June 23, 1964 | B. L. HENKE | 3,138,729

ULTRA-SOFT X-RAY SOURCE

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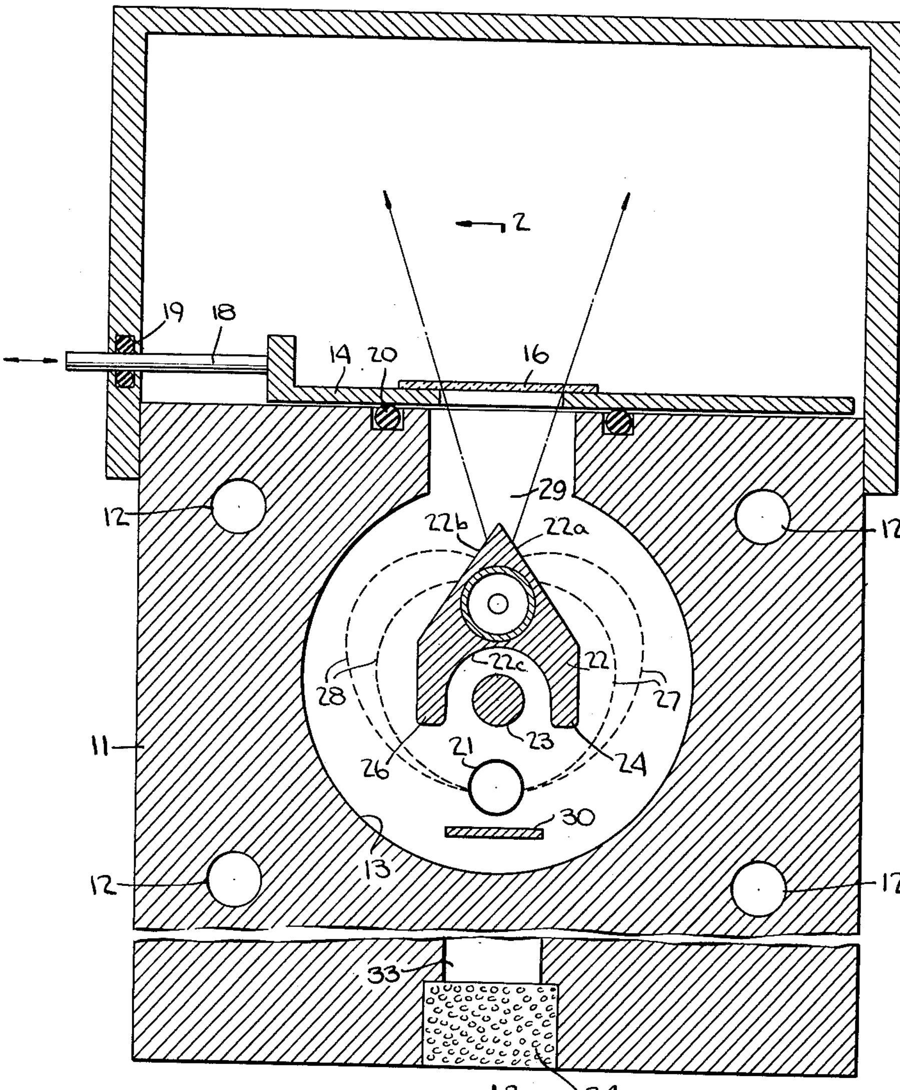

Fig. 1.

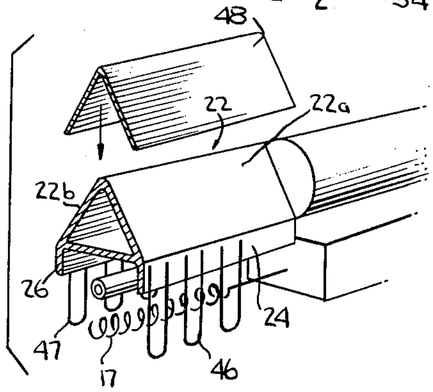

Fig. 3.

