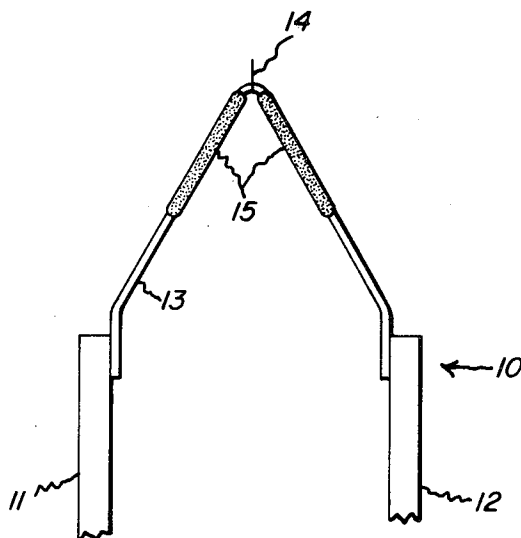


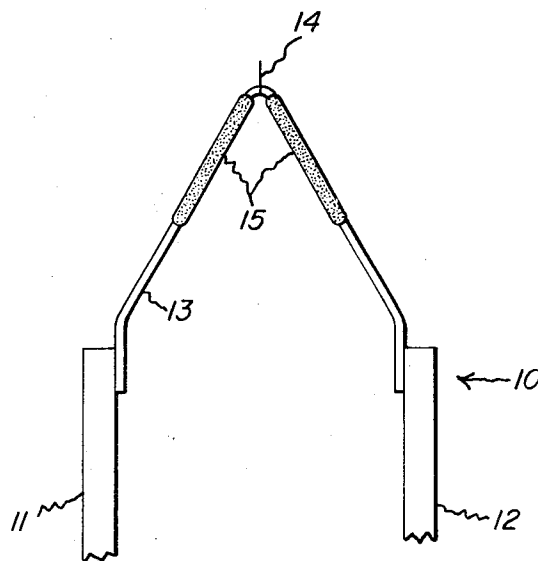
[11] 3,631,291

ABSTRACT: A field emission cathode comprises a hairpin rhenium filament coated with lanthanum boride and with a fine tungsten tip attached to the rhenium filament serves as an efficient source of electrons. The presence of free lanthanum atoms at the tungsten surface lowers the work function and enhances the field emission from the tungsten tip.



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FIELD EMISSION CATHODE WITH METALLIC BORIDE COATING

This invention relates generally to field emission cathodes and more particularly to cathodes having a metallic boride coating.

The emission of electrons from the surface of a conductor into a vacuum or into an insulator under the influence of a strong electric field have found many useful applications. One such application includes field emission microscopy in which some of the most powerful microscopes known have been constructed. Such microscopes generally utilize a "hairpin" cathode with a fine tungsten point at the apex of the hairpin as a source of electrons. Since the degree of magnification obtained by field emission microscopes is a function of the emission levels from the tungsten tip, it is desirable to utilize a hairpin filament with high emission levels so that high magnification can be obtained. Conditions conducive to high emission are a high operating temperature, an ultrahigh vacuum, and a high electric field. With these conditions, a relatively high emission can be obtained; however, the useful life of a hairpin filament operated in this manner is considerably reduced. Additionally, as a result of the high temperatures, the field emission microscope is limited in application to an investigation of those metals having a melting point higher than the operating temperature of the filament. Accordingly, it would be desirable to have a filament which provides the same or higher emission current with a lower work function than existing filaments.

As disclosed in U.S. Pat. No. 2,639,399 to J. M. Lafferty, properties of the rare earth metal borides and in particular lanthanum boride, LaB_6 , exhibit particularly desirable characteristics for electron emitters.

It is therefore an object of this invention to provide a field emission cathode having a lower work function with enhanced field emission.

It is another object of this invention to provide a field emitter that is highly efficient and has a longer useful life than prior art emitters even when operated at emission levels several orders of magnitude higher than prior art emitters.

Briefly, the field emitter of the present invention includes a hairpin filament of rhenium metal with a fine tungsten point at its apex and a coating of lanthanum boride applied to the sides of the rhenium filament. The presence of free lanthanum atoms on the tungsten surface lowers the work function and enhances the field emission from the tungsten tip.

The invention will be better understood from the following description taken in connection with the accompanying drawing and its scope will be pointed out in the appended claims.

In the drawing, the FIGURE illustrates a cross-sectional view of a hairpin cathode constructed in accord with the present invention.

In the FIGURE, a field emission cathode 10 comprises a pair of side support members 11 and 12 having a filament 13, preferably of rhenium wire, connected therebetween in the form of an inverted V and secured, as by welding, to support members 11 and 12, respectively, at the extremities thereof. Secured to the apex of the hairpin-shaped filament is a fine tungsten point 14 of conventional design, fabricated by an electrolytic etching technique well known to those skilled in the art. Unlike conventional hairpin field emitters of pure tungsten, however, lanthanum boride is applied to each side or leg of the filament 13. The lanthanum boride coating is illustrated in the FIGURE by the numeral 15. The sides of the rhenium filament 13 to which the lanthanum boride coating 15 is applied, is typically 10 mil diameter.

