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Rogers et al.

[11] **3,735,187**

[45] **May 22, 1973**

[54] **CATHODE BLADE FOR A FIELD EMISSION X-RAY TUBE**

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[52] **U.S. Cl.** **313/355,** 313/56, 313/336

[51] **Int. Cl.**.....**H01j 35/06**

[58] **Field of Search**.....313/355, 336, 309, 313/351, 55–57, 60

[56] **References Cited**

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Primary Examiner—David Schonberg
Assistant Examiner—Paul R. Miller
Attorney—John S. Bell and William S. Thompson

[57] **ABSTRACT**

A cathode blade comprising a thin electron emitting layer formed from tungsten that projects from a copper support layer. The tungsten layer is extremely thin so that electrons will be readily emitted from the edge of the blade without requiring that the portion of the blade proximate the electron emitting edge be tapered. The copper support layer is spaced from the electron emitting edge of the tungsten layer, and therefore, does not reduce the sharpness of that edge. The blade is formed by vapor depositing a thin tungsten layer on a copper layer that is somewhat larger than the desired blade. The copper and tungsten layers are covered with coatings that are unaffected by electro-etching processes for removing unwanted portions of those layers. The portions of the copper and tungsten layers having outlines corresponding to the desired outlines of the copper and tungsten layers respectively of the desired blade are masked. The protective coating is removed from the remaining unmasked surfaces. The exposed portion of each layer is then removed by electro-etching.

4 Claims, 7 Drawing Figures

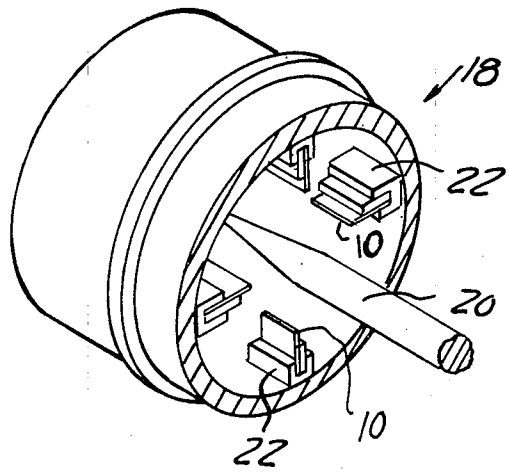


FIG. 1

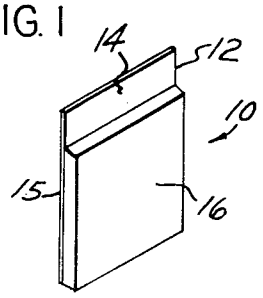


FIG. 3

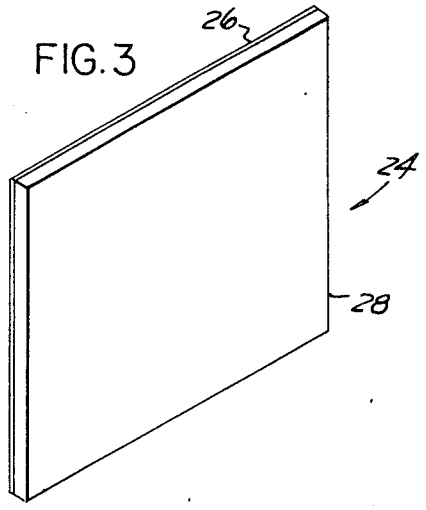
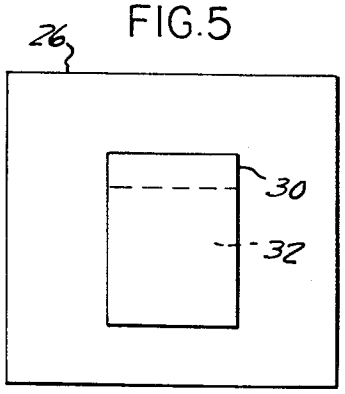