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3 Sheets-Sheet 2

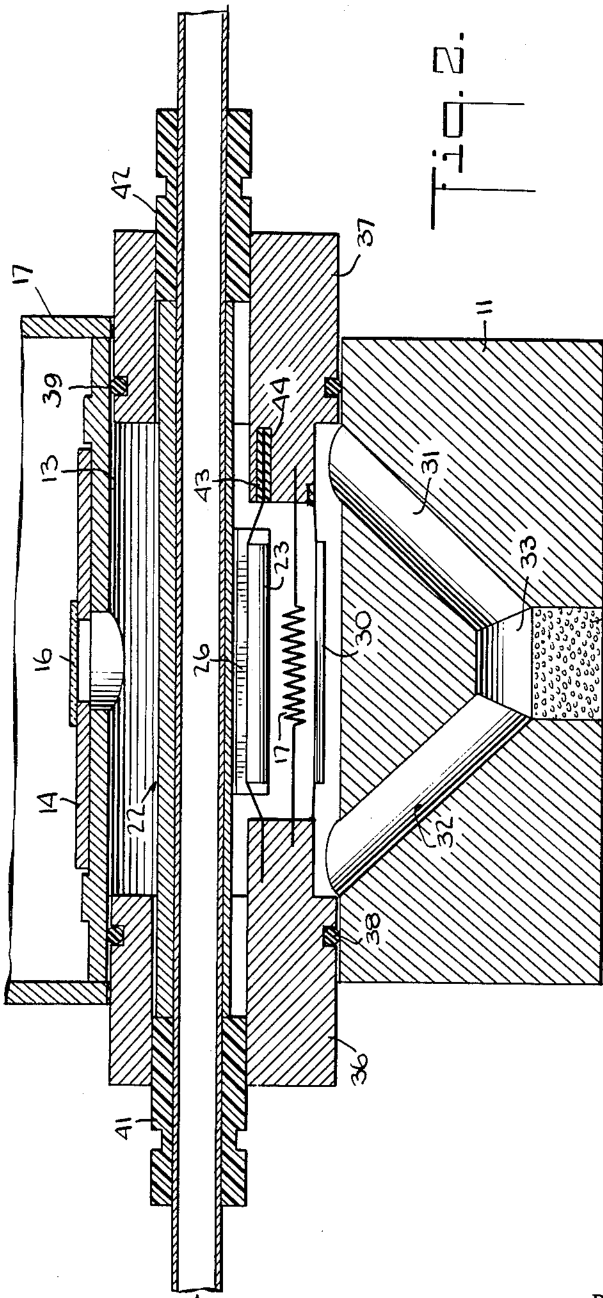

Fig. 2.

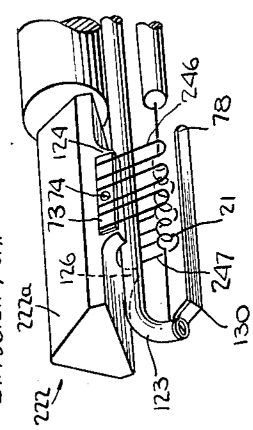

Fig. 5.

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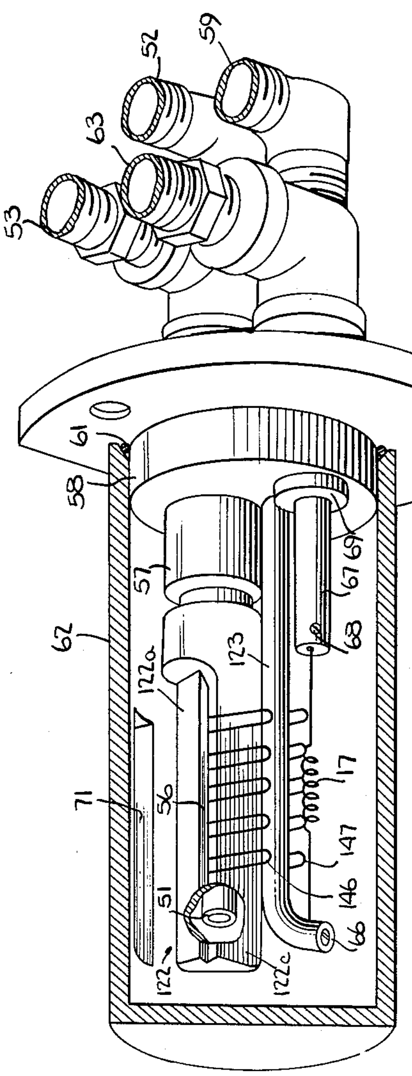

FIG. 4.

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ULTRA-SOFT X-RAY SOURCE

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This invention relates to an X-ray generator capable of producing so-called ultra-soft X-rays, which are X-rays having wave lengths of between about 10 and 200 Angstroms.

