

- [54] **BINARY MATERIAL FIELD EMITTER STRUCTURE**
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[52] U.S. Cl. **313/309, 313/336, 313/351**
[51] Int. Cl. **H01j 1/02**
[58] Field of Search **313/309, 336, 351**

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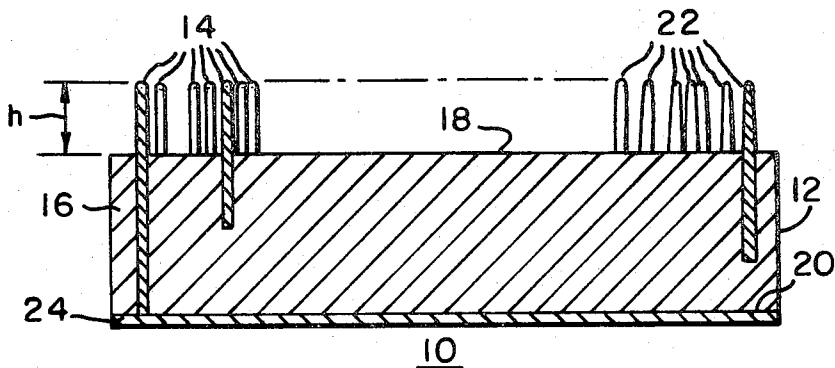
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[57] **ABSTRACT**

A field emitter structure comprises a body of a binary eutectic alloy wherein thin filaments of the minor component of the alloy are embedded in, and a plurality of the thin filaments project above, a surface of a matrix enriched by the major component of the alloy thereby providing a highly effective and inexpensive non-thermionic source of electrons for a variety of vacuum and other applications.

5 Claims, 3 Drawing Figures



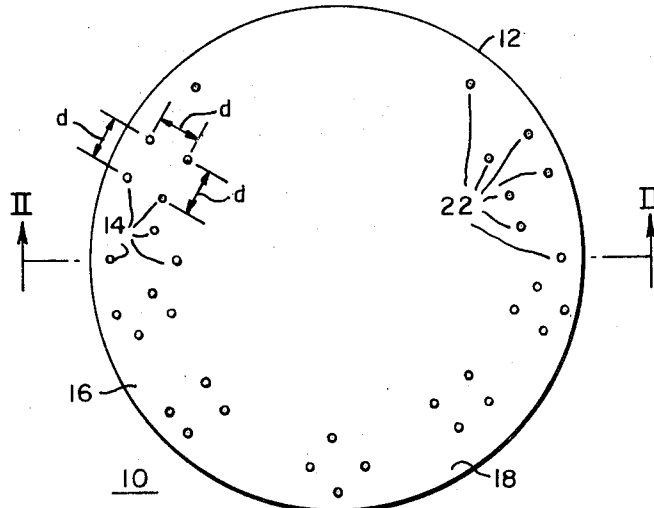


FIG. 1.

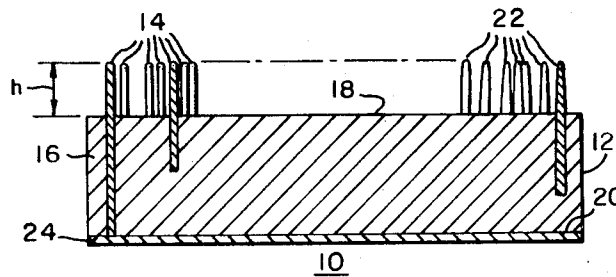


FIG. 2.

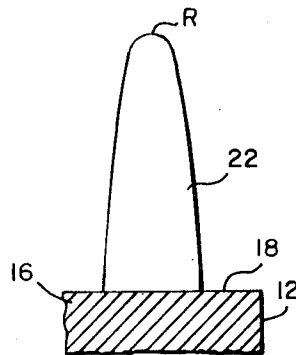


FIG. 3.

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BINARY MATERIAL FIELD EMITTER STRUCTURE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to non-thermionic electron sources, and in particular, to a field emitter structure suitable for use as a non-thermionic source of electrons for a variety of vacuum and non-vacuum applications.