FIG. 5



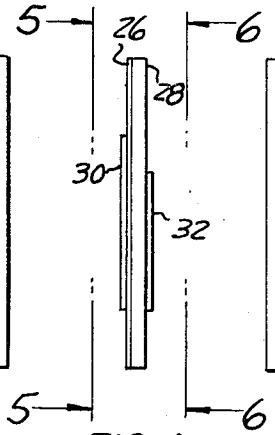


FIG. 6

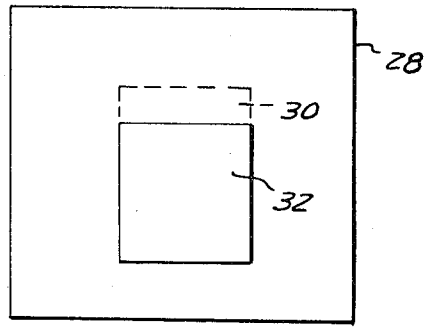


FIG. 4

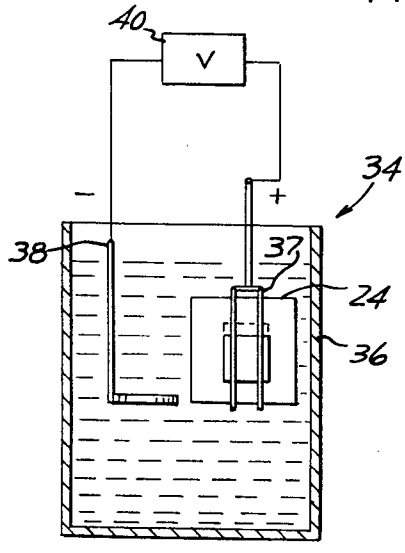
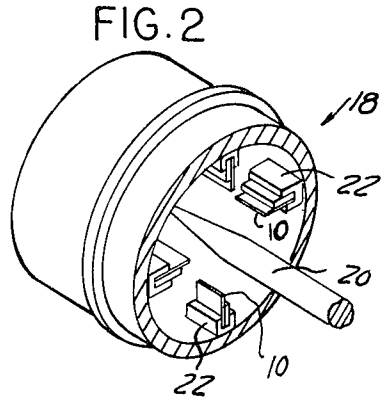


FIG. 7

FIG. 2



CATHODE BLADE FOR A FIELD EMISSION X-RAY TUBE

BACKGROUND OF THE INVENTION

1. Field of the Invention

X-ray technology.

2. Brief Description of the Prior Art

Field emission x-ray tubes, which are sometimes called cold cathode x-ray tubes, have been known since the 1920's. A field emission x-ray tube includes an anode and a cathode disposed in an evacuated envelope. A high electric voltage pulse is supplied to the anode to provide a large potential difference between the anode and cathode. This potential difference causes electrons to flow from the cathode to strike the anode. Electrons striking the anode cause x-rays to be emitted from that anode. The number of x-rays provided, or in other words the output of the x-ray tube, is determined by the number of electrons that can be made to flow from the cathode to strike the anode. Electrons are more readily emitted from a sharp edge or point than from a flat surface. The electron flow produced by a particular potential difference is increased as the sharpness of the electron emitting edge or point is increased.

A blade shaped cathode in a practical x-ray tube embodiment must have an extremely sharp edge from which electrons are emitted in order to provide an acceptable high x-ray output. The electron emitting edge of cathode blades used in most embodiments must have a radius of curvature between $1 \cdot 10^{-4}$ and $1 \cdot 10^{-6}$ inches. Cathode blades having edges with the required degree of sharpness have been produced by tapering the edges of the blades so that they resemble razor blades. However, the required radius of curvature is so small that it is very difficult to accurately control the taper of the cathode blade and provide precisely a determined sharpness. It is also difficult to duplicate a result once obtained and provide a large number of different cathode blades having precisely the same taper so that the electron emitting edges of those blades have precisely the same sharpness. Since the sharpness of the electron emitting edge of the cathode blade determines the tendency of that blade to emit electrons, it is very difficult to produce a large number of tapered blades having the same operating characteristics.

In addition, field emission x-ray tubes operate at such high voltages that a portion of the cathode is vaporized whenever a voltage pulse is supplied to the tube in order to produce x-rays. The vaporization of a tapered blade cathode blunts that blade and therefore changes the operating characteristics of the x-ray tube. The useful life of such a tube is limited because the blade rapidly becomes so blunted that the tube will not provide a sufficient x-ray output.

SUMMARY OF THE INVENTION

The subject invention comprises a cathode blade having one lamina or layer that is so thin that there is no requirement that the blade taper toward one edge in order to provide an electron emitting edge that is sufficiently sharp so that the electrons will be readily emitted from that layer. The thinness of this electron emitting layer may vary for different embodiments, but will generally be between $1 \cdot 10^{-4}$ and $1 \cdot 10^{-6}$ inches. The thickness of the electron emitting layer is the same at each point on that layer so that the sharpness of the electron emitting edge will not change as that blade is vaporized during operation of the x-ray tube. The cathode blade of this invention, therefore, has a relatively long operating life. And, it has relatively uniform operating characteristics throughout that life.

