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[54] **FIELD EMISSION X-RAY TUBE HAVING A GRAPHITE FABRIC CATHODE**

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[52] **U.S. Cl.** **313/55;** 313/55; 313/309; 313/336; 313/351

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

[58] **Field of Search** 313/55, 56, 58, 309, 336, 313/351

[56] **References Cited**

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[57] **ABSTRACT**

Several field emission diode x-ray tubes, each having a graphite fabric cathode mounted in a spaced, insulated relationship with respect to an anode are described herein. The different tubes illustrate various shaped cathodes. The tubes are pulse type x-ray generators. A burst of x-ray is generated by transmitting a high potential pulse of electrical energy, generally on the order of 100 to 300 kilovolts to the x-ray tube. This high potential causes electrons to be emitted from the cathode and strike the anode with sufficient energy to generate x-rays. The fabric cathode is woven from carbon graphite threads. Each of the threads forming the fabric is formed from a large number of thin carbon graphite filaments. The high electric potential supplied to the tube during operation causes the ends of the filaments to fray or spread so that each of the individual filaments acts as an electron emitter.

1 Claim, 7 Drawing Figures

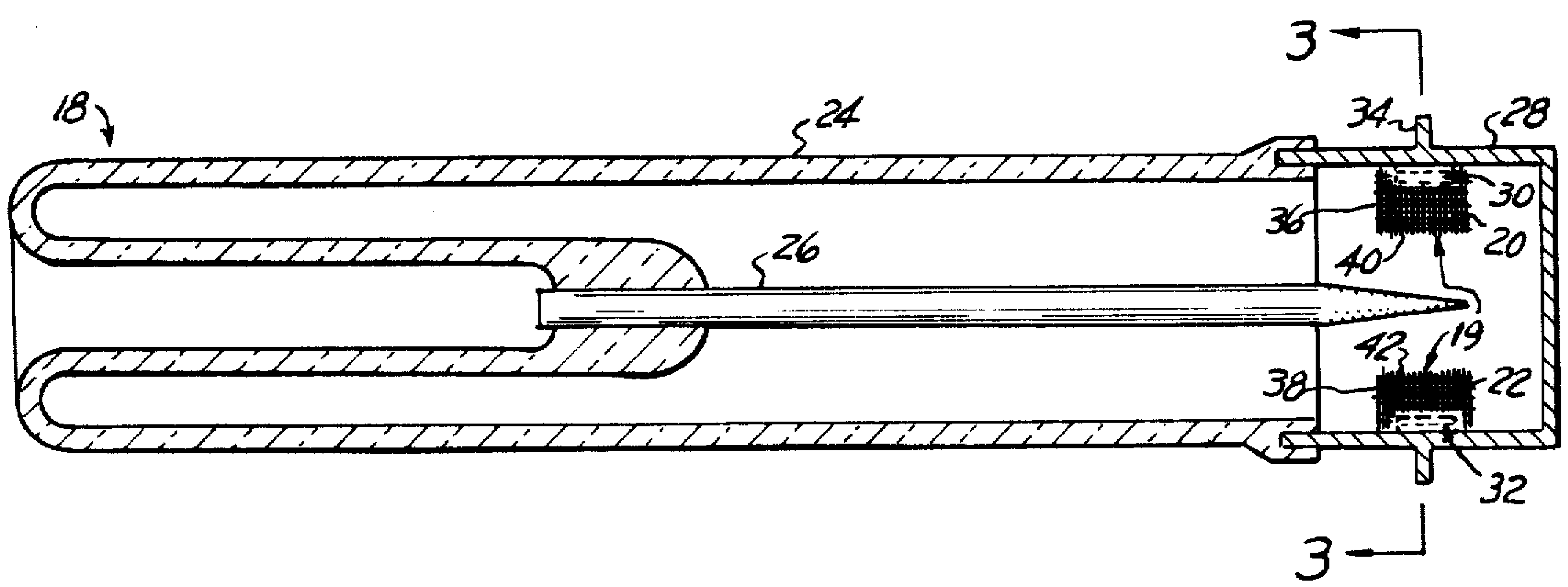


FIG. 1

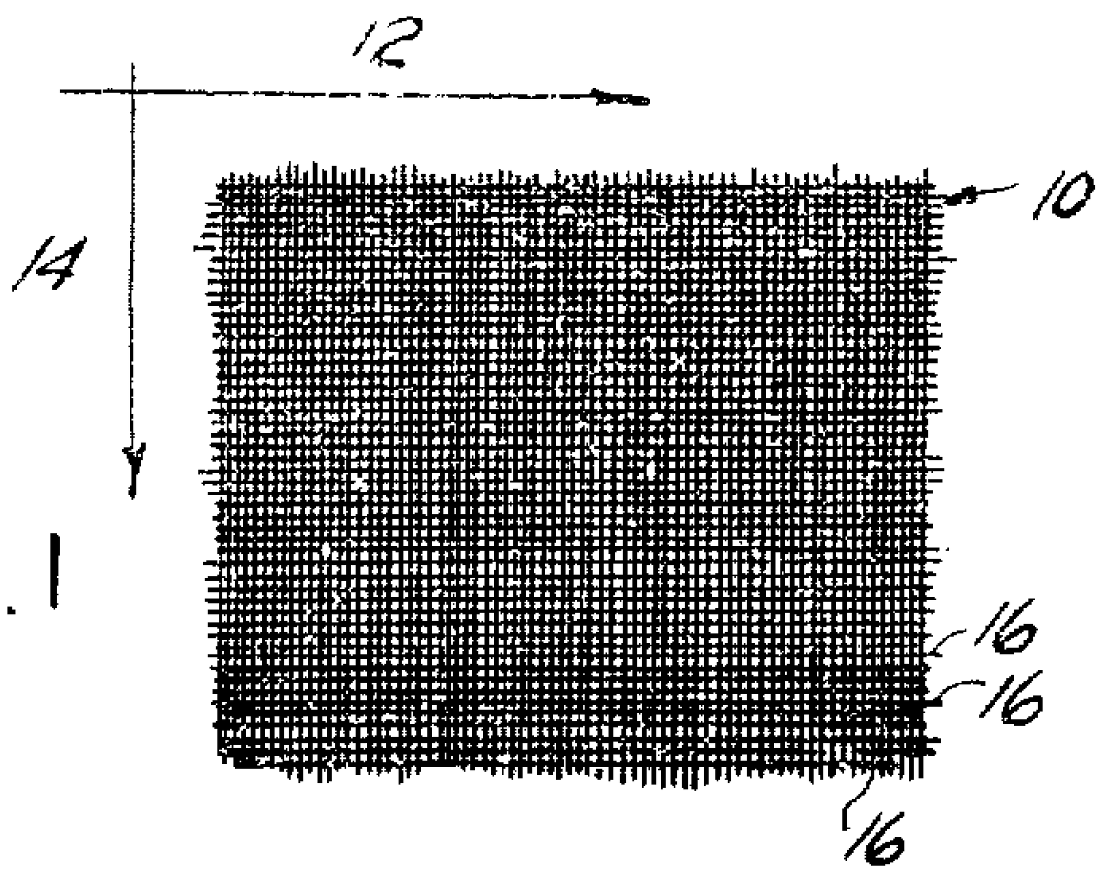


FIG. 3

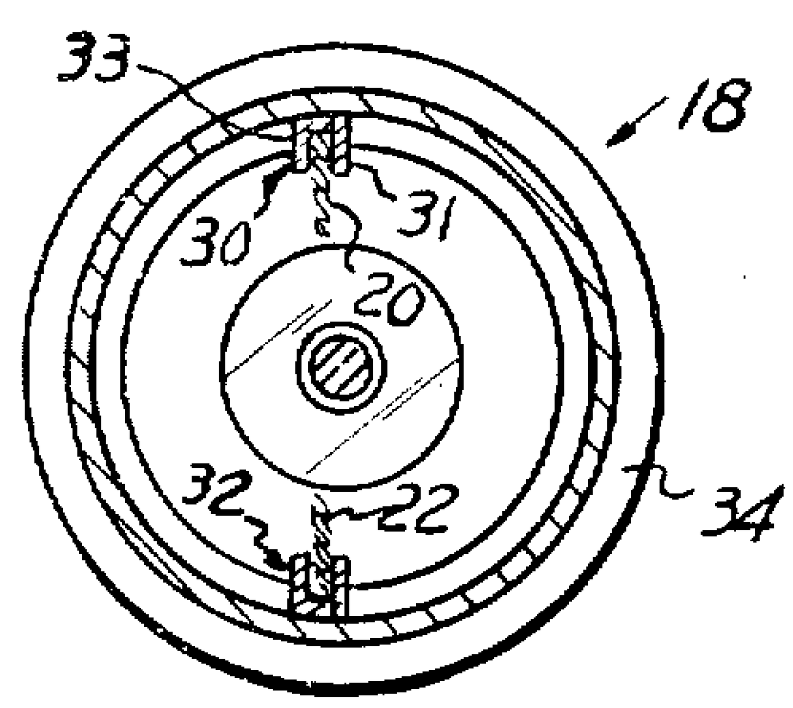


FIG. 2

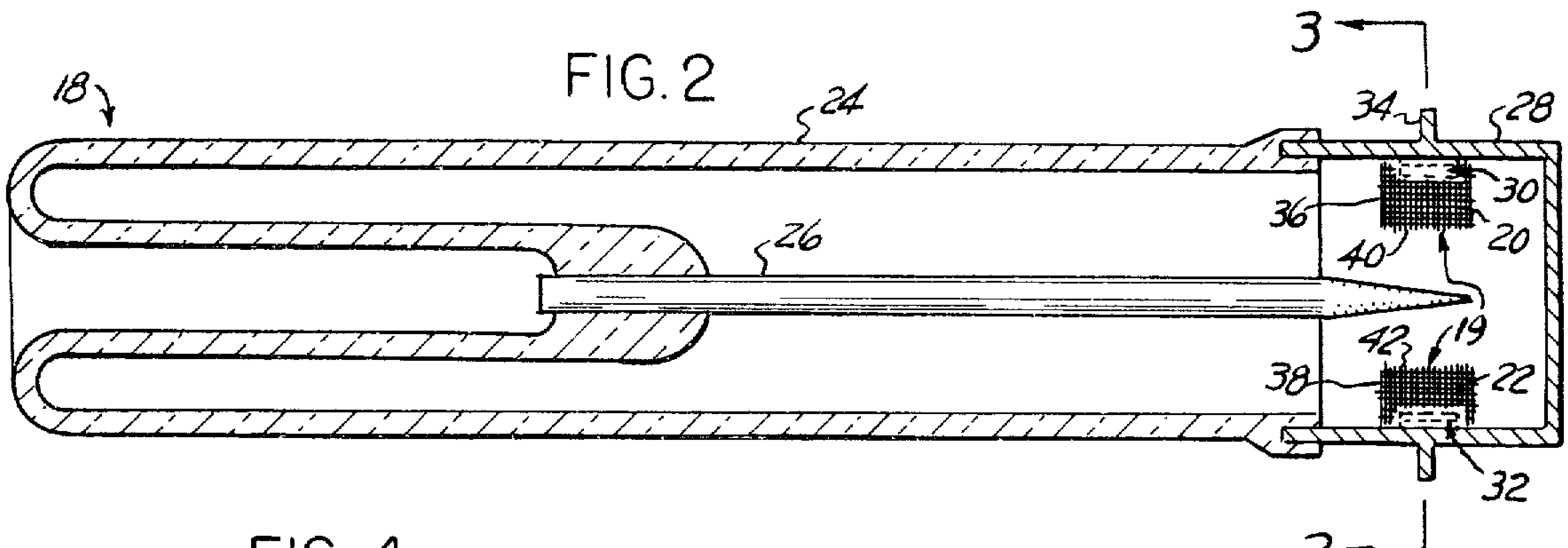


FIG. 4

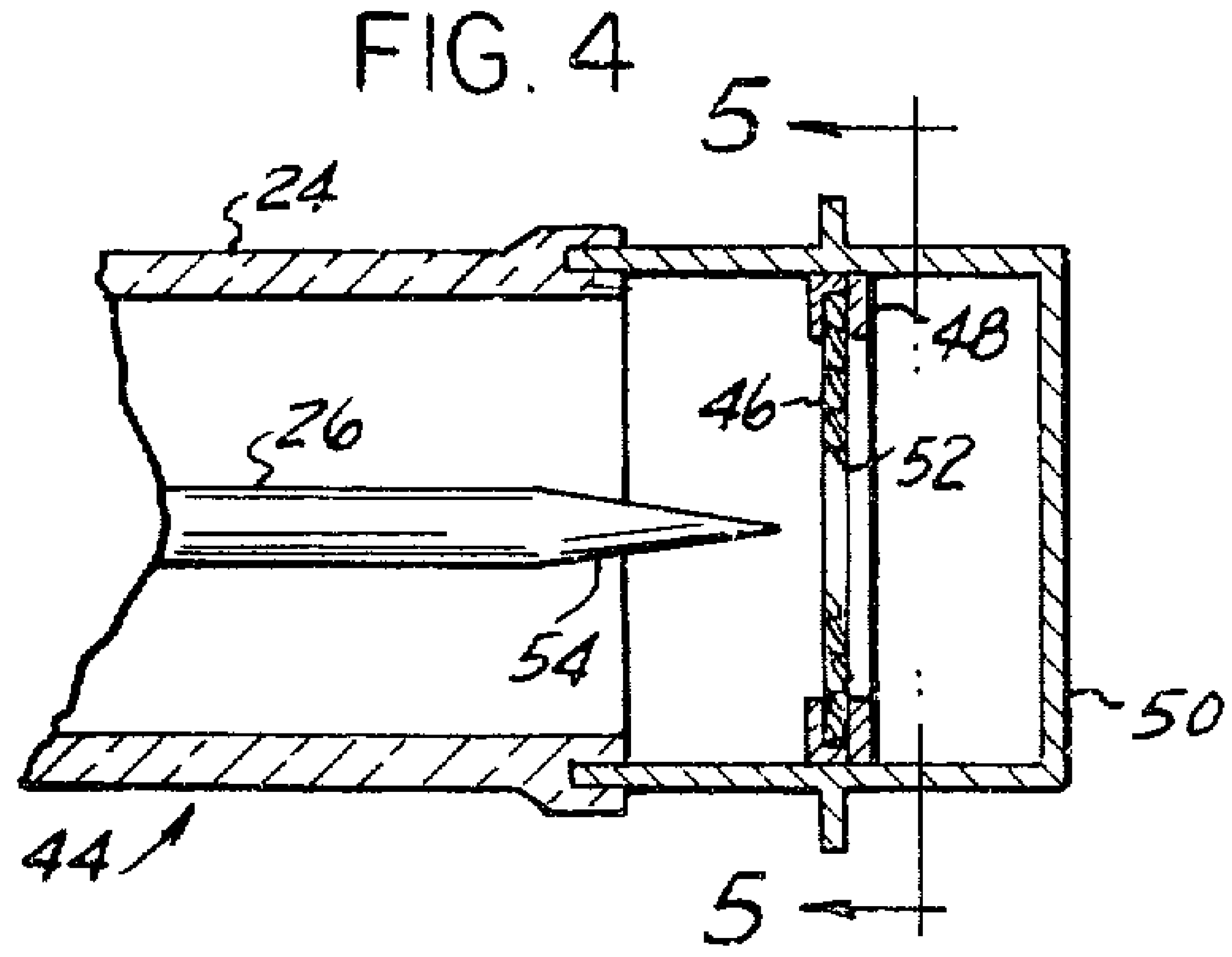


FIG. 5

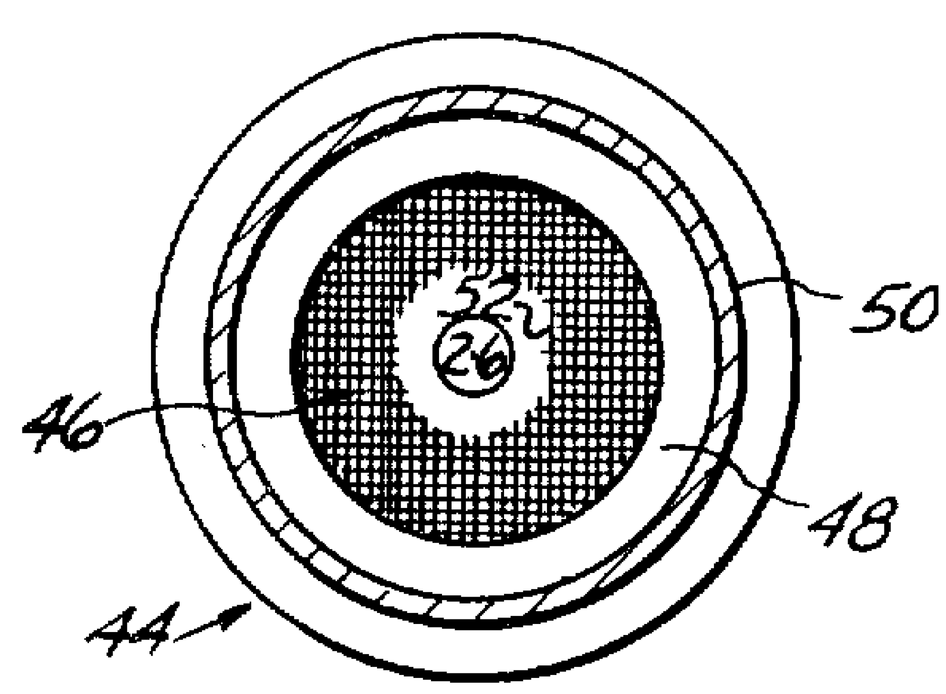


FIG. 6

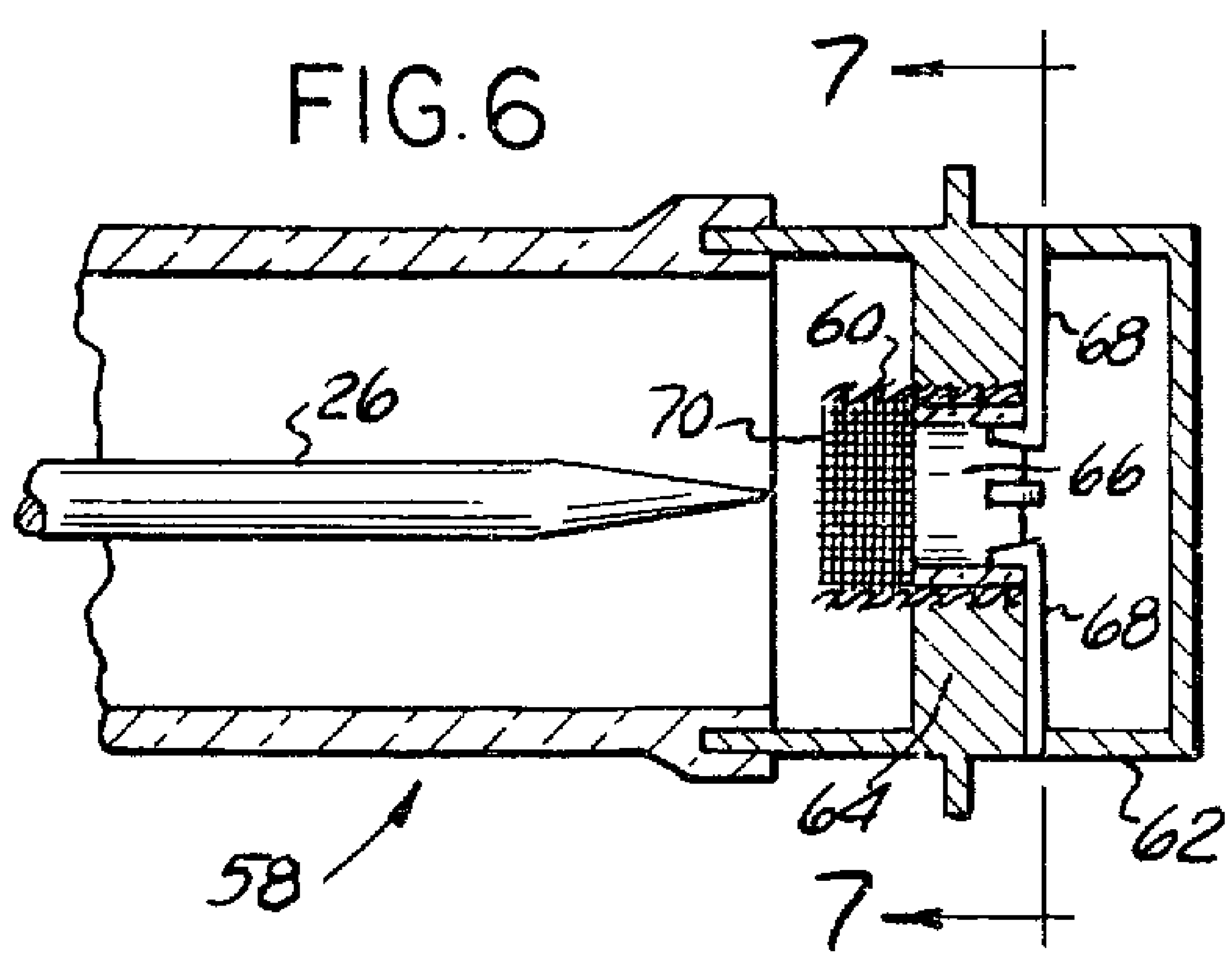
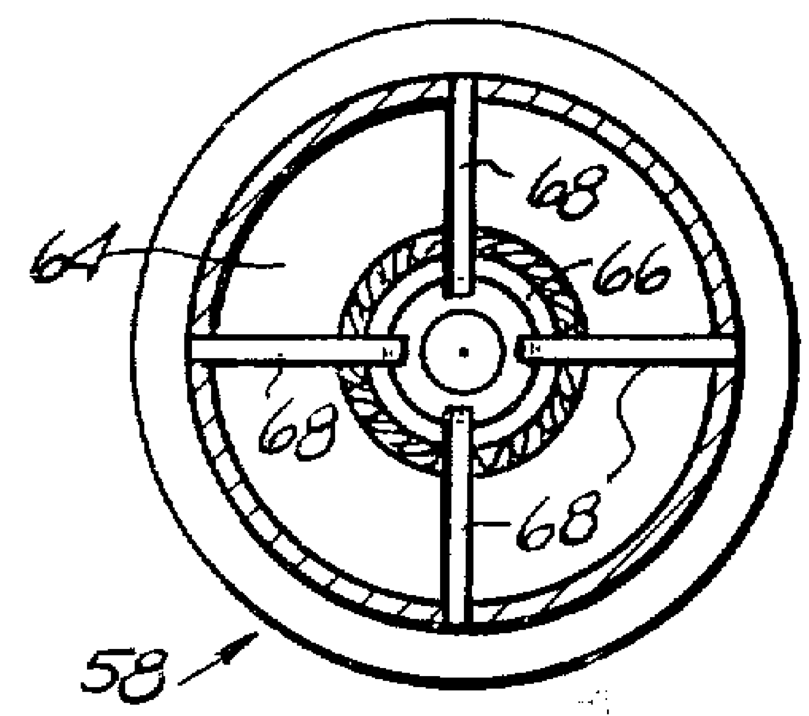


FIG. 7



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FIELD EMISSION X-RAY TUBE HAVING A GRAPHITE FABRIC CATHODE

BACKGROUND OF THE INVENTION

1. Field of the Invention

X-ray technology.

2. Brief Description of the Prior Art

Prior art field emission x-ray tubes, which are sometimes called cold-cathode x-ray tubes, have cathodes comprising a plurality of sharpened blades or a plurality of arrays of sharpened needles. It is very difficult to construct these blade-type and needle array-type cathodes because various dimensions of the cathodes are believed to be critical. For example, it is believed that the electron emitting blade edges and needle points must be very precisely formed to have a radius of curvature between 10^{-3}cm to 10^{-5}cm. It is believed that if a more pointed needle or blade cathode having a smaller radius of curvature is used, the dynamic impedance of the x-ray tube will be lowered, making it impossible to maintain a sufficiently high potential between the anode and cathode to cause electrons to strike the anode with sufficient energy to generate x-rays with enough penetrating power to be useful. Conversely, it is believed that if more rounded blades or needles having larger radii of curvature are provided, the dynamic impedance of the tube will be so increased that the electric potential supplied to the tube will very likely arc over across the outside of the tube instead of causing electrons to flow from the cathode to the anode of the x-ray tube and generate x-rays. This higher arcing voltage could also break through the insulation surrounding the tube and be dangerous to anyone in the vicinity of the tube.

