

[54] **FIELD EMISSION X-RAY TUBE**
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[58] Field of Search **313/55, 59, 336**

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[57] **ABSTRACT**

A miniature X-ray tube with D.C. power supply and a cold cathode field emission electron beam for continuous or steady state X-ray output. A tube a few centimeters in length with a needle cathode along the axis of the tube and with an exit window at the end behind the cathode for optimum X-ray output.

6 Claims, 3 Drawing Figures

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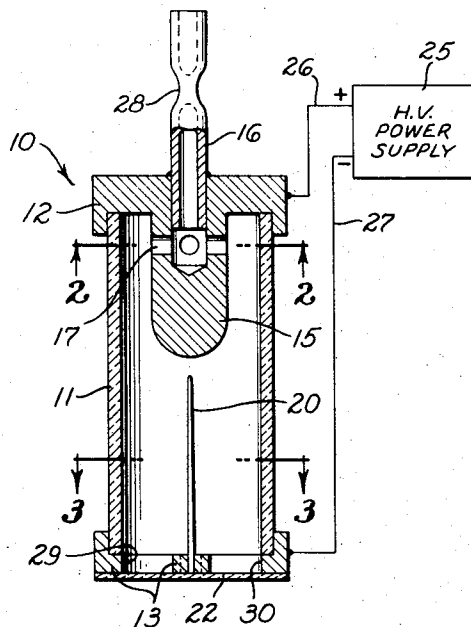


Fig. 1.

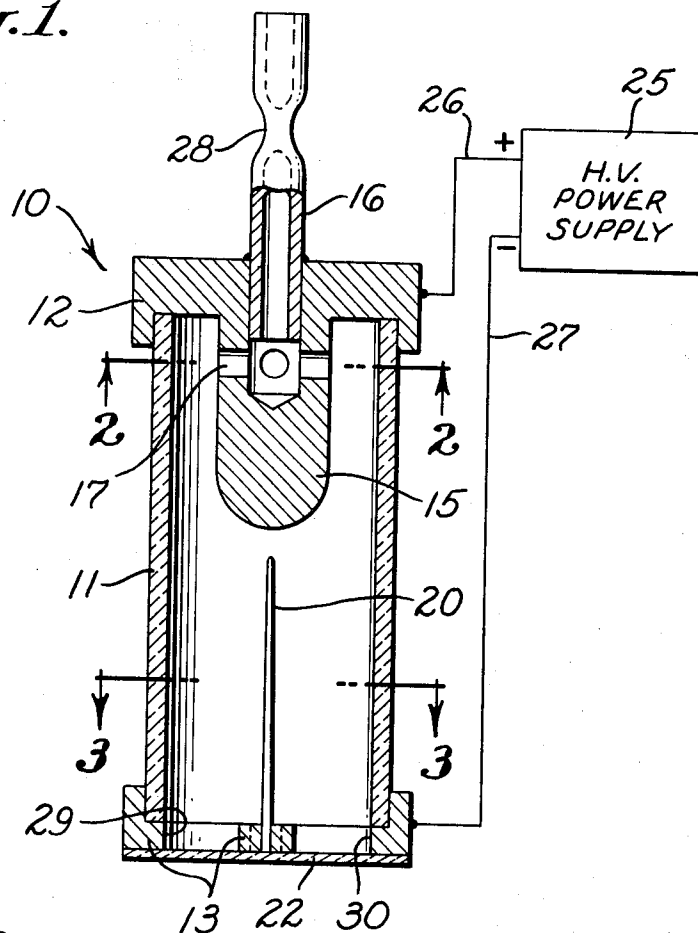


Fig. 2.

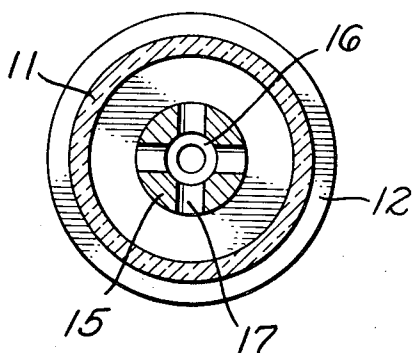
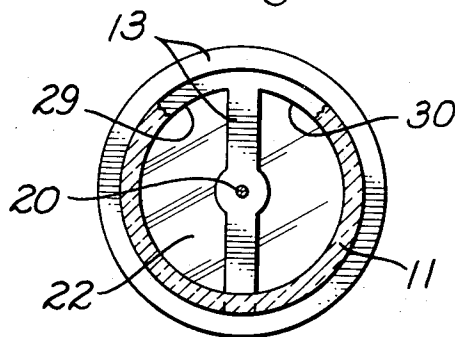


Fig. 3.



