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2,810,088

CATHODES FOR ELECTRON DISCHARGE DEVICES

Filed June 15, 1953

2 Sheets-Sheet 1

FIG. 1

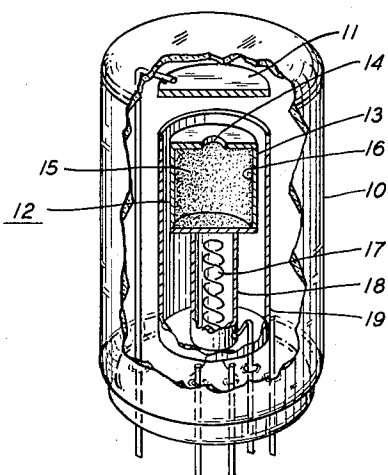


FIG. 2

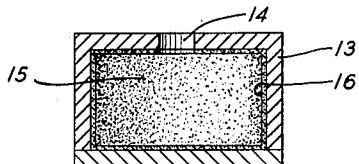


FIG. 3

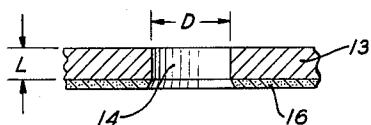


FIG. 5

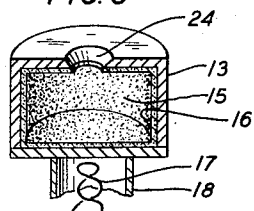


FIG. 6

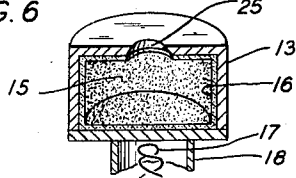


FIG. 7

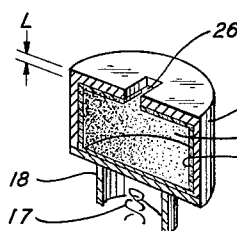


FIG. 8

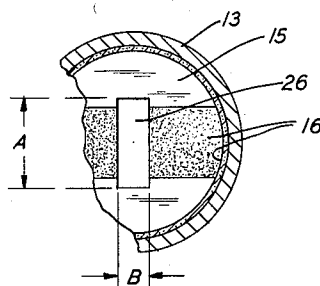


FIG. 9

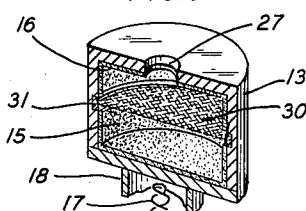


FIG. 10

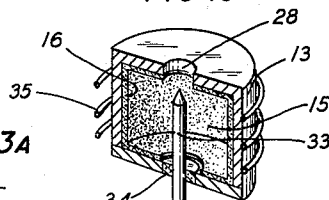
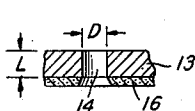


