

Oct. 15, 1957

D. MacNAIR

2,810,089

CATHODES FOR ELECTRON DISCHARGE DEVICES

Filed June 15, 1953

2 Sheets-Sheet 1

FIG. 1

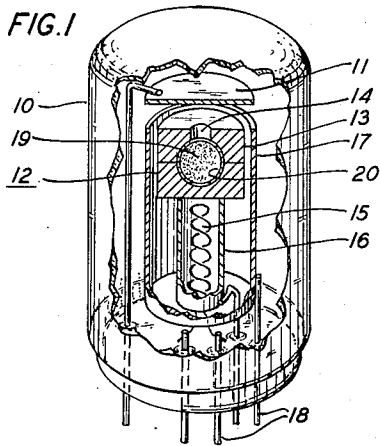


FIG. 2

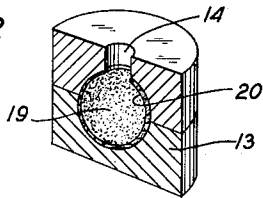


FIG. 4

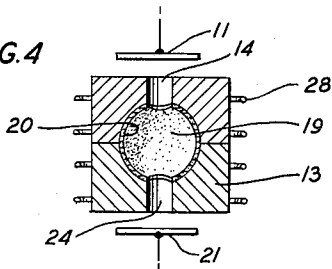


FIG. 5

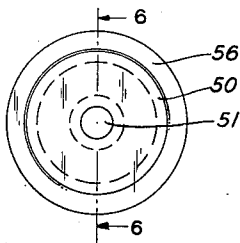


FIG. 6

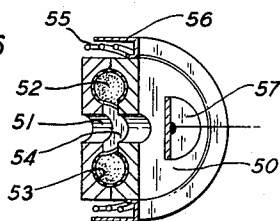


FIG. 7

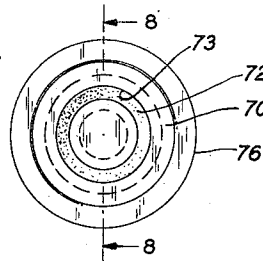


FIG. 8A

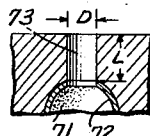


FIG. 8

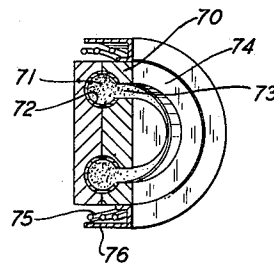


FIG. 8B

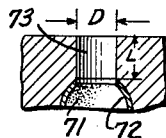


FIG. 9

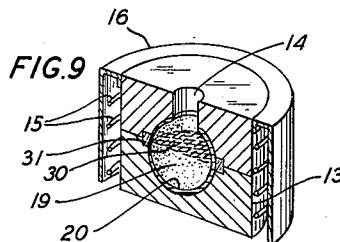
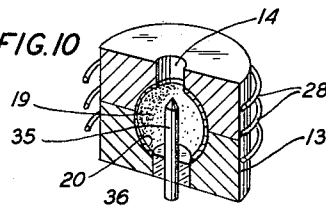