While normal high-voltage X-ray tubes produce some X-radiation at very long wave lengths, most of the radiation produced by such tubes has much shorter wave lengths and the long wave length X-radiation that is produced is absorbed by the windows of the usual X-ray tube. Another problem which arises when an attempt is made to produce long wave length X-rays is the difficulty of avoiding spurious results due to carbonaceous deposits and deposits of vaporized cathode material on the anode surface. Such deposits are particularly objectionable because of the fact that long wave length X-rays are produced by electron beams accelerated with rather low anode voltages. The beams, therefore, do not penetrate the target anode to any great extent, but instead cause the emission of X-rays from the outermost surface of the target and hence from such material as happens to be deposited on that surface.

One of the objects of the present invention is to provide an improved X-ray tube capable of generating relatively long wave length X-rays with good efficiency. In addition, it is an object of the invention to provide a demountable X-ray tube which is relatively free from carbonaceous deposit contamination and tungsten deposit contamination on the anode and in which the X-ray beam has a relatively large exit angular breadth. Additional objects will be apparent from the following specification together with the drawings.

The X-ray tube of the present invention comprises a hollow, metal member having a cylindrical cavity. A filamentary cathode and an anode are located within the cavity, and both extend parallel to the axis of the cavity. The target surface of the anode faces away from the cathode, and electrons are directed to the target surface by a deflection field between the anode and the inner wall of the cavity, and in order to prevent electrons from traveling directly from the cathode to the undersurface of the anode, a barrier electrode in the form of a conductive member electrically connected to a voltage source at or close to the cathode voltage level is placed between the filament and the anode. One or more electron-permeable screens or grids may be attached to the anode to draw electrons from the cathode and into the deflection field. The anode may be water cooled to permit operation at higher anode currents, and separate target members or layers having different X-ray emission characteristics may be placed on the target surface, if desired. X-rays emitted from the target anode pass out of the cylindrical cavity through an opening adjacent to the target anode.

The invention will be described in greater detail in connection with the drawings, in which:

FIG. 1 shows a simplified cross-sectional view of an X-ray source constructed according to the invention;

FIG. 2 shows a cross-sectional side view of the tube in FIG. 1;

FIG. 3 shows a perspective view of a section of the electron beam-forming elements of the tube of FIG. 1;

FIG. 4 shows a modified form of the tube of FIG. 1; and

FIG. 5 shows an improved grid arrangement for the tube of FIG. 4.

The tube of FIG. 1 comprises a metal block **11** shown in cross section. The block may be water-cooled by means of water circulating through channels **12** formed in the block, and it is provided with a cylindrical cavity having an inner wall **13**. A removable plate **14** supports a thin window **16** which is preferably less than one micron thick so as to permit even those ultra-soft X-rays which would be absorbed by ordinary windows to escape.

The space above the plate **14** is enclosed by a vacuum-tight cover **17** to form an upper chamber which may be opened to permit specimens to be changed. When the X-ray tube is in use, the upper chamber is evacuated, and although it may not be evacuated to the same high vacuum as the space within the cylindrical cavity **13** of the tube, nevertheless the vacuum in the upper chamber is sufficient to prevent any great pressure from being exerted upon the thin window **16**.

The plate **14** also acts as a vacuum isolation gate and may be slid back and forth by means of a rod **18** that extends through the wall of the cover **17**. The opening in the wall through which the rod **18** extends is closed off by an O-ring **19** to prevent air from getting into the upper chamber. Another O-ring **20** seals off the highly evacuated cylindrical cavity **13** from the less highly evacuated upper chamber enclosed by the cover **17**.

Within the cylindrical cavity **13** in the block **11** is a cathode **21** in the form of a helical filament of electron-emissive wire, such as, for example, tungsten. The helix extends in a direction parallel to the axis of the cylindrical cavity **13** but is displaced therefrom. Furthermore, at least one point of the filament **21** is electrically connected to the block **11** so that both operate at substantially a common voltage level.

Directly above the filament **21** is an anode **22** which also extends parallel to the axis of the cylindrical wall **13**. The anode **22** may be formed in any convenient way, such as by flattening parts of the surface of a hollow tube or by machining an elongated metal bar into the proper shape. The shape of the anode **22** is such that it has at least one target surface facing away from the cathode, and the embodiment of FIG. 1 has two target surfaces **22***a* and **22***b* which face generally upwardly and away from the filament **21** while the third surface **22***c* is directly above the filament **21**. The anode **22** is electrically insulated from the block **11** and from the filament **21** so as to operate at a voltage which is positive with respect to the filament.