2. Description of the Prior Art

The provision of non-thermionic (cold) electron sources for a variety of scientific and commercial applications is highly desirable. Heretofore one field emission cathode was produced by spot welding 40 tungsten wires to form a comb structure. Later, multiple-needle field emission cathodes were produced by growing molybdenum whiskers on a substrate. Other prior art endeavors have been centered on thin film sandwich techniques and related field emitter structures which have been extensively investigated. However, such structures are difficult to fabricate, sensitive during operation and relatively fragile. In particular, the sensitivity of such structures allows for easy destruction by localized hot spots during normal operation. Additionally, the sandwich type structure of a cathode tends to show a progressive deterioration in performance as a result of non-reversible changes in the exit metal layer. Field emitter structures consisting of a single emitter point or a small number of emitter points have a very limited emission capability. Consequently, a demand for an inexpensive, extended area non-thermionic source of electrons exists.

More recently, H. E. Cline in his paper "Multineedle Field Emission from the Ni-W Eutectic," Journal of Applied Physics, volume 41, No. 1, January 1970, described a method of making a multineedle field emitter structure from an alloy of nickel and tungsten of essentially eutectic composition. H. E. Cline does not teach any specific geometrical structural orientation of the multineedle field emitter and is restricted to the nickel-tungsten binary eutectic alloys.

Field emitter structures consisting of a single or a small number of eutectic points have a limited emission capability. A demand for an inexpensive, extended area non-thermionic source of electrons exists.

SUMMARY OF THE INVENTION

In accordance with the teachings of this invention, there is provided a field emitter structure comprising a body having a surface and comprising a material consisting essentially of a lamellar microstructure of an ordered structure of thin filaments of the minor component of said lamellar microstructure being substantially perpendicular to the surface and embedded in a matrix of the major component of the material. The matrix comprises a cermet or a binary eutectic alloy of chromium copper, or alloys of tungsten, molybdenum or tantalum with silicon. A plurality of the thin filaments project out of the body above the surface to a predetermined height and are oriented within $\pm 20^\circ$ of the vertical axis of the body.

DRAWINGS

FIG. 1 is a greatly enlarged top plan view of a field emitter structure made in accordance with the teachings of this invention;

FIG. 2 is a greatly enlarged elevation, partly in cross-section, of the field emitter structure of FIG. 1 taking on the cutting plane II—II; and

FIG. 3 is a fragmentary magnified view of a single etched filament.

DESCRIPTION OF THE INVENTION

With reference to FIGS. 1 and 2, there is shown a field emitter structure, or cathode, 10 suitable for use as a non-thermionic source of electrons. The structure 10 comprises a body 12 comprising a binary eutectic alloy or a cermet having a fibrous, or lamellar, microstructure wherein a dense ordered structure of thin filaments 14 comprising the minor component of the alloy or the cermet is embedded in and projects above the surface 18 of a matrix 16 enriched by the major component of the alloy or the major component of the cermet respectively. Examples of suitable binary eutectic alloys for comprising the body 12 are copper-chromium, tungsten-silicon, molybdenum-silicon, and tantalum-silicon. An example of a suitable cermet is uranium dioxide-tungsten. The alloy composition by weight percent may vary about 1 percent from the eutectic composition but a preferred range is $\pm \frac{1}{4}$ weight percent from the eutectic composition. The tungsten may comprise from 5 to 15 weight percent of the uranium dioxide-tungsten cermet. In the cermets the thin filaments 14 extend from the face surface 18 to the rear surface 20.

The body 12 is made by cooling a molten mass of binary eutectic alloy or a cermet material at a predetermined rate from one end to the other to cause progressive solidification in order to produce the fibrous, or lamellar, microstructure wherein the thin filaments 14 are substantially parallel to the vertical axis of the resulting ingot, for example, within $\pm 20^\circ$ of the vertical axis. By controlling the composition of the alloy or cermet, as well as the cooling rate and impurity content, one is able to control the number, distribution and diameter of the thin filaments 14. Control of the composition and the cooling rate to do this is within the competence of one skilled in the art. After the alloy or cermet has been preferentially solidified by slow cooling to form an ingot of rod-like shape, a transverse section is removed from the ingot and a first major top surface 18 of any desired shape is prepared by polishing. The top surface 18, if substantially flat, is within $\pm 20^\circ$ of being perpendicular to the filaments 14 and preferably is substantially perpendicular to the ordered orientation of filaments 14. A second major rear surface 20 is also prepared by a polishing technique and may be flat and substantially parallel to the surface 18 or it may be prepared to a predetermined curvature.

