

- [54] METHOD OF MANUFACTURING OF X-RAY  
TUBE HAVING THORIATED TUNGSTEN  
FILAMENT
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- [22] Filed: Feb. 24, 1972
- [21] Appl. No.: 228,951
- [52] U.S. Cl. .... 316/26, 313/55
- [51] Int. Cl. .... H01j 9/00
- [58] Field of Search ..... 316/1, 17, 18, 19, 20,  
316/21, 22, 26; 313/55

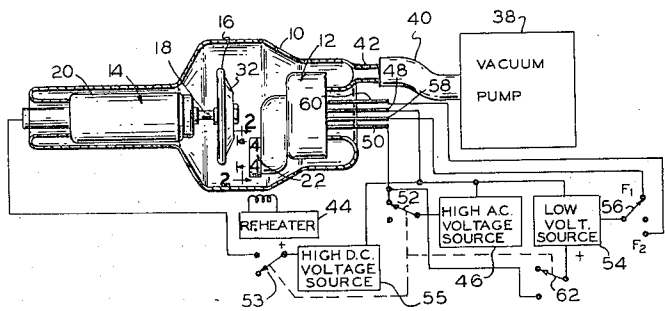
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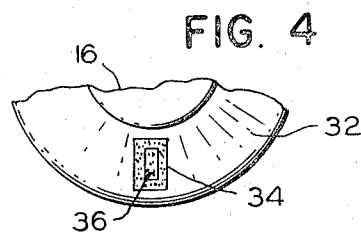
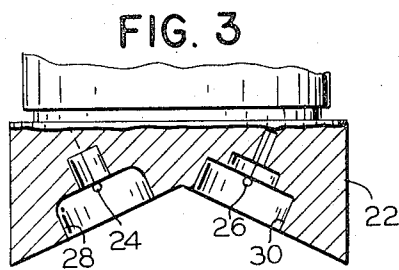
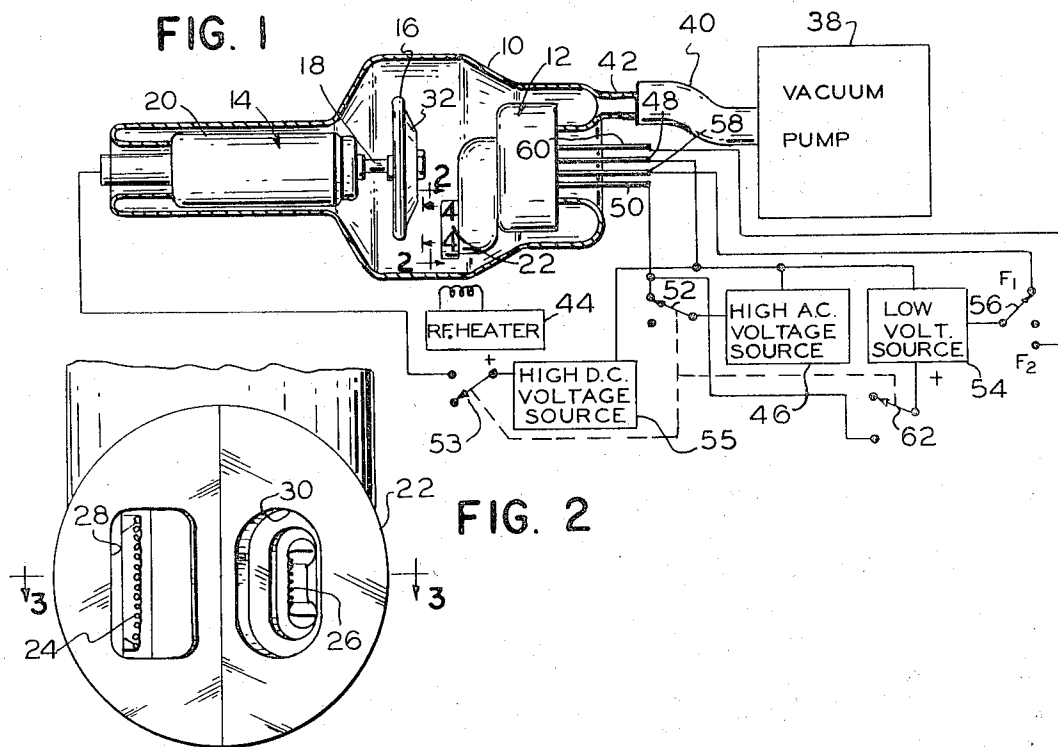
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Campbell, Leigh, Hall & Winston