A barrier electrode **23**, which is electrically connected to the filament **21** and to the block **11** to operate at approximately the same voltage, effectively shields the lower surface **22***c* of the anode from receiving direct electron bombardment from the filament **21**. Such a barrier electrode is likely to cause space charge limiting of the anode current, and in order to prevent this a pair of skirts **24** and **26** extend downwardly from the anode **22** alongside the filament **21** to attract electrons from the filament and to give the electrons an initial impetus toward the wall **13**.

The paths followed by the electrons from the filament **21** are indicated by reference characters **27** and **28**. As may be seen, these paths are initially directed from the filament **21** toward the closest points of high potential, namely, the adjacent portions of the skirts **24** and **26**. However, the location and configuration of the anode **22** and skirts **24** and **26** causes the latter to intercept very few electrons, thus permitting most of the electrons to enter the space between the skirts **24** and **26** and the cylindrical wall **13**. At this point electrostatic deflection of the electrons takes place; the electrons are repelled by the wall **13** and are attracted by the anode **22** and the skirts 24 and 26. As a result, the electron beams 27 and 28 follow the curved paths shown and strike the upwardly facing surfaces 22*a* and 22*b* of the anode 22. One of the advantages of this arrangement is that it keeps tungsten particles, which boil off of the filament 21, from flying directly to the target surfaces 22*a* and 22*b* of the anode. By keeping these target surfaces free of tungsten deposits, the X-ray emission characteristics of these surfaces may be better controlled.

X-rays are emitted from the target surfaces 22*a* and 22*b* of the anode, and those X-rays which travel upwardly at the proper angle pass out of the generator by way of the window 16 as indicated by the diverging X-ray beam 29. The electron beams may be focused more precisely on the surfaces 22*a* and 22*b* by means of a focusing electrode 30.

FIG. 2 shows a cross-sectional view of the X-ray generator of FIG. 1. The block 11 is provided with passageways 31 and 32 which connect opposite ends of the cylindrical cavity 13 to a common channel 33 in which is located a filter 34, which may be a molecular sieve, such as a charcoal filter, or a refrigerated trap. The channel 33 is also connected to a vacuum pump (not shown) which produces a high vacuum of the order of about 10^{-6} to 10^{-5} mm. of pressure, or less, within the cylindrical cavity 13. The arrangement of the channels 31 and 32 keeps the filter 34 out of the line of sight from the cavity 13 while still permitting the filter to capture foreign mater including carbonaceous material from the vacuum pump.

The filament 21 and the anode 22 are mechanically connected together in a unit comprising two metal end plugs 36 and 37 which close up the opposite ends of the cylindrical cavity 13, the final sealing being accomplished by a pair of O-rings 38 and 39, respectively. The O-rings also space the plugs slightly away from the block 11 to permit the necessary heater voltage to be connected across the filamentary cathode 21 by merely attaching battery or transformer terminals to the plugs 36 and 37. The anode 22 which is hollow is supported within the end plugs 36 and 37 by a pair of insulating plugs 41 and 42 of a suitable material such as Teflon which has the required insulating property as well as the ability to stand up under heat developed in the anode 22 by electron bombardment. The plugs 41 and 42 are sealed vacuum-tight to the plugs 36 and 37 and to the anode 22. The electrode 23, which serves as a barrier between the filament 21 and the under-side of the anode 22, is mechanically connected to both of the end plugs 36 and 37 but is insulated from the plug 37 by layers 43 and 44 of insulation.

FIG. 3 shows a perspective view of the electrodes within the cylindrical cavity 13. In FIG. 3 the triangular form of the anode 22 is obtained by suitably deforming a previously cylindrical metal tube. To the skirts 24 and 26 are attached rows of hairpin-shaped, relatively fine wire grids 46 and 47, respectively, to extend downwardly from the edges of the anode 22. The purpose of the wire grids 46 and 47 is to provide a more direct accelerating field than is provided by the skirts 24 and 26 to draw off electrons from the filament 21 and to prevent the establishment of a space charge when the anode 22 is operated at voltages only a few hundred volts positive with respect to the filament 21. As may be seen, the wire grids 46 and 47 would intercept relatively few electrons emitted by the filament 21 so that the current flowing to these grids would not be sufficient to heat them up very much.