FIG. 3A



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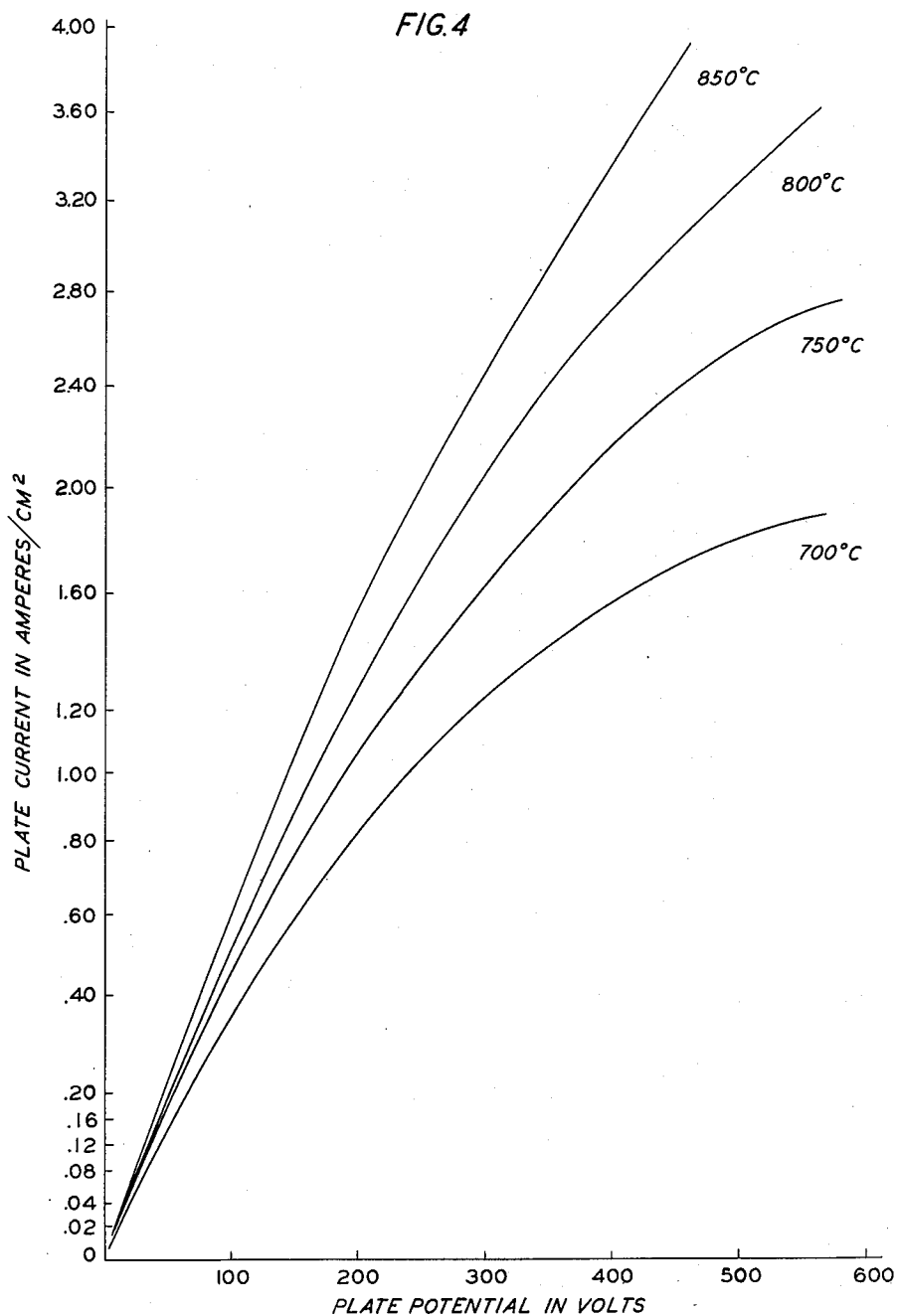
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CATHODES FOR ELECTRON DISCHARGE DEVICES

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2 Sheets-Sheet 2



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CATHODES FOR ELECTRON DISCHARGE DEVICES

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13 Claims. (Cl. 313—339)

This invention relates to electron discharge devices and more particularly to thermionic cathodes for such devices of the high vacuum type.

The heart of all electron discharge devices is the cathode. Characteristics of prime moment in the evaluation of any cathode are the electron currents that can be obtained therefrom, the voltages requisite to obtain a given current, and the cathode life. Basically, presently used thermionic cathodes comprise a support or base and an electron emissive coating thereon. During operation the cathode is heated to an elevated temperature, usually, in the case of cathodes of the oxide coated type, of the order of 800° C.

In known cathodes heretofore the maximum current density obtainable under continuous operation is relatively small, say of the order of 500 milliamperes per square centimeter of cathode surface for oxide coated cathodes. As is known, in high vacuum discharge devices, the electron current is governed by Child's law, i. e., the current is proportional to the three halves power of the accelerating voltage effective upon the cathode. Further, realization of currents of this order of magnitude necessitates use of high fields at the cathode. Consequently, the permeance is small, permeance being defined as

$$\frac{I}{v^{3/2}}$$

where I is the electron current in amperes and v the accelerating voltage in volts effective upon the cathode. In well designed known structures, permeances of about 1 to 2×10^{-6} have been obtained.

In a number of electron discharge devices, particularly those of the cathode ray or electron beam type, it is desirable frequently that the beam be of a particular configuration and direction. For example, in some traveling wave tubes and klystrons, a hollow cylindrical beam is advantageous. Also, for example, in different discharge devices paraxial, converging or diverging electron beams are desired. Further, in some, beams of cylindrical cross section are required; in others, beams of rectangular section are advantageous. Such beams of different configurations and directions have been produced heretofore, but their realization has necessitated use of complex electrode geometries or intricate focusing and collimating systems, or both.