- [57] ABSTRACT
- A method of manufacture of an x-ray tube having a

thoriated tungsten filament cathode is described in which, during evacuation of the tube envelope, the filament and adjacent focusing electrode are seasoned by causing field emission discharges between such electrodes and then the filament is activated. This enables the activated filament to bombard a high mass rotatable anode within such tube at a high electron beam current to heat the anode sufficiently for outgassing such anode while continuing evacuation prior to sealing the envelope. The seasoning prior to activation prevents the removal of thorium from the filament due to field emission during subsequent operation of the tube. The method includes the steps of seasoning by the application of A.C. voltages between the unactivated filament and an adjacent focusing electrode during evacuation after bake out of the envelope to cause field emission discharges therebetween until their surfaces are sufficiently smooth to prevent further field emission discharges at such voltage, and activation by thereafter heating the unactivated filament during continued evacuation at a high temperature to convert thorium oxide in such filament to thorium metal and cause a layer of such thorium metal to form on the surface of the filament to provide an activated filament. In order to cause the thorium metal layer to better adhere to the tungsten body of the filament, a coating of carbon is provided on the surface of the unactivated filament by dipping it in a liquid suspension of graphite particles prior to mounting the envelope so that the activation heating step also forms a layer of tungsten carbide under the thorium metal layer.

15 Claims, 4 Drawing Figures





# METHOD OF MANUFACTURING OF X-RAY TUBE HAVING THORIATED TUNGSTEN FILAMENT

## BACKGROUND OF THE INVENTION

The subject matter of the present invention relates generally to the manufacture of x-ray tubes having thoriated tungsten filament cathodes, and in particular to a method of manufacture of such tubes in which the thoriated tungsten filament is activated during evacuation of the tube envelope to enable it to bombard a target anode with an electron beam of high current during continued evacuation prior to sealing of the tube envelope. In addition, the method of the present invention includes a seasoning step prior to activation in which A.C. voltages are applied between the unactivated filament and an adjacent focusing electrode to cause field emission electron discharges between such electrodes until their surfaces are sufficiently smooth to prevent such discharges at such voltages. This method is especially useful for manufacturing double focus X-ray tubes having a high mass rotatable target anode and two thoriated tungsten filaments.

Activation of the thoriated tungsten filament is achieved by heating the filament for a few seconds at a high temperature above that necessary to reduce thorium oxide in the unactivated filament to thorium metal and then maintaining it at a lower temperature above the melting point of thorium for several minutes to cause a layer of thorium metal to form on the surface of the filament. A carbon coating may be provided on the surface of the filament, which during activation combines with the tungsten to form an intermediate layer of tungsten carbide which causes the thorium metal outer layer to better adhere to the tungsten body of the filament. Previously it was thought that if the filament was activated prior to the time the tube was fully evacuated and sealed, this thorium metal layer would be lost from the surface of the filament due to field emission and to bombardment by positive ions of residual gas produced by the electrons emitted by the filament during bombardment of the target anode for removal of gas absorbed in the surface of such anode (sometimes called "outgassing"). Of course, this evaporation of thorium metal from the activated filament is undesirable because the evaporated thorium metal would be deposited on the focusing electrode and other unwanted surfaces making them electron emitters which would result in erratic emission and an unstable tube performance.

Previously, thoriated carbonized tungsten filament cathodes have been employed in high voltage rectifier tubes such as that shown in U.S. Pat. No. 2,588,603 of Z. J. Atlee granted June 26, 1951. With the prior method of manufacture of such rectifier tubes, the filament is not seasoned and activated until after the tube envelope is completely exhausted and sealed to prevent removal of the thorium metal layer from the filament due to field emission and the above mentioned positive ion bombardment of such filament during the electron bombardment of the anode for "outgassing" purposes prior to sealing. As a result, the anode was bombarded by a low current electron beam emitted by the unactivated filament having a current of only about one to two milliamperes for outgassing of the anode. Unfortunately, such a low current electron beam cannot be used for outgassing in the manufacture of an x-ray tube due to the greater mass and higher operating tempera-

ture of the target anode of such x-ray tube. Also, the seasoning of the rectifier tubes is accomplished by applying a very high voltage between the anode and the cathode which cannot be done practically during exhaust due to external flashover, among other things. In addition, the carbon layer was applied to the unactivated filament of the rectifier tubes by a cataphoretic deposition process in such prior method which is not suitable for the manufacture of an x-ray tube having a focusing electrode, sometimes called a "cathode cup" because it is mounted adjacent the filament so the carbon coating would also form on such focusing electrode.

