

[54] **IMPROVED COMPOSITE ANODE FOR ROTATING-ANODE X-RAY TUBES THEREOF**

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[52] U.S. Cl. **313/330, 313/60**

[51] Int. Cl. **H01j 35/10**

[58] Field of Search 313/330, 345-346, 313/60

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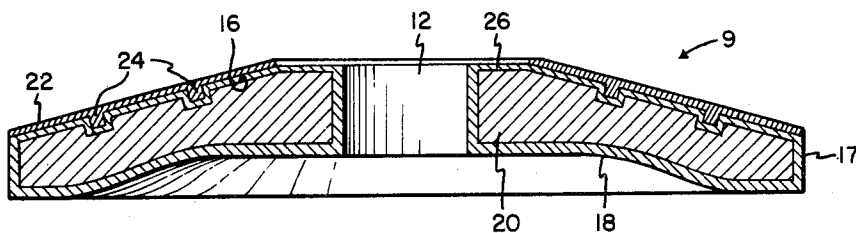
[57] **ABSTRACT**

Disclosed is an improved composite anode for rotating-anode x-ray tubes and an improved method of fabrication thereof.

The anode comprises a substrate disk, a portion of whose focal track is scored, for example by scratching or engraving of one or more annular grooves of rectangular cross-section. A coating of x-ray emissive material covers the scored region. In certain embodiments of the invention, the emissive coating is undercoated with an interlayer of a material which is a poor emitter of x-rays. The emissive coating and/or the undercoating may cover other portions of the disk and, in particular, may cover all exposed surfaces thereof.

The method comprises providing such a disk, scoring it in the focal track region and applying an x-ray emissive coating to the scored region. The last step may be preceded by the application of an undercoating of a material which is a poor x-ray emitter. Either or both coatings may be applied to other surfaces of the disk.