In the preferred embodiment described herein, this layer is formed from tungsten. The electron emitting tungsten layer is so thin that it would not be self-supporting or structurally rigid over an area equal to the area of a typical cathode blade for a field emission x-ray tube if that thin layer were not supported. The thin electron emitting layer is therefore joined to and supported by a second layer which is formed from copper in the embodiment illustrated herein. The copper support layer is spaced from the edge of the thin tungsten layer from which electrons are emitted and therefore does not reduce the sharpness of that electron emitting edge.

Since there is no requirement to taper the electron emitting layer of the cathode blade of this invention, that blade can be fabricated using a readily controllable process capable of providing a large number of cathode blades having precisely the same dimension. This process comprises providing a laminae structure having a thin lamina joined to a support lamina. In the embodiment illustrated herein, this laminae structure is provided by vapor depositing a layer of tungsten on a layer of copper. Any portions of the electron emitting and support layers extending beyond the outlines of the electron emitting and support layers of the desired cathode blade are removed in order to produce that blade. This removal of undesired portions includes the removal of any portion of the support layer within a predetermined distance of one edge of the electron emitting layer so that the support layer will not reduce the effective sharpness of this edge. In the embodiment illustrated herein, undesired portions of the layers are eliminated by first coating each side of he laminae structure with a protective coating that will be unaffected by a process such as an electro-etching process for removing unwanted material. Each laminae structure is ten masked with a mask having an outline corresponding to the outline that the lamina masked thereby will have in the finished cathode blade. The protective coating is then removed from all portions of the laminae structure not covered by a mask. The exposed portion of each layer is then removed by an electro-etching process that will not effect the other layer so that no portion of either layer will be removed inadvertently.

The thickness of a layer such as tungsten that is vapor deposited on a support layer of a material such as copper can be very precisely controlled. The above-described process can, therefore, be used to provide a large number of cathode blades in which the electron emitting layers of those blades have precisely the same thicknesses, and in which the edges of those layers have precisely the same radius of curvature. The various cathode blades thus have identical operating characteristics.

BRIEF DESCRIPTION OF THE DRAWINGS

Further objects, features and advantages of this invention, which is defined by the appended claims, will become apparent from a consideration of the following description and accompanying drawings in which:

FIG. 1 is a perspective view of one embodiment of the cathode blade of this invention;

FIG. 2 is a schematic, cutaway view of the x-radiating end of an x-ray tube having the cathode blade of FIG. 1 mounted therein;

FIG. 3 is a perspective view of a two-layer lamina structure from which the cathode blade of FIG. 1 can be produced;

FIG. 4 is an end view of the lamina structure of FIG. 2 with masks having the desired shapes of the various layers of the cathode blade to be formed covering portions of opposite sides of that structure;

FIG. 5 is a plan view of the masked laminar structure of FIG. 4 viewed from the position defined by line 5—5;

FIG. 6 is a plan view of the masked laminar structure of FIG. 4 viewed from the position defined by line 6—6; and

FIG. 7 is a schematic diagram of apparatus that can be used to remove unwanted portions of the structure shown in FIGS. 2 and 3 by electro-etching and thereby produce the cathode blade shown in FIG. 1.

DETAILED DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a cathode blade **10** for a field emission x-ray tube. The blade comprises a very thin electron emitting lamina or layer **12** formed from a material such as tungsten. The thinness of layer **12** causes edge **14** of that layer to be extremely sharp so that electrons will be readily emitted from that layer during operation of the x-ray tube. The precise dimensions of layer **12** will vary for different embodiments, but this layer will generally have a thickness between $1 \cdot 10^{-4}$ and $1 \cdot 10^{-6}$ inches in most embodiments and therefore will have an electron emitting edge with a radius of curvature between $1 \cdot 10^{-4}$ and $1 \cdot 10^{-6}$ inches. A typical cathode blade may have a length along electron emitting edge **14** of approximately 3/16 inch and a length along side **15** of approximately 1/2 inch.

The thinness that layer **12** must have in order to provide an appropriately sharp electron emitting edge **14** is such that the layer would not be self-supporting or structurally rigid over an area as large as the area of a typical cathode blade. Layer **12** is, therefore, joined to and supported by a support layer **16** formed from a material such as copper. Support layer **16** supports only a portion of electron emitting layer **12** and is spaced from the electron emitting edge **14** of layer **12** so that it does not reduce the effective sharpness of that edge. In a typical embodiment, support lamina **16** would be spaced approximately 10 to 20 mils from edge **14.** Support layer **16** has a sufficient thickness so that the blade **10** can be mounted in a field emission x-ray tube using conventional mounting techniques such as spot welding or clamping. In a typical embodiment, support layer **16** will have a thickness on the order of 100 times the thickness of electron emitting layer **12.**