FIG. 10



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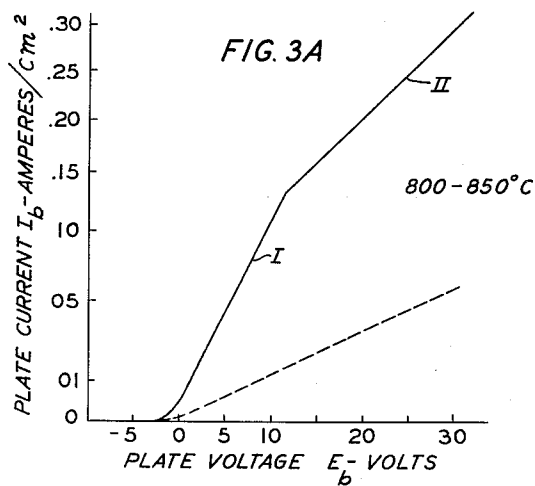
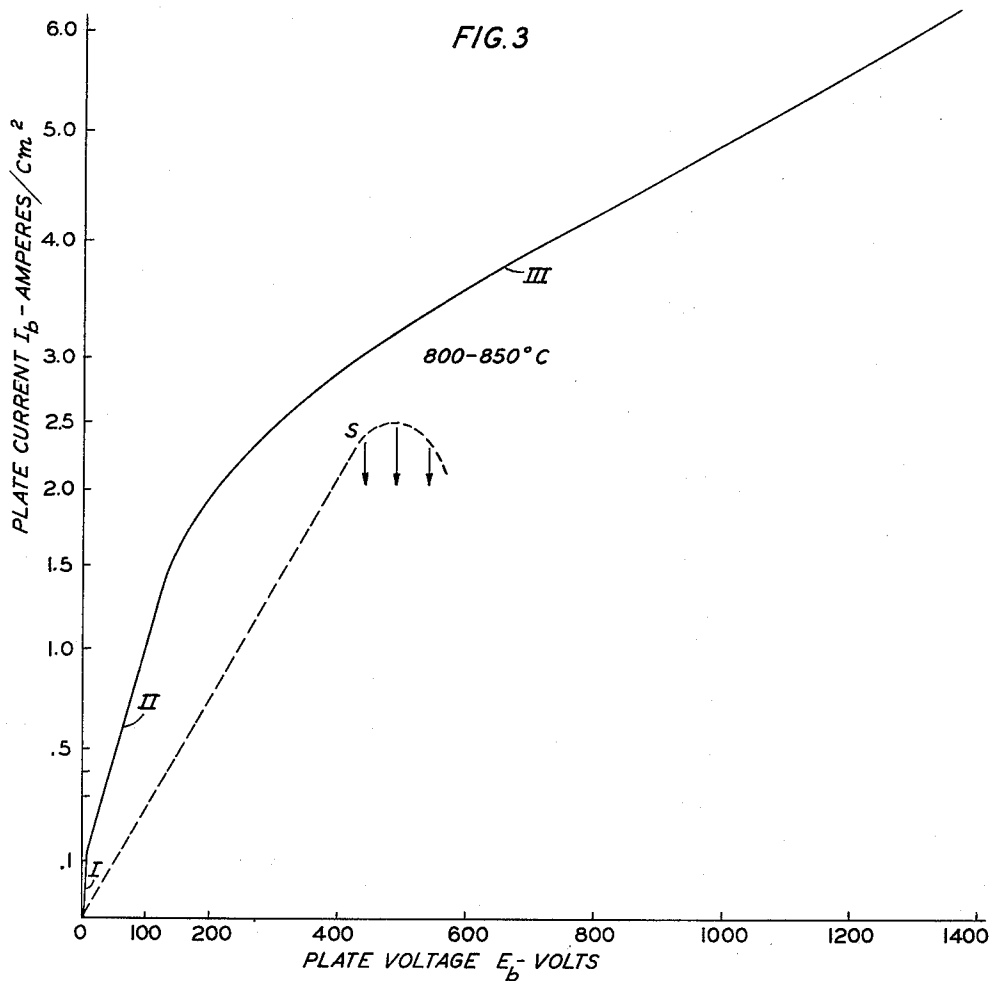
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2 Sheets-Sheet 2



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CATHODES FOR ELECTRON DISCHARGE DEVICES

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Application June 15, 1953, Serial No. 361,623

6 Claims. (Cl. 313—339)

This invention relates to high vacuum electron discharge devices and more particularly to thermionic cathodes of the general type disclosed in my application Serial No. 361,527, filed June 15, 1953.

As disclosed in the above-identified application, novel and particularly advantageous performance characteristics, notably high density electron streams, can be realized from a thermionic cathode wherein the emissive surface is on the interior of a hollow body. Such emitters are now referred to as hollow cathodes.

One general object of this invention is to improve thermionic emitters for electron discharge devices.

More specific objects of this invention are to increase the intensity of electron emission from hollow cathodes, to facilitate control of the emission, and to expedite the production of hollow electron beams.

In one illustrative embodiment of this invention, a cathode comprises a hollow body having an aperture therein, a coating of electron emissive material upon the inner wall of the body, and a heater for the body to raise the coating to emissive temperature.

In accordance with one feature of this invention, the cathode is constructed so that the interior surface thereof is a surface of revolution of circular section. For example, in one illustrative embodiment, this surface is spherical. In another illustrative embodiment, this surface is toroidal.

In accordance with another feature of this invention, in a hollow spherical cathode, two diametrically opposed apertures are provided whereby two similar high intensity electron beams are produced.

In accordance with a further feature of this invention, in a hollow toroidal cathode, the body is provided with an annular opening whereby a hollow beam is produced.

In accordance with still another feature of this invention, an auxiliary electrode is provided within the cathode to augment or control the electron emission. In one embodiment, the auxiliary electrode may be a grid and operated as a signal controlled electrode to vary the intensity of the electron beam issuing from the aperture in the cathode. In another embodiment, the auxiliary electrode may be operated as an accelerating electrode to enhance the density of the emission. In still another embodiment, the auxiliary electrode is provided with a secondary electron emissive coating, thereby to augment the primary emission from the thermionic coating.

A particular substantive feature of devices constructed in accordance with this invention is the intensity of the beams which is realizable. For example, in typical devices electron beams having a density of 5 amperes per square centimeter have been produced.

Another particular substantive feature of devices constructed in accordance with this invention is that the current to an anode associated with the cathode is not limited in accordance with Child's law and does not saturate even at very high anode voltages. For example, in typical devices cathode currents which do not reach saturation at anode potentials of 1500 volts have been obtained.

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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:

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

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

10 Fig. 3 is a graphical representation of the variation in current from the hollow spherical cathode of Fig. 2 with respect to plate voltage;

Fig. 3A is an enlarged portion of the graphical representation of Fig. 3;

15 Fig. 4 is a sectional view of a cathode including a pair of beam emitting apertures;

Fig. 5 is an elevational view of an embodiment of this invention including a toroidal cavity;

20 Fig. 6 is a sectional perspective view of the embodiment of Fig. 5;

Fig. 7 is a plan view of another embodiment of this invention including a toroidal cavity;

Fig. 8 is a sectional view in perspective of the embodiment of Fig. 7;

25 Figs. 8A and 8B are fragmentary sections of the cathode of Fig. 8 illustrating the relationship between the diameter and the length of the emitting orifice of cathodes in accordance with this invention;

30 Fig. 9 is a sectional view in perspective of a hollow spherical cathode incorporating an auxiliary electrode therein;

Fig. 10 is a sectional view in perspective of an electrode assembly including a hollow spherical cathode and a rod auxiliary electrode.

35 Referring now to Fig. 1, an electron discharge device may be seen comprising a highly evacuated envelope 10 which contains an anode 11 and a cathode assembly generally designated 12. Cathode assembly 12 comprises a hollow cylinder 13 which includes a spherical cavity and an orifice 14 in the end adjacent anode 11. At the end of cylinder 13 opposite aperture 14, a heater 15 of resistance wire is mounted in heat transfer relationship. A heater shield 16 surrounds heater 15 and a radiation shield 17 encompasses the entire cathode assembly 12.

40 The cylinder 13, heater shield 16 and radiation shield 17 advantageously are fabricated of nickel. An electron emissive coating in the form of a layer 20 of the oxides of barium, strontium and calcium covers the interior of cylinder 13. Suitable terminal and support means such as pins 18 mount each of the elements within envelope 10.

45 The interior of cylinder 13, cavity 19 and emissive coating may be seen in Fig. 2 which is a longitudinal sectional view of cylinder 13. Layer 20 of electron emissive material covers substantially all of the internal spherical surface of cylinder 13. Electrons emitted from the layer 20 to within cylinder 13 all pass through orifice 14 and then to anode 11 since the cathode is closed except for orifice 14. Electron beam emission through orifice 14 forms a high intensity electron stream in the order of 1 to 5 or more amperes per square centimeter of orifice size depending upon the temperature at which the cathode is operated. Electron beam densities of over one ampere per square centimeter are produced by cathodes in accordance with this invention at a temperature in the order of 750° C. 55 which is at least 50 degrees lower than the operating temperature of conventional oxide coated cathodes. Of course, the electron emission increases with cathode temperature and greatly enhanced emission can be obtained by operation of the cathode in the order of 900° C.

60 The emission characteristics of cathodes of this invention may be seen in Figs. 3 and 3A which depict the electron beam density of a hollow spherical cathode having a

cavity diameter of 250 mils and a circular orifice 20 mils in diameter. The variation of anode current I_b with respect to the anode potential E_b is shown in Fig. 3 with the cathode operating at a temperature between 800° C. and 850° C. The ordinate scales are compressed by the factor of the two-thirds power so that the emission perveance, defined as the anode current in amperes divided by the anode voltage to the three-halves power, is indicated by the slope of linear portions of the emission characteristic curves.

The emission characteristic of the hollow spherical cathode includes three substantially linear portions in order of decreasing slope. The initial region of emission labeled I has the greatest slope giving a perveance as defined heretofore in the order of 100×10^{-16} . The region I is best seen in Fig. 3A which shows the low voltage characteristic with the scales expanded for clarity. After this initial region which includes anode potentials up to in the order of 10 volts, a second linear portion of the emission curve labeled II is seen. The slope of the second region is less than that of the initial region but indicates the perveance and anode current far in excess of that expressed within Child's law. A third linear region, III, extends upward at a slope less than a second region from anode potentials in the order of 150 volts.

The dotted line of Fig. 3 depicts the emission characteristic of a conventional exteriorly coated cathode giving continuous electron emission. The curve is typified by a linear portion extending upward to a knee region at emission in the order of 2 to 3 amperes per square centimeter or less. The linear portion of the emission curve indicates space charge limited operation of the cathode up to the knee of the curve, labeled S, at which saturation takes place, i. e., the anode collects all of the electrons emitted by the cathode. Above point S, increases in anode potential have a slight effect upon the cathode emission as indicated by the slope of the curve, nearly parallel to the voltage axis. In the region of the saturation point S, the conventional exposed oxide coated cathode usually becomes deactivated presumably by products from the anode and emission falls sharply. The point at which deactivation takes place depends upon many unascertained factors so is indicated by the arrows pointed downward.

By comparison of the emission curves of the hollow spherical cathode and a conventional oxide coated cathode several important distinctions are noted. First, and of prime importance, the emission of a hollow spherical cathode is far in excess of that obtained at each value of anode potential. In the normal operating potential range the values differ by a factor of two or more. In each of the linear portions of the hollow spherical cathode emission curve the perveance or slope is greater than that of the conventional cathode. No abrupt saturation point is witnessed in the hollow spherical cathode emission curve, instead, a smooth curve marks the beginning of the third linear region. Another significant difference between the emission curves is that there is no indication whatsoever of deactivation of the hollow spherical cathode with a resultant fall in emission. The anode potential when raised in the third region to a value of 1400 volts and higher results in a uniform rise in anode current. In typical devices constructed in accordance with this invention, the anode potential has been raised as high as 3000 volts, still without deactivation.

The markedly distinct emission curve of the hollow spherical cathode results, it is believed, from the disturbance of the normal space charge relationship between the anode and an exposed coated cathode. In the anode potential range I of from zero to 10 volts there is believed to exist a space charge region between the orifice of the hollow spherical cathode and the anode as well as a space charge region within the spherical cavity of the cathode. The electrons emitted from the portions of the coating near the orifice see an accelerating field component away from the orifice so that they cannot add to the inter-

electrode space charge. The replenishment of this charge when current is first drawn then must be from the back of the cathode. Electrons emerging from the orifice which were previously emitted at the rear will be from the high velocity end of the Maxwellian distribution resulting in an electron emission far in excess of that expected within Child's law which assumes an initial electron velocity of zero. In the anode potential region II between 10 and 150 volt portions forming the second linear portion of the curve, the accelerating field of the anode is believed to penetrate the cathode through the orifice allowing electrons of lower initial velocity to be drawn to the anode augmenting electron emission at a slightly lower perveance. In the linear portion III of the emission characteristic curve, the accelerating field penetration within the cathode is greater and portions of the emitting area surrounding the orifice are believed to be under temperature limited operation, thereby offering a space charge free emissive surface. In order to attain the full emission capabilities of the hollow spherical cathode particularly in the third linear region, it is advantageous that the portions of the cavity surrounding each orifice be coated with emissive material.

Bombardment of the emissive coating by particles from the anode is practically eliminated in the hollow spherical cathode since only a comparatively small region of emissive coating is exposed to the anode. Owing to the hollow spherical configuration of the cathode, any positive ions liberated within the cavity, for example from impurities in the coating, are trapped therein and will tend to neutralize the space charge within the cathode thereby enhancing electron emission. In this manner the harmful result, deactivation of the cathode due to anode products including positive ions, is practically eliminated while positive ions liberated within the cathode are utilized to promote electron emission.

The above-described understanding of the operation of the hollow spherical cathode is given by way of explanation but this invention, of course, is not to be limited thereby.

In another embodiment of a hollow spherical cathode illustrated in Fig. 4, cylinder 13 includes a spherical cavity 9. A heater 28 surrounds cylinder 13. The internal surface of the cylinder defining cavity is coated with a layer 20 of electron emissive material. Oppositely disposed in the cylinder are a pair of orifices 14 and 24 which communicate between opposite portions of the cavity and the exterior of the cylinder 13. Positioned at the exterior of apertures 14 and 24 are anodes 11 and 21 respectively. The anodes 11 and 21 are electrically biased individually with respect to the cylinder and each draws an electron beam from its respective opening in the cylinder. The intensity of the electron beam emerging from the aperture 14 is dependent upon accelerating voltage upon the anode 11. Likewise, the intensity of the electron beam emerging from the aperture 24 is dependent upon the accelerating voltage upon the anode 21. The electron beam drawn from each aperture is independent of the voltage or changes of voltage of the remote anode whereby a pair of independently controllable high intensity electron beams may be produced from a single cathode.

Referring now to Figs. 5 and 6, there may be seen another embodiment of this invention comprising a hollow body 50 including a central aperture 51. Within the interior of body 50 is a toroidal cavity 52 of circular cross section best seen in Fig. 6. Cavity 52 is bounded by a surface of body 50 upon which a coating 53 of electron emissive material is located. An annular orifice 54 communicates between cavity 52 and aperture 51. A heater 55 comprising a series of turns about the cylindrical wall of body 50 is enclosed within heater shield 56. Anode 57 is positioned adjacent one face of body 50 in position to receive electrons emitted from aperture 51.

In this embodiment, an extremely large emissive sur-

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face is located within the interior of cathode body 50. The toroidal emissive surface 53 is almost completely shielded from deactivation products from the anode 57. In fact, no portion of the emissive coating directly faces the anode. Emitted electrons under the influence of the accelerating field of the anode are formed easily into a beam through aperture 51. Particles from the anode, particularly positive ions, having an extremely great mass by comparison with the electrons find it nearly impossible to negotiate a path from the anode to the emissive coating within the cathode. Instead, they either strike the outer known emissive surface of body 50 or pass completely through aperture 51; in either case, having no detrimental effect upon the emissive coating 53.

Another embodiment of the hollow spherical cathode of toroidal shape is shown in Figs. 7 and 8. The cathode comprises a hollow body 70 including an internal toroidal cavity 71, the bounding surface of which is coated with a layer 72 of electron emissive material. Cavity 71 is joined to the external surface of body 70 by annular orifice 73 in face 74 of body 70. A heater 75 is formed by a series of turns of resistance wire about body 70 within heater shield 76.

This embodiment of the hollow cathode produces an annular beam of electrons advantageous for use in high vacuum devices, particularly of the dual stream traveling wave tube type. The emissive surface of the hollow body obtains the advantage of substantially complete shielding from positive ion deactivation while furnishing the high electron emission of the hollow cathode in the form of an annulus. Where it is desired to produce a pair of coaxial annular beams of electrons, the parameters of orifice 73 are correlated so that the distance between the bounding walls of orifice 73 is greater than their length as is illustrated in Fig. 8B where the width of the aperture D exceeds the thickness L of the metallic body between its exterior surface and the cavity. One electron beam is adjacent each bounding wall with a comparatively electron free region therebetween. A single hollow electron beam is produced from the single orifice 73 when the distance between the bounding walls of orifice 73 is less than their length as is illustrated in Fig. 8A where the transverse dimension D of the aperture is less than the thickness L of the wall of the body. The correlation of parameters generally to produce high density electron beams is taught in my related application cited heretofore.

Still another embodiment of this invention is shown in Fig. 9 involving a cathode of the type shown in Fig. 2 wherein cylinder 13 defines the spherical cavity 19 bounded by layer 20 of electron emissive material and includes orifice 14. Within the spherical cavity 19 an auxiliary electrode 30 in the form of a mesh grid is mounted as by insulating ring 31. Suitable electrical biasing means as shown in the drawing for the electrode 30 is an insulated lead which passes through the wall of cylinder 13 adjacent ring 31. This embodiment obtains the high electron emission of hollow spherical cathodes generally and by operation of electrode 30 as a control grid, modulation of the electron beam is readily accomplished.

In Fig. 10 an electrode assembly is shown including another form of auxiliary electrode. Cylinder 13 defines cavity 19 bounded by layer 20 of electron emissive material and includes aperture 14 communicating between spherical cavity 19 and its external surface. A metallic rod 35 is positioned as by insulating bushing 36 within cavity 19 with one end adjacent aperture 14. Rod 35 may be utilized, similar to the mesh grid of Fig. 9, as a modulating electrode within the cathode or be employed as an accelerating electrode which is main-

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tained at a potential slightly positive with respect to body 13. Rod 35 under the latter conditions will enhance emission of the electrode assembly by drawing electrons to a position adjacent aperture 14 where the electrostatic field established by the accelerating electrode may have greater effect. Rod 35 when coated with a secondary electron emissive coating such as barium oxide is subject to bombardment by primary electrons from coating 20 due to its advantageous position in proximity to the entire spherical emissive coating. Primary electrons from layer 20 along with secondary electrons from rod 35 all emitted from aperture 14 constitutes a high intensity electron beam.

Reference is hereby made to the application Serial No. 361,663, filed June 15, 1953, wherein a related invention is described.

In each of the embodiments of the invention shown in the drawing, the emissive coating covers the entire surface bounding the cavity. Portions of the coating may be omitted without impairing the operation of the cathode. It is advantageous, however, for the reasons mentioned heretofore that the internal surface of the cathode adjacent the apertures be coated.

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 cathode for high vacuum electron discharge devices comprising a body having therein a cavity the bounding surface of which is toroidal, said body being substantially closed except for an electron emission aperture communicating with said cavity, means for heating said body, and a coating of thermionic emissive material on said bounding surface.

2. A cathode for a high vacuum type electron discharge device comprising a conducting body including a toroidal cavity, a coating of electron emissive material upon the bounding surface of said cavity, said body including an annular opening communicating between the cavity and the exterior of said body, and a heater for said body.

3. A cathode in accordance with claim 2 wherein said body includes a substantially planar face and the annular opening communicates between the cavity and the face of said body.

4. The cathode in accordance with claim 2 wherein the bounding walls of the annular opening are of greater length than the width of the annular opening whereby a single hollow electron beam is produced.

5. The cathode in accordance with claim 2 wherein the bounding walls of the annular opening are of lesser length than the width of the annular opening whereby a pair of coaxial hollow electron beams are produced.

6. A cathode for an electron discharge device comprising a metallic body having a cavity therein the bounding surface of which is toroidal, said body being closed except for an electron emission aperture communicating between the cavity and an external surface of said body, a coating of electron emissive material on the bounding surface of said cavity at least in the region adjacent said aperture, and means for heating said body.

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