11 Claims, 7 Drawing Figures



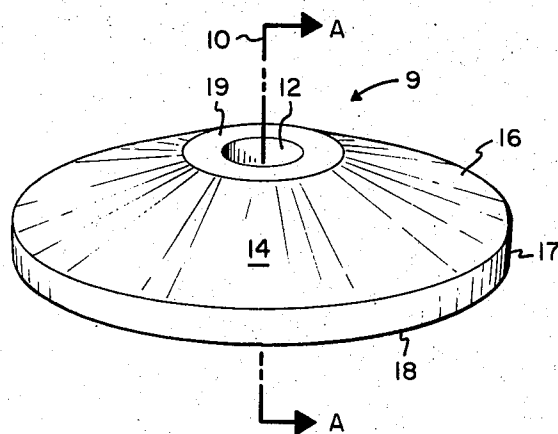


Fig. 1

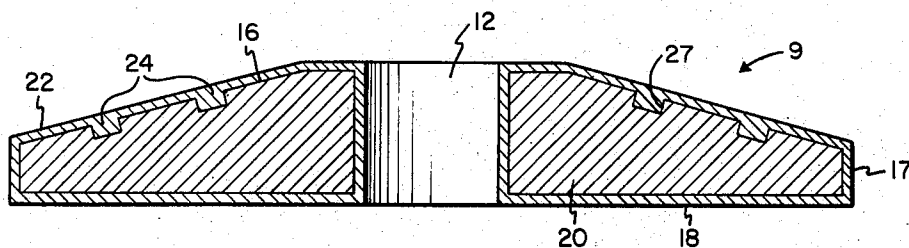


Fig. 4

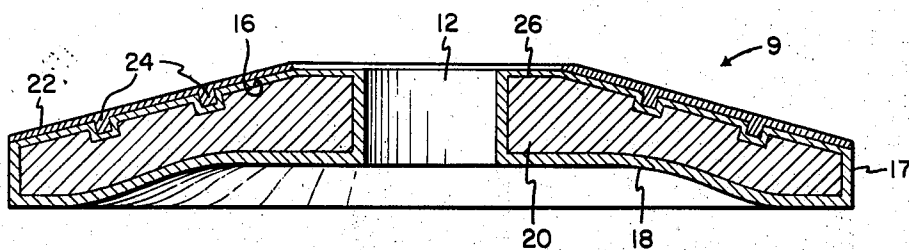


Fig. 5

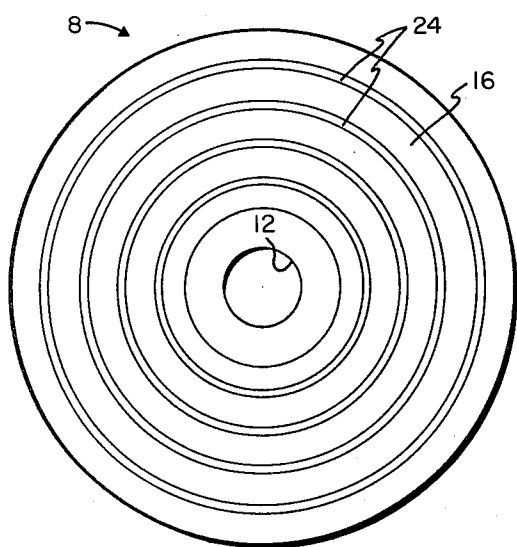
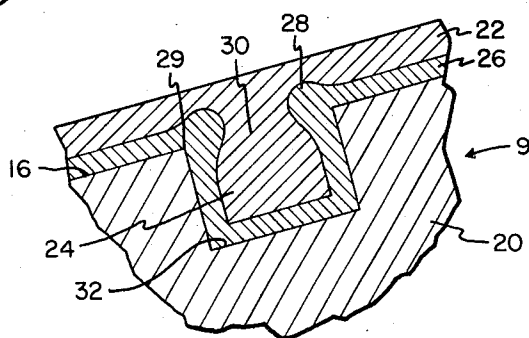
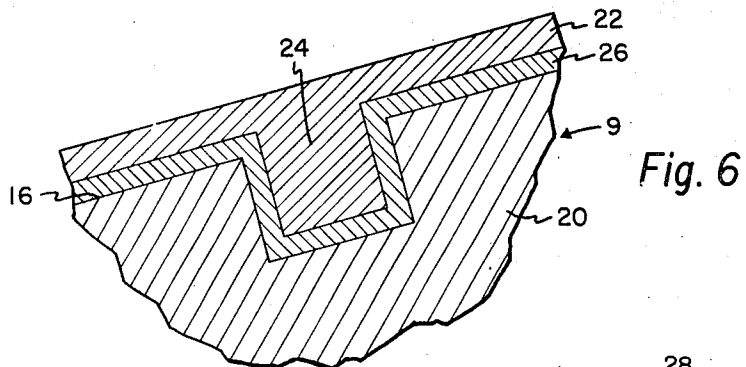


Fig. 2

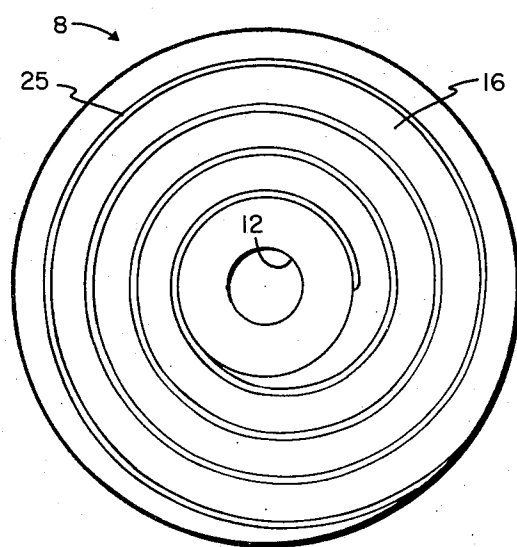


Fig. 3

IMPROVED COMPOSITE ANODE FOR ROTATING-ANODE X-RAY TUBES THEREOF

REFERENCE TO PRIOR, COPENDING APPLICATION

This is a division of application Ser. No. 236,898, filed Mar. 22, 1972.