One general object of this invention is to provide cathode structures having performance characteristics heretofore unattainable.

More specific objects of this invention are to increase the current density attainable with thermionic cathodes, to realize thermionic emission which is not restricted by Child's law and to enhance the permeance of thermionic devices.

Other objects of this invention are to simplify the construction of electron emitters and to facilitate the production of electron beams of prescribed configurations and directions.

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In accordance with one broad feature of this invention, a thermionic cathode is constructed to provide an emissive region which is completely enclosed except for a restricted aperture for egress of electrons. In one illustrative embodiment, the cathode comprises a conductive block, for example of nickel, having a cavity therein and a restricted aperture communicating with the cavity. The bounding wall of the cavity, or portions of this wall, has thereon an electron emissive coating. The cathode comprises also a heater element for raising the coating to emissive temperature.

In accordance with another feature of this invention, the aperture is constructed to provide a beam of prescribed configuration. For example, in accordance with one specific aspect of this feature, in a cathode wherein the aperture is circular or substantially so, the diameter and length of the aperture are correlated so that a hollow cylindrical electron beam is projected. As another example, in accordance with another specific aspect of this feature, in a cathode wherein the aperture is rectangular, the dimensions thereof are correlated so that two parallel beams are projected.

In accordance with a further feature of this invention, the bounding walls of the aperture are constructed to provide a beam or beams of prescribed direction, for example parallel, divergent or convergent.

Cathodes constructed in accordance with this invention are capable of producing continuous electron currents of several amperes per square centimeter of emissive orifice. Further, such large emission is realizable at low accelerating voltages whereby permeances of the order of 10×10^{-6} to 100×10^{-6} are attained. Also copious emission is obtainable at relatively low temperatures, specifically of about 700° C. or lower, which is at least 100 degrees less than the temperature of substantial emission for known thermionic cathodes. Further, as indicated above, electron beams of a variety of desirable configurations and directions are readily obtained and with relatively simple structures.

Also, it may be noted particularly that the emission may be made to vary substantially linearly with the accelerating voltage effective thereon.

The invention and the above-noted and other features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawing in which:

Fig. 1 is an elevational view of an electron discharge device incorporating this invention with portions cut away for clarity;

Fig. 2 is a diametrical sectional view of the cathode of Fig. 1;

Fig. 3 is a magnified view of a fragmentary portion of the cathode of Fig. 2 illustrating the relative magnitudes of the diameter and length of the emitting orifice of the cathode of Fig. 2;

Fig. 3A is a fragmentary section of a cathode of the type of Fig. 2 including an orifice of length greater than its diameter;

Fig. 4 is a graphical representation of the electron emission characteristic of typical cathodes constructed in accordance with this invention;

Fig. 5 is a longitudinal sectional view of another embodiment of this invention;

Fig. 6 is a longitudinal sectional view of a further embodiment of this invention;

Fig. 7 depicts another embodiment of this invention including a rectangular electron emitting orifice;

Fig. 8 is a fragmentary transverse sectional view of another embodiment of this invention including a rectangular electron emitting orifice;

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Fig. 9 is a longitudinal sectional view of an electrode assembly in accordance with this invention; and

Fig. 10 is a longitudinal sectional view of another electrode assembly of this invention.

Referring now to Fig. 1, an electron discharge device may be seen comprising generally a highly evacuated envelope 10 which encloses an electrode system including an anode or accelerating electrode 11 and a cathode assembly 12. The cathode assembly 12 includes a hollow cylinder 13, for example of nickel, which is enclosed except for an orifice or aperture 14. The internal surface of the cylinder 13 defines a cavity 15, the bounding walls of which are coated with a layer 16 of electron emissive material. The layer 16 of electron emissive material, such as a mixture of the oxides of barium, strontium and calcium, covers substantially the entire internal surface of the cylinder 13. Electron emission from the cathode assembly comes from the orifice 14 which communicates between the cavity 15 and the external surface of the cathode.

