March 25, 1941. A. W. HULL 2,236,289

THERMIONIC DEVICE

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Fig. 1.

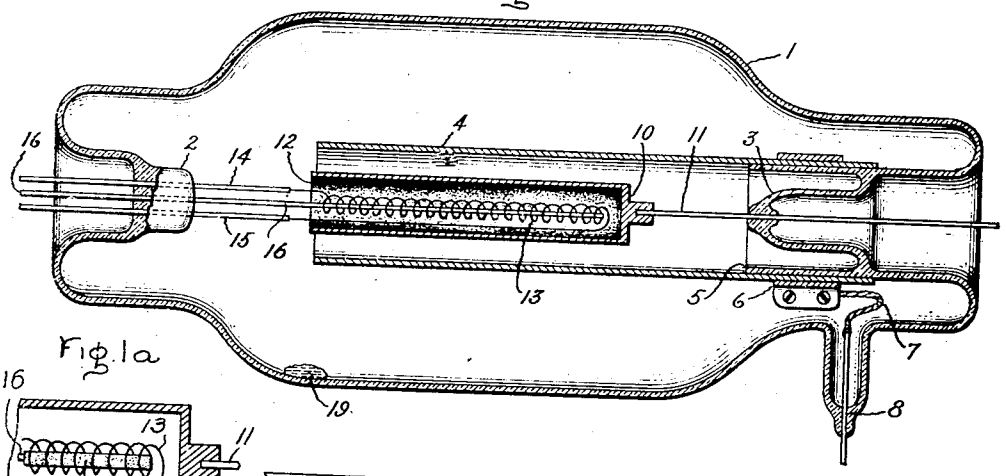


Fig. 1a

Fig. 2.

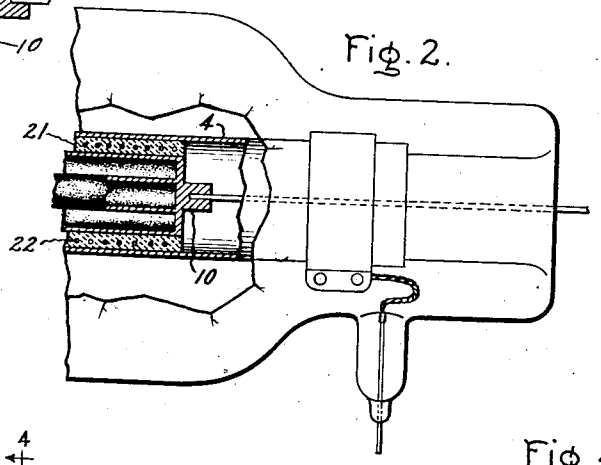


Fig. 3.

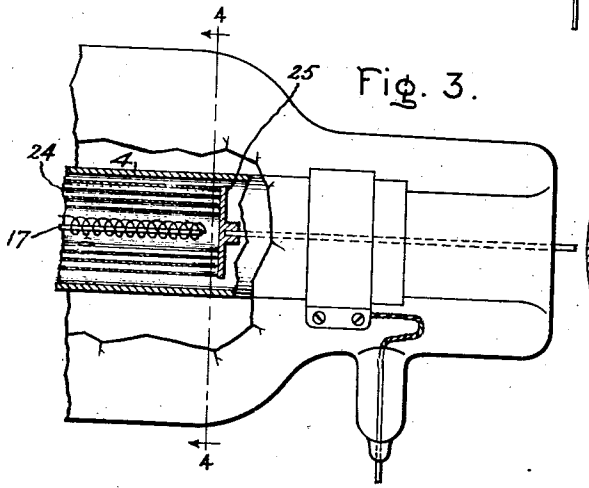
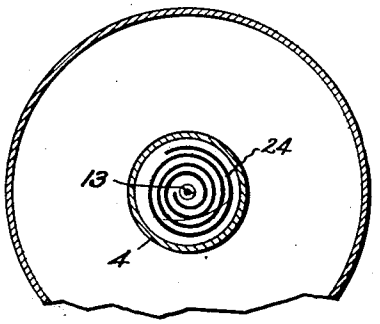


Fig. 4.



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Fig. 5.