Field emission type x-ray tubes require such a high potential during operation, generally between 100 and 1,000 kilovolts, that a portion of the cathode is vaporized each time an electric potential pulse is supplied to the x-ray tube. The portions of the blade and needle cathodes leading to the electron emitting edges and tips of those cathodes are formed with a 7 percent taper so that the desired radius of curvature will be maintained as portions of the cathode are vaporized. The cathodes are quite small. For example, the cathode needles have a shank diameter of 0.002 inches. It is obviously difficult to construct an element of this size to have exactly a predetermined taper. And even though the needles are provided with exactly a predetermined taper, the life of these field emission type x-ray tubes is relatively short because the needles are changed by local metal during operation. The needle point cathodes have a relatively small number of individual needles so that the high potential supplied to the x-ray tubes during operation creates an extremely high current density in the limited number of available needle points. This high current density melts those needle points and thus limits the life of the tube.

In spite of these drawbacks, it is generally agreed in the art that needle array cathodes are superior to the blade type cathodes. It is believed necessary to precisely control the spacing between the various needles of such a cathode in order to obtain a uniform electric field between the anode and cathode during the initial stages of the generation of a burst of x-rays, and to thereafter create a localized vacuum arc between a few needles of the cathode and the anode. It is believed necessary to provide a localized vacuum arc in order to maintain exactly a preselected impedance across the x-ray tube during generation of x-rays so that the x-rays produced will have exactly the desired energy and penetrating power. The needles are so thin, and are spaced so close together, generally from 0.005 inches to 0.01 inches apart, that it is difficult to provide exactly a desired spacing.

The cathodes now used for field emission type x-ray tubes are formed by intricate and painstaking mechanical grinding, chemical etching, and electrolytic etching processes in which a piece of material is reduced to the proper shape and size, or by a crystal growth process in which a solution containing the material from which the cathode is to be formed is brought into contact with an agent that causes the material to be deposited from the solution in a manner that creates needle-like forms. The construction of the types of cathodes presently used in field emission x-ray tubes, satisfying all of the above-discussed requirements, is thus extremely complex, time consuming, and costly.

SUMMARY OF THE INVENTION

The subject invention comprises an improved and extremely effective cathode that is very easy to construct. The cathode comprises one or more pieces of fabric having a high melting point, a high electrical conductivity, and sublimation temperature, or in other words a low electrical resistivity, and a high tensile strength. The invention also comprises an improved field emission type x-ray tube having this fabric cathode mounted in an insulated, spaced relationship with respect to an anode. The particular fabric illustrated herein is a graphite fabric. The fabric is woven from a large number of individual threads, which are in turn formed from a large number of individual filaments. During operation of the x-ray tube, a high potential electric pulse is supplied to the x-ray tube. This pulse establishes a large potential difference between the anode and the cathode and causes electrons to be emitted from the cathode. These electrons flow to and strike the anode to cause x-rays having a predetermined energy to be emitted from the anode. This large potential difference also causes the ends of the filaments to spread so that each filament can act as an electron emitter. The field emission type x-ray tube illustrated herein has an extremely long operating life because the fabric cathodes have an extremely large number of individual filaments. Each of these filaments can act as an electron emitter during operation of the tubes. Therefore, each fabric filament will thus not be subjected to a current of as high a density as that supplied to each needle of the prior art needle cathodes each time that the tube is operated. In addition, the tube has a long operating life because the fabric has a high melting point and sublimation temperature and thus resists deformation or erosion during operation. The fabric cathode provides a large number of electrons during operation because it has a low electrical resistivity and a large number of filaments. The tube, therefore, supplies a high density x-radiation output which produces clear x-ray pictures. The high tensile strength of the fabric prevents the high electric potential supplied to the x-ray tube during operation causing the cathode to break apart during operation. That is, the large potential difference maintained between the anode and cathode of the x-ray tube acts to repel the various filaments of the fabric cathode from each other and to attract those filaments toward the anode. The fabric must have a high tensile strength in order to resist the force provided by this potential difference.

Three different x-ray tubes having cathodes formed from graphite fabric cut to various shapes are illustrated herein. Each of the graphite fabric cathodes are mounted so that one edge of the fabric is spaced from the anode of the x-ray tube. Electrons are emitted from along this edge and flow to the anode when a large potential difference is provided between the anode and the cathode. The spacing between this edge of the cathode and the anode, the potential difference to be maintained between the anode and cathode, and the energy of the x-rays produced by the tube, is similar to that of prior art field emission x-ray tubes having blade and needle array cathodes.

BRIEF DESCRIPTION OF THE DRAWINGS

Further objects, features and advantages of the subject 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** illustrates the graphite fabric used to form the cathodes of the various x-ray tubes illustrated herein;

FIG. **2** is a plan, cutaway view of a field emission x-ray tube having a rod shaped anode and a cathode comprising a plurality of fabric pieces spaced from the anode and mounted so that the fabric pieces extend longitudinally along the axis of the anode;

FIG. **3** is a plan view of the x-ray tube of FIG. **2** cutaway along the plane defined by the lines **3—3**;

FIG. **4** is a plan, cutaway view of an x-ray tube having a ring shaped graphite fabric cathode mounted slightly in front of a pointed rod anode;

FIG. **5** is a plan view of the x-ray tube of FIG. **4** cutaway along the plane defined by line **5—5**;