A heater 17, in this case a helical resistance wire, is mounted in heat transfer relationship at the opposite end of the cylinder 13 from orifice 14. Heater 17 is surrounded with a heat shield 18 of metal, e. g. nickel, to insure efficient heating of the cylinder 13 and the cathode assembly 12 itself is enclosed within a radiation shield 19 of similar material to that of heat shield 18.

Anode 11 is positioned opposite orifice 14, for example in a specific embodiment at a distance of 0.030 inch from the cylinder 13. The anode is a circular disk suitably mounted from the envelope 10. Advantageous mounting means for each of the electrodes are terminal pins extending through envelope 10.

The cylinder 13 of Fig. 1 may be seen more clearly in Fig. 2 as including cylindrically shaped cavity 15, layer 16 of electron emissive material on the bounding walls of the cavity 15, and a central orifice 14 in an end wall. The cylinder 13, shown enlarged for clarity, actually has, in an illustrative embodiment, an overall diameter of 0.150 inch, a height of 0.060 inch and wall thickness in the order of 0.005 inch. Orifice 14 is circular with a uniform diameter of 0.020 inch throughout its length. The diameter of orifice 14 may be varied within limits of from 5 to 40 percent of the cavity diameter with a minimum orifice size in the order of 0.010 inch while obtaining the enhanced emission of this hollow cathode; e. g., in a cathode of dimensions given above, the orifice may be between 0.010 and 0.050 inch obtaining the superior performance characteristics of the hollow cathode. In the case of hollow cathodes including non-circular cavities or apertures, enhanced electron emission is obtained when the aperture area is in the order of 5 to 40 percent of the area of a projection of the cavity in the plane of the aperture.

Although the orifice diameter may be varied over wide limits, it has been found that when the diameter of the orifice bears a prescribed relationship to its length or, in other words, the cathode end wall thickness, certain characteristics of the electron beam produced by the cathode may be controlled. When the diameter D , of a circular orifice 14 is greater than its length L , the cathode will produce a hollow beam of electrons substantially equal in outside diameter to the orifice diameter D . On the other hand, when the orifice diameter D is less than its length L , the beam produced is solid. The relationship may be expressed as follows: If $D/L > 1$, a hollow beam is produced and if $D/L < 1$, the beam produced is solid. The terms hollow and solid are used to denote in the first case, that substantially all of the electron energy is carried in an annular shaped beam while the latter form indicates that the beam intensity is substantially uniform throughout any transverse section. In one specific cathode having an overall diameter of 0.150 inch and a wall thickness of 0.005 inch, and an orifice having a diameter of 0.040 inch, the beam produced was distinctly hollow, 75

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the D/L ratio being equal to 8. The inner diameter of the hollow beam was in the order of 0.8 of the outer diameter.

Fig. 3 is an enlarged segment of the cathode of Fig. 2 showing portions of the cylinder wall 12, emissive layer 16 and indicating the D and L parameters. Fig. 3A illustrates a form of cathode orifice in which the transverse dimension D is less than its length L .

Fig. 4 represents graphically the electron emission obtained from a hollow cathode of the construction represented in Figs. 1 to 3 which is operated at temperatures of 700° C., 750° C., 800° C., and 850° C. respectively. Operating this cathode at a temperature of 700° C., which is well below the useful temperatures of conventional oxide coated cathodes, emission of from 1 to 2 amperes per square centimeter of orifice size is easily obtained. If the cathode is operated in a similar temperature range as used for conventional oxide coated cathodes, an emission of 4 to 5 amperes per square centimeter may be continuously drawn from the cathode. The latter emission constitutes an eight to tenfold improvement over the emission characteristics of conventional cathodes.

It will be noted especially from Fig. 4, that the current voltage characteristic, particularly at the higher operating temperatures, approaches linearity over a wide range of potentials. For operation at 850° C., for example, the characteristic includes two substantially linear portions, of slightly different slopes, one extending from zero to about 200 volts and the other from about 200 volts up.

Apart from the high emission obtained, the perveance as defined heretofore of hollow cathodes of this invention is in the range of from 10 to 100×10^{-6} as compared with a perveance of 1 or 2×10^{-6} for oxide coated cathodes generally. The perveance of cathodes in accordance with this invention under an accelerating potential of zero to 5 volts, reaches the high value of 100×10^{-6} in counter-distinction to extremely low perveance values, for example, 0.1×10^{-6} , of conventional cathodes in this low accelerating voltage region. The high perveance characteristic of this cathode under low accelerating potentials, extends the useful range of cathodes to allow low voltage operation of cathodes. In the usual anode potential range of 60 to 500 volts, cathodes in accordance with this invention maintain a perveance of 10×10^{-6} or above.