A plurality of the thin filaments 14 must extend entirely through the body 12 when the material is a cermet. When the body 12 comprises a binary eutectic alloy, the thin filament 14 need not extend entirely through the body 12 since the matrix 16 will be electrically conductive.

After initial preparation of the body 12, selective etching of the top surface 18 removes substantially only the matrix 16 from about the filaments 14, leaving the filaments projecting out of the surface 18 as shown in FIG. 2. As prepared, many of the etched filaments have blunt ends although others appear to taper to a point with about one-tenth the diameter of the average fila-

ment. The prepared body 12 at this point is suitable for use as a highly effective field emission structure 10. However, the efficiency of the structure 10 may be further increased by selectively etching the tips of the exposed filaments 14 to produce filaments 22 having a tip radius R as shown in FIG. 3. The field emission of the tips of the filaments 22 increases approximately inversely with the tip radius, while the emission goes up exponentially with the field. Filaments 22 having a tip radius R of from 3000 Å to 4000 Å are suitable for use in partial vacuum of the order of 1 to 50 cm. of Hg., while those filaments 22 having a tip radius R of from 100 Å to 200 Å are suitable for use in air or gas at atmospheric pressure. If the material comprising the body 12 is prepared properly extremely small diameter filaments result so that little or no selective etching is required for shaping the tips of such very thin filaments. Even in this instance, however, the structure 10 is not as an efficient emitter as that prepared by selectively etching all the filaments. In any event, the structure 10 does provide an economical and effective non-thermionic source of electrons.

The exposed height, h , of the filaments 10 should be a minimum of at least 10 to 15 microns in order to assure a good source of electron emission. If the filaments 14 are spaced closer together they mutually shield each other thereby decreasing the efficiency of the field emitter structure 10. Therefore, it has been determined that the distance, d , in microns between any two adjacent filaments 14 should be at least of the order of $4\sqrt{hR}$, where h is in microns and R is the top radius in angstroms. A close to optimum structure 10 has been determined as being one where the filaments 14 extend approximately 100 microns in height above the top surface 18 and are spaced apart from each other a distance given by the above expression, namely $40\sqrt{R}$.

In order to more fully describe this invention, particular reference will be made to a structure 10 wherein the body 12 comprises a chromium copper alloy wherein chromium is from ½ percent to 2 percent by weight of the alloy, which upon melting and controlled progressive longitudinal solidification forms five filaments of chromium. A suitable etchant for selectively etching the copper matrix 16 from about the chromium filaments 14 is nitric acid.

More particularly, an ingot of a copper-chromium eutectic alloy containing 1.5 weight percent chromium was cast, rolled, and swaged into a 0.2 inch diameter rod. The alloy contained approximately 200 parts per million of impurities. The swaged rod was encapsulated in a high purity, 99.9 percent, alumina tube and regrown in a vertical Bridgman furnace at a rate of ½ inch per hour. The molten metal in the furnace was at 1200° C and there was a temperature gradient of the order of 150° C per inch at the interface of the newly regrown rod and the initial swaged rod. The vertical regrowth of the rod caused a lamellar structure characterized by a fine, uniform distribution of chromium whiskers, or filaments 14, axially oriented in substantially the direction of the rod axis.

The grown rod was cut perpendicular to its axis to produce a substrate wafer about 1/16 inch in thickness. The opposed major surfaces of the substrate wafer were polished and one surface was exposed to a 50 per-

cent solution of nitric acid for 20 seconds to selectively etch the copper rich matrix 16 away from the chromium filaments 14. The result of this selective etching was to produce filaments 14 protruding about 0.1 millimeter from a surface 18. The filaments 14 were not further etched. The structure 10 was mounted in a holder comprising an electrically insulating material, polytetrafluoroethylene with an electrical contact was affixed to the rear surface 20, and the assembled components placed in a high vacuum system for emission studies. The separation between the emitting surface, that is, the plane of the tips of the filaments 14, and a plain stainless steel anode was arranged so that it could be varied and could be measured to ± 1 mil.