BACKGROUND OF INVENTION

1. Field of Invention

This invention relates to the field of composite anodes for rotating-anode x-ray tubes and the methods of fabrication thereof.

2. Description of Prior Art

In essence, a rotating-anode x-ray tube comprises a cathode and a disk-shaped anode, housed in an evacuated glass chamber. Electrons emitted by the cathode are caused to impinge upon the anode. The interaction of these electrons with the atomic nuclei of the anode surface material causes this material to emit x-radiation. The stream of emitted x-ray exits from the tube at a designated spot — ordinarily a hole in a lead shielding surrounding the tube. Focusing means is generally provided for the electron beam, causing it to impinge on the anode at a fixed distance from its axis (the focal track). The angle of the focal track area of the anode's upper surface, with respect to the axis of the anode, determines the angle of the resultant x-ray beam.

During the course of operation, a great deal of heat is generated as a result of the x-ray generation process. Accordingly, the anode, which is axially bearing mounted, is rotated at high angular velocity to continuously change the site of x-ray emission. Heat is transferred from the focal track through the anode and its supporting structure to a heat sink.

Many rotating anodes presently in use comprise a solid metal disk which is either composed entirely of an x-ray emissive metal (typically tungsten) or of another metal to which an x-ray emissive coating is applied. Due to their great weight and consequent high moment of inertia, these anodes require considerable time to reach full angular velocity. Furthermore, this weight imposes a great burden on the support bearings, about which they rotate at several thousand rpm. Consequently, x-ray tubes with such anodes have a rather short service life.

In order to solve such problems, composite anodes have recently come into increasingly common use. A composite anode comprises a substrate disk — usually of graphite or molybdenum — on whose focal track is applied a coating of x-ray emissive material. Such anodes, particularly those whose substrate disk is composed of graphite, are lightweight and, consequently, are not subject to the aforementioned limitations of "solid" anodes.

However, composite anodes fabricated according to methods heretofore applied suffer a notoriously high failure rate. Typically, the emissive coating (ordinarily a thin, frusto-conical shell) warps, cracks or spalls away when subjected to the thermal stresses resulting from the x-ray generation process. Rotation of the anode at its high operating speed further contributes to separation of the emissive coating.

Furthermore, also owing to the poor bond between the emissive coating and the substrate resulting from

coating directly onto the smooth substrate surface, these anodes exhibit poor heat transfer characteristics. This results in serious overheating and further contributes to the sort of coating separation mentioned above.

Finally, particularly in the case of graphite-substrate anodes, sublimation of the substrate material occurs from exposed surfaces of the anode, decreasing the vacuum strength within the tube and eventually rendering the tube useless. Further electrical breakdown occurs due to migration of micro-particulate matter from the exposed substrate surfaces into the region of high electrical field between the electrodes. These problems may be solved by applying the emissive coating to all exposed surfaces of the anode, but this will tend to cause off-focus x-radiation.

SUMMARY OF INVENTION

Accordingly, it is an object of this invention to provide a composite anode for rotating-anode x-ray tubes having improved structural integrity.

It is a further object of this invention to provide a composite anode having improved heat transfer characteristics.

It is a yet further object of this invention to provide a composite anode having a diminished tendency toward substrate material sublimation and particle migration.

It is another object of this invention to provide a composite anode having a diminished tendency toward off-focus x-radiation.

It is an even further object of this invention to provide a method for fabricating composite anodes having such improved characteristics.

Briefly, the method of the present invention involves scoring the region of the substrate disk surface to which the x-ray emissive coating is applied (i.e., the focal track). Scoring may comprise abrading, scratching, grooving or any other suitable method. In certain embodiments of the invention, the emissive material is applied to substantially all exposed surfaces of the disk. In other embodiments, it comprises two layers — one, a non-emissive layer which may be applied to substantially all exposed surface of the disk, and a second, emissive layer, overlaying the first, applied to the focal track region.

