Nov. 1, 1966 W. P. DYKE ETAL 3,283,203

X-RAY TUBE TEMPERATURE ENHANCED FIELD EMISSION CATHODE

Filed Dec. 19, 1961

2 Sheets-Sheet 1

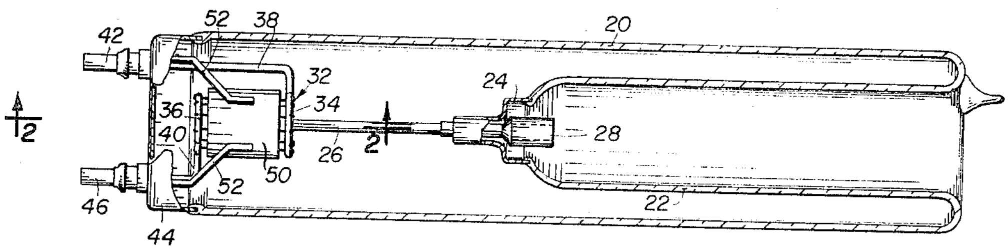

Fig. 1

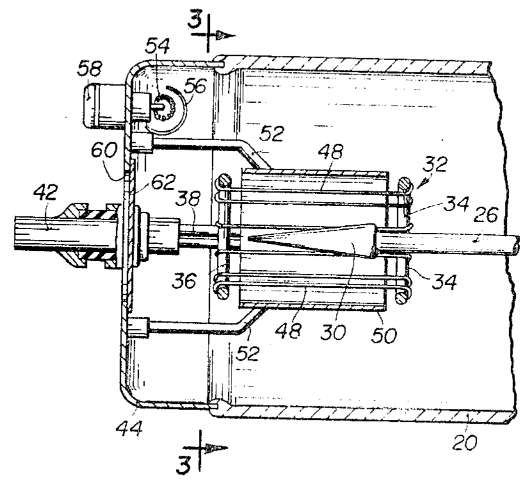

Fig. 2

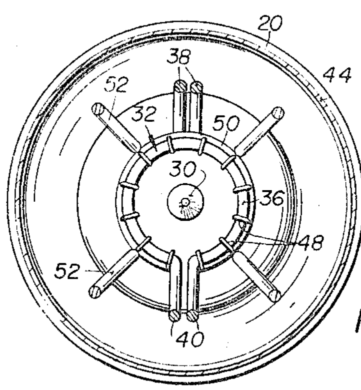

Fig. 3

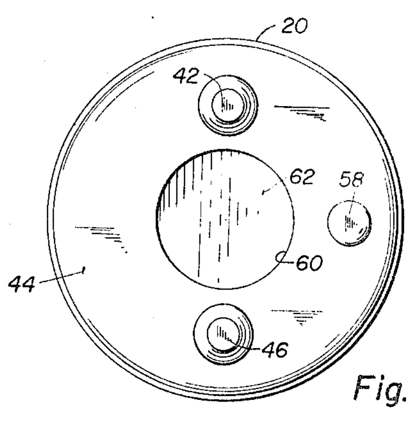

Fig. 4

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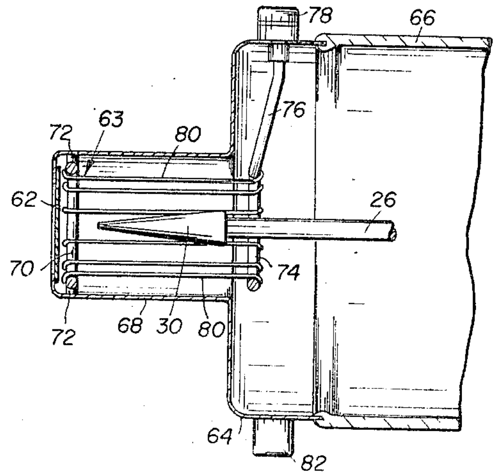

