

[54] **HIGH VOLTAGE INSULATOR HAVING
A THICK FILM RESISTIVE COATING**

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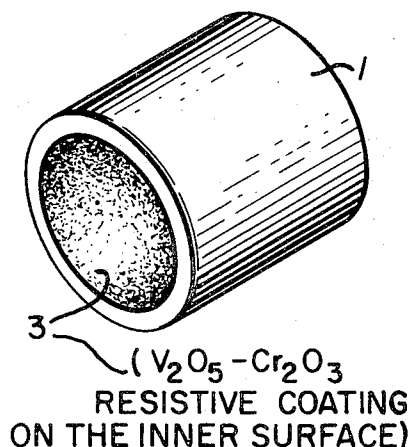
Attorney—Ronald M. Goldman et al.

[57]

ABSTRACT

A hollow cylindrical electrical high voltage insulator, suitably an aluminum oxide ceramic material, adapted for use in an electron discharge device includes a fused thick film resistive coating on its inner surface that is on the order of 0.002-inch in thickness and which has a resistivity in the range of 3×10^8 to 10^{13} ohms per square at an ambient temperature of 75°F. In one embodiment the thick film resistive coating is a vanadium-pentoxide chrome-sesquioxide mixture. The coating permits dissipation of surface charges and prevents high energy electrons from penetrating through to the insulator surface.

8 Claims, 4 Drawing Figures



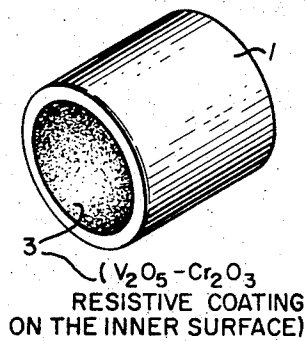


Fig. 1