The method of manufacture of the present invention overcomes the above disadvantages by activating the cathode during evacuation of the tube envelope after bake out of the envelope so the envelope is at a good vacuum of  $10^{-6}$  torr or less, but before it is completely exhausted and sealed. This greatly reduces the number of positive ions produced during outgassing when the activated filament bombards the target anode with the high current electron beam which prevents removal of thorium due to positive ion bombardment. The electron beam emitted by the activated filament is on the order of 50 to 70 milliamperes of current during outgassing of the anode while the remainder of the exhaust cycle is carried out so that the anode is heated to a high enough temperature for adequate outgassing. In addition, prior to activation of the filament, a relatively low A.C. voltage is applied between the unactivated filament and the adjacent focusing electrode, which because of their close spacing, if of a high enough value to cause field emission discharges between such electrodes for seasoning them until the surfaces of the electrodes are sufficiently smooth to prevent further field emission discharges. This seasoning also prevents removal of thorium from the filament during subsequent operation of the tube.

As stated above, the unactivated filament may be provided with a carbon coating before activation. With the present method this is done by dipping the filament into a liquid suspension of graphite particles which prevents any carbon coating from being formed on the cathode cup or focusing electrode into which such filament is subsequently mounted. The carbon coating is converted into a tungsten carbide coating during activation of the filament which causes the thorium metal surface layer to adhere better to the tungsten body of the filament.

It is, therefore, one object of the present invention to provide an improved method of manufacture of electron tubes, such as x-ray tubes, having thoriated tungsten filament cathodes.

Another object of the invention is to provide such a method in which the filament is activated during evacuation of the tube envelope prior to the sealing of such envelope to enable the filament to bombard the anode of such tube at a high electron current for "outgassing" of the anode.

A further object of the invention is to provide such a method in which a high voltage is applied between the unactivated filament cathode and a focusing electrode adjacent thereto during evacuation to cause field emission electron discharges between such electrodes until their surfaces are sufficiently smooth to prevent further field emission discharges for a more stable operating tube.

An additional object of the invention is to provide such a method in which the unactivated filament is provided with a carbon coating prior to mounting it in the envelope by dipping the filament in a liquid suspension of graphite particles and thereafter heating a coated filament to form a layer of tungsten carbide beneath the thorium metal surface layer on the activated filament.

Still another object of the invention is to provide such a method of manufacture in which bombardment of the target anode by the activated filament cathode takes place during evacuation at a relatively high vacuum after bake out of the envelope to prevent removal of thorium metal from the filament surface due to positive ion bombardment.

#### BRIEF DESCRIPTION OF THE DRAWING

Other objects and advantages of the present invention will be apparent from the following detailed description of a preferred embodiment thereof and from the attached drawing of which:

FIG. 1 is a plan view of an x-ray tube and associated apparatus for manufacturing such tube in accordance with the method of the present invention, with a portion of the tube envelope broken away for clarity;

FIG. 2 is a plan view taken along the line 2—2 of FIG. 1 showing the filament cathodes and cathode cup focusing electrode on an enlarged scale;

FIG. 3 is a horizontal sectional view taken along the line 3—3 of FIG. 2; and

FIG. 4 is a plan view taken along the line 4—4 of FIG. 1 showing a portion of the rotating anode target on an enlarged scale.