Fig. 5

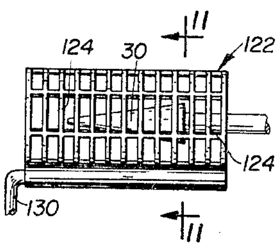

Fig. 10

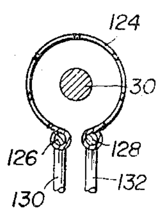

Fig. 11

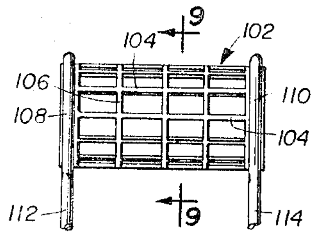

Fig. 8

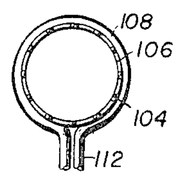

Fig. 9

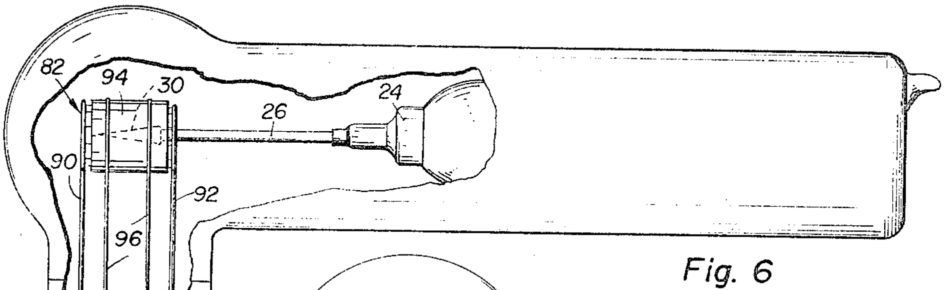

Fig. 6

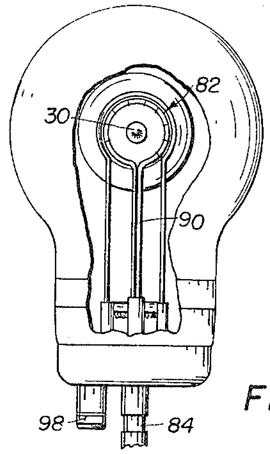

Fig. 7

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United States Patent Office

3,283,203
Patented Nov. 1, 1966

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3,283,203
X-RAY TUBE TEMPERATURE ENHANCED FIELD EMISSION CATHODE

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Filed Dec. 19, 1961, Ser. No. 160,534
16 Claims. (Cl. 313—56)

This invention relates to a temperature enhanced field emission X-ray tube and more particularly to an X-ray tube having a conical anode and employing both thermal emission and field emission of electrons from a cathode structure.

Tubes in accordance with the present invention are of the general type disclosed and claimed in applicants' copending application Serial No. 2,033, filed January 12, 1960 now Patent No. 3,179,832 granted Apr. 20, 1965. In common with such previously disclosed tube, electrons are emitted from cathode filament wires by a combination of thermal and field emission and strike an anode at high velocity. The emission current may, for example, be the order of 2,000 to 4,000 amperes per square centimeter of emitting surface. Sufficient emitting surface may be provided in the tubes of the present invention so that emission currents of the order of 1,000 to 2,000 amperes or greater may be obtained. Such currents are produced for very short times, for example, times of the order of .1 to .2 microsecond and the spacing of the anodes and cathodes is such that the voltage applied between an anode and cathode may be of the order of 300 to 600 kva. or greater and such that the tubes have impedances of the order of 300 ohms. The power applied to the tubes may be of the order of 300 to 1200 million watts or greater. Electrons traveling at extremely high velocities strike the conical surface of the anode so that an intense source of X-rays is provided for a very short period of time.

The anodes of the tubes of the present invention are elongated conical elements with their smaller ends directed toward a wall of the tube in which they are employed. Electron emission is from a plurality of cathode elements arranged in cage-like structure surrounding the anode and concentric with its axis. The cathode elements are in the form of filament wires and such wires are spaced from each other either circumferentially of the anode or axially of such anode. The cathode wires are heated to a thermal electron emission temperature by a cathode heating current and upon supplying a high voltage, high current pulse of electric energy to the anode and cathode, electrons are emitted from the cathode elements and travel at high velocity in converging paths toward the anode. Such electrons repel each other circumferentially of the anode during their travel and the result is a diffused cloud of rapidly traveling electrons which strike the conical surface of the anode with substantially uniform distribution over such surface. The major portion of the conical surface of the anode is thus substantially uniformly bombarded by the electrons so that "hot" spots and uneven displacements of metal from the surface of the anode are avoided. X-rays are emitted substantially uniformly from the conical surface of the anode and since such anode can be of small diameter, a very intense source of X-rays of very small area as viewed from the smaller end of the conical surface of the anode is produced.

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The cathode structure also includes cathode connectors, one of which connects one end of each of the filament wires together and another of which connects the other end of each of the filament wires together. Such connectors preferably also form the supports for the filament wires. The surfaces of such connectors which are in the vicinity of the anode and which are directed toward such anode are carefully smoothed to avoid points or edges of small radius of curvature to thus avoid undesired electron emission from such connectors. Consistent repeated operation of such tubes requires that such surfaces remain in a smooth condition even though metal particles may be removed from the surface of the anode during operation of the tubes and deposited upon such connectors. The tubes of the present invention are therefore constructed so that such connectors for the cathode elements are self-cleaning and self-smoothing. Thus, the connectors forming the supports for the filament wires are so proportioned in cross section relative to the filament wires that a cathode heating current flowing through both such connectors and the filament wires and of a value which will raise the temperature of the filament wires to a thermal electron emission will also raise the temperature of such connectors to a self-cleaning and smoothing temperature. The increase in temperature of the connectors is partly by conduction of heat from the filament wires and partly by resistance heating due to the current flow in the connectors themselves. Such self-cleaning temperatures are of the order of 1900 to 2000° K. and are below temperatures at which substantial thermal emission of electrons occurs.