FIG. 2 is a cutaway illustration of the radiation emitting end of the field emission x-ray tube **18** having four blades **10** mounted in a spaced relationship with respect to the anode **20** of that tube. The blades **10** are held in U-shaped clamps **22** which are spot welded to the walls of the tube **18.** The blades **10** are mounted in positions corresponding to the positions of prior art tapered blade cathodes. The blades **10** operate in a manner similar to that of the prior art tapered blades except that the radius of curvature of edge **14** of the blade **10** will not change as portions of layer **12** are vaporized during operation of the x-ray tube. The blade **10** thus has a long operating life and has relative uniform operating characteristics throughout that life. The operating characteristics of blade **10** will not change substantially until electron emitting layer **12** is vaporized back to the edge of support layer **16.**

The blade **10** can be formed from a lamina structure such as structure **24** illustrated in FIG. 3 which comprises a thin lamina or layer **26** of tungsten that has been vapor deposited on a copper support layer **28.** Laminae structures such as structure **24** having tungsten layers with a very uniform thickness precisely equal to any desired thickness are commercially available and can be readily purchased. The cathode blade **10** is formed from the lamina structure **24** by first coating each side of that structure with a protective coating that will resist electro-etching processes that affect copper and tungsten. For example, a P type photo resist material may be sprayed and baked onto each side of the lamina structure **24.** Masks **30** and **32** (FIGS. **4, 5,** and **6**) having outlines identical to the outlines of layers **12** and **16** of blade **10** respectively are placed opposite each other on the surfaces of the tungsten and copper layers of lamina **24** respectively. The masked lamina structure illustrated in FIG. **4** is then placed in an evacuated environment and both sides of that structure are exposed to ultraviolet light. The ultraviolet light breaks down the photo resist material not covered by masks **30** and **32.** The masks **30** and **32** are then removed, and the lamina structure **24** is washed in a trichloroethylene solution which removes the portions of the protective photo resist coating that have been exposed to ultraviolet light. The exposed portions of lamina structure **24,** that is those portions not covered by the photo resist coating, are then removed by electro-etching.

FIG. **7** illustrates apparatus **34** for electro-etching structure **24.** Apparatus **34** includes a container **36** for holding an etching solution, a conductive clamp **37** for holding the structure **24,** and a stainless steel cathode plate **38.** A voltage source **40** is connected to provide an electric potential between the cathode plate **38** and the lamina structure **24** to be etched. In order to remove the unwanted or exposed portions of the tungsten layer **26,** lamina structure **24** and the cathode plate **38** are immersed in a 3 percent by weight sodium hydroxide solution which is placed in container **36.** A positive potential of approximately 10 volts is supplied to structure **24** in order to provide a potential difference of approximately 10 volts between that structure and the cathode plate **38.** This potential need be supplied for only a very short time interval such as 20 seconds in order to remove all unwanted portions of tungsten layer **26.**

The Stoddard electro-etching process is used to remove the unwanted or exposed portions of copper layer **28.** According to this process, the 3 percent sodium hydroxide solution in container **36** is replaced with a solution of chromic acid and sulfuric acid dissolved in water. The solution contains approximately 27 to 35 ounces of chromic acid for each gallon of water, and one part sulfuric acid for each 100 parts chromic acid. The stainless steel cathode plate is replaced by a copper cathode plate. A positive potential of approximately 5 volts is supplied to structure **24** in order to provide a potential difference of approximately 5 volts between that structure and the cathode plate **38** to thereby form the blade **10** by etching away the exposed or unwanted portions of copper layer **28.**

Having thus described one embodiment of this invention, a number of modifications will be obvious to those skilled in the art.

Therefore, what is claimed is:

1. In a field emission x-ray tube, an improved cathode blade comprising:

a support lamina; and

an electron emitting lamina being sufficiently thin to lack structural rigidity over an area equal to he area of the cathode blade, said electron emitting lamina being joined to and supported by said support lamina, said electron emitting lamina having an end portion with an electron emitting edge extending from said support lamina.

2. The cathode blade of claim **1** in which the thickness at each point on said electron emitting lamina is substantially equal to the thickness at every other point on said electron emitting lamina.

3. The cathode blade of claim **2** in which said electron emitting lamina is a tungsten lamina having a thickness of approximately $1 \cdot 10^{-4}$ to $1 \cdot 10^{-6}$ inches to eliminate any requirement that the blade taper toward one edge in order to provide an electron emitting edge that is sufficiently sharp so that electrons will be readily emitted from that edge.

4. The cathode blade of claim **3** in which:

said electron emitting end portion of said tungsten lamina extends approximately 10 to 20 mils from said support lamina; and

said electron emitting edge has a length of approximately three-sixteenths of an inch.

* * * * *