THIN-FILM COLD CATHODE

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7 Claims

ABSTRACT OF THE DISCLOSURE

A thin film tunneling cold cathode formed as an assembly of contacting layers in the following order: a first layer of a conductive metal such as aluminum capable of serving as an electron source, a layer of dielectric material typically aluminum oxide, a very thin layer of a high-work functional material such as platinum and a layer of another conductive metal such as gold.

This invention relates to a novel source of electrons and more particularly to the construction of a thin-film tunneling cold cathode and the resulting element which is formed.

There are many devices for which it is necessary to provide a source of electrons. Among such devices may be listed vacuum tubes, microwave tubes, ionization-type gauges and mass spectrometers, to name but a few. It has been customary to use what may be termed "hot cathodes," as electron sources in these devices. For some applications these hot cathodes have disadvantages which are inherent in their construction and in their operational characteristics. For example, they must operate at high temperatures (e.g., from 1000 to 2500° K.) and since noise is directly related to temperature their noise can not be reduced below a certain level which is a function of their operating temperatures. In the use of hot cathodes in vacuum system problems are encountered which are traceable to an appreciable pumping action by the filament and excessive vapor pressure of the cathode. There is also light output associated with the use of a hot cathode and this is undesirable, if not intolerable, in their use where electron multipliers are used as detectors.

One of the more recent developments in the field of electron source devices has been to overcome the disadvantages associated with a hot cathode by the construction of a so-called cold cathode which is a solid-state diode, the anode of which is thin enough to allow some of the diode current to escape from the anode into the neighboring vacuum. Typically, such a cold cathode is constructed of an assembly of layers of aluminum, aluminum oxide, and gold. In the operation of such a cold cathode the bias applied between the aluminum and the gold causes the electrons to be injected into the gold at some height above the gold Fermi level. Because of the potential barriers between the various parts of the device the electrons will first tunnel into the conduction band of the aluminum oxide at the aluminum Fermi level. There is evidence that the energy losses for electrons in the conduction band of aluminum oxide are so severe that almost all of the injected electrons will emerge from the aluminum oxide at the bottom of its conduction band which is about 2.4 electron volts above the gold Fermi level at the gold-aluminum oxide interface. The electrons must then traverse the gold, where a less severe energy loss occurs, and surmount the potential barrier between the gold and the vacuum. Only that portion of the injected electrons which suffered negligible attenuation will be able to surmount the 4.8 electron volt gold-vacuum barrier and contribute to the emission current. The emission efficiencies (emission current/current introduced) reported for cold cathodes of this type are generally of the order of 10^-4. Moreover, cold cathodes constructed in this manner are short lived. It would therefore be desirable to have available a thin-film cold cathode which does not suffer from the inherent disadvantages associated with the hot cathodes and which at the same time represents a marked improvement over the cold cathodes now known.

It is therefore a primary object of this invention to provide a thin-film cold cathode which is not temperature dependent and hence is one which can be operated at such low temperatures as to minimize noise. It is another object to provide a cathode of the character described which is particularly suitable for incorporation in micro-wave tubes such as klystrons, traveling wave tubes and the like and in gauges for the measurement of extremely good vacua. It is yet another object of this invention to provide thin-film cold cathodes which operate at low power levels making them attractive for airborne equipment, which have no associated light output permitting their use where electron multipliers are used, and which exhibit no boil-off or pumping effect making them highly desirable for vacuum gauges and the like. It is another object to provide thin-film cold cathodes which can be made in complex geometries and which can be switched on and off at very high frequencies making them adaptable for many uses.

It is an additional primary object of this invention to provide a novel thin-film cold cathode which has an improved efficiency and, which, at the same time, is capable of carrying more current than is now possible with the cold cathodes available. It is another object to provide a cold cathode of the character described which is easy to construct and reliable in its performance. Other objects of the invention will in part be obvious and will in part be apparent hereinafter.

The invention accordingly comprises the several steps and the relation of one or more such steps with respect to each of the others, and the article possessing the features, properties, and the relation of elements set forth in the following detailed disclosure, and the scope of the invention will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention reference should be had to the following detailed description taken in connection with the accompanying drawings in which:

FIG. 1 illustrates a cross-section of a cold cathode constructed in accordance with this invention; and

FIG. 2 is a diagrammatic representation of the energy band structure of the cold cathode of FIG. 1.

The cold cathode of this invention may be seen in FIG. 1 to comprise an assembly of four layers 10, 11, 12, and 13. No attempt has been made in this drawing, or in FIG. 2, to draw thicknesses, or energy levels, to scale, and it will be appreciated that FIG. 1 represents a very great enlargement of the actual thickness of layers involved. Each of these layers forming the assembly which makes up the cold cathode of this invention must be of a certain class of material and there must be a prescribed interrelationship among them.

Layer 10 must be an electrically conductive metal capable of serving as a source of electrons. It should, moreover, be a material which is capable of undergoing a chemical reaction thereby to form on its surface, a compound which in thin layer form is a good dielectric material, i.e., either an insulator or a semiconductor and serves as layer 11. Thus, layer 10 is one which preferentially forms an oxide or nitride. Aluminum may be cited as an example of a metal suitable for layer 10.

Layer 11 must, as noted, be either an insulator or a semiconductor and preferably it is formed by chemical reaction as a thin (e.g. 50 A.) layer on the surface of the electron source metal layer 10. A convenient method for
forming this insulation or semiconducting layer, which permits electron tunneling, is described in U.S. Ser. No. 282,187 filed in the name of John L. Miles and assigned to the same assignee as this application. The contact between layer 10 and layer 11 must be a barrier contact and should be sufficiently high to inhibit thermionic emission from metal 10 to metal 12. Finally, layer 11 should be a material having a relatively low electron affinity. If aluminum is used as the metal for layer 10, then layer 11 must be a high-conductivity aluminum oxide formed by oxidizing the aluminum surface.

Layer 12 must be of a metal which exhibits a high work function. It should also be present as a very thin layer, preferably no greater than a few molecules thick. The high work function layer 12 should form a barrier contact with layer 11, the barrier being as high as possible. In light of present knowledge, platinum is the preferred high work function layer 12.

Finally, the remaining layer 13 should be an electrically conducting metal having a low but stable work function. Typically, this layer may be gold. Gold is preferred because of its high degree of inertness and ability to resist contamination at its surface.

It is the presence of the high work function layer 12 that accounts for the improved performance of the thin film cathode of this invention. This may be explained with reference to FIG. 1. The presence of this thin layer of high work function material brings about the situation wherein the insulator-high work function material barrier (i.e., that between layers 11 and 12) is higher than the insulator-second metal barrier, i.e., the layer 11-layer 13 barrier when the high work function layer 12 is not present. This may be further illustrated with reference to a specific example in which the layers 10-13 are aluminum, aluminum oxide, platinum and gold in that order. Since the barrier height is equal to the difference between the work function of the metal (5.4 electron volts for platinum, 4.8 electron volts for gold) and the electron affinity of the insulator (2.4 electron volts for aluminum oxide). The aluminum oxide-platinum barrier height should be about 3.0 electron volts versus 2.4 electron volts for the aluminum oxide-gold barrier.

It is advantageous to raise the layer 12-layer 13 barrier height because the extreme energy losses in the insulator layer 11 cause most of the electrons injected from layer 10 to enter layer 12 at an energy approximately equal to this barrier $E_1$ (FIG. 2). If all of the electrons arrive at layer 12 at energy $E_1$ no improvement will be realized by raising the barrier height. However, the actual distribution in energy of electrons as they enter layer 12, though unknown as yet, is not likely to be completely confined to $E_1$. In fact, electrons will arrive at layer 12 with all energies between $E_2$ and $E_3$ but heavily weighted toward $E_2$. Raising the barrier height $E_1$ modifies the entire distribution of electrons between $E_2$ and $E_3$ so that an increased fraction of electrons will have energy greater than $E_2$ by the time they reach the vacuum barrier.

The placing of a high-work function material between the dielectric layer 11 and the second metal layer 13 is to be distinguished from the prior art technique for greatly enhancing electron emission from metals by coating them with a thin metallic monolayer of low-work function material. The use of a low-work function material as a coating has always suffered from the fact that all of the known low-work function materials poison rapidly at the pressures which are encountered in the devices in which they are used. Thus, this invention has as an important feature the inversion of the prior art technique for enhancing emission and the substitution of a high-work function material for a low-work function material in a position where it is inaccessible to poisoning by the ambient atmospheres.

An example of the construction of a cold cathode in accordance with this invention, as illustrated in FIGS. 1 and 2, may be cited. The cathode formed first by vacuum evaporating a layer of about 2,000 A. of aluminum on a suitable substrate material such as glass or other suitable inert material and then oxidizing the aluminum film until a layer of aluminum oxide of approximately 50 A. is formed. On this aluminum oxide layer is then formed a very thin platinum layer, e.g., on the order of 5-10 A., and finally a second metal such as gold is deposited up onto the platinum. For thin film circuitry, deposition of the metal films (aluminum, platinum and gold) is preferably accomplished by well-known vacuum deposition techniques.

The raising of the barrier height which results from the inclusion of the thin high work function material in accordance with this invention has been demonstrated experimentally as follows. When the gold (layer 13) of FIG. 1 is made negative and the aluminum layer 10) is made positive, the diode draws approximately the same amount of current at a given voltage whether the platinum (layer 12) is present or not. However, when the aluminum (layer 10) is made negative and the gold (layer 13) is made positive, the diode containing the platinum (layer 12) draws much less current at a given voltage than one constructed without the platinum layer. This is a clear indication that the aluminum-aluminum oxide barrier is the same for both diodes; but that the platinum-aluminum oxide barrier is higher than the gold-aluminum oxide barrier. The exact barrier height difference is determined by breakdown voltage measurements, and in this case, amounts to about 0.6 electron volt.

In addition to eliminating many of the problems associated with either hot filament or high field cold cathodes, the thin-film tunnel cathode of this invention should be capable of producing emission currents of several milliamps with a power consumption of less than 100 milliwatts. This feature is clearly very desirable in gauges which are to be incorporated in spacecraft, for example.

As an evaporated thin film device the tunnel cathode of this invention can be fabricated in a large variety of geometries with emitting areas ranging from 1 square millimeter to several square centimeters. Moreover, it can be contoured or constructed on a contoured surface and need not be flat.

There is thus provided an electron emission device in the form of a cold cathode which does not possess the disadvantages of the hot cathode and which, at the same time, exhibits improved efficiency over the thin-film cold cathodes as they now exist in their present state of their development.

It will thus be seen that the objects set forth above and among those made apparent from the preceding description are efficiently attained, and since certain changes may be made in carrying out the above method and in the article set forth without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

I claim:
1. A thin-film tunneling cold cathode structure, comprising an assembly of contacting layers, said layers being in order:
   (a) a first electrically conducting metal capable of serving as a source of electrons and of forming a chemical compound by reaction with its surface;
   (b) a dielectric material forming a contact barrier with said first metal, said barrier being sufficiently high to achieve the prior art technique for the desired emission and said dielectric material being a reaction product resulting from said chemical reaction with the surface of said first layer;
   (c) a high-work function metal of a thickness no greater than a few molecules; and
   (d) a second electrically conducting metal having a low work function and being essentially inert to
atmospheric conditions and resistant to contamination on its surface.

2. A thin-film cold cathode structure in accordance with claim 1 wherein said chemical reaction is oxidation.

3. A thin-film cold cathode structure in accordance with claim 1 further characterized in that said assembly is affixed to a supporting substrate.

4. A thin-film cold cathode structure in accordance with claim 1 wherein said first metal is aluminum and said dielectric material is aluminum oxide.

5. A thin-film cold cathode structure in accordance with claim 1 wherein said high-work function metal is platinum.

6. A thin-film cold cathode structure in accordance with claim 1 wherein said second metal is gold.

7. A thin-film cold cathode structure in accordance with claim 1 wherein said first metal is aluminum, said dielectric material is aluminum oxide, said high-work function metal is platinum and said second metal is gold.

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