The cathode structure of the present invention lends itself to providing electron emitting areas which are substantially greater in total area than the tube of the copending application referred to above. This means that for a given total quantity of electron emission from the cathode elements, the emission per unit area may be reduced, for example, by lowering the temperature to which the cathode elements are heated. Thus with the tubes of the present invention electron thermal emission temperatures of the order of 2700° K. for tungsten filament wires are entirely possible instead of the 2900 to 3000° K. contemplated in the copending application referred to above. This results in less deterioration of the cathode structure and longer tube life.

Also in the construction of the tubes of the present invention, the connectors or supports for the cathode filament wires may be kept well away from the anodes or connections to the anodes such that the likelihood of unwanted electron emission from points or projections which may occur on such connectors is reduced. The pulses of electric energy applied to the anode and the cathode are also preferably sufficiently short that the high voltage of such pulses is removed before ions from the anode have reached the cathode wires or cathode connectors. The result is that very little material is carried from the anode to the cathode structure and, if the surfaces of the connectors or supports for the cathode filament wires are initially made very smooth, the heating action referred to retains such smoothness.

The cathode structure described above is preferably surrounded by a shield and focusing element of metal which is ordinarily maintained at substantially the same potential as the cathode filament wires but which may be maintained at a negative potential relative to the filament wires. Such element is preferably in the form of a continuous metallic cylinder concentric with the axis of the anode and concentric with the cage formed by the cathode filament wires. By maintaining such shield at substantially the same voltage as the cathode during operation of the tube or at a potential somewhat negative with respect to the cathode, the shield acts to focus the electrons emitted from the cathode elements upon the surface of the anodes by driving such electrons toward the surface of the anode. Such shield also prevents electron bombardment of any glass portion of the envelope of the tube by electrons from the cathode as well as preventing any positive ion bombardment due to ions which might escape from the anodes and pass between the cathode filament wires.

The conical anode and the cathode structure just described enables the smaller end of the anode to be positioned very close to a wall of the envelope of the tube so that high intensity X-rays can be projected from such tube. That is to say, the X-rays have their highest intensity immediately adjacent the surface of the anode which is being struck by the rapidly traveling electrons and for purposes requiring extremely high intensity X-rays, the material being subjected to X-ray radiation may be placed immediately adjacent the wall of the tube opposite the small end of the anode. It is even possible to make the shield of the cathode structure a part of the wall of the envelope of the tube to provide such shield with an end closure so that the resulting shield structure projects from the remainder of the tube. The anode and cathode structure may then be placed within such shield structure so that the X-ray emitting portion of the tube may be inserted into an aperture in a body to be X-rayed, or treated with X-ray radiation.

It is therefore an object of the present invention to provide an X-ray tube in which electrons emitted both by thermal emission and field emission are caused to strike the conical surface of a conical anode.

Another object of the invention is to provide an X-ray tube in which a cathode structure made up of a plurality of spaced filament wires surrounds the conical surface of a conical anode in order to produce a diffused cloud of rapidly traveling electrons striking such surface when a high voltage, high current pulse of electric energy is supplied to such cathode and anode.

Another object of the invention is to provide an X-ray tube in which a cathode structure made up of a cage of heated filament wires is employed to emit electrons both by thermal emission and field emission and in which a shield and focusing structure causes such electrons to strike the conical surface of an anode positioned within such cage in a manner in which the electrons striking the anode are substantially uniformly distributed over the surface of such anode.

A further object of the invention is to provide an X-ray tube capable of producing intense pulses of X-ray radiation in which the anode surface from which such radiation emanates is positioned closely adjacent the wall of such tube so that intense radiation is present immediately externally of such wall.

A still further object of the invention is to provide an X-ray tube capable of producing intense pulses of X-rays and in which such X-rays may be produced in a small portion of the envelope projecting from the main portion envelope of such tube.

A still further object of the invention is to provide an X-ray tube in which a cage-like cathode structure made up of filament wires extending between connectors forming supports for such wires surrounds the conical surface of a conical anode and in which heating the connectors of such cage structure to a surface cleaning and smoothing temperature occurs whenever the filament wires are heated to a suitable thermal electron emission temperature.

Other objects and advantages of the invention will

appear in the following description of preferred embodiments shown in the attached drawing of which:

FIG. 1 is a view of an X-ray tube in accordance with the present invention partly in side elevation and partly in axial section;

FIG. 2 is a partial axial sectional view of one end of the tube of FIG. 1 on an enlarged scale and taken on the line 2—2 of FIG. 1;

FIG. 3 is a transverse vertical section of the tube of FIGS. 1 and 2, taken on the line 3—3 of FIG. 2;

FIG. 4 is an end elevation on the same scale as FIGS. 2 and 3 of the tube of FIGS. 1 to 3, looking to the right in FIG. 1;

FIG. 5 is a view similar to FIG. 2 of a modified tube structure;

FIG. 6 is a side elevation of a modified X-ray tube in accordance with the present invention with parts broken away to show internal structure;

FIG. 7 is an end elevation of the tube of FIG. 6 looking to the right in such figure with parts broken away to show internal structure;

FIG. 8 is a side elevation of a modified cathode structure, usable in any of the tubes of the present invention;

FIG. 9 is a transverse vertical section through the cathode structure of FIG. 8, taken on the line 9—9 of FIG. 8;

FIG. 10 is a view similar to FIG. 8, showing a further modified cathode structure and also a conical anode in position in such structure; and

FIG. 11 is a transverse section of the cathode structure of FIG. 10, as taken on line 11—11 of FIG. 10.