In order to otbain different characteristic X-rays from the target surfaces 22*a* and 22*b* of the anode 22, the tubing of which the anode 22 is formed, may be selected to cause the target portions to emit a desired type of X-radiation. However, it is not always possible to form an anode out of certain types of materials and still retain the necessary conductivity and strength characteristics. Therefore, I have found it desirable to provide V-shaped target plates of the type indicated by reference character 48 to fit over and to rest upon the target surfaces 22*a* and 22*b*. These plates may be made of materials which would be unsuitable for the anode 22, itself, and since the electrons do not penetrate deeply, the X-rays generated would be only those characteristic of the material out of which the plate 48 is formed.

More or less monochromatic characteristic X-radiation, which is relatively much more intense than the associated white radiation for the low voltage generators, may be obtained by using suitable materials for the target plate 48. Some target materials which have been found to be useful and the characteristic wave lengths emitted by these materials are as follows: Cu–L(13.3 A.), Fe–L(17.6 A.), Cr–L(21.7 A.), O–K(23.7 A.), Ti–L(27.4 A.) and C–K(44 A.).

It is not necessary to use a separate target plate in each instance. For example, the Cr–L radiation may be obtained by chrome-plating the anode 22. O–K radiation may be obtained by oxidizing the anode surface. C–K radiation may be obtained by painting the target surfaces 22*a* and 22*b* of the anode with a colloidal graphite.

In the latter instance, carbonaceous contamination does not affect the essential character of the target surfaces and so the temperature of the anode is of relatively little importance and the anode may be cooled as much as possible. Alternatively, because of the very high melting point of graphite, and provided that a suitable high melting point material is used for the anode 22, high anode dissipation may be obtained without water-cooling but depending simply upon radiation-cooling alone.

FIG. 4 shows a single-ended X-ray tube similar to that of FIGS. 1 and 2 but with all connections both electrical and for water cooling made to one end of the structure. The anode 122 is a hollow member machined out of a solid block which remains closed at one end, as shown. The under-surface of this block is indicated by reference character 122*c* and one of the target surfaces is indicated by reference character 122*b*, but the other target surface is not shown in this figure. A portion of the anode 122 is shown broken away to illustrate the hollow interior thereof and the interior water supply pipe 51 which carries cooling water into the anode from an external nipple 52 and releases it near the closed end of the anode so that the water can flow back outside of the pipe 51 but within the anode to an exit pipe 53.

The anode 122 is machined so as to have a pair of recesses at opposite sides of the bottom surface 122*c* of which only the recess 56 appears in this figure. These recesses serve to permit the edges of V-shaped plates, similar to the plate 48 shown in FIG. 3, to be clamped in place so as to be held securely while the grids 146 and 147 are secured by being welded to the walls of these recesses.

The anode 122 is supported by means of an insulating cylinder 57 within a metal base 58 which is provided with a hollow channel (not shown) to which cooling water is supplied by means of a pipe 59. The purpose of providing a water-cooled channel in the base 58 is to keep the base sufficiently cool to avoid ruining the resilient O-ring 61 that acts as a seal between the base 58 and a closed metal cylinder 62 that takes the place of the cylindrical cavity 13 of FIG. 1. After the water has circulated around within the base 58, it is withdrawn through an exhaust pipe 63.

The shielding electrode 123 is also supported in the base 58 and it serves both as a shielding member to keep electrons emitted by the filament 21 from striking the under-surface 122*c* directly and as a connector and support for one end of the filament 21. For the latter purpose, one end of the filament is threaded through a small hole near the end of the electrode 123 and is secured in place by a set screw 66. The other end of the filament 21 is threaded into a hole in a rod 67 and is secured by means of a set screw **68**. The rod **67** is supported in the base **58** but is insulated therefrom by a bushing **69**.

Electrically the single-ended tube of FIG. 4 operates in the same way as the double-ended structure of FIG. 2, with electrons from the filament **21** following curved paths to strike the target surfaces **122***a* and **122***b* of the anode **122**. X-rays generated when the electrons strike these surfaces leave the cylinder **62** by way of a slot **71**. A thin window (not shown) similar to the window **16** of FIG. 1 may be provided to cover and to seal off the slot **71**.