The improved anode of this invention comprises a scored substrate disk overlaid with an x-ray emissive coating on its focal track. In certain embodiments, this emissive coating is underlaid with a non-x-ray-emissive layer covering substantially all exposed surfaces of the disk.

DESCRIPTION OF THE DRAWING

FIG. 1 is a perspective view of an anode made in accordance with this invention.

FIG. 2 is a plan view of a grooved substrate disk according to one embodiment of this invention.

FIG. 3 is a plan view of a grooved substrate disk according to another embodiment of this invention.

FIG. 4 is a sectional view of the anode shown in FIG. 1 taken along line A—A.

FIG. 5 is a sectional view of the anode shown in FIG. 1 taken along line A—A, illustrating a different embodiment of the invention from that shown in FIG. 4.

FIG. 6 is a detail sectional view of the anode shown in FIG. 5.

FIG. 7 is a detail sectional view, as in FIG. 6, but illustrating a different embodiment of the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The improved composite anode of this invention is best described and understood by reference to the method which is employed in its manufacture. Consequently the major emphasis of the present detailed description will be laid on the preferred embodiments of the method. The preferred embodiments of the anode itself will be independently described, but in more summary fashion.

In order to fabricate the composite anode of this invention, a substrate disk 20 must first be provided. This is the base to which the x-ray emissive coating is to be applied. The substrate disk 20 is not illustrated in perspective in the drawing. (See FIGS. 4 and 5 for a sectional view). However, its preferred configuration is substantially similar to that of the anode 9, shown in FIG. 1.

Accordingly, in the preferred embodiment of this invention, the substrate disk 20 has a lower surface 18 and a frusto-conical upper surface 14, both symmetric about an axis 10. The lower surface 18 may be planar, as shown in FIG. 4 or of any desired shape, for example that shown in FIG. 5. The upper surface 14 and the lower surface 18 may be separated by a band 17 of any desired width or may directly abut at their peripheries.

In the embodiments illustrated, a cylindrical axial cavity 12 is provided for axial mounting of the anode 9 to the shaft of the x-ray tube (not shown). However in other embodiments, the anode 9 might be prepared with an integral axial cylindrical shaft which is mounted at either end, remote from the anode 9, itself. The total surface of the anode 9 exposed to the environment within the x-ray tube would, therefore, vary according to the particular mounting structure employed. Accordingly, the exposed surfaces of the substrate disk 20 would normally constitute annular portions of the lower surface 18 and summit 19, the sloped region 16 of the upper surface 14 and the band 17.

The site of x-ray generation is located in the sloped region 16 of the upper surface 14. Here the electron beam from the cathode (not shown) impinges upon the anode 9, causing the generation of x-rays. Accordingly, the angle of inclination of the sloped region 16 with respect to the summit 19 (or the lower surface 18) depends on the desired angle of the resulting x-ray beam and, ultimately, on the dimensional and other requirements of the particular x-ray tube itself. For some applications, this inclination angle might even be negative, i.e., the upper surface 14 might be recessed; or zero, i.e., the upper surface 14 might be flat.

The substrate disk 20 must be composed of a refractory material, since extreme heat is created during the x-ray generation process. It is desirable, that the material selected also possess high heat capacity, light weight and a low atomic number, the latter reducing the tendency toward x-radiation by the substrate. Examples of materials possessing all these characteristics are molybdenum, silicon carbide and sintered graphite, the latter being employed in the preferred embodiment of this invention.

The substrate disk 20 may be prepared by any method, such as sintering, casting, forging, machining, etc., which is appropriate to the particular material selected and the form in which it is obtained. Those skilled in the art of basic structural fabrication will doubtless be able both to select a satisfactory material for the substrate disk 20, and to devise and implement suitable procedures for fabricating a substrate disk 20 from this material.