The X-ray tube shown in FIGS. 1 to 4 of the drawing includes an elongated cylyindrical envelope **20** having a reentrant portion **22** at one end thereof. Such reentrant portion terminates at its inner end in a cap **24** of suitable metal having a thermal coefficient of expansion similar to that of glass of the reentrant portion **22**. An anode support member **26** in the form of an elongated rod extends through the cap **24** in sealing relation therewith and terminates at its end within the reentrant portion **22** in a socket member **28** for the reception of a conductor such as the inner conductor of a coaxial cable. As shown in FIG. 2, the other end of the anode support member **26** terminates in a conical anode element **30** having its axis extending substantially concentric with the axis of the envelope **20**.

The anode element **30** is surrounded by a cathode structure **32** including a pair of axially spaced cathode connectors **34** and **36**, each formed of a relatively heavy wire bent into an annular portion. Lead portions **38** projector radially from the annular portion of the connector **34**. Such lead portions extend parallel to each other and, as shown most clearly in FIG. 1 and FIG. 2, are secured at their ends to a cathode connector pin **42** extending to the exterior of the tube and mounted in and insulated from a metal cap **44** forming an end closure for the envelope **20** at the end opposite the reentrant portion **22**. Similar lead portions **40** project radially from the annular portion of the connector **36** and extend parallel to each other. The lead portions **40** are secured to a connector pin **46** mounted in and also insulated from the cap **44** so as to extend axially of the tube to the exterior thereof. The lead portions **38** and **40** thus form supports as well as electrical connections for the cathode structure **32**.

A plurality of filament wires **48** are welded to the annular portions of the connectors **34** and **36** and extend in a direction axially of the anode **30** between such portions. Each of the filament wires **48** thus has one end connected to a connector **34** and its other end to a connector **36**. Such wires are uniformly spaced circumferentially around the anode **30** and form a cathode cage surrounding and concentric with the axis of the anode element **30**. The filament wires will ordinarily each be of the order of 5 to 20 mils in diameter, while the wires, of the annular portions of the connectors will, in general, be of a diameter providing a cross-sectional area somewhat larger than the total of cross-sectional area of the filament wires. It will be apparent from the drawing that the filament wires 48 are straight wires extending between the connectors 34 and 36, i.e., they are uncoiled filament wires.

A hollow cylindrical shield and focusing member 50 surrounds the cage formed by the filament wires 48 of the cathode structure 32. Such cylindrical shield 50 may be supported by a plurality of support rods 52 secured to the end cap 44 of the tube at one of their ends and to the shield 50 at the other of their ends, for example, by spot welding.

A getter element 54 is also shown in FIG. 2 as being positioned within a shielding member 56 and as having one end connected to the connector pin 58 extending through and insulated from the cap 44. It will be understood that the other end of the getter element 54 will be connected to one of the filament leads, such as the lead 38, so that such getter may be heated during evacuation of the tube.

The cap 44 has an aperture 60 therein which is aligned with the end of the anode element 30. A thin element 62 of a suitable metal is secured to the cap 44 so as to cover such aperture and form a substantially transparent window for X-rays generated on the conical surface of the anode element 30.

In operation of the tube of FIGS. 1 to 4, a suitable source of filament current is connected between the connector pins 42 and 46 so as to supply heating current to the cathode structure 32. With tungsten filament wires, the heating current is sufficient to raise the temperature of the filament wires 48 of the cathode structure 32 to a temperature of approximately 2700° K. and is applied to the cathode structure a short time before a high voltage, high current pulse of electric energy is applied to the anode and cathode of the tube. The connectors 34 and 36 are so proportioned in size with respect to the filament wires that for tungsten connectors, the temperature thereof is raised to approximately 1900–2000° K. during heating of the cathode. The cap 44 of the tube is either connected to one of the cathode connector pins 42 or 46, or is connected to a voltage somewhat negative to that of either of pins 42 or 46. A high voltage, high current pulse of electric energy is then impressed between the anode 30 and the cathode structure 32 by suitable connections to the socket 28 of the anode support 26 and to one side of the filament heater circuit through one of the connector pins 42 and 46. Such pulse may be from a pulser of the type disclosed in the copending application of Dyke, Grundhauser and Stunkard, Serial No. 103,796, filed April 18, 1961, and may be the order of 300 to 600 kv. or greater with the current of 1000–2000 amperes or greater and for a time ranging from .1 to .2 microsecond.