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FIELD EMISSION X-RAY TUBE

This invention relates to X-ray tubes and in particular to steady state field emission tubes which provide continuous output with low power requirements and high efficiency and which can be provided in very small sizes.

The X-ray tube in common use utilizes a heated cathode to provide an electron beam directed toward an anode to generate the X-rays. Typically the cathode comprises a filament in the form of a coil of tungsten wire and is energized from a low voltage AC source which produces resistive heating and an electron beam by thermionic emission. A substantial amount of electrical power is required to heat the cathode and the resultant tube and associated power supply are large and cumbersome and expensive, usually weighing hundreds of pounds and costing thousands of dollars.

An electron beam may be produced between a cathode and an anode by field emission, that is, by emission of electrons from an unheated, pointed metal cathode due to an intense electric field in the vicinity of the cathode. Some field emission X-ray machines are presently known for producing intense, fast pulses of X-rays. Such machines utilize large banks of capacitors which are charged to high voltage from a DC source, with the capacitors then being discharged across the electrodes of the tube to provide a single burst of X-rays. These pulse type field emission machines with their capacitors are also large, cumbersome, and expensive, typically weighing many hundreds of pounds and costing tens of thousands of dollars and substantially filling a room.

The X-ray tube of the present invention utilizes a high voltage power supply connected across the electrodes to provide a field emission electron beam and a continuous X-ray output. This instrument provides a number of significant advantages over the presently known equipment. The efficiency is very high as most of the electrical power delivered to the tube is converted into X-rays, since a cold cathode is utilized. Also, operation with a cold cathode results in no deposit of cathode material on the anode. The simplicity of tube design and efficient power utilization permit miniaturization of the system, with the tube being a few centimeters long and with the tube and power supply requiring a very small volume, typically in the order of 50 cubic inches, weighing about 2 pounds and selling for less than a thousand dollars. The instrument is quite small and is readily operated from batteries, thereby making it readily portable.

The instrument has relatively high radiation output in terms of electrical power consumption, has a very small anode focal spot, and permits fabricating the anode from various metals to provide different characteristic X-ray outputs.

Other objects, advantages and results will more fully appear in the course of the following description. The drawing merely shows and the description merely describes a preferred embodiment of the present invention which is given by way of illustration or example.

In the drawing:

FIG. 1 is a longitudinal sectional view of an X-ray tube incorporating the preferred embodiment of the invention;

FIG. 2 is a sectional view taken along the line 2—2 of FIG. 1; and

FIG. 3 is a sectional view taken along the line 3—3 of FIG. 1.

In the preferred embodiment, a housing 10 is formed of a glass tube 11 with an anode end ring or anode holder 12 and a cathode end ring or cathode holder 13. An anode 15 preferably is formed as part of the ring 12 and projects into the tube 11. A plurality of openings 17 in the anode communicate with the interior of a hollow stem 16 and provide a passageway for evacuation of the interior of the tube. A needle-shaped cathode 20 is supported at the center of the end ring 13. The end of the tube is closed by a window 22 formed of a material which passes X-rays, typically beryllium.

A DC power supply 25 is connected to the anode and cathode, as by conductors 26, 27. The power supply provides a high voltage for producing a high intensity electric field in the vicinity of the cathode. The voltage desirably should be variable, permitting variation of the X-ray intensity. While a well regulated DC power supply is preferred, an AC supply can be used. The output intensity would be less since X-rays are produced only when the anode is at a high positive voltage with respect to the cathode. Operation at 60Hz. would provide the desired continuous X-ray output.

The cathode end ring 13 typically may be of brass and the cathode 20 typically may be a conventional nickel-plated steel sewing needle pressed into an opening in the center of the holder 13. The anode 15 may be made of any metal, although metals which are easily machined and plated are preferred. Copper and aluminum are presently being used. The stem 16 may be pressed into the end ring 12, the parts may be soldered or welded together, or the parts may be made as a single piece, if desired. The tube 11, end rings 12, 13, and window 22 may be assembled using a vacuum compatible epoxy. The glass tube 11 provides electrical insulation between the anode and cathode.

The assembled housing may be evacuated following conventional techniques and typically is evacuated to a pressure of about 10^{-7} Torr and the stem 16 is sealed at 28. Conventional gettering material may be used if desired. The cathode end ring 13 provides a support for the window 22 and the openings 29, 30 in the cathode end ring define the X-ray beam from the tube.