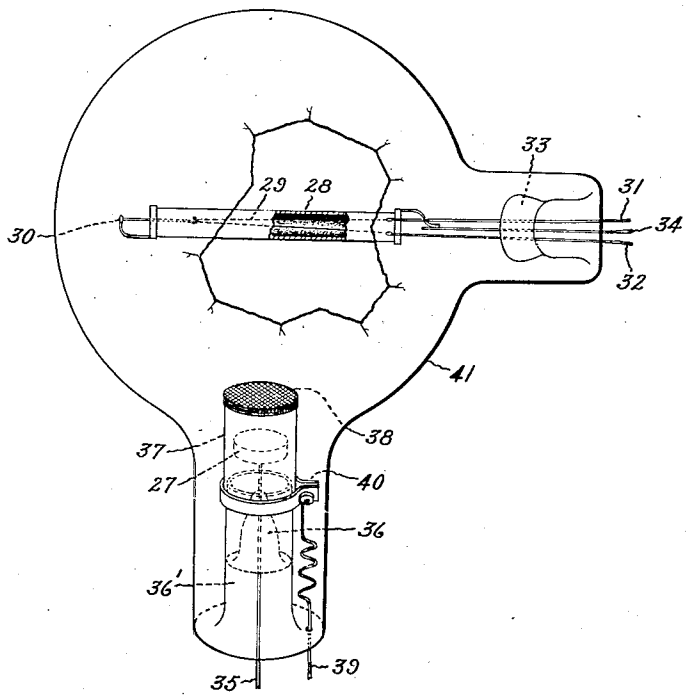
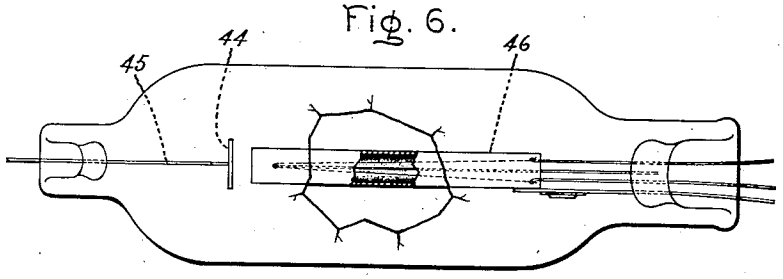


Fig. 6.



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UNITED STATES PATENT OFFICE

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THERMIONIC DEVICE

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Application December 23, 1926, Serial No. 156,713

14 Claims. (Cl. 250—27.5)

The present invention comprises improvements in electrical discharge devices. In particular it relates to thermionic devices which are adapted for various uses, but more especially for the rectification of alternating current.

My invention relates to the class of thermionic devices which contain cathodes provided with an activating material which has a higher electron emissivity, or lower work function, than the foundation material or main body of the cathode. It is the main object of my invention to increase the life and improve the efficiency of devices provided with cathodes of this class. Another object of my invention is to provide a construction whereby the undesired enhancement of electron emission from an anode or other cooperating electrode caused by the deposition of activating material thereon is prevented. My invention also provides a construction whereby the energy required to maintain a thermionic cathode at an elevated operating temperature may be conserved, namely, by constructing the cathode so that heat radiation from its exterior is materially reduced.

As will be more fully explained hereinafter, a prominent feature of my invention is the provision of solid activating material upon an internal surface of a thermionic cathode, thereby reducing both the loss of active material by evaporation and the loss of heat from the cathode, as will be later explained.

Prior to my invention activating material has been applied to an external surface of a thermionic electrode. For example, vacuum tubes have been provided with filamentary electrodes coated externally with oxides of alkaline earth metals. As these devices operated without a substantial amount of positive ionization, this construction was advantageous as the electron-emitting surface could be brought very close to the anode, thereby reducing the space charge effect, and thus increasing the current. Operation of such cathodes at temperatures of high electron emissivity was accompanied by a corresponding rapid evaporation of the activating material and a rapid reduction in electron emissivity of the cathodes. It was necessary to effect a compromise by operating at a temperature of relatively low emissivity to secure a commercial length of life. This was desirable also because the evaporated material was a particularly active electron-emitter and imparted to any surface or electrode, such as anode or grid, upon which it became deposited an undesired high electron emissivity.