FIG. **6** is a plan, cutaway view of an x-ray tube having a cylindrical graphite fabric cathode that is concentric with the axis of a pointed rod anode; and

FIG. **7** is a plan view of the x-ray tube of FIG. **6** cutaway along the plane defined by line **6—6.**

DETAILED DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a piece **10** of the graphite fabric used to form the cathodes in the three x-ray tubes illustrated in the remaining six drawings. Graphite fabric is an example of a strong fabric having a high sublimation temperature and a low electrical resistivity. Graphite has a sublimation temperature range of 3652°C to 3697°C, an electrical resistivity of 8×10^{-4} ohm-cm, and filament tensile strengths of 50,000 to 100,000 psi. Various grades of graphite fabric having a warp -- the density of parallel threads running in direction **12** -- between **20** and **50** threads per inch, and a fill -- the density of parallel threads running in a second direction **14** and crossing the warp threads -- between **20** and **50** threads per inch are commercially available, and have been found to make effective cathodes. Each of the threads **16** of the fabric piece **10** are formed from a large number of individual filaments. The various above-described grades of commercially available graphite fabric have between 480 and 1,440 filaments forming each thread. The individual filaments have a diameter of 0.0003 or 0.0004 inches in readily available grades of graphite fabric. During operation of a field emission x-ray tube, a high potential difference is maintained between the tube anode and cathode. This high potential causes the ends of the filaments to fray or spread so that each filament can act as an electron emitter. A cathode formed from a graphite fabric thus has an enormous number of individual electron emitting elements. For example, the lowest grade fabric described above having the fewest potential electron emitting elements would have a warp and fill of 24 threads per inch. Each thread would be formed from 480 individual filaments. And the fabric would thus have over 11,500 potential electron emitting elements per inch along each of its edges.

A graphite fabric cathode can be constructed far more easily than can the prior art cathodes. A piece of fabric is first woven from rayon threads. The fabric is then heated in an inert or oxygen-free atmosphere to change the rayon to amorphous carbon. The carbonized cloth is then heated in an inert or oxygen-free atmosphere to a higher temperature to convert the amorphous carbon to graphite carbon.

FIGS. **2** and **3** illustrate two views of an x-ray tube **18** that is similar to present field emission type x-ray tubes except for the cathode **19** which is formed from two pieces **20** and **22** of graphite fabric. The x-ray tube **18** includes a glass envelope **24**, an anode **26** which comprises a pointed tungsten rod, and a cylinder **28** formed from a suitable metal such as nickel having a high electrical conductivity and a high x-radiation absorption coefficient encircling the x-ray emitting portion of the anode. The cylinder **28** will have a window (not shown) formed from a material transparent to x-rays such as berylium in the front thereof to facilitate the emission of x-rays in a desired direction. Cylinder **28** includes two rectangular conductive clamp elements **30** and **32** that hold the fabric cathode pieces **20** and **22**, respectively. Each clamp comprises two parts **31** and **33** formed from an appropriate conductive metal such as nickel. The clamp parts are spot-welded or otherwise bonded together, and are shaped so that the fabric cathodes are held between the clamped parts when the parts are so bonded. The clamps are spot-welded or otherwise bonded to the metallic cylinder **28** of the x-ray tube **18.** An electrically conductive path between the fabric cathode **19** and any circuit for providing an electric potential difference across the tube **18** is provided by the elements **30** and **32**, cylinder **28**, and an electrically conductive annular flange **34.**

The relative dimensions of the graphite fabric pieces **20** and **22**, the spacing between those pieces and the anode **26**, and the magnitude of the electric potential to be provided across the x-ray tube **18** during operation determine the energy and penetrating power of the x-radiation produced. X-ray tubes having larger spacings between the anode and cathode and thus larger tube impedances, and those receiving larger electric potential pulses during operation will produce higher energy x-radiation having greater penetrating power than those with smaller anodes-cathodes spacing and receiving smaller electric potential pulses. In a typical embodiment, such as an x-ray tube designed to operate receiving an electric potential pulse between **100** and 300 kilovolts, the fabric cathode pieces **20** and **22** would have a length of about 0.20 inches along edges **36** and **38**, respectively. The distance between edges **40** and **42** of those cathode pieces and the anode **26** would be about 0.5 inch.

In operation, x-rays are produced by supplying either a large positive electric potential to the anode **26** or a large negative electric potential to the cathode pieces **20** and **22** in order to create a large potential difference between the anode and the cathode of the x-ray tube. This potential difference causes electrons to be emitted from the individual filaments of the fabric cathode. These emitted electrons flow to and strike the anode with sufficient velocity to generate x-rays. It is found that well controlled pulses of x-rays having predictable and predetermined energies and penetrating power are obtained from the x-ray tube **18.** The tube **18** also has a long life span. Since the filaments are so thin that they are not required to be formed with a tapered end portion, and since they extend completely through the cathode, slow erosion of the cathode during operation of the tube will not change the cross-sectional shape of the filaments, and will thus not affect the performance of the x-ray tube until such time that an extremely large portion of the cathode has been eroded. The tube also has a long operating life because the individual threads disposed generally perpendicular to the anode **26** will act as electron emitters even after they have been eroded sufficiently so that there are threads running parallel to the anode between the anode and the ends of those eroded threads. The energy and penetrating power of x-radiation produced by voltage pulses of the same magnitude also remains substantially constant during the life of this tube.