The X-ray tube may be made quite small and one unit assembled as illustrated in the drawing is 5.5 centimeters long over the end rings with an outside diameter of 2.54 centimeters. The end of the anode 15 preferably is hemispherical and in this embodiment has a radius of 0.64 centimeters. The tip of the cathode needle has a radius approximately 0.03 millimeters. The window 22 is formed of beryllium in the order of 0.025 to 0.05 mm thick.

Electrode spacing is determined by the desired operating voltage and beam current, with the X-ray intensity being a function of the applied voltage. The electrode spacing is in the order of a few millimeters and preferably in the range of 0.2 to 2 mm. The applied voltage preferably is in the range of about 10 kv to 30 kv.

In an instrument manufactured as shown in the drawing, with a copper anode, and a space of 1.5 mm between the electrodes, an applied voltage of 25 kv DC produces a beam current of about 20 microamperes, indicating anode-cathode impedance to be in excess of one million ohms. Moving the electrodes closer

together would provide the same current with a lower voltage. With 25 kv dc applied, the X-ray intensity measured 30 cm from the window 22 is 100 mR/h. Increasing the voltage to 30 kv dc increases the X-ray intensity to 1,000 mR/h. The power consumption is less than 1 watt, with little heating, thereby eliminating the requirement for anode cooling. Analysis of cathode shadows observed in radiographs utilizing the tube indicate that the effective diameter of the radiation source is 0.1 mm or less. The shape of the X-ray spectrum as measured with a Si(Li) spectrometer shows the typical bremsstrahlung spectrum cutting off at 25 keV with intense Cu K_{α} and K_{β} lines at 8.0 keV and 8.9 keV respectively.

The electron beam trajectories between cathode and anode are parallel with the axis of the tube 11 and the housing construction permits locating the outlet window 22 behind the cathode and perpendicular to the trajectories. This results in a more efficient utilization of X-rays than in the conventional design where the exit window is located at the side of the housing parallel to the trajectories. Exiting X-rays traverse less anode material in the present design.

The X-ray tube illustrated and described above is extremely small, light and simple in design. It has low power consumption and high efficiency and does not have any heat dissipation problems, since it is a cold cathode device. The power supply requirements are low resulting in an inexpensive, reliable, small and portable unit.

In operation, a high voltage is connected across the anode and cathode, producing a field emission electron beam from the tip of the cathode to the anode. Impingement of electrons on the anode produce X-rays which exit through the window 22 providing the desired output of the tube.

Although an exemplary embodiment of the invention has been disclosed and discussed, it will be understood that other applications of the invention are possible and that the embodiment disclosed may be subjected to various changes, modifications and substitutions without necessarily departing from the spirit of the invention.

I claim:

1. In a tube for continuously producing X-rays by

field emission, the combination of:

a housing;
 an anode mounted in said housing;
 an unheated cathode mounted in said housing and spaced and electrically insulated from said anode;
 an X-ray transmitting window in said housing; and
 a high voltage DC electric power supply connected across said anode and cathode for producing by field emission, a continuous stream of electrons from said cathode to said anode producing a continuous X-ray output through said window, with the electrical impedance across said anode and cathode in excess of 1,000,000 ohms.

2. An X-ray tube as defined in claim 1 in which said housing includes an insulating tube, an anode support ring at one end of said tube and a cathode support ring at the other end of said tube,

with said anode having a generally hemispherical end and carried in said anode support ring along the axis of said tube, and

with said cathode being needle shaped and carried in said cathode support ring along the axis of said insulating tube with the needle tip pointing to and spaced from the anode end.

3. An X-ray tube as defined in claim 1 in which the anode-cathode spacing is in the order of 0.2 to 2 mm. and with an anode-cathode potential in the order of 10-30 kv.

4. An X-ray tube as defined in claim 1 in which said housing is generally tubular in configuration and in the order of a few centimeters in length, and in which the anode-cathode spacing is in the order of a millimeter.

5. An X-ray tube as defined in claim 4 with said anode carried at one end and said cathode carried at the other end of said tubular housing with the electron beam from cathode to anode parallel with the longitudinal axis of said housing, and with said window disposed at said other end of said housing generally perpendicular to said axis.

6. An X-ray tube as defined in claim 5 in which said anode has a convex end, said cathode is needle shaped and pointing toward said anode end, and including a bracket at said housing other end supporting said cathode centrally of said window.

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