In accordance with the main feature of my invention a high efficiency of electron emission is obtainable by so constructing the electron-emitting electrode that it provides a cavity open to the exterior, for example by shaping the electrode in the form of an open cylinder, and providing solid activating material within such a cavity. Loss of activating material at high electrode temperatures thereby is greatly reduced, the material evaporating from one point being condensed on other hot parts of the cathode, reciprocal evaporation and condensation of activating material thus occurring without loss and without deleterious effect upon the operation of the device.

The high space charge which such a construction otherwise would entail is neutralized by providing in the device means for producing positive ions, such as a gas or vapor, at low pressure. I have discovered that under these conditions an exceedingly efficient operation is secured with inappreciable space charge limitation of current.

In accordance with another feature of my invention the cooperating electrodes, such as the anode, or anodes, are so aligned with respect to the cavity containing the activating material that a wall or walls of the cathode acts as a shield between the evaporating material and the cooperating electrode so that material unavoidably lost by evaporation from the cathode will not deposit on the anode or other cooperating electrode. When the cooperating electrode is thus kept free from deposition, it may be operated at a relatively high temperature without the risk of electron emission therefrom. This feature of my invention is of particular utility in a rectifier of alternating current.

In accordance with still another feature of my invention the anode is structurally so related to the cathode, as by being placed close to, and preferably enclosing the cathode, so that the operating temperature of the anode assists in maintaining the cathode at a desired elevated temperature.

For a particular understanding of this invention reference may be made to the accompanying drawings taken in connection with the following specification. The drawings show in Fig. 1 a longitudinal section of a simple embodiment of my invention in a rectifier for alternating current; Fig. 1*a* illustrates a modification, Figs. 2, 3 and 4 illustrate modifications, Figs. 2 and 3 being longitudinal sections, and Fig. 4 being a cross section of the device shown in Fig. 3; Fig. 5

is a somewhat diagrammatic longitudinal section of a three-electrode tube embodying my invention, and Fig. 6 illustrates another modification.

The device shown in Fig. 1 comprises an elongated vitreous envelope 1, having inwardly projecting stems 2, 3. The anode is constituted by a cylinder 4, consisting of nickel, molybdenum, carbon, or other suitable material. The anode is supported by an extension 5 of the envelope, being held in place by an encircling band 6 to which the anode conductor 7 is attached by suitable screws as shown, and is sealed into the envelope wall at the seal-off 8.

The tubular cathode 10, consisting of nickel, a nickel alloy, molybdenum, or other material, which is suitable for operation at moderately elevated temperatures, is supported by a stiff wire 11 which is sealed into the stem 3. The surface of the cathode cavity is coated with a solid activating material 12, that is, material having a higher electron emissivity than the cathode metal, for example, barium oxide, or other alkaline earth oxide or mixtures, or one or more rare earth metals such as cerium, or the mixture known commercially as "Mischmetall." These substances as a class, unlike substances such as caesium which act upon a cathode in the vapor phase, are substantially non-volatile at the operating temperature of the container and hence will be termed herein,—solid substances or materials. Such earth material tending to evaporate from the inner surface of the cavity is redeposited on the intercepting wall of the cavity. Hence, the cathode enclosure should be so shaped that the paths of particles volatilizing from one portion of the heated surface are largely intercepted by other portions of said surface, preferably the greater part of the volatilizing particles being thus intercepted. The activating material hence remains substantially intact within the cavity during the operation of the device, although it is slowly volatilizable when coated on an unshielded surface of a thermionic cathode. The external surface of the cathode has the heat emissivity which is characteristic of the foundation material of the cathode, such as nickel or other metal, which is about ten per cent of the heat emissivity of a "black body." The heat emissivity of such a surface when a layer of activating material is superimposed thereon is about 80 per cent of that of a "black body." As a consequence the heat loss from the external surface of a cathode embodying a simple form of my invention (such as illustrated in Figs. 5 and 6) is as little as one-eighth of the heat loss from an externally coated cathode. As the heat loss from the interior coated surface is but small due to its small exposure at the mouth of the cavity, the total heat loss is low. In more highly developed forms of my invention embodying external heat shields, large internal surfaces and other improved features, the thermal efficiency is very high. In some cases the heat input required to maintain my improved cathodes at an operating temperature is as low as one per cent of the heat which would be required for heating unshielded forms of cathodes utilizing similar coating materials.

