Sept. 22, 1964 D. V. GEPPERT 3,150,282

HIGH EFFICIENCY CATHODE STRUCTURE

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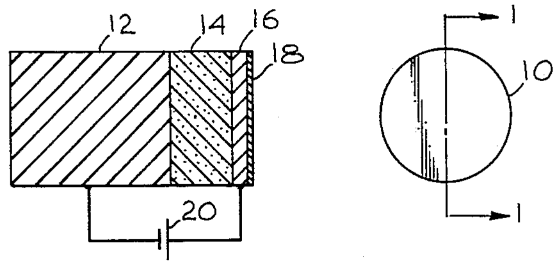
Fig. 1



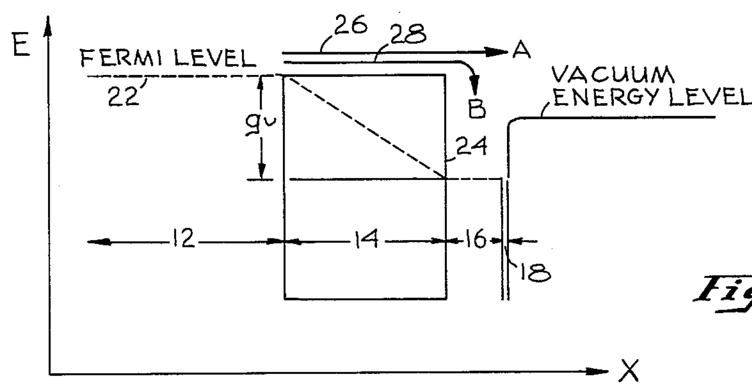


Fig. 2

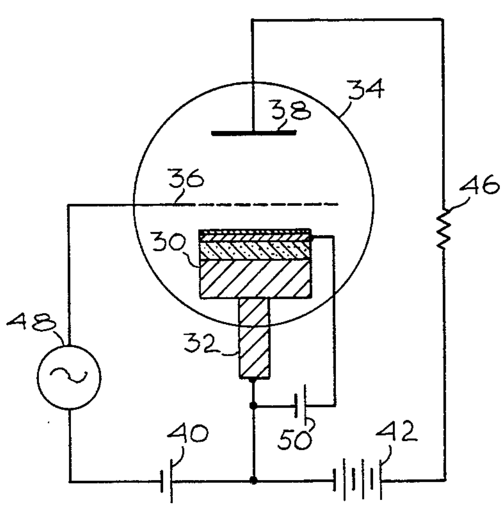


Fig. 3

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HIGH EFFICIENCY CATHODE STRUCTURE

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This invention relates to a structure for cathodes which may be employed with vacuum tube devices and more particularly to improvements therein.

An object of this invention is to provide a high efficiency cathode construction.

Another object of this invention is to provide a novel structure for a cathode, suitable for use with a vacuum tube;

Still another object of the present invention is the provision of a cathode structure which requires less energy input to cause electron emission than those employed heretofore.

These and other objects of this invention may be achieved in a cathode structure comprised of four sections. A first of these sections comprises a metal having a low work function. Contiguous with this metal is placed a large band-gap semi-conductor having a thickness in the range of 100 Angstroms to several microns. Contiguous to the semi-conductor material is another metal which has a high work function compared to the low work function metal. This metal constitutes a thin film in the range of 30 to 1000 Angstroms thick. On the thin metal film there is deposited a surface layer of material which has a low work function. This structure is then placed in a vacuum, and when the high work function metal is biased positive relative to the low work function metal, electrons are emitted from the low work function surface layer into the vacuum.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention itself, both as to its organization and method of operation, as well as additional objects and advantages thereof, will best be understood from the following description when read in connection with the accompanying drawings, in which:

FIGURE 1 is a cross sectional view of the embodiment of the invention.

FIGURE 2 is an energy diagram of an embodiment of the invention.

FIGURE 3 is a circuit diagram showing the embodiment of the invention in a vacuum tube.

Reference is now made to FIGURE 1 of the drawings, which is a cross-sectional view along the lines 1—1 of the circular configuration **10** of the embodiment of the invention. This configuration is shown by way of example and should not be construed as a limitation upon the invention which, can assume any desired shape. The cathode comprises a first, or base portion **12** which is a metal having a low work function. This may be indium, by way of example. The dimensions of this base portion are not critical. There is deposited upon the low work function metal, either by vacuum evaporation or any other desirable known technique, a material constituting a large band-gap semi-conductor material **14**. This may be a material such as silicon, or cadmium sulphide or gallium arsenide, or any other band-gap semi-conductor material which has a band-gap of one electron volt or higher. The thickness of this layer should preferably be in the range between 100 Angstroms to several microns.

There is deposited upon the semi-conductor material a metal thin film **16** having a thickness in the range between 30 to 1000 Angstroms. This metal is selected to have a high work function and may be one of the metals selected from platinum, molybdenum, gold, etc. Surface

layer **18** is deposited on the surface of the high work function metal film. This last layer is a low work function surface layer which may be compounds such as Cs_3Sb, Cs_3Bi, Ca_2Pb, Ba_2Pb or compounds such as BaO, SrO, CaO. The thickness of this last metal film ranges from a fraction of a monolayer to several atomic or molecular layers thick.

In order to cause this cathode to emit electrons from the circular surface film **18** into a vacuum, it is necessary to establish a field by applying a bias which renders the high work function metal **16** positive, with respect to the low work function metal **12**. This bias is provided by the potential source **20**. A complete tube results from incorporating the cathode into an evacuated enclosure with a set of conventional vacuum tube electrodes, as will be shown in FIGURE 3.