#### DESCRIPTION OF PREFERRED EMBODIMENT

As shown in FIG. 1, an x-ray tube made in accordance with the method of the present invention includes a glass envelope 10 containing a cathode means 12 provided within one end of the envelope and an anode means 14 provided within the other end of the envelope which are sealed thereto in a conventional manner with glass to metal seals. The anode means 14 may include a rotating target anode 16 attached to a shaft 18 mounted within a rotor and bearing means 20 for rotation in a conventional manner in response to an electromagnetic field produced by coils (not shown) supported exterior to the envelope. The cathode means 12 includes a cathode cup focusing electrode 22 and a pair of filament cathodes 24 and 26 mounted within two separate openings 28 and 30 provided in the focusing cup 22 spaced and insulated therefrom. As a result, the electron beams emitted by filaments 24 and 26 strike a target surface 32 on the rotating anode 16 at two different sized focal spots 34 and 36 corresponding respectively to filaments 24 and 26. The target anode is made of tungsten or other conventional x-ray emitting material so that at high voltages between the cathode filaments and the target anode, the electrons emitted by the filaments bombard the target surface with sufficient energy to cause x-rays to be emitted therefrom.

Both of the filament cathodes 24 and 26 are thoriated tungsten filaments which may be of the carbonized type shown in U.S. Pat. No. 2,558,603 so they are provided with a tungsten carbide layer on the surface of the filament beneath a thorium metal outer layer to cause such thorium metal layer to better adhere to the tungsten

body of the filament. Thorium has a lower thermionic work function than tungsten so the thorium metal layer provides the filament with a higher electron emission. It should be noted that other rare earth metals, such as cerium, can be employed in place of thorium for the electron emissive metal layer, and the following method also applies to the use of such other metal layers.

The filaments are formed by first winding metal wire containing tungsten and thorium oxide (or other rare earth metal oxide) into the coil shape shown and crimping the ends of such wire into nickel tubing for supporting the filament within the focusing cup 22. Next, the filament coil is coated with a layer of carbon by dipping the filament into a liquid suspension of distilled water and graphite particles. Then the coated filament is blown dry with low air pressure and mounted within the focusing cup 22 so it is electrically insulated therefrom. The mounted filament is then heated to a temperature of about 700° to 800° Centigrade in a reducing atmosphere, such as hydrogen, for several seconds sufficient to clean the surface of the filament and to cause the carbon layer to better adhere to the filament. It should be noted that this temperature is not sufficient to cause the carbon to react with the tungsten of the filament to produce tungsten carbide which is present in the final activated filament.

After the above steps have been completed, the completely assembled cathode means 12 is mounted within the envelope 10 along with the anode means 14 which are then sealed to the glass envelope in a conventional manner. A vacuum pump 38 is then attached by hose connection 40 to a tubular exhaust tip portion 42 of the envelope to begin exhausting gas from within such envelope. The envelope 10 and its contents are baked in an oven or other heated chamber to bake out the gas absorbed in the surface of the envelope and metal parts contained therein while continuing evacuation of the envelope with the vacuum pump 38. In addition, a radio frequency induction heater 44 may be employed to heat the cathode and other metal parts to an even higher temperature for greater outgassing. When bake out of the envelope and induction heating of the cathode is completed, the envelope 10 has been evacuated to a low pressure on the order of  $10^{-6}$  torr or less.

Next, while continuing evacuation, a variable high A.C. voltage source 46 having a maximum peak voltage of up to 10 kilovolts is applied between the filaments 24 and 26 and the focusing cup 22 for "seasoning" of these electrodes to prevent erratic electron emission during normal operation of the x-ray tube. Thus, the high voltage source 46 is connected at one output terminal to a common lead 48 attached to one end of each of the filaments 24 and 26. The other terminal of the voltage source 46 is connected to a lead 50 attached to the focusing cup electrode 22 when a switch 52 is in the position shown. The output voltage of the voltage source 46 is gradually increased from a low initial value of several hundred volts to a maximum of several thousand volts to cause field emission electron discharges between both of the filaments and the focusing cup electrode adjacent thereto due to the close spacing of about 0.025 inch between such electrodes. The discharges will be alternately from the filament to the focusing electrode and from the focusing electrode at the sharp edges of holes 28 and 30 to the filament on successive half cycles of the A.C. voltage waveform. This

continues, until as a result of localized heating, the discharge surfaces of the filament and the focusing cup are smoothed sufficiently to prevent further field emission discharges at such high voltage. It should be noted that the filaments 24 and 26 are unactivated during this step and such filaments are electrically insulated from the focusing cup with sufficient insulation to withstand the high voltage used during this "seasoning" operation.