In the construction illustrated the major portion of solid angles having their origin at different points at the surface of the cathode cavity removed at some distance from the mouth of the cavity, are intercepted by the walls of the cavity, the interception being more nearly complete as their distance from the mouth increases. In other words, the walls of the cavity are positioned in reciprocal shielding relation to one another—thus materially reducing the propagation of matter or radiant energy outwardly from the cavity.

Projecting into the cathode is a heater 13, consisting of tungsten or other suitable material, this heater being supplied with current by the conductors 14, 15 which are sealed into the stem 2. The heater 13 is supported by a wire 16 which is also sealed into the stem 2 and which may be suitably insulated from the heater wire by a coating of thoria or magnesia. Such a coating is shown in Fig. 1a at 16'. The support also may constitute the return conductor as shown at 17 in Fig. 3.

The container 1 preferably should be freed from moisture and evacuated to the degree required for the operation therein for a substantially pure electron discharge, and then it is supplied with a suitable gas at pressure below the value at which the discharge becomes arc-like and tends to concentrate or become localized on the cathode. For example, a rare gas, such as argon, or neon, or a mixture of rare gases, may be used at a pressure of about one to one hundred microns, the particular pressure depending on the character of the device. As illustrated at 19 in the modification shown in Fig. 1, mercury vapor may constitute the ionizable medium by providing in the bulb a small quantity of mercury, the bulb being evacuated of other gas. When the coolest part of the container operates at a temperature of 30° C. the pressure of the mercury vapor will be about three microns of mercury pressure.

The cathode is heated during operation by radiation from the heater 13. The cathode heat also is conserved by the close proximity and high temperature of the anode 4 which substantially encloses the cathode. This is true of the devices shown in Figs. 2 to 4 as well as the device of Fig. 1.

In the modified structure of Fig. 2, the space between the cathode 10 and the anode 4 is filled with refractory insulating material 21, for example, alumina or magnesia in which is imbedded a heater wire 22 consisting of a suitable material, such as tungsten. The tube structure in general corresponds to structure shown in Fig. 1. By thus closely surrounding and heat insulating the cathode, the heat necessary to maintain the cathode at an electron emitting temperature is conserved and the efficiency of the device is improved. The cathode shown in Fig. 2 provides a multiple cavity as it has the form of a double-walled cylinder. The active material is placed both within the cavity formed by the inner wall and in the space between the walls.

In some cases the cathode may be constructed advantageously of a number of convolutions of sheet material. An example of such a structure is shown in Figs. 3 and 4. The cathode in the modification illustrated by these figures consists of a spiral plate 24 which is supported on an end plate 25 and which provides a plurality of emitting surfaces bounding contracted cavities. The spaces between the turns of the spiral which constitute partitions of the enclosed space contain a charge of activating material as already described in connection with Figs. 1 and 2. The spirally wound sheet metal cathode is main-

tained at an electron-emitting temperature by the centrally positioned heater 13.

It is not essential that in all embodiments of my invention the anode should closely surround the cathode nor that the cathode wall should constitute a shield to prevent deposition of active material on the anode. In the embodiment of my invention shown in Fig. 5 the anode 27 is disc-shaped and is located at a distance from the tubular cathode 28, which, as shown, is materially greater than the diameter of the cathode. The cathode is heated by radiation from a filamentary resistance heater 29. The heater 29 is held taut by an anchor 30, and current is supplied thereto by the conductors 31, 32 which are sealed into a glass stem 33. Separate electrical connection to the cathode is furnished by a seal-in conductor 34. The anode conductor 35 is sealed into a reentrant bulb stem 36. Upon the glass sleeve 36' which constitutes an extension of the stem 36 is mounted a metal tube 37 over the end of which is affixed a wire screen 38. This tube 37 and the screen 38 constitute a grid or control electrode. Electrical contact is made by a seal-in conductor 39, connected thereto by a clamping ring 40. As set forth in connection with Figs. 1 to 4, a gas or vapor at low pressure is provided in the bulb 41, as for example one of the rare gases, or an easily vaporizable material, such as mercury or an alkali metal, such as caesium or rubidium.