FIGURE 2 is an energy diagram for the embodiment of the invention. The diagram is drawn for the operating bias voltage applied. The dotted line **22**, represents the Fermi level throughout the cathode. The substantially rectangular FIGURE **24** represents the band-gap region of the semi-conductor. The barrier at the interface between metal **12** and semi-conductor **14** is low because metal **12** has a low work function. The barrier at the interface between **14** and **16** is high because metal **16** is selected to have a work function which is high with respect to the work function of metal **12**. The barrier height at such an interface is equal to the difference between the work function of the metal and the electron affinity of the semi-conductor or insulator, As an example, the electron affinity is typically about 3 volts. Then if the work function of the metal **12** is on the order of 3 volts, the barrier height is substantially zero, as represented in FIGURE 2. This permits electrons from the metal **12** to enter the conduction band of the semi-conductor **14** readily. This may be illustrated by the respective paths **26**, **28** of the electrons A and B, when the metal **16** is biased positive relative to the metal **12**.

Electrons entering the metal **16** (such as typical ones A and B) are hot electrons because of the high barrier at the interface between metals **14** and **16**. This barrier height might typically be 1½ to 2 volts, depending on the work functions of the metals **16**. For example, if the work function of the metal **16** is five volts then the barrier is 5 minus 3 equal 2 volts high.

The hot electrons may penetrate the thin metal film **16** and reach the surface and escape into the vacuum such as electron A. However, some of the hot electrons, such as electron B, may lose energy in the film **16** before reaching the surface. These electrons cannot be emitted into the vacuum but must be drained off by the cathode bias voltage supply.

The low work function treatment of the surface of metal **16** by the surface layer **18** is necessary in order to reduce the vacuum energy level below the barrier top at the interface between semi-conductor **14** and metal **16**. Without the surface layer **18** the vacuum level would be higher than the barrier top and the vacuum emission would be very low.

Depending upon the exact materials used for semi-conductor **14** and metal **16**, impurity doping may be found desirable for best performance. For example, it may be found desirable to make the semi-conductor material "n-type" by doping with donors. Similarly, if the layer **18** is a semi-conductor or an insulator rather than a pure metal such as cesium or barium, it may be found desirable to make the layer **18** "n-type" by doping with donors. It should be seen from FIGURE 2, that successful vacuum emission requires that the bias voltage "v" be large enough so that qv is approximately equal to or greater than the work function of the layer 18. (q is the charge of an electron.)

FIGURE 3 illustrates an application of the cathode. A cathode 30, constructed in accordance with this invention, is mounted on a metal support 32 which provides good electrical and thermal contact to the outside of the vacuum envelope 34. Losses of the cathode (as from electron B in FIGURE 2) tend to heat the cathode, and it is desirable to carry this heat away in order to minimize the cathode temperature. This is the function which is served by the metal support 32. For some applications, low noise for example, it may even be desirable to refrigerate the cathode by means of the metal support. Also inside the envelope 34 is a grid electrode 36 and an anode 38 as in conventional triodes.

The circuit is shown connected as a conventional triode amplifier with a grid bias battery 40, an anode bias battery 42, a load resistor 46 connected in series with the anode and the battery 42, and a source of signals 48 which is connected between the grid bias battery and the grid. A potential source 50 is connected to make the high work function metal layer of the cathode 30 positive with respect to the low work function portion of the cathode.

The cathode is extremely efficient since it does not require power for heating a filament in order to emit electrons, but rather requires that the heat which is developed within the cathode be carried away. The potential source 50 does not have to provide a large current but only a biasing potential for establishing a field as described previously.

There has accordingly been described and shown herein a novel, useful, unique and efficient arrangement for a cathode structure.

I claim:

1. A cathode structure comprising a first metal section, a contiguous large band-gap semi-conductor section, a second metal section contiguous to said semi-conductor section, and a surface layer for said second metal section, the metal of said first section being selected to have a low work function relative to the metal of said third section, said surface layer being selected to be a material which has a low work function relative to said first metal section.

2. A cathode structure comprising a first metal layer section, a contiguous layer of a large band-gap semi-conductor material which ranges in thickness between 100 Angstroms to several microns, a metal thin film contiguous to said semi-conductor layer, said thin film having a thickness of between 30 to 1000 Angstroms, said thin film being selected to provide a work function which is high compared to the work function of said metal section, and a surface layer covering said metal film, said surface layer ranging in thickness from a monolayer to several molecular layers thick, said surface layer material being selected to have a work function which is low when compared to the work function of said first metal section.

3. A cathode structure as recited in claim 2 wherein said first metal section is made of indium.

4. A cathode structure as recited in claim 2 wherein the semi-conductor material which is employed is selected to have a band-gap of one electron volt or higher, and is selected from a group consisting of silicon, cadmium sulphide, aluminum arsenide, stannous aluminum, GaN, GaP, gallium arsenide.

5. A cathode structure as recited in claim 2, wherein said high work function metal layer is selected to be one of the group consisting of platinum, W, molybdenum, gold.

6. A cathode structure as recited in claim 2 wherein said surface layer material is selected to be one of the group consisting of Cs_3Sb, Cs_3Bi, Ca_2Pb, Ba_2Pb, cesium, barium, barium oxide, calcium oxide, SrO.

7. A cathode structure comprising a base of indium, a layer of semi-conductor material deposited on said base, said semi-conductor material being selected to have a band-gap of at least one electron volt, a thin metal film deposited on said semi-conductor layer, said thin metal film being selected to have a work function which is greater than that of indium, and a surface layer deposited on said thin film, said surface layer being selected to have a work function which is lower than that of indium.

No references cited.