, as in the construction of Figs. 7 and 10.

In the appended claims, reference is made to anode and control-electrode means having portions alternately mounted around the cathode of the tube. By this expression is meant that, in a path around the cathode, there exists, for example, first a control electrode or control-electrode portion, then an anode or anode portion, then a control electrode or control-electrode portion, etc. This expression is intended to be applicable to and to describe the electrode arrangement of all of the tube constructions disclosed.

It will be evident from the foregoing description of the invention that a tube embodying the present invention is not only capable of delivering appreciable power outputs due to effective anode dissipation, but has the advantage of a relatively sharp cutoff operating characteristic not obtainable in prior art tubes of similar general type.

While there have been described what are at

present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A vacuum tube comprising, an evacuated envelope enclosing a cathode having an electron-emissive surface over only a portion of the area thereof, an anode supported in spaced opposing relation to said cathode with substantially only the nonemissive surface of said cathode facing toward said anode, and a control electrode supported in spaced opposing relation to both said anode and said cathode and outside of the space current path therebetween.

2. A vacuum tube comprising, an evacuated envelope enclosing a cathode having an electron-emissive surface over only a portion of the area thereof, an anode supported in spaced opposing relation to said cathode with substantially only the nonemissive surface of said cathode facing toward said anode, and a control electrode supported in spaced opposing relation to both said anode and said cathode and having a continuous conductive surface outside of the space current path between said anode and said cathode.

3. A vacuum tube comprising, an evacuated envelope enclosing a cathode having an electron-emissive surface over only a portion of the area thereof, an anode supported in spaced opposing relation to said cathode with substantially only the nonemissive surface of said cathode facing toward said anode, and a control electrode supported in spaced opposing relation to both said anode and said cathode with said cathode-emissive surface facing toward said control electrode.

4. A vacuum tube comprising, an evacuated envelope enclosing a cathode having an electron-emissive surface over only a portion of the area thereof, an anode supported in spaced opposing relation to said cathode with substantially only the nonemissive surface of said cathode facing toward said anode, and a control electrode supported in opposing relation to both said anode and said cathode and on the opposite side of said cathode from said anode.

5. A vacuum tube comprising, a substantially planar anode, a cathode comprising a plurality of cathode members supported in spaced opposing relation to said anode with said members aligned in a plane substantially parallel to that of said anode, a substantially planar grid supported in spaced opposing relation to both said anode and said cathode and on the opposite side of said cathode from said anode, and electron-emissive coatings only on the sides of said cathode members which are exposed to said control electrode.

6. A vacuum tube comprising, a cathode having an electron-emissive surface, an anode of generally hyperbolic configuration consisting of anode surface portions which are substantially unexposed to said cathode-emissive surface, means supporting said anode in spaced relation to said cathode with the plane of symmetry of said anode surface portions substantially including the axis of said cathode, and a control electrode supported in spaced opposing relation to both said anode and said cathode and outside of the space current path therebetween.

7. A vacuum tube comprising, a cathode having an electron-emissive surface, an anode of generally hyperbolic configuration consisting of anode surface portions which are substantially unexposed to said cathode-emissive surface, means supporting said anode in spaced relation to said cathode with the plane of symmetry of said anode surface portions substantially including the axis of said cathode, a control electrode having a surface of generally hyperbolic configuration, and means supporting said control electrode in spaced relation to both said anode and cathode with the plane of symmetry of said control-electrode surface substantially including the axis of said cathode.

8. A vacuum tube comprising, a cathode having an electron-emissive surface, a pair of anodes each of generally hyperbolic configuration and each consisting of anode surface portions which are substantially unexposed to said cathode-emissive surface, means supporting said anodes in spaced relation to said cathode and on opposite sides thereof with the planes of symmetry of said anode surface portions substantially coincident with each other and including the axis of said cathode, a pair of control electrodes each having a surface of generally hyperbolic configuration, and means supporting said control electrodes in spaced relation to said cathode and on opposite sides thereof with the planes of symmetry of said control-electrode surfaces substantially coincident with each other, substantially normal to those of said anodes, and including the axis of said cathode.

9. A vacuum tube comprising, a cathode having an electron-emissive surface over only a portion of the area thereof, a planar anode, means supporting said anode with the plane thereof substantially including the axis of said cathode, and a control electrode supported in spaced opposing relation to both said anode and said cathode and outside of the space current path therebetween.

10. A vacuum tube comprising, a cathode having an electron-emissive surface over only a portion of the area thereof, a planar anode, means supporting said anode with the plane thereof substantially including the axis of said cathode, and a planar control electrode supported in spaced opposing relation to both said anode and cathode with the plane of said control electrode substantially parallel to the plane of said anode.

11. A vacuum tube comprising, a cathode having an electron-emissive surface over only a portion of the area thereof, a pair of planar anodes supported in spaced relation to said cathode and on opposite sides thereof with the planes of said anodes substantially coincident with each other and including the axis of said cathode, and a pair of planar control electrodes supported in spaced opposing relation to said cathode and on opposite sides thereof with the planes of said control electrodes substantially parallel with each other and with the plane of said anodes.

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