Prior to testing the structure 10, a polished flat stainless steel wafer was mounted in the test fixture to act as a cathode with a space of 10 mils. between the anode and cathode, and 10 KV was applied to the anode. No observable emission was noted under a high vacuum. It was determined that leakage currents, if they existed, were less than 1×10^{-13} amps and therefore were neglected. The emission currents were measured with an electrometer.

In the high vacuum system, the structure 10 as processed, was electrically connected to a linear motion feed-through of a UHV system, the stainless steel anode being disposed near and parallel to the structure 10, and the system evacuated to about 10^{-8} Torr and voltage applied between the emitter structure 10 and the anode. The resulting emission current was measured with the electrometer as a function of accelerating voltage and plate separation. Test results obtained were as follows:

TABLE I

CONSTANT VOLTAGE OF 500 VOLTS APPLIED

Separation between anode and cathode ($\approx$ mils)	Emission Current (μ A)
10	4.5
15	4.3
20	4.0
30	3.6

The results as shown in Table I indicate that emission currents are not greatly affected by the separation distance between cathode and anode.

TABLE II

CONSTANT SEPARATION BETWEEN CATHODE AND ANODE 10 MILS

Voltage (volts)	Emission Current (μ A)
100	0.65
200	1.7
300	2.6
400	3.6
500	4.5

The results as shown in Table II indicate that emission currents vary almost linearly with the applied voltage. This was an unexpected result which, however, was repeated over a range of various separation spacing between the cathode and anode, with the voltage being varied as in Table II at each separation distance.

The successive tests which verified the test results were conducted at voltages varying from 100 volts to several kilovolts and increasing separations between

the cathode, or field emitter structure, and the anode of up to and including $\frac{1}{8}$ of an inch.

As a control, a polished stainless steel plug of the same geometry as the field emitter structure was inserted in the test apparatus in place of the field emitter structure. No emission was detected at any setting previously used, and no leakage currents were observable at an ammeter setting of 10^{-11} ampere, which was full scale deflection. Therefore, any emission current, if there be any at all, was necessarily below 10^{-13} ampere.

Emission currents as high as 250 microamperes are obtainable with the field emitter structure described heretofore. These currents have been maintained for days without degradation.

Field emitter structures embodying the chromium-copper binary eutectic alloy compositions have been found to resist deterioration after exposure to air and yielded the same emission currents upon retesting in the high vacuum system as were obtained during previous testing in the same high vacuum system.

When a cermet such, for example, as uranium dioxide-tungsten comprises the body 12, electrical contact is made to the bottom ends of the filaments 14 by plating the bottom surface 20 with a layer 24 of an electrically conductive metal such as copper. The layer 24 provides a means of applying an electrical potential to the filaments 14 which extend through the entire body 12. Since the ordered structure of filament growth provides substantially all filaments grown the complete length of the ingot, very few, if any, of the filaments 14 will not be connected electrically by the layer 24. The layer 24 is not needed for the binary eutectic alloy materials since the matrix 16 of such alloys comprises

an electrically conductive material.

I claim as my invention:

1. A field emitter structure comprising
 - a body having a surface and comprising a material consisting essentially of a lamellar microstructure of an ordered structure of thin filaments of the minor component of said lamellar microstructure substantially perpendicular to the surface and embedded in a matrix of the major component of said material;
 - a plurality of the thin filaments projecting out of said body matrix a predetermined height above said surface, the thin filaments being within $\pm 20^\circ$ of the vertical axis of said body, said material comprising said body being a binary eutectic alloy of copper-chromium wherein the major component chromium varies from the eutectic alloy composition by up to ± 1 weight percent.
2. The field emitter structure of claim 1 wherein said filaments are spaced apart from each other at least of the order of $4\sqrt{hR}$ microns where h is the height in microns that the filament projects above the surface of the matrix, and R is the radius in angstroms of the tip of the filament.
3. The field emitter structure of claim 2 wherein said filaments project above said one of the two opposed surfaces at least 10 microns.
4. The field emitter structure of claim 3 wherein R is at least about 100A.
5. The field emitter structure of claim 2 wherein said filaments are spaced 100 microns apart from each other and each of the filaments projects 100 microns above said surface. * * * * *

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