In the device of Fig. 6, the plate-shaped anode 44 is supported by its conductor 45 directly opposite the open end of the tubular cathode 46. In this case, of course, some deposition of activating material from the interior wall of the cathode will occur on the anode. In the case of a tube operated at low wattage, this will do no harm, that is, if the energy dissipation at the anode is kept below the value required to heat the anode to an electron-emitting temperature then this construction can be used with satisfactory results.

From the foregoing description it will be apparent to those skilled in the art that the area of the opening is preferably but a small fraction of the internal area of the cavity. It is apparent that unless the inner surface of the cavity is at least twice as great as the cross-sectional area of the opening the desired results will not be secured in any large degree, although it will be understood that such ratio is not a critical one. In the case of simple tubular cathode constructions such as shown in Figs. 1, 5 and 6 the depth of the cavity is preferably considerably greater than the internal diameter.

Devices embodying the features of my invention, and in particular the combination of a thermionic cathode having a cavity provided with a relatively non-volatile activating material, are capable of wide application in the electrical industry. In particular, rectifiers embodying my invention may be used to rectify large currents of high voltage. A rectifier embodying my invention may be used for example in rectifying currents of hundreds of amperes at voltages of the order of ten thousand volts or higher.

Although I have described my invention with particular reference to rectifying and control devices, I wish it to be understood that cathodes embodying my invention are capable of general application. For example, they may be used in lamps, a suitable gas, such as neon, for example, at suitable pressure being present to produce the desired luminosity.

In U. S. application Serial No. 683,143, filed August 1, 1933, which is assigned to the same assignee as the present application, I have described and claimed a modified heater construction for a cavity-type electrode.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. An electrical discharge device comprising a sealed container, an anode, a tubular cathode having a length at least twice the diameter thereof, heat insulation surrounding said cathode, an oxide of high electron emissivity upon the interior surface of said cathode, a heater within the space enclosed by said cathode, and a gaseous material in said container having at the operating temperature of the device a pressure within the limits of about 1 to 100 microns of mercury.

2. An electrical discharge device comprising an envelope containing an ionizable medium, electrodes within the envelope including an anode and a thermionic cathode, said cathode comprising a body provided with adjacent opposed walls one of which encloses another forming a plurality of relatively deep cavities providing openings to permit passage of electrons from the cathode to said anode, the walls of said cavities being coated with an activating material of higher electron emissivity than the material of the walls, resistance means within the body of the cathode for heating the same, and a heat insulator surrounding said body.

3. An electrical discharge device comprising an envelope, electrodes therein one of which is an open-ended contracted hollow cathode, a relatively non-volatile material of high electron emissivity applied to the interior surfaces of said cathode, a highly refractory insulating material coating the outside of said cathode, a heater embedded in said insulating material, and a gas in said envelope at a pressure sufficiently high to neutralize space charge.

4. An electrode for an electrical discharge device constituted of conducting material formed into a hollow body having an opening, the area of said opening being a small fraction of the internal area of said hollow body, and having convolutions within its confines, an alkaline earth oxide coating interior surfaces of said electrode including surfaces of said convolutions and means for heating said electrode arranged within the confines of said body.

5. A thermionic electrode for an electrical discharge device comprising a hollow body, a partition therein providing a plurality of contracted cavities open to the exterior, an emitting material of low work function which is substantially non-volatilizable at a temperature of effective electron emission coating interior surfaces of said hollow body, means for heat insulating said body and a heater within the body for maintaining said body at a temperature of thermionic emissivity.

6. An electrical discharge device comprising an envelope, an attenuated gas, an anode, and a thermionic cathode therein, said cathode comprising an enclosure having one or more openings through which a discharge will pass from the cathode to said anode in the presence of positive ions, a solid material of high electron emissivity in said enclosure, said enclosure having closely adjacent wall portions providing one or more deep contracted spaces whereby particles volatilizing from different points of the internal surface of said enclosure are largely intercepted before reaching an opening, and a resistance heater within said enclosure for generating heat

in proximity to the said wall portions for maintaining them at a temperature of thermionic emissivity.