The second step in fabricating the composite anode is that of scoring the substrate disk 20. The term "scoring" is here used in the broadest generic sense and should be understood to mean any method of creating an impression — of any size, shape or depth — in a surface. By way of illustration, and not of limitation, scoring may comprise scratching, indenting, abrading, etching, drilling or grooving. The preferred method, however, is the last named.

Accordingly, in the preferred embodiment, one or more grooves (ordinarily 20 or so) are produced in at least a portion of the sloped region 16 of the upper surface 14 of the substrate disk 20, forming a grooved disk 8. The portion of the sloped region 16 in which the grooves 24 are produced is that portion at or in proximity to the focal track, where the x-ray emissive coating is to be applied. Any desired number of grooves 24 may be fashioned in this region, and grooves 24 may, of course, be produced in any other portion of any or all surfaces of the substrate disk 20.

The grooves 24 may be produced by any desired method. For example, the substrate disk 20 may, itself, be molded, cast, etc., already grooved. In the preferred embodiment, however, they are produced by machining the already-fabricated sintered graphite substrate disk 20.

They may be machined concentrically, producing one or more annular grooves 24, as shown in FIG. 2. Likewise, they may be machined in a spiral fashion, for example by revolving the substrate disk 20 on its axis 10 and impressing a stylus, in the manner in which master phonograph discs are made, producing a spiral groove 25 as shown in FIG. 3. Indeed, any desired method may be employed to machine any desired number of grooves of any desired configuration.

The cross-section of the grooves may likewise have any desired shape or, indeed, no uniform shape at all. In the preferred embodiment, grooves 24 of rectangular or square cross-section, as illustrated in FIGS. 4 — 7, are machined into the sintered graphite substrate disk 20.

The function of the scoring, regardless of its precise nature or method of application, is essentially the same.

First, it increases the surface area of the region of the substrate disk 20 to which the emissive coating 22 is applied. This has two major effects. One of these is to increase the effective area of the bond interface between the surface of the substrate disk 20 and the emissive coating 22, providing a generally more secure bond. The other is to promote the flow of heat from the coating 22 into the substrate disk 20 for ultimate transmission into the heat sink or the ambient. Thus the anode of this invention exhibits greater structural integrity and improved heat transfer characteristics over those fabricated by methods previously known in the art.

In addition, it increases the amount of force necessary to separate the coating 22 from the substrate disk

20 and accordingly, provides the anode 9 with still greater structural integrity. Considering the anode 9 shown in FIG. 4, it can be seen that high-speed rotation (as would occur in operation in an x-ray tube) would impress a large centrifugal force on the portion of the coating 22 on the sloped region 16. This would tend to lift the coating 22 away from the sloped region 16 in a radial direction. Such action would, without the scoring of the sloped surface, be hampered only by rather weak tensile forces, in a direction perpendicular to the interface between the coating 22 and the sloped region 16, and by shear forces, in a radial direction, parallel to the interface. Likewise, the warping and buckling of the emissive coatings observed to occur in unscored anodes subjected to the thermal stresses resulting from ordinary use (similar to the effect of heat in a dry lake bed) are restrained only by these weak tensile forces. It is the weakness of these inhibiting forces which is the primary cause of the high failure rate of "unscored" composite anodes made by heretofore applied methods.

However, in the anode of the present invention, the scoring adds additional constraints to the movement of the coating 22. From a study of FIG. 4 it can be understood that the abutment of the portion of the coating 22 within the grooves 24 with the outer edges 27 thereof restrains radial movement of the coating 22. The shear forces generated within the grooves 24 would also tend to restrain action of the coating 22 in a direction perpendicular to the sloped region 16, whether caused by centrifugal force or thermal stresses.