Next, one of the unactivated cathode filaments is heated to a high temperature to activate such filament while continuing evacuation of the envelope. Previous to this step the unactivated filaments consist of a coiled wire of tungsten and thorium oxide having a carbon coating thereon. At this time one of these unactivated filaments is heated by transmitting current thereto to a temperature of about 2,527° to 2,627° Centigrade for approximately ten seconds to reduce at least some of the thorium oxide to thorium metal. Then, the temperature is reduced to about 2,127° Centigrade, still above the melting point of 1,840° Centigrade for thorium, and maintained at that temperature to cause the liquid thorium metal to flow to the surface of the filament. At the same time, the carbon coating migrates into the wire and reacts with the tungsten of of such wire to produce a layer of tungsten carbide ( $W_2C$ ) on the surface of the filament beneath the thorium metal layer. The tungsten carbide layer may have a thickness on the order of 25 percent or less of the cross-sectional area of the wire which is controlled by the heating time of about 10 minutes. The resulting activated filament has an outer layer of thorium metal bonded to the tungsten filament by an intermediate layer of tungsten carbide. Since this outer layer of thorium metal has a lower work function than tungsten, the activated filament emits a greater electron current than the unactivated filament or a filament solely of tungsten at a given voltage and temperature.

Then, the activated filament is used to bombard the target anode 16 with an electron beam of high current on the order of 50 to 70 milliamperes for outgassing the anode while continuing evacuation of the envelope. This is accomplished by moving the switch 52 to the other position to disconnect A.C. voltage source 46 from the focusing cup and by moving another switch 53 to the other position from that shown to connect the positive terminal of a variable high D.C. voltage source 55 of 0 to 60 kilovolts to the target anode 16. A low voltage source 54 is connected by a switch 56 across one of the filaments 24 and 26 to heat the activated filament sufficiently for thermionic emission of electrons. The low voltage source 54 is connected at one terminal to the common filament lead 48 and at its opposite terminal to the moveable switch contact 56 which may be connected to the other end of either filament 24 or 26 through leads 58 and 60, respectively. It should be noted that another switch contact 62 may connect a low positive D.C. voltage terminal on source 54 to the cathode cup focusing electrode at this time to focus the electrons onto the target. Thus, movable switch contact 62 may be ganged to switch contact 52 and switch contact 53 so that when contact 53 is connected to the anode, the contact 62 is connected to the focusing cup. However, it is also possible to connect the focusing cup to the same potential as the energized filament.

After bombardment of the target anode, the exhaust cycle is completed and the tube envelope is sealed by

melting the exhaust tip 42. This provides an evacuated envelope of extremely high vacuum which may be maintained by providing a suitable gettering material which is flashed to form a coating on the inner surface of the glass envelope. Next, the tube is further seasoned by applying high anode to cathode voltages in excess of its maximum rated voltage while operating the activated filament with a relatively low heating current to cause an electron emission of a few milliamperes.

If not already activated, the second filament may now be activated in a similar manner to that described above and then both filaments are aged by heating them above the melting temperature of thorium, for example about 1,900° Centigrade, for a long time which may vary from about 30 minutes to several hours to provide a more uniform layer of thorium metal over the surface of the filaments. Following this ageing, the tube is again seasoned by applying high anode to cathode voltages while causing heating current to flow through the filaments to provide electron emission on the order of a few milliamperes. Finally, high milliamper electron beam currents are caused to be emitted from the filaments for different exposures on the order of 30 to 500 milliamperes depending on the size of the focal spot on the target surface 32 at the normal operating voltages of the tube, and the corresponding heating current flowing in the filaments is recorded.

It will be obvious to those having ordinary skill in the art that many changes may be made in the above-described details of the preferred embodiment of the present invention without departing from the spirit of the invention. For example, the tungsten filament cathodes can be provided with an electron emissive layer of a low work function material other than thorium, such as cerium or the other rare earth metals disclosed in U.S. Pat. No. 2,919,362 of Z. J. Atlee. Also the filaments 24 and 26 need not both be insulated from the focusing cup in which case only the insulated filament would be seasoned and activated during evacuation. Therefore, the scope of the present invention should only be determined by the following claims.