In order to eliminate contamination in the form of carbonaceous compounds having extremely low vapor pressure on the target surfaces **122***a* and **122***b* of the anode **122**, it has been found desirable to operate the X-ray generator with anode surfaces at temperatures of several hundred degrees centigrade. The anode **122** may be maintained at elevated temperatures by limiting the amount of conduction cooling so that for a given range in anode power dissipated the temperature of the anode is held at a figure between atbout 300° C. and the melting point of the particular target material.

FIG. 5 shows a modified electrode assembly for the tube of FIG. 4. The anode **222** of FIG. 5 is formed with a pair of skirts **124** and **126** between which the barrier electrode **123** extends. In this embodiment the grids **246** and **247** are attached to individual plates, of which the plate **73** is shown, and these plates are, in turn, affixed to the sides of the anode by means of screws so that the grids can be replaced. In FIG. 5 the plate **73** is attached to the skirt **124** by means of a machine screw **74**. A further modification, which is also shown in the embodiment of FIG. 1, is an additional focusing electrode **130** which is mechanically and electrically attached to the barrier electrode **123** to cooperate with the latter in defining the electron beam paths from the filament **21** to the target surfaces of the anode.

While this invention has been described in terms of specific embodiments, it will be understood by those skilled in the art that modifications may be made therein without departing from the true scope of the invention as defined by the following claims.

What is claimed is:

1. An ultra-soft X-ray source comprising an evacuated envelope, a window in said envelope for the passage of ultra-soft X-rays, an anode, a cathode on the side of the anode remote from the window, a barrier electrode positioned between the cathode and anode for focusing an electron beam onto the side of the anode facing window, and a space-charge elimination electrode positioned between the cathode and the anode and partially surrounding said barrier electrode.

2. An ultra-soft X-ray source comprising: a generally cylindrical chamber having a conductive cylindrical wall; an elongated filamentary cathode extending substantially parallel to the axis of said chamber; an elongated anode extending generally parallel to the axis of said chamber and having at least one X-ray emissive surface facing away from said cathode; an opening in the wall of said cylinder adjacent to said X-ray emissive surface of said anode; a barrier electrode extending generally parallel to the axis of said chamber between said cathode and said anode to prevent electrons from passing along straight lines from said cathode to said anode; and electrode means extending from said anode adjacent to said barrier electrode to draw electrons from said cathode into the space between said anode and said cylindrical wall, said cylindrical wall being operated at a voltage which is negative with respect to said anode to cooperate with said anode in deflecting electrons to said X-ray emissive surface.

3. The X-ray source of claim 2 in which one end of said cathode is electrically connected to said cylindrical wall.

4. The X-ray source of claim 2 in which said anode

is hollow, said source comprising in addition liquid cooling pipe means connected to said anode to carry liquid coolant into and out of said anode.

5. The X-ray source of claim 4 in which said pipe means extends straight through said anode and said anode extends straight through said cylindrical chamber.

6. The X-ray source of claim 4 in which one end of said anode is closed and said anode includes a hollow pipe extending inwardly from the other end and said liquid cooling pipe means includes a pipe connected to said hollow pipe and a separate pipe connected to the space between said hollow pipe and said anode.

7. An ultra-soft X-ray source comprising: a generally cylindrical chamber having a conductive end wall and a conductive cylindrical wall, the other end wall of said chamber being open; an electrode support structure extending into said other end of said chamber; electrodes supported thereon, said electrodes including a filamentary cathode extending substantially parallel to the axis of said chamber, an anode extending substantially parallel to the axis of said chamber and having at least one X-ray emissive surface facing away from said cathode, a barrier electrode connected electrically to said cathode to operate at substantially the same voltage and extending substantially parallel to the axis of said chamber between said cathode and said anode to prevent electrons from passing directly from said cathode to said anode, and space-charge elimination means electrically connected to said anode to operate at the same electric voltage and extending physically adjacent to said barrier electrode to provide an electric field cooperating with said cathode to draw electrodes therefrom into the space between said anode and said cylindrical wall, said cylindrical wall being electrically connected to said cathode to operate at substantially the same voltage to cooperate with said anode in deflecting said electrons from said cathode to said surface of said anode; and a window in said cylindrical wall adjacent to said surface of said anode to permit ultra-soft X-rays to pass therethrough.