FIGS. **4** and **5** illustrate a second x-ray tube **44** that differs from the x-ray tube **18** in that the cathode comprises a washer-shaped graphite fabric ring **46** mounted slightly in front of the tip of anode **26.** The washer-shaped cathode **46** is held by an annular clamp **48** that is clamped to cylinder **50** of the x-ray tube **44.** In operation, electrons are emitted from the graphite filaments defining the inside edge **52** of the cathode washer **46.** These emitted electrons strike all points on the tapered portion **54** of anode **26.** However, since the tip of that anode is closest to the cathode, a very large number of emitted electrons strike the anode tip. A large portion of the x-rays emitted by x-ray tube **44** are therefore emitted from the tip of anode **26.** Even though some x-rays are emitted from other portions of the anode **26,** a substantial portion of the x-radiation emitted by tube **44** is emitted from a small source that approaches a point source. A small x-ray source provides very high resolution x-ray pictures. This is because an x-ray picture is a shadow picture. With a large radiation source, radiation from one portion of the source can partially obscure or irradiate an edge portion of a shadow provided by radiation from another portion of the source. This is not possible with a small source or a point source since all radiation emanates from the same point. The x-ray tube **44** thus provides a high resolution picture.

FIGS. **6** and **7** illustrate a third x-ray tube **58** having a graphite fabric cathode **60** that is concentric with the axis of the anode **26** and is also mounted slightly in front of that anode. The structure for holding cathode **60** in place includes a metallic cylinder **62** having a wide annular flange **64** that encircles and contacts the outside of the fabric cathode cylinder **60,** and a wide conductive ring **66** that fits inside of the cathode cylinder **60.** Four bent metal pieces **68** clamp ring **66** against flange **64** and thus hold graphite fabric **60** firmly between those two elements.

In operation, electrons are emitted from the edge **70** of graphite cylinder **60.** X-ray tube **58** provides a well defined cone of x-radiation. A large number of the electrons emitted from cathode **60** strike the tip of anode **26** and produce a well-defined cone of x-radiation. In addition, the wide metallic flange section **64** absorbs x-radiation and thus reduces the number of x-rays propagating in directions diverging sharply from the axis of the x-ray tube.

Having thus described several embodiments of the invention, a number of modifications will be obvious to those skilled in the art. For a first example of such a modification, graphite fabric cathodes can be formed from grades of graphite cloth having either fewer or more filaments per inch than the particular grades described above. The fabrics used in the illustrated embodiments were selected simply because those grades are readily commercially available, and because they do act as effective cathodes. For example, graphite fabric having filament diameters between 0.0001 and 0.0016 inches, and fabric having filaments having as few as 200 individual filaments are available and can be used to form cathodes. Second, cathodes can be formed from fabrics other than graphite fabric having a high resistance to temperature, a high tensile strength, and a low electrical resistivity. Third, the cathodes need not be exactly as shown in the three embodiments. For example, an x-ray tube similar to tube **18** can have more than two fabric elements. In a tube similar to either **44** or **58,** the cathode can be mounted along side the anode and need not be mounted in front of it. And cathodes can be used having shapes other than the particular shapes illustrated. And fourth, the use of fabric cathodes need not be limited to the x-ray art. Fabric cathodes such as those described herein may be used in various microwave applications, in field emission electron-projection microscopes, and in any other system having a high vacuum space surrounding an electron emitting fabric electrode and requiring a high electric potential, on the order of **100** kilovolts or greater, to be maintained between the fabric electrode and another element of the system

What is claimed is:

1. In a field emission x-ray tube requiring a large electric potential in order to provide x-rays and having an evacuated envelope with an anode mounted within said envelope, the improvement comprising:

a field emission cathode formed from a woven fabric, said fabric having a predetermined number of threads disposed in a first direction and having free ends for emitting electrons, a second predetermined number of threads disposed in a second direction, said second number of threads crossing and supporting said electron emitting threads;

said fabric also having a sufficiently high resistivity to temperature to resist erosion by melting and sublimation during operation of the field emission x-ray tube, a sufficiently high tensile strength to resist being pulled apart by the large electric potential required by the field emission x-ray tube during operation, and a sufficiently low electric resistivity to provide a predetermined large number of electrons in response to said large electric potential;

said electrons being accelerated by said large electric potential to strike said anode and provide a predetermined number of x-rays;

said fabric cathode being mounted within said envelope in a spaced, insulated relationship with respect to said anode;

said anode comprising a pointed rod; and

said fabric cathode comprising a washer-shaped annulus defining a plane spaced from said anode, said spacing causing a large portion of the electrons

emitted from said cathode during operation of the x-ray tube to strike the tip of said anode and thereby causing a large portion of the x-radiation emitted by said x-ray tube to be emitted from substantially the same position.

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