The final effect of scoring further increases the structural integrity of the anode of this invention. Since the coating 22 will, as hereinafter more thoroughly discussed, tend to enter the grooves 24 upon application, the coating 22 on the sloped region 16 will have a more complex geometry than the simple, thin frusto-conical shell of the prior art anodes. In particular, the preferred embodiment of the method of this invention in which grooves 24 are machined into the substrate disk 20, will yield a coating 22 with integral ribs. These ribs, or the other structures integral to the coating 22 provided by the other types of scoring which may be applied to the substrate disk, enable the coating 22 to further resist the tendency to warp and crack under thermal stress and other severe conditions of the operating environment.

Thus the step of scoring ultimately yields an anode 9 having increased structural integrity as well as improved heat transfer characteristics. By a careful selection of the precise scoring procedure employed and a precise arrangement of the resulting scoring on the exposed surfaces of the substrate disk — these being well within the skill of typical mechanical or structural engineers — such qualities may be optimized.

The final step in fabricating composite anodes by the method of this invention is that of applying a coating 22 of a second, x-ray emissive material to the sloped region 16 of the scored substrate disk 8.

The material itself may be any of those which have the ability to emit x-rays in response to electron bombardment. As is well-known to those in the art of roentgenology, these are elements having a relatively high atomic number — ordinarily over 70. Typical of such materials are tantalum, tungsten, rhenium and alloys of tungsten and rhenium. In the preferred embodiment of

this invention, tungsten and alloys of tungsten and rhenium are employed for this purpose.

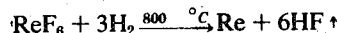
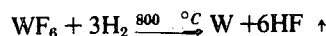
The coating 22 is applied to at least that area of the sloped region 16 of the substrate disk 20 comprising the focal track of the anode. Of course the coating may be applied to other areas of the disk 20 and, in particular, may be applied to all exposed surfaces thereof. This latter is desirable for reasons hereinafter explained.

In any event, the coating 22 is applied, at least in part, to areas of the exposed surfaces of the disk 20 which have been previously scored as hereinabove described. The coating 22 may be applied by any suitable method, many of which will be known to those skilled in the plating art. For example, the method of fused salt electrolysis may be applied. Here a fused mixture of potassium fluoride (and/or sodium fluoride) and a salt of the emissive material is brought in contact with the surface to which the coating is applied, and a dc current is passed through the mixture, causing the emissive material to be electroplated onto the substrate surface.

However, in the preferred embodiment of this invention, the coating 22 is applied by the method of chemical vapor deposition.

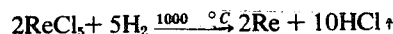
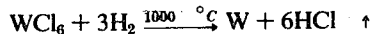
Although the operator will perhaps be required to conduct a nominal amount of experimentation to determine the precise conditions necessary to coat the selected emissive material onto the selected substrate material, the following method has proved satisfactory for use in the preferred embodiment of this invention wherein a coating 22 of tungsten or rhenium or alloys thereof is applied to a substrate disk 20 of sintered graphite.

In an evacuated chamber maintained at a temperature of 800°C, tungsten hexafluoride (WF₆), rhenium hexafluoride (ReF₆) or a mixture thereof are brought into contact with the area of the exposed surfaces of the substrate disk 20 to be coated. Gaseous hydrogen is introduced (either independently or premixed with the hexafluoride(s)), and one or both of the following reduction reactions:



causes the desired emissive coating 22 to deposit onto the substrate surface. Which of these reactions occurs will, of course, depend on which hexafluoride is introduced into the chamber. In particular, if both are introduced, an alloy of tungsten and rhenium will be deposited, the proportion being adjustable as desired by adjusting the proportion of the hexafluorides in the introduced vapor.

An alternative procedure consists in vaporizing tungsten hexachloride (WCl₆) and/or rhenium pentachloride (ReCl₅) and introducing one or both or any desired mixture into the evacuated chamber maintained at 1000°C. As before, gaseous hydrogen is introduced, and the desired coating will deposit accordingly to one or both of the following reactions:



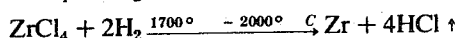
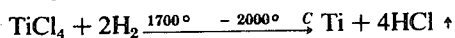
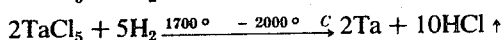
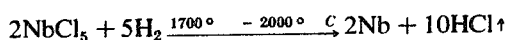
Either of these two procedures may be accomplished by maintaining the exposed surfaces of the substrate disk 20 at 800°C or 1000°C, respectively, in an evacuated chamber not maintained at that temperature.