8. The X-ray source of claim 7 in which said barrier electrode also comprises support means for one end of said cathode.

9. The X-ray source of claim 7 in which said surface of said anode comprises two portions angularly disposed with respect to each other and each substantially equidistant from said cathode.

10. The X-ray source of claim 7 in which said space-charge elimination means comprises a pair of skirts extending from said anode on each side of said barrier electrode.

11. The X-ray source of claim 10 comprising in addition a pair of grid assemblies attached to said skirts.

12. The X-ray source of claim 7 comprising in addition a focusing electrode extending generally parallel to said cathode on the side thereof away from said anode.

13. The X-ray source of claim 12 in which said focusing electrode is connected electrically to one end of said cathode.

14. An ultra-soft X-ray source comprising: a generally cylindrical chamber having a conductive cylindrical wall; an elongated filamentary cathode extending substantially parallel to the axis of said chamber; an elongated anode extending generally parallel to the axis of said chamber and having at least one X-ray emissive surface facing away from said cathode; a layer of material having pre-determined X-ray emission characteristics attached to said surface; an opening in the wall of said cylinder adjacent to said X-ray emissive surface of said anode; a barrier electrode extending generally parallel to the axis of said chamber between said cathode and said anode to prevent electrons from passing along straight lines from said cathode to said anode; and electrode means extending from said anode adjacent to said barrier electrode to draw electrons from said cathode into the space between said anode and said cylindrical wall, said cylindrical wall being op-

erated at a voltage which is negative with respect to said anode to cooperate with said anode in deflecting electrons to said X-ray emissive surface.

15. An ultra-soft X-ray source comprising: a generally cylindrical chamber having a conductive cylindrical wall; an elongated filamentary cathode extending substantially parallel to the axis of said chamber; an elongated anode extending generally parallel to the axis of said chamber and having a pair of angularly disposed surfaces facing away from said cathode; an angular X-ray emissive member attached to said angularly disposed surfaces; an opening in the wall of said cylinder adjacent to said X-ray emissive surface of said anode; a barrier electrode extending generally parallel to the axis of said chamber between said cathode and said anode to prevent electrons from passing along straight lines from said cathode to said anode; and electrode means extending from said anode adjacent to said barrier electrode to draw electrons from said cathode into the space between said anode and said cylindrical wall, said cylindrical wall being operated at a voltage which is negative with respect to said anode to cooperate with said anode in deflecting electrons to said X-ray emissive surface.

16. An ultra-soft X-ray source comprising: a generally cylindrical chamber having a conductive cylindrical wall; an elongated filamentary cathode extending substantially parallel to the axis of said chamber; an elongated anode extending generally parallel to the axis of said chamber and having at least one X-ray emissive surface facing away from said cathode; an opening in the wall of said cylinder adjacent to said X-ray emissive surface of said anode; a barrier electrode extending generally parallel to the axis of said chamber between said cathode and said anode to prevent electrons from passing along straight lines from said cathode to said anode; an evacuating channel extending through the wall of said chamber; a molecular sieve filter in said channel; and electrode means extending from said anode adjacent to said barrier electrode to draw electrons from said cathode into the space between said anode and said cylindrical wall, said cylindrical wall being operated at a voltage which is negative with respect to said anode to cooperate with said anode in deflecting electrons to said X-ray emissive surface.

17. An ultra-soft X-ray source comprising an evacuated envelope, an anode, means to support the anode within the envelope, a cathode, a barrier electrode positioned between a cathode and anode for focusing electrons generated by said cathode on to the side of the anode remote from the cathode, a space-charge elimination electrode directly electrically connected to said anode and located adjacent to the path travelled by electrons passing from said cathode to said anode, and a thin filter window in the envelope facing the anode surface upon which the electrons impinge for suppressing undesired wave-lengths of X-rays.

References Cited in the file of this patent

UNITED STATES PATENTS

1,685,928	Morrison	Oct. 2, 1928
2,046,808	Bouwers et al.	July 7, 1936
2,097,002	Thaller	Oct. 26, 1937
2,108,573	Alfter	Feb. 15, 1938
2,569,872	Skeham et al.	Oct. 2, 1951
2,663,812	Jamison et al.	Dec. 22, 1953
2,866,114	Hardenberg	Dec. 23, 1958
3,012,163	Goss	Dec. 5, 1961

FOREIGN PATENTS

626,183	Great Britain	July 11, 1949