We claim:

1. A method of manufacture of an x-ray tube having an activated tungsten filament cathode, including the steps of:

assembling an unactivated filament of tungsten and a rare earth metal oxide, a focusing electrode, and a target anode within an envelope;

evacuating gas from the envelope;

applying a sufficiently high voltage between the unactivated filament and the focusing electrode adjacent thereto during said evacuation to cause field emission discharges between said filament and said focusing electrode thereby to effect localized heating and vaporization of irregularities on their discharge surfaces, and maintaining said high voltage until the surfaces of said filament and focusing electrode are made smoother to prevent further field emission discharges at said voltage;

thereafter heating the unactivated filament during said evacuation above the temperature necessary to convert said metal oxide to an electron emissive metal having a lower thermionic work function than tungsten and to cause a layer of said emissive metal to form on the surface of said filament and provide an activated filament;

bombarding the target anode with electrons while continuing said evacuation; and thereafter terminating said evacuation and sealing said tube envelope.

2. A method in accordance with claim 1 in which the metal oxide is thorium oxide and the emissive metal is thorium and which also includes applying a coating of carbon on the surface of the unactivated filament and heating said carbon coated filament during said evacuation to provide a layer of tungsten carbide compound under the thorium metal layer on the activated filament.

3. A method in accordance with claim 2 in which the carbon coating is formed by dipping the filament in a liquid suspension of carbon particles and drying the coated filament to remove the liquid from the coating before assembly of the filament in the tube envelope.

4. A method in accordance with claim 2 in which the tungsten carbide layer is formed by the same heating step which forms the thorium metal layer.

5. A method in accordance with claim 4 in which the carbon coated filament is preheated in a reducing atmosphere to a temperature below that necessary to form said tungsten carbide compound before applying the high voltage to the unactivated filament.

6. A method in accordance with claim 1 in which the high voltage applied between the unactivated filament and the focusing electrode is an A.C. voltage which alternately causes field emission of electrons from the filament to the focusing electrode and from the focusing electrode to the filament.

7. A method in accordance with claim 1 in which the bombardment of the target anode is by thermionic emission electrons emitted by the activated filament.

8. A method in accordance with claim 7 in which the bombardment takes place after the envelope is heated and evacuated to a low pressure of less than about  $10^{-6}$  torr within the envelope.

9. A method in accordance with claim 1 in which the tube is an x-ray tube having a rotatable target anode.

10. A method in accordance with claim 9 in which a

second filament is provided within the tube envelope and is activated in the same manner as the first mentioned filament, and the focusing electrode is a cathode cup electrode surrounding the two filaments to provide a dual focus x-ray tube.

11. A method in accordance with claim 10 in which the second filament is activated after sealing the tube envelope.

12. A method in accordance with claim 1 in which the metal oxide is thorium oxide and the emissive metal is thorium.

13. A method of manufacture of an x-ray tube having an activated tungsten filament cathode, including the steps of:

providing an unactivated filament of tungsten and a rare earth metal oxide;

applying a coating of carbon on the surface of the unactivated filament;

assembling the filament and a target anode within an envelope;

evacuating gas from the envelope;

heating the carbon coated filament during such evacuation to provide a layer of tungsten carbide compound on said filament, and to convert said metal oxide to an electron emissive metal having a lower thermionic work function than tungsten so that a layer of said emissive metal forms on the surface of said filament over said tungsten carbide layer to provide an activated filament;

bombarding the target anode with electrons emitted by said activated filament while continuing said evacuation; and

thereafter terminating said evacuation and sealing said envelope.

14. A method in accordance with claim 13 in which the carbon coating is formed by dipping the filament in a liquid suspension of carbon particles and drying the coated filament to remove the liquid from the coating before assembly of the filament in the tube envelope.

15. A method in accordance with claim 13 in which the metal oxide and the emissive metal is thorium.

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UNITED STATES PATENT OFFICE  
CERTIFICATE OF CORRECTION

Patent No. 3,846,006 Dated November 5, 1974

Inventor(s) ZED J. ATLEE and ROBERT M. GAGER

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Claim 15, line 2, after "metal oxide" insert

--is thorium oxide--.

In the title, "Manufacturing" should be "Manufacture".

Signed and sealed this 31st day of December 1974.

(SEAL)

Attest:

McCOY M. GIBSON JR.  
Attesting Officer

C. MARSHALL DANN  
Commissioner of Patents