Electrons are emitted from the filament wires by both field emission and thermal emission and such electrons travel at extremely high velocity toward the anode and strike the conical surface of the anode. Such electrons form a diffused cloud of electrons traveling at high velocity so that substantially all portions of the conical surface of the anode are struck by such electrons. A high intensity pulse of X-rays is produced and viewing the anode from its smaller end, such electrons are produced from a very small projected area. This provides high resolution of X-ray photographs.

The extremely short pulses of electrical energy at high voltage, which are employed to energize the tube of the present invention, cause electrons to travel at speed approaching the speed of light toward the anode and such electrons strike the anode before such pulse ceases. However, there is not sufficient time for any positive ions which may be produced at the anode to reach the cathode before the pulse ceases. Thus very little material removed from the surface of the anode by electron bombardment travels as far as the cathode structure and most of any of such material passes between the cathode filament wires and is stopped by the shield 50. Such shield therefor not only has a focusing effect causing the electrons to be directed toward the anode but also protects the envelope of the tube against ions or any other particles traveling radially outward from the anode. The heating of the connectors 34 and 36 to a heating and smoothing temperature substantially eliminates any deposition of such particles upon the surfaces of the connectors and substantially eliminates unwanted electron emission from such surfaces to thus eliminate the production of X-rays from other than the conical surface of the anode. The heating current is preferably discontinued immediately after a pulse of X-ray radiation has thus been produced and is again supplied just prior to the production of another pulse of such radiation.

The tube of FIG. 5 is similar to the tube of FIGS. 1 to 4 but has a modified cathode structure 63 and end cap 64. Such cap has an axially projecting portion 68 in which the cathode structure 63 is positioned and which forms a shield for the cathode structure. Such projecting shield 68 has a cathode connector 70 in the form of an annular ring of wire positioned within its end which is remote from the remainder of the cap 64. Such ring is supported in spaced relation to the shield 68 by spaced support portions 72. A similar connector 74 is positioned within the shield 68 at its end adjacent the remainder of the cap 64 and is similar in form to the connectors 34 and 36 of the tube of FIGS. 1 to 4. Such connector 74 has lead and support portions 76 secured to a cathode connector pin 78 extending to the exterior of the tube and supported in and insulated from the cap 64.

The two connectors 70 and 74 have axially spaced annular portions concentric with the shield 68 and with the anode element 30. A plurality of filament wires 80 are secured at their ends to such annular portions and extend axially of the tube to form a cathode cage around the conical anode element 30. Such anode element may be of the same construction as the anode element 30 of the tube of FIGS. 1 to 4. The cap 64 may have another cathode connector pin 82 secured to and connected to such cap so that heating current can flow from such pin through the cap 64 and then through the support portions 72, connector 70, filament wires 80, and connector 74 including support portions 76 to the pin 78. A metallic window 62 is secured to and closes an aperture in the projecting end of the shield 68.

The operation of the tube of FIG. 5 may be entirely similar to that described with respect to the tube of FIGS. 1 to 4. The major difference in tube construction is that the anode 30 is positioned closer to the end wall of the tube having the metallic window 62 substantially transparent to X-rays so that the high intensity of X-rays immediately adjacent the anode can be brought nearer to the object or material being X-rayed or being subjected to X-ray radiation. It will be apparent that the cap 64 may be at ground potential and that the projecting portions 68 of the cap 64 may be inserted into an aperture in an article being X-rayed.

The tube of FIGS. 6 and 7 is similar to the tubes of FIGS. 1 to 5, but the anode 30 and a modified cathode structure 82 are shown as being positioned in a glass envelope having a right angle bend therein so that the connector pins 84 and 86 for the cathode heater circuit can be mounted in a metal cap 88 which is out of the path of the usable X-rays produced by the tube. The cathode structure 82 of the tube of FIGS. 6 and 7 may be very similar to the cathode structure 32 of the tube of FIGS. 1 to 4 and may be supported by connectors 90 and 92 secured to and connected to the connector pins 84 and 86, respectively. The shield 94 may be similar to the shield 50 of FIGS. 1 to 4 and may surround the cathode structure 82 and be supported upon support elements 96 secured to and extending from the cap **88**. A getter element **100** may have one terminal connected to a connector pin **98** and its other end connected to one of the connector pins **84** or **86**.

In the tube of FIGS. 6 and 7, the usable X-rays are projected through the left end of the tube as viewed in FIG. 6 and the anode can be positioned quite close to the wall of the envelope of the tube. The operation of the tube of FIGS. 6 and 7 may be entirely similar to that described with respect to the tubes of FIGS. 1 to 4 and the tube of FIG. 5.

A modified cathode structure **102** of a type usable with any of the tubes described above instead of the cathode structures **32**, **63** or **82**, is shown in FIGS. 8 and 9. Such cathode structure **102** includes a cylindrical grid structure made up of a plurality of conducting portions **104** extending axially of the cylindrical structure and joined together by a plurality of circumferentially extending conductor portions **106** which form intermediate supports for the conducting portions **104**. The ends of the grid structure thus formed are secured to axially spaced connectors **108** and **110** which may be similar in form to the connectors **34** and **36** of the tube of FIGS. 1 to 4. Such connectors may have support portions **112** and **114** projecting radially therefrom so that the cathode structure **102** may be suitably supported in a tube, for example, in the same manner as the cathode structures **32** of FIGS. 1 to 4. It will be apparent that the conductor portions **104** are, in fact, filament wires extending between the connectors **110** and **112** and that the operation of tubes containing the cathode structures of FIGS. 8 and 9 is substantially similar to that of the other tubes described above.