The coating 22 will naturally tend to enter into the grooves 24 during deposition, as the tungsten and rhenium atoms will rather freely drift within the deposition chamber. This is desirable, as it is responsible in part for the increased structural integrity and improved heat transfer characteristics of the coating 22 (and, generally, of the anode of this invention), as hereinabove discussed. It should be noted that because of the high motility of the reactant gas molecules, grooves are more easily plated by this method than by, for example, the method of fused salt electrolysis.

The coating 22 may be applied to any desired thickness by adjusting the timing and the volume and pressure of the input vapors as required. For a more complete description of these procedures, see *Vapor Plating* by Powell, Blocher and Oxley.

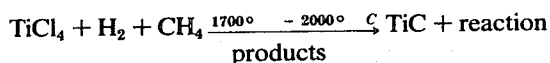
In order to provide an improved bond between the coating 22 and the substrate disk 20, and for other reasons hereinafter explained, it is desirable to precede the emissive coating application with the application of a first layer of refractory material. Examples of such materials are niobium carbide, tantalum carbide, titanium carbide and zirconium carbide. In the preferred embodiment of this invention, in which a substrate disk 20 of sintered graphite is provided, niobium carbide and/or titanium carbide are employed for this purpose. The reason for this selection will be hereinafter explained.

This first layer 26 is preferably applied by the chemical vapor deposition technique described above, modified in that the chamber temperature (or substrate disk 20) is maintained at between 1,700° and 2,000°C. Otherwise the procedure is similar, and the reduction reactions giving rise to the deposition are:



The thinly deposited first layer will, by carbon diffusion from the graphite substrate, be transformed into the carbide(s) of metal(s) deposited.

A carbide may also be applied directly, if methane is added to the plating vapor mixture. Here, a typical reaction would be:



Following deposition of this first layer 26, the second, x-ray emissive layer 22 is deposited as hereinabove described. Ordinarily the second layer 22 will be deposited onto the focal track, but it may be deposited onto the entire sloped region 16 (see FIG. 5) or, for that matter, onto all exposed surfaces of the substrate disk 20. In any event, the first layer 26 will greatly improve (and ultimately increase the life of) the bond between the emissive layer 22 and the substrate disk 20 by impeding the diffusion of carbon between the graphite substrate disk 20 and the x-ray emissive layer 22.

The first layer 26 will ordinarily be deposited on all exposed surfaces of the substrate disk 20, in order to prevent sublimation and micro-particle migration from the substrate, which would, as hereinabove discussed, eventually lead to electrical breakdown and failure of the tube.

The particular advantage of a first layer of niobium carbide or titanium carbide is that niobium and titanium have low atomic numbers, and are thus poor x-ray emitters. Consequently, if all exposed surfaces of the substrate disk 20 are coated with a first layer of niobium carbide or titanium carbide, off-focus x-radiation by the anode will be greatly reduced with respect to that of an exposed surface containing an element of a higher atomic number.

Accordingly, in this embodiment the emissive layer 22 is undercoated with a layer of refractory material — preferably a first layer 26 of niobium carbide or titanium carbide — covering all exposed surfaces of the substrate disk 20, as shown in FIG. 5.

The detailed geometry of this double layer is seen in FIGS. 6 and 7. Referring to FIG. 6, the first layer 26 covers the surface of the substrate disk 20, including those portions within the groove 24. Overlaying the first layer 26 is the second, x-ray emissive layer 22.