In each of the embodiments heretofore described, the walls of the aperture of orifice are parallel to the axis of the emitted beam of electrons. In Figs. 5 and 6, the electron emitting orifice, however, is shaped; in one embodiment, diverging toward the exterior of the cathode cylinder and in the other embodiment, converging toward the exterior of the cathode cylinder. The configuration of the cathode aperture may be used to supplement the action of electrostatic beam controlling means after the electron stream leaves the cathode emitting orifice. No beam forming electrode is required in the hollow cathode for it produces a distinct high intensity electron beam.

In Fig. 5, cylinder 13 includes internal cavity 15 bounded by cylinder walls which are covered with a coating 16 of electron emissive material. Frusto-conical aperture 24 communicates between the cavity and exterior of the cathode at a divergent angle with respect to the beam axis. Diverging aperture 24 allows the beam to be collimated or converged. In Fig. 6, cylinder 13 including cavity 15 and electron emissive coating 16 has an inwardly extending aperture 25 which is convergent with respect to the electron beam axis. In this embodiment, aperture 25 facilitates the collimation or divergence of the electron stream.

As shown in Fig. 7, a cylinder 13 defines a cavity 15 having emissive coating 16 upon the inner walls and an aperture 26 which is rectangular in shape. In one specific embodiment, the major dimension A of aperture 20 is 0.250 inch and the minor dimension B is 0.070 inch while the wall thickness of cylinder 13 is in the order of

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0.005 inch. When heated, this cathode produces an electron beam of rectangular cross section. Similar to the relationship of the hollow cathode including a circular aperture, the configuration of the electron beam produced by a rectangular aperture depends upon the relationship between the dimensions of the aperture. In this case, when the minor dimension B is greater than the length L of the aperture, a hollow rectangular beam is produced. If, on the other hand, the minor dimension of the aperture is less than its length, the rectangular beam is solid. The relationship may be expressed as follows: If $B/L > 1$, a hollow rectangular beam is produced; if $B/L < 1$, a solid rectangular beam is produced. The major dimension B of aperture 26 determines the major dimension of the rectangular electron stream whether it be hollow or solid.

In each of the embodiments mentioned heretofore, the entire surface of the cathode cylinder bounding the cavity is coated with electron emissive material. In Fig. 8, a transverse section of an embodiment similar to the cathode of Fig. 7 is shown in which cylinder 13 defining cavity 15 is internally coated with layer 16 of electron emissive material and includes rectangular aperture 26. Emissive layer 16' which covers the closed end and inner cylindrical wall of cylinder 13 extends in a strip across the apertured wall of cylinder 13 perpendicular to and of lesser width than the major dimension A of aperture 26, whereby the internal surface adjacent the ends of aperture 26 is uncoated. In accordance with this embodiment, a B/L ratio of less than 1 results in a solid beam of electrons while a B/L ratio greater than 1 produces a pair of parallel planar sheets of electrons distinct from one another. One sheet of electrons emerges along each of the major sides of aperture 26.

A further embodiment of the cathode of this invention is shown in Fig. 9. There, cylinder 13 defining cavity 15, internally coated with a layer 16 of electron emissive material, and including aperture 27 also encloses a screen electrode 30 mounted within the interior of cylinder 13 opposite aperture 27. Electrode 30 is supported within cylinder 13 by an insulating ring 31 of, for example, ceramic material, and may serve several functions one of which is to operate as a control grid with appropriate signal input means. The electrode 30 is in an advantageous position for control of electron beams passing through aperture 27. In the form shown in Fig. 9, the cathode including cylinder 13, emissive coating 16, aperture 27 and control electrode 30 along with an anode comprise the requisite electrodes for a triode vacuum tube. Electrode 30 may be operated as a conventional signal modulated control grid as, for example, negatively biased with respect to its enclosing cathode cylinder. Electrode 30 may be biased by an insulated lead, not shown, extending through the wall of cylinder 13.