The cathode structure of FIGS. 10 and 11 is similar to that of FIGS. 8 and 9, except that the conductor portions **124** which form the filament wires extend circumferentially of the cathode structure instead of axially thereof. Such conductor portions have their ends connected to connectors **126** and **128** extending longitudinally of the cathode structure. The various conductor portions **124** may have intermediate portions connected together by connector portions **128** so that the cathode structure is in the form of a hollow cylindrical grid surrounding the anode **30**. The connectors **125** and **128** may have lead and support portions **130** and **132** for supporting the cathode structure in a tube and for forming heating current connections for the cathode structure. It will be understood that a shield similar to the shield **50** of the tube of FIGS. 1 to 4 will be positioned around the cathode structures of FIGS. 8 to 11 and that with slight modification, such cathode structures may be employed in tubes of the type shown in FIG. 5 or in FIGS. 6 and 7. The cathode structures of FIGS. 8 and 9 may be made, for example, by photoetching apertures in a tubular metal member having thin walls or in the case of FIGS. 10 and 11, by etching apertures in a thin sheet of metal which is later formed into a slotted tubular member.

The anode elements and also the filament wires and cathode connectors and supports of the various cathode structures described above are preferably made of tungsten although other refractory metals may be employed. The other elements such as the support elements for the anode and cathode structures are also preferably made of tungsten but may be made of various other metals. The caps **24**, **44**, **64** and **88**, which are sealed directly to portions of the glass envelopes of the tubes may be of any suitable alloy having a thermal temperature coefficient of expansion similar to that of the glass employed, and a number of combinations of glass and such alloys are available commercially. The conical anode can be quite small in diameter at its large end, for example, of the order of 50 to 100 mils, and have a small angle between the elements of its conical surface and its axis, for example, of the order of 7°.

While I have disclosed the preferred embodiments of my invention, it is apparent that the invention is not to be limited to details thereof but that the scope of the invention is to be determined by the following claims.

We claim:

1. An X-ray tube comprising:
an evacuated envelope,
an elongated conical anode supported in said envelope,
anode connector means extending to the exterior of said envelope,
a combined field emission and thermal emission cathode structure supported in said envelope and surrounding said anode,
said cathode structure including a plurality of uncoiled filament wires positioned around said anode and spaced from each other and substantially parallel to each other and radially spaced from said anode,
and cathode connector means including electrical connections extending from the opposite ends of said filament wires to the exterior of said envelope to provide for heating said filament wires and causing the emission of electrons from said filament wires by combined field emission and thermal emission.

2. An X-ray tube comprising:
an evacuated envelope,
an elongated conical anode positioned in said envelope,
anode connector and support means providing an electrical connection extending to the exterior of said envelope,
a hollow cylindrical combined field emission and thermal emission cathode structure in said envelope and concentrically surrounding said anode,
said cathode structure including a plurality of uncoiled filament wires positioned around said anode and spaced from each other and substantially parallel to each other and radially spaced from said anode,
cathode connector and support means including electrical connections extending from the opposite ends of said filament wires for connecting said wires in parallel and extending to the exterior of said envelope to provide for heating said filament wires and causing the emission of electrons from said filament wires by combined field emission and thermal emission,
and an elongated hollow cylindrical shield concentrically surrounding and radially spaced from said cathode structure.

3. An X-ray tube comprising:
an evacuated envelope,
an elongated conical anode positioned in said envelope,
anode connector and support means providing an electrical connection extending to the exterior of said envelope,
a combined field emission and thermal emission cathode structure including an elongated circular cage of uncoiled filament wires supported in said envelope and concentrically surrounding said anode,
said filament wires being spaced from each other and substantially parallel to each other and being radially spaced from said anode,
cathode connector means making electrical contact with the opposite ends of said wires for connecting said wires in parallel and extending to the exterior of said envelope to provide for heating said filament wires and causing the emission of electrons from said filament wires by combined field emission and thermal emission,
an elongated hollow circular shield of electrical conducting material concentrically surrounding and radially spaced from said cage,
and means for supporting said shield in said envelope and providing an electrical connection thereto to the exterior of said envelope.

4. An X-ray tube comprising:
an evacuated envelope,
an elongated conical anode supported in said envelope,
anode connector means providing an electrical connection extending to the exterior of said envelope,

said anode and substantially parallel to each other and spaced from said anode and from each other axially of said anode,

a cathode connector means connecting one end of each of said wires together,

a similar cathode connector means connecting the other end of each of said wires together,

said cathode connectors including electrical connections extending to the exterior of said envelope to provide for heating said filament wires and causing the emission of electrons from said filament wires by combined field emission and thermal emission,

an elongated hollow circular shield of conducting material concentrically surrounding and radially spaced from said cathode structure,

and means for supporting said shield in said envelope and providing an electrical connection to said shield from the exterior of said envelope.