FIG. 7 shows a slight modification of the coating shown in FIG. 6. Here it is noted that the opening 30 of the groove 24 is narrower than its base 32, following application of the first layer 26. This effect will normally be achieved without special action, since the corners 29 of the groove 24, being exposed to the ambient through an angle of 270°, will naturally receive a greater number of molecules of the material being deposited than would a flat surface. This effect may also be promoted by increasing temperature and pressure in the plating chamber, thus causing the gas to "plate out" on the first available surface. The result in either case will be that the emissive layer 22 will be even more securely bonded to the substrate disk 20 by the "dove-tail" effect. It should be noted that this effect can, of course, be achieved by machining the grooves 24 into the substrate disk 20 with a dove-tail cross-section, in the first instance.

Having now described in detail the preferred embodiments of the method of this invention, the preferred embodiment of the anode of this invention will be described in summary fashion.

Briefly, in its preferred embodiment, the anode comprises a sintered graphite substrate disk 20, having substantially the configuration of the anode 9, shown in FIG. 1. The substrate disk 20 comprises a substantially frusto-conical upper surface 14, the latter comprising a summit 19, and a sloped region 16; a lower surface 18, which is preferably recessed, as shown in FIG. 5; a band 17; and a cylindrical axial cavity 12. The entire substrate disk 20 is substantially symmetric about an axis 10. The sloped region 16 possesses one or more annular grooves 24 of substantially square cross-section (when viewed parallel to the axis 10). These grooves 24 are located at or near the focal track (not shown) of the anode 9. All exposed surfaces of the grooved substrate disk 8 are coated with a first layer 26 of a refractory, poorly x-ray emitting material, such as niobium carbide or titanium carbide. The focal track area of the sloped region 16 is coated with a second layer 22 of an x-ray emitting material, such as tungsten. Both layers extend into the grooves 24, the second layer 22 substantially filling them.

Without departing from the spirit of the invention, the preferred embodiment of the anode may be altered by any or all of the substitutions of materials, configurations, etc. shown in the drawings or hereinabove discussed in connection with the preferred embodiments

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of the method of this invention, or which may be devised by or apparent to those skilled in the art to which this invention pertains.

We claim:

1. A composite anode for a rotating anode x-ray tube, comprising:
 - a substrate disk of a first, refractory material, said disk having:
 - an axis;
 - a scored, substantially frusto-conical upper surface, said scoring being located at least in part in the sloped region of said upper surface; and
 - a lower surface;
 - said upper and lower surfaces each being substantially symmetric about said axis; and
 - a coating in juxtaposition with substantially all exposed surfaces of said substrate disk; said coating comprising a second material differing from said first material, said second material having the ability to emit x-rays in response to electron bombardment, at least a portion of said coating extending into said scoring.
2. Anode as in claim 1, wherein said coating comprises a material selected from the group consisting of tungsten and all alloys of tungsten and rhenium.
3. Anode as in claim 2, wherein said coating comprises tungsten.
4. Anode as in claim 1, wherein said scoring comprises at least one substantially annular groove.

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5. Anode as in claim 4, wherein:

said groove is substantially rectangular in a cross-section taken parallel to said axis; and
said coating substantially fills said groove.

6. Anode as in claim 4, wherein a plurality of annular grooves is provided.

7. Anode as in claim 1, wherein said coating comprises a first, substantially non-x-ray emissive layer and a second, x-ray emissive layer:

said first layer being in juxtaposition with substantially all exposed surfaces of said substrate disk; and

said second layer being in juxtaposition with said first layer.

8. Anode as in claim 7, wherein said first material comprises carbon and said first layer comprises a material selected from the group consisting of:

Niobium Carbide;
Tantalum Carbide;
Titanium Carbide; and
Zirconium Carbide.

9. Anode as in claim 7, wherein:

said second layer comprises Tungsten.

10. Anode as in claim 1 wherein said scoring comprises a groove which is substantially spiral with respect to said axis.

11. Anode as in claim 1 wherein said upper surface is substantially flat.

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