In Fig. 10, another form of auxiliary electrode is shown enclosed within the hollow cathode cylinder. In that embodiment, cylinder 13 defining cavity 15 bounded by the internal surface of cylinder 13 and layer 16 of electron emissive material includes aperture 28 and also encloses a rod 33 coaxially supported within cylinder 13 by insulating bushing 34. A heater 35 comprises a series of turns of resistance wire about cylinder 13. A heat shield, not shown, may take the form of a tube encompassing cylinder 13 and heater 35. Rod 33 terminates in a point within cylinder 13 adjacent aperture 28. Auxiliary electrodes of the form shown in Fig. 10 may be used similarly to those of the type shown in Fig. 9, to wit, as a control grid similar to the screen of Fig. 9 or may be used to increase the electron intensity around the orifice by being maintained at a slightly positive potential with respect to the cathode, thereby drawing electrons toward electrode 33 and thence to the anode.

Reference is made of the application Serial No. 361,623, filed June 15, 1953, and Serial No. 361,663, filed June, 15, 1953, wherein related inventions are disclosed.

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It is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A high density electron beam device comprising a highly evacuated envelope, a hollow body within said highly evacuated envelope, said body being closed except for an electron exit aperture, a coating of electron emissive material upon the interior of said body, a heater for said body, and an electron accelerating electrode positioned opposite the aperture in said body.

2. A device in accordance with claim 1 for obtaining a hollow electron beam wherein the minimum transverse dimension of said aperture is greater than the length of said aperture.

3. A device in accordance with claim 1 for obtaining a solid electron beam wherein the minimum transverse dimension of said aperture is smaller than the length of said aperture.

4. A device in accordance with claim 1 for obtaining a collimated electron beam wherein said aperture is of substantially uniform size throughout its length.

5. A high density electron beam electron discharge device of the high vacuum type comprising a highly evacuated envelope, a hollow cathode body, closed except for a frusto-conical aperture therein, a coating of electron emissive material upon the interior of said body, an electron accelerating electrode positioned opposite said aperture, and a heater for said body.

6. A cathode in accordance with claim 5 wherein said aperture is of smaller size at the interior than at the exterior of said hollow body.

7. A cathode in accordance with claim 5 wherein said aperture is of larger size at the interior than at the exterior of said hollow body.

8. A high vacuum electron discharge device comprising a highly evacuated envelope, a cathode comprising a conducting body including an internal surface bounding a cavity within said body and including also a single opening of at least 0.010 inch in transverse dimension communicating between said cavity and the exterior of said body, the area of the opening in said body being in the order of less than 40 percent of the area of a projection of the cavity in the plane of the opening, a coating of electron emissive material on said internal surface, an electron accelerating electrode positioned adjacent said opening, and a heater for said body.

9. A high vacuum electron discharge device comprising a highly evacuated envelope, a cathode comprising a conducting body within said envelope including a cavity therein and an opening having a minimum dimension greater than in the order of 0.010 inch communicating between said cavity and the external surface of said body, said body being imperforate except for said opening, the area of the opening in said body being in the order of 5 to 40 percent of the area of a projection of the cavity in the plane of the opening, a coating of electron emissive material on portions of the cavity defined by said body, an electron accelerating electrode in spaced juxtaposition with the opening in said body, and a heater for said body.

10. A high vacuum electron discharge device comprising a highly evacuated envelope, a cathode within said envelope comprising a conducting body including an internal surface defining a cavity and including a restricted opening communicating between said cavity and the exterior of said body, the bounding walls of said restricted opening including a pair of parallel major sides, a coating of electron emissive material upon the internal surface of said body adjacent the central portion of said major sides, an electron accelerating electrode positioned adjacent said opening, and a heater for said body.

11. A high vacuum electron discharge device comprising a highly evacuated envelope, a hollow body within

said envelope having an aperture in one wall thereof, means for heating said body, an electron emissive coating upon the interior of said body, means within said body for modulating the electron beam emitted therefrom, and an electron accelerating electrode within said envelope positioned adjacent said aperture. 5

12. An electron discharge device in accordance with claim 11 wherein said modulating means comprises a screen disposed within said hollow body opposite said aperture and insulated from said body.

13. An electron discharge device in accordance with claim 11 wherein said modulating means comprises a rod axially aligned with said aperture. 10

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