7. A thermionic cathode comprising an enclosure of conducting material, a solid material of high electron emissivity therein, one or more openings in said enclosure permitting the free passage of electrons in the presence of positive ions, said enclosure having closely adjacent walls providing one or more deep contracted spaces whereby particles volatilizing from different points of the internal surface of said enclosure are largely intercepted by the walls of said enclosure before reaching an opening, resistance heating means within the enclosure and in effective heat-exchanging relation with the said walls for maintaining them at a temperature of thermionic emissivity and means forming part of the cathode structure for suppressing heat loss from said enclosure.

8. An electrical discharge device comprising a sealed envelope containing electrodes including an anode and a thermionic electrode having a cavity of large internal surface provided with a relatively small opening for the passage of electrons from the interior of said cathode to said anode to maintain the discharge between said cathode and anode and an alkaline earth oxide coated on the interior walls of said cavity, said walls being positioned in shielding relation to one another, a filamentary heater positioned in said cavity and an attenuated gas in said envelope at a pressure sufficiently high to neutralize space charge.

9. An electric discharge device comprising the combination of an envelope, electrodes therein including an anode and a cathode, and an ionizable medium within the envelope, the said cathode including a generally tubular hollow enclosure having a length greater than its diameter and containing extended interior wall surfaces adapted to act as a source of thermionic emission, electronically active solid material applied to the said wall surfaces, and a resistance heater within the said hollow enclosure for maintaining the said wall surfaces at an effective emitting temperature, there being an opening in one end of the said hollow enclosure of a diameter which approximates the diameter of the enclosure itself and through which a substantially unobstructed discharge may occur between the said anode and the said emitting surfaces.

10. An electric discharge device comprising the combination of an envelope, electrodes therein including an anode and a cathode, and an ionizable medium in the envelope having a substantial pressure during normal operation of the device, said cathode comprising as a part thereof an enclosure having an opening therein for passage of a discharge into the enclosure, means within the enclosure and occupying the enclosure for a substantial portion of its length for providing an extended wall surface in addition to the interior wall surface of the enclosure itself, electronically active solid material coating the said wall surfaces for enhancing their electron emissivity, and a resistance heater within the enclosure and extending longitudinally thereof for a distance approximately coextensive with the said surface-providing means for generating heat in proximity to the said wall surfaces, thereby to maintain said surfaces at a temperature of effective electron emission.

11. An electric discharge device comprising the combination of an envelope having an ionizable medium therein, an anode within the envelope, an enclosure also within the envelope and having an opening for the passage of a discharge into the enclosure from the said anode, metallic sheet material subdividing the interior of the enclosure for providing a plurality of extended wall surfaces within the enclosed space, solid electronically active material on the said surfaces for enhancing their emissivity, and resistance heating means within the enclosure for generating heat in proximity to the said surfaces so as to maintain them at a temperature of effective electron emission.

12. A thermionic electrode for an electrical discharge device comprising a hollow enclosure having an opening therein, partitioning means within the said enclosure providing a plurality of contracted cavities at least partially exposed to the exterior of the electrode through the said opening, an emitting material of low work function which is substantially non-volatilizable at a temperature of effective electron emission coating surfaces of the said partitioning means, and a heater within the said enclosure for generating heat in proximity to the said coated surfaces to maintain them at a temperature of thermionic emissivity.

13. A thermionic cathode consisting at least in part of conductive sheet material spirally wound upon itself with its surfaces spaced apart to provide a spiral cavity, a coating of solid electronically active substance on said sheet material, and a resistance heater within the body of the cathode for maintaining the coated surfaces of said sheet material at a temperature of effective electron emission.

14. An electrical discharge device comprising a sealed envelope containing electrodes including an anode, a thermionic cathode and an interposed discharge-controlling electrode, said thermionic cathode having a cavity of large internal surface provided with a relatively small opening for the passage of electrons from the interior of said cavity to said anode to maintain the discharge between said cathode and anode, and an alkaline earth oxide coated on the interior walls of said cavity, said walls being positioned in shielding relation to one another, a resistance heater positioned in said cavity and an attenuated gas in said envelope at a pressure sufficiently high to neutralize space charge.

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