11. An X-ray tube comprising:

an evacuated envelope,

an elongated conical anode supported in said envelope,

anode connector means providing an electrical connection extending to the exterior of said envelope,

a cathode structure supported in said envelope and surrounding said anode,

said cathode structure including a plurality of filament wires spaced from each other and substantially parallel to each other and radially spaced from said anode,

a cathode connector means connecting one end of each of said wires together, a similar cathode connector means connecting the other end of each of said wires together,

said cathode connectors providing cathode electrical connections extending from said connectors to the exterior of said envelope, and having portions adjacent said anode which are greater in cross-sectional area than the combined cross-sectional areas of said filament wires and proportioned with respect to said filament wires to provide for heating said portions to a surface cleaning and smoothing temperature below a thermal electron emission temperature when a filament heating current is passed in series through said cathode connector means and said wires in an amount heating said wires to a thermal electron emission temperature.

12. An X-ray tube comprising:

an evacuated envelope,

an elongated conical anode supported in said envelope,

anode connector means providing an electrical connection extending to the exterior of said envelope,

an elongated circular cage of filament wires supported in said envelope and concentrically surrounding said anode,

said filament wires being spaced from each other and substantially parallel to each other and being radially spaced from said anode,

cathode connector means making electrical contact with the opposite ends of said wires and providing electrical connections connecting said wires in parallel and extending to the exterior of said envelope,

and an elongated circular shield concentrically surrounding and radially spaced from said cage,

said cathode connector means having their portions adjacent said anode greater in cross-sectional area than the combined cross-sectional areas of said filament wires and proportioned with respect to said filament wires to provide for heating said portions to a surface cleaning and smoothing temperature below a thermal electron emission temperature when a filament heating current is passed in series through said cathode connector means and said wires in an amount heating said wires to a thermal electron emission temperature.

13. An X-ray tube comprising:

an evacuated envelope,

an elongated conical anode supported in said envelope,

anode connector means providing an electrical connection extending to the exterior of said envelope,

a combined field emission and thermal emission cathode structure supported in said envelope and surrounding said anode,

said cathode structure including a plurality of uncoiled filament wires positioned around said anode and spaced from each other and substantially parallel to each other and radially spaced from said anode,

cathode connectors including electrical connections extending from the opposite ends of said filament wires to the exterior of said envelope to provide for heating said filament wires and causing the emission of electrons from said filament wires by combined field emission and thermal emission,

said anode having its smaller end adjacent and directed toward a wall of said envelope.

14. An X-ray tube comprising:

an evacuated envelope,

an elongated conical anode supported in said envelope,

anode connector means providing an electrical connection extending to the exterior of said envelope,

an elongated circular cage of uncoiled filament wires supported in said envelope and concentrically surrounding said anode,

said filament wires being spaced from each other and substantially parallel to each other and being radially spaced from said anode,

cathode connector means making electrical contact with the opposite ends of said wires and including cathode electrical connections extending to the exterior of said envelope to provide for heating said filament wires and causing the emission of electrons from said filament wires by combined field emission and thermal emission,

and an elongated hollow circular shield concentrically surrounding and radially spaced from said cage,

said anode having its smaller end adjacent and directed toward a wall of said envelope.

15. An X-ray tube comprising:

an evacuated envelope,

a conical anode supported in said envelope,

anode connector means providing an electrical connection extending to the exterior of said envelope,

an elongated circular cage of filament wires supported in said envelope and concentrically surrounding said anode,

said filament wires being spaced from each other and substantially parallel to each other and being radially spaced from said anode.

cathode connector means making electrical contact with the opposite ends of said wires and providing cathode electrical connections extending to the exterior of said envelope,

and an elongated hollow circular shield concentrically surrounding and radially spaced from said cage,

said shield having an end wall and being a part of said envelope and projecting in a direction axially of said shield from the remainder of said envelope,

said anode having its smaller end adjacent and directed toward said end wall.

16. An X-ray tube comprising:

an evacuated envelope,

a conical anode supported in said envelope,

anode connector means providing an electrical connection extending to the exterior of said envelope,

an elongated circular cage of filament wires supported in said envelope and concentrically surrounding said anode,

said filament wires being spaced from each other and substantially parallel to each other and being radially spaced from said anode,

cathode connector means making electrical contact with the opposite ends of said wires and providing cathode electrical connections extending to the exterior of said envelope,

a combined field emission and thermal emission cathode structure supported in said envelope and surrounding said anode,
said cathode structure including a plurality of similar uncoiled filament wires positioned around said anode and spaced from each other and substantially parallel to each other and radially spaced from said anode,
a cathode means connecting one end of each of said wires together, and a similar cathode connector means connecting the other end of each of said wires together,
said cathode connector means including cathode electrical connections extendiing to the exterior of said envelope to provide for heating said filament wires and causing the emission of electrons from said filament wires by combined field emission and thermal emission.