The coating 15 may be applied to the sides of the rhenium filament by painting, spraying, or dipping. For example, a paste slurry of lanthanum boride powder and ethyl alcohol may be applied by painting or dipping. Reference may be made to the aforementioned U.S. Pat. No. 2,639,399 for a description of other methods which may also be used to provide the desired coating 15 on the rhenium filament 13.

As described in U.S. Pat. No. 3,312,856 to J. M. Lafferty and W. R. Grams, when certain metal borides are in contact with commonly used refractory metals such as tungsten, molybdenum, platinum, niobium, or tantalum at high temperatures, boron diffuses into these metal lattices forming interstitial boron alloys which are very brittle and which reduce the supply of emissive material in the metal. Rhenium metal, however, possesses physical and mechanical properties which are impervious to boron atoms and make its use desirable in practicing the present invention; however, other metals which are affected by boron diffusion at high temperatures could likewise be used.

The field emission cathode constructed in accordance with the instant invention has several advantages over prior art devices. In particular, the lanthanum boride coating serves as a dispenser of free lanthanum metal atoms which at a temperature of approximately 1,400° C. migrate to the tungsten tip thereby lowering the work function and enhancing the field emission from the tungsten tip. Laboratory tests have demonstrated that emission levels of approximately 1,000° times higher are achieved with the instant invention over hairpin filaments with a tungsten tip but without the lanthanum boride coating. Additionally, under vacuum conditions such as 10^{-6} torr, which would be completely unsuitable for operation of an uncoated hairpin filament, the field emission cathode of the instant invention provides emission currents which were very stable and were attained with anode-to-cathode potentials of only 3.5 kilovolts. Additionally, whereas conventional hairpin filaments require a tungsten tip of a half-micron radius of curvature to provide emission currents of 10^{-7} amperes, the hairpin filament of the instant invention can achieve the same or higher levels with a tungsten tip of 2-3 microns radius of curvature. Since it is very difficult and costly to fabricate tungsten tips of a half-micron radius of curvature, the cost of highly emissive field emitters is greatly reduced.

Another advantage of the instant invention is that field emission from the activated tungsten tip is enhanced by approximately 10 times by slightly heating the filament; that is, given a particular emission level, it can be increased tenfold by slightly heating the filament. The temperature is so low that no color temperature is visible; however, increased field emission is observed. The reason for the field emission enhancement under this condition is not clearly understood since the temperature of the cathode is not high enough for thermionic emission from the lanthanum hexaboride coating. If desired, however, the field emission cathode of the instant invention can serve as a thermionic by simply heating the filament to a temperature of approximately 1,000° C. so as to enable the lanthanum hexaboride to emit thermionic electrons. In this mode of operation, only a few hundred volts anode-to-cathode voltage would be required. This mode of operation would be most useful for out-gassing of electrodes by electron bombardment.

From the foregoing, it may be appreciated that there is disclosed a field emitter having a hairpin configuration with a lanthanum boride coating in which emission currents a thousand times greater than pure tungsten tips are achieved. Additionally, good emission is achieved with a tungsten tip of 2 to 3 microns radius of curvature whereas prior art tungsten tips with a half-micron radius of curvature could not produce the same results. Stable emission is also achieved in vacuums of 10^{-6} torr with the field emitter of the present invention whereas prior art emitters require a vacuum in the order of 10^{-9} or 10^{-10} torr for stable emission.

While the invention has been described in connection with a specific hairpin structure, it is to be understood that the present invention is not limited thereto. Many variations and modifications of the specific embodiment disclosed will occur to those skilled in the art. Therefore, it is intended by the following claims to include all such structures as fall within the true spirit and scope of this invention.

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

1. A field emission cathode comprising:

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a hairpin filament;
said filament including at least two sides with a tungsten tip
connected at the apex thereof; and
a coating of lanthanum boride on at least one side of said
filament for enhancing the field emission from said tung-
sten tip, the sides of said filament being impervious to
boron diffusion.

2. A field emission cathode as recited in claim 1 wherein
said sides are made of rhenium metal.

3. A field emission cathode as recited in claim 2 further
comprising support means connected to the ends of said rheni-
um filament for supporting the same.

4. A field emission cathode as recited in claim 1 wherein
said lanthanum boride coating is applied to each side of said
filament for providing a source of free lanthanum atoms which

migrate to said tungsten tip at elevated temperatures thereby
lowering the work function of said tungsten tip.

5. A field emission cathode as recited in claim 4 further
comprising support means connected to the ends of said fila-
ment for supporting the same.

6. A field emission cathode as recited in claim 2 wherein
said lanthanum boride coating is applied to the sides of said
filament for providing a source of free lanthanum atoms which
migrate to said tungsten tip at elevated temperatures thereby
lowering the work function of said tungsten tip.

7. A field emission cathode as recited in claim 1 further
comprising support means connected to the ends of said rheni-
um filament for supporting the same.

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