United States Patent

Nishida et al.

[15] **3,678,325**

[45] **July 18, 1972**

[54] **HIGH-FIELD EMISSION CATHODES AND METHODS FOR PREPARING THE CATHODES**

[72] Inventors: **Jun Nishida; Takahumi Ohhara,** both of Osaka, Japan

[73] Assignee: **Matsushita Electric Industrial Company, Limited,** Kadoma City, Osaka, Japan

[22] Filed: **March 10, 1970**

[21] Appl. No.: **18,176**

[30] **Foreign Application Priority Data**

March 14, 1969 Japan....................................44/21072

[52] **U.S. Cl.** **313/346,** 313/309, 313/336, 313/351

[51] **Int. Cl.** **H01j 1/14,** H01j 19/06, H01k 1/04

[58] **Field of Search** 313/346, 309, 336, 351

[56] **References Cited**

UNITED STATES PATENTS

3,356,912	12/1967	Rairden et al.	313/346 X
3,259,782	7/1966	Shroff	313/346 X
3,425,111	2/1969	Denison	313/346 UX

Primary Examiner—David Schonberg
Assistant Examiner—Toby H. Kusmer
Attorney—John Lezdey

[57] **ABSTRACT**

High-field emission cathodes fabricated by implanting metal ions of low work function into a pointed tip portion of a formed cathode which is stable at high temperatures and chemically inert to gas molecules including oxygen. The cathodes provide for operation stability for a prolonged period of time with a low applied voltage.

5 Claims, 6 Drawing Figures

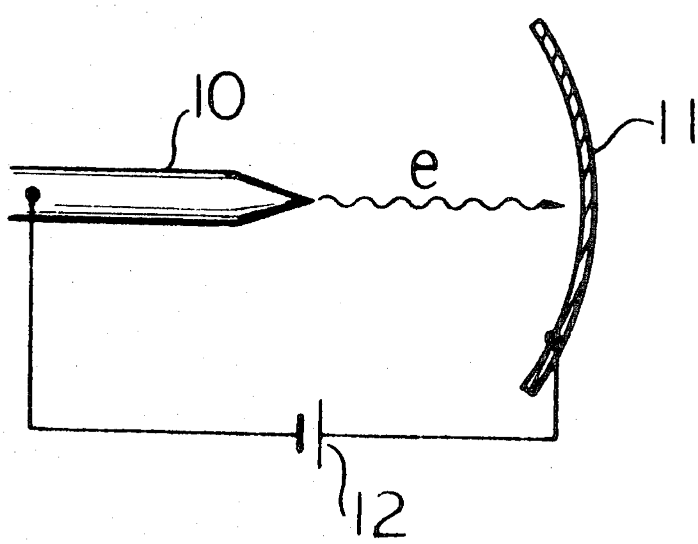


Fig. 1

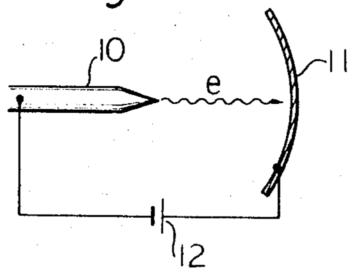


Fig. 2

(a) (b)

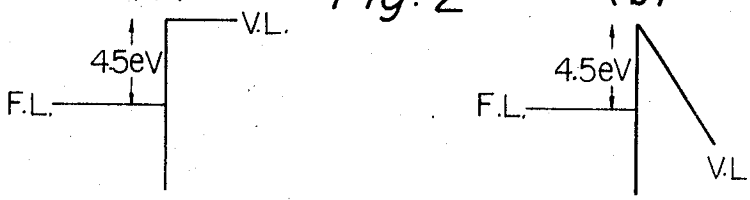
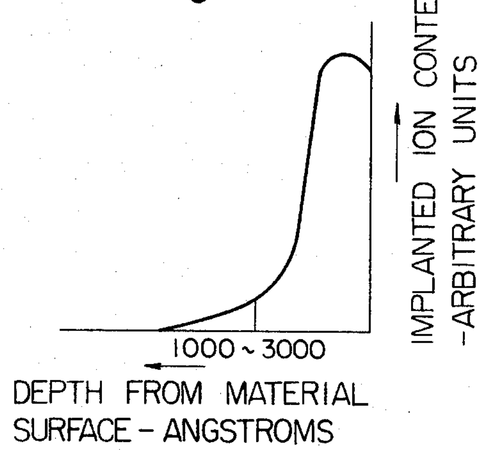


Fig. 3

(a) (b)

Fig. 4



INVENTOR
Jun Nishida Takahumi Ohhara
BY
John Lezdey
ATTORNEY

HIGH-FIELD EMISSION CATHODES AND METHODS FOR PREPARING THE CATHODES

This invention relates to cathodes as applicable to electron tubes and particularly to high-field emission cathodes used as a point source of an electron beam.

If a high positive electric field is applied at the surface of a conductor, it is possible to pull electrons directly out of the material at ordinary temperatures. The emission of electrons from the surface of a conductor into a vacuum under the influence of a high electric field is an elementary effect comparable with thermionic emission, photoelectric emission or secondary emission. Here, if the emission of as many electrons as possible from a conductor or metal is considered as the purpose of a cathode, a high-field emitter surpasses all other cathodes because current densities of millions of amperes per square centimeters are easily obtained. The experimental results thus far obtained as to the high-field emission have proved that the performance of the emission is very sensitive to the surface conditions of the material used as an emitter. More specifically, the surface potential barrier is closely dependent upon the surface conditions. For example, the cleanliness of the surface, and whether the surface is coated with another metal or with adsorbed gas atoms are two of the important factors dictating the height of the surface potential barrier. Therefore, a low work function and stability at a high temperature are desirable features for the high-field emission cathodes. The low work function is required for these cathodes in order to lower an operating voltage necessary for a given electron emission, which will be discussed later in more detail.

Materials which have been employed for conventional high-field emission cathodes, in general, possess such characteristics as satisfactory mechanical strength, producibility of a fine wire having a pointed tip at its leading end, chemical inertness to gases including oxygen and stability at a high temperature. These characteristics limit the type of usable cathode materials to, for example, rigid metals such as tungsten (W), molybdenum (Mo), tantalum (Ta) and rhenium(Re) and whiskers which are obtained from filamentary growths of metals in air at elevated temperature and characterized by their distinct rigidness, all of which are characterized by their relatively high work functions. This invites an undesirable fact that a high operating voltage is required for operating the cathodes to extract a sufficient electric current therefrom. In order to draw a desired amount of current with a less voltage applied, there has been proposed and put into practice a cathode using the above specified materials as a substrate wire but having other metals or their oxides coated thereon. These metals or their oxides are, preferably, of the type having low work function, thus permitting the reduction in the operating voltage. Such coating has been conventionally carried out in practical applications by the vacuum-evaporation method.

According to a typical vacuum-evaporation method, a low work function material such as barium is evaporated in a vacuum and coated on a fine tungsten wire having an etched tip. The binding force between the tungsten and barium is deficient except in there several-atom layer. The tungsten tip coated with barium is then taken out from the vacuum and exposed to the surrounding air before it is accommodated as a cathode in an electron tube. While being exposed to the air, however, the coated barium is subject to oxygen gases existing in the air, resulting in the formation of an oxide layer on the tip surface. In order partly to deoxidize and desorb the oxygen gases and other adsorbed gases, respectively, from the barium oxide layer and partly to cause the barium to distribute uniformly in the substrate of tungsten by diffusing partially thereinto, the coated metal material together with the tungsten wire is subjected to a heat treatment at an elevated temperature. In the practical fabrication of an electron tube, it is desirable that the wire cathode be accommodated in the tube and subjected to a subsequent heat treatment to degas the tube itself. In this manner, a high-field emission cathode usable at a low operating voltage is obtained by such prior art method.

Drawbacks are, however, encountered in the thus obtained high-field emission cathode. The coated metal material is located as a barium layer directly on the surface of the substrate of the cathode so that it is easily affected by the surrounding gas molecules when exposed thereto. On top of this, the metal material tends to evaporate into the surrounding vacuum during the heat treatments. Even though the material is partially penetrated into the cathode, say, into the several-atom layer of the coated metal material, the penetration depth is not great enough. This is reflected by the likelihood of diffusion and surface migration of the metal atoms when the metal material is heated for activation, thus leading to a shortened operating life of the existing cathodes.

It is therefore a primary object of this invention to provide a high-field emission cathode operable with a low applied voltage.

It is another object of the invention to provide a high-field emission cathode which is stable at an elevated temperature and chemically inert to gas molecules such as oxygen.

It is still another object of the invention to provide a high-field emission cathode which is repeatedly activated to provide for operation stability for a prolonged period of time.

It is a further object of the invention to provide an electron device having provided therein the cathode of the invention.

It is a further object of the invention to provide a method for fabricating the cathode of the invention by implanting metal ions of low work function into a pointed tip portion of a formed cathode which is stable at high temperatures and chemically inert to gas molecules including oxygen.

Advantages and features of the invention will be apparent to those skilled in the art from the following description taken in conjunction with accompanying drawing, in which:

FIG. **1** is a schematic view illustrating the operating concept of a high-field emission cathode of the invention;

FIG. **2**(*a*) shows, in an explanatory manner, the energy level of tungsten placed in a vacuum;

FIG. **2**(*b*) is similar to FIG. **2**(*a*) but shows the energy level with a high electric field built up;

FIG. **3**(*a*) shows, also in an explanatory manner, the energy level of tungsten coated thereon with barium and placed in a vacuum;

FIG. **3**(*b*) is similar to FIG. **3**(*a*) but shows the energy level with a high electric field built up; and

FIG. **4** is a graphical representation of the distribution of the low work function metal atoms implanted in the form of ions into the substrate of the cathode.

Referring now to FIG. **1**, a typical high-field emission cathode as designated by **10** is provided with a pointed tip which is produced, for example, by electro-chemically etching or by arcing in disruptive breakdown discharge. Into the surface of this sharp tip are implanted metal ions of low work function by establishing an accelerating electric field. The initial cathode **10** and the metal ions may be made of tungsten and barium, respectively, by way of example. An electrode **11** acting as an anode is located opposite to the cathode **10**. An appropriate voltage is applied from a power source **12** between the two electrodes **10** and **11**. In operation, when a high electric field is established between the electrodes **10** and **11** with the applied voltage, this field serves to lower the surface potential barrier and draws electrons through the surface. In this instance, the electric field required to overcome the surface barrier is so high that the electrons hardly escape from the surface, provided the cathode **10** has thereon no metal of low work function: On the other hand, with the metal implanted thereinto, the work function of the cathode as a whole is lowered. The electric field now makes the electrons escape through the potential barrier at the surface, thus constituting a flow of electrons, as designated by letter *e*, from the surface under the influence of the field. These phenomena will be discussed in the following in accordance with FIG. **2**(*a*) to FIG. **3**(*b*).

In FIG. 2(*a*), vacuum energy level of tungsten, as abbreviated to V.L., is on the flat and the potential barrier is, as a whole, in a stepped form. The work function, the value of which is exemplified as 4.5eV in this instance, is defined as a difference between the vacuum level V.L. and so-called Fermi level as abbreviated to F.L. In other words, the work function is an energy required to have an electron at the Fermi level F.L. freed out of the surface of the tungsten. When an electric field is established in the neighborhood of the surface, the vacuum level V.L. drops with a certain slope and the potential barrier appears as a triangular hump, as shown in FIG. 2(*b*). This triangular hump grows sharper as the electric field established becomes more intense. The work function 4.5eV nevertheless remains substantially unchanged. Actually, however, the work function decreases a few tenths of 1eV, which is referred to as the Shottky effect. Therefore, the electrons inside the tungsten bulk can not leave the surface, unless the energy of 4.5eV is given to the respective electrons.

Where the tungsten is coated thereon or implanted thereinto with metal of low work function such as barium, the vacuum level V.L. is lowered so that the value of the work function shifts from 4.5eV to 1.5eV, as shown in FIG. 3(*a*). It follows that the electrons inside the tungsten bulk are pulled out or pass over the barrier easily from the surface if the attractive electric field is relatively intense. Referring further to FIG. 3(*b*), the potential barrier assumes in turn a sharp triangular hump lowered with respect to the Fermi level F.L. when a high-field develops. The vacuum level V.L. has also a negative slope, which grows steeper as electric field is increased. In this instance, even the electrons having energies below the Fermi level can tunnel through the narrow portion of the potential barrier. This phenomenon is well known as the tunnel Effect and is used in the high-field emission cathode of this invention.

In one preferred method of the invention, metal of low work function is accelerated in the form of ions by an intense electric field and thereafter implanted deep into the inside of a substrate made of a usual cathode material. After this ion-implantation, the cathode obtained is taken out into the open air. Then, the cathode may be subjected to a heat treatment in a vacuum, preferably in an electron tube, to remove a oxidized part of a resulting oxide layer and adsorbed gases in the surface layer, if any. During the heat treatment, the tube is degassed and the surface of the cathode activated by diffusing the metal ions from the substrate bulk to the surface.

The ion-implantation is, in this instance, accomplished in a manner as follows: The barium ions are obtained from a plasma, where the barium is at least partially ionized at an elevated temperature. Practically, with an intense accelerating voltage of, for instance, about 40kV established, the barium ions are oriented in a uniform direction thereby to form a beam. This barium-ion beam is implanted deep into the inside of the cathode substrate of tungsten.

The distribution of the implanted barium ion content is illustrated in FIG. 4 in terms of the penetration depth from the substrate surface. It will be appreciated from FIG. 4 that the summit of the distribution is located at a distance inboard from the surface, namely, not at the very surface and that the barium ions penetrate as deep as 1,000 to 3,000 angstroms into the substrate bulk. This deep penetration is conducive to maintaining the surface of the ion-implanted tungsten unaffected by the surrounding gas molecules. Therefore, the surface of the tungsten fabricated by the method of the invention behaves as a simple substance. Consequently, a high-field emission cathode according to the invention offers advantages that the cathode stays so stable as to be free from evaporation at an elevated temperature and chemically inert to gas molecules and that the cathode can operate stably with reduced operating voltage for a prolonged period of time.

Examples of metals as usable in the invention to be implanted into the substrate are alkali metals such as lithium (Li), sodium (Na), potassium (K) and cesium (Cs); alkaline earth metals such as barium (Ba), strontium(Sr) and calcium(Ca) and other metals such as thorium (Th) and zirconium (Zr). As has been described in detail, these metals have low work functions and easily ionize at a high temperature.

In another preferred method of the invention, the usual simple substance cathode is once coated with a material to improve the implantation of the low work function metals, namely, to permit more amount of metals to penetrate deeper into the substrate material. The ion-implantation is accomplished to the once coated substrate. The coating material may preferably by oxides or carbides of the substrate material such as tungsten (W), molybdenum (Mo), tantalum (Ta) or rhenium(Re) and should also be stable at an elevated temperature, chemically inert to gases including oxygen and adapted to be coated on the substrate surface.

The high-field emission cathodes of the invention can be used, in general, as a point source of an electron beam with less operating voltages. Furthermore, the cathodes will find a wide variety of applications for an emitter of an electron tube, especially, for a cathode of an electron gun.

What is claimed is:

1. A high-field emission cathode composed of a substrate having a pointed tip portion and a low work function metal, said metal being implanted deep into said pointed tip portion of said substrate, which cathode is produced by a process comprising, obtaining ions of said metal from a plasma having ions of said metal accelerating said ions of said metal by applying high voltage of about **40** kV thereto for forming a high speed ion beam, and implanting said ion beam into said substrate.

2. A high-field emission cathode according to claim **1**, wherein said implanted metal is diffused toward the surface of said substrate by heating under vacuum.

3. A high-field emission cathode according to claim **1**, wherein said substrate is a rigid metal selected from the group consisting of tungsten, molybdenum, tantalum and rhenium.

4. A high-field emission cathode according to claim **1** wherein said substrate is a whisker.

5. A high-field emission cathode according to claim **1** wherein said metal is selected from the group consisting of lithium, sodium, potassium, cesium, barium strontium, calcium, thorium and zirconium.

* * * * *