5. An X-ray tube comprising:
an evacuated envelope,
an elongated conical anode supported in said envelope,
anode connector means providing an electrical connection extending to the exterior of said envelope,
a combined field emission and thermal emission cathode structure supported in said envelope and surrounding said anode,
said cathode structure including a plurality of similar filament wires extending axially of said anode and substantially parallel to each other and radially spaced from said anode and spaced from each other circumferentially around said anode,
a cathode connector means connecting one end of each of said wires together,
and a similar cathode connector means connecting the other end of each of said wires together,
said cathode connector means including cathode electrical connections extending to the exterior of said envelope to provide for heating said filament wires and causing the emission of electrons from said filament wires by combined field emission and thermal emission.

6. An X-ray tube comprising:
an evacuated envelope,
an elongated conical anode supported in said envelope,
anode connector means providing an electrical connection extending to the exterior of said envelope,
a combined field emission and thermal emission cathode structure supported in said envelope and surrounding said anode,
said cathode structure including a plurality of similar uncoiled filament wires extending axially of said anode and substantially parallel to each other and radially spaced from said anode and spaced from each other circumferentially around said anode,
reinforcing elements extending circumferentially of said cathode structure and connecting said filament wires together at intermediate points along their lengths,
a cathode connector means connecting one end of each of said wires together,
and a similar cathode connector means connecting the other end of each of said wires together,
said cathode connector means including electrical connections extending to the exterior of said envelope to provide for heating said filament wires and causing the emission of electrons from said filament wires by combined field emission and thermal emission.

7. An X-ray tube comprising:
an evacuated envelope,
an elongated conical anode supported in said envelope,
anode connector means providing an electrical connection extending to the exterior of said envelope,
a combined field emission and thermal emission cathode structure supported in said envelope and surrounding said anode,
said cathode structure including a plurality of similar uncoiled filament wires extending axially of said anode and substantially parallel to each other and radially spaced from said anode and spaced from each other circumferentially around said anode,
a cathode connector means connecting one end of each of said wires together,
a similar cathode connector means connecting the other end of each of said wires together,
said cathode connector means including electrical connections extending to the exterior of said envelope to provide for heating said filament wires and causing the emission of electrons from said filament wires by combined field emission and thermal emission,
an elongated hollow circular shield of conducting material concentrically surrounding and radially spaced from said cathode structure,
and means for supporting said shield in said envelope and providing an electrical connection to said shield from the exterior of said envelope.

8. An X-ray tube comprising:
an evacuated envelope,
an elongated conical anode supported in said envelope,
anode connector means providing an electrical connection extending to the exterior of said envelope,
a combined field emission and thermal emission cathode structure supported in said envelope and surrounding said anode,
said cathode structure including a plurality of similar uncoiled filament wires extending circumferentially around said anode and substantially parallel to each other and spaced from said anode and from each other axially of said anode,
a cathode connector means connecting one end of each of said wires together,
and a similar cathode connector means connecting the other end of each of said wires together,
said cathode connector means including electrical connections extending to the exterior of said envelope to provide for heating said filament wires and causing the emission of electrons from said filament wires by combined field emission and thermal emission.

9. An X-ray tube comprising:
an evacuated envelope,
an elongated conical anode supported in said envelope,
anode connector means providing an electrical connection extending to the exterior of said envelope,
a combined field emission and thermal emission cathode structure supported in said envelope and surrounding said anode,
said cathode structure including a plurality of similar uncoiled filament wires extending circumferentially around said anode and substantially parallel to each other and spaced from said anode and from each other axially of said anode,
reinforcing elements extending axially of said cathode structure and connecting said filament wires together at intermediate points along their lengths,
a cathode connector means connecting one end of each of said wires together,
and a similar cathode connector means connecting the other end of each of said wires together,
said cathode connector means including electrical connections extending to the exterior of said envelope to provide for heating said filament wires and causing the emission of electrons from said filament wires by combined field emission and thermal emission.

10. An X-ray tube comprising:
an evacuated envelope,
an elongated conical anode supported in said envelope,
anode connector means providing an electrical connection extending to the exterior of said envelope,
a combined field emission and thermal emission cathode structure supported in said envelope and surrounding said anode,
said cathode structure including a plurality of uncoiled filament wires extending circumferentially around

and an elongated hollow circular shield means concentrically surrounding and radially spaced from said cage,

said shield means having an end wall and being a part of said envelope and projecting in a direction axially of said shield from the remainder of said envelope,

said shield means forming a part of said cathode connector means and providing part of the electrical connection to one end of said wires,

said anode having its smaller end adjacent and directed toward said end wall.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,283,203 November 1, 1966

Walter P. Dyke et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 4, line 51, for "projector" read -- project --; column 9, line 27, before "filament" insert -- uncoiled --.

Signed and sealed this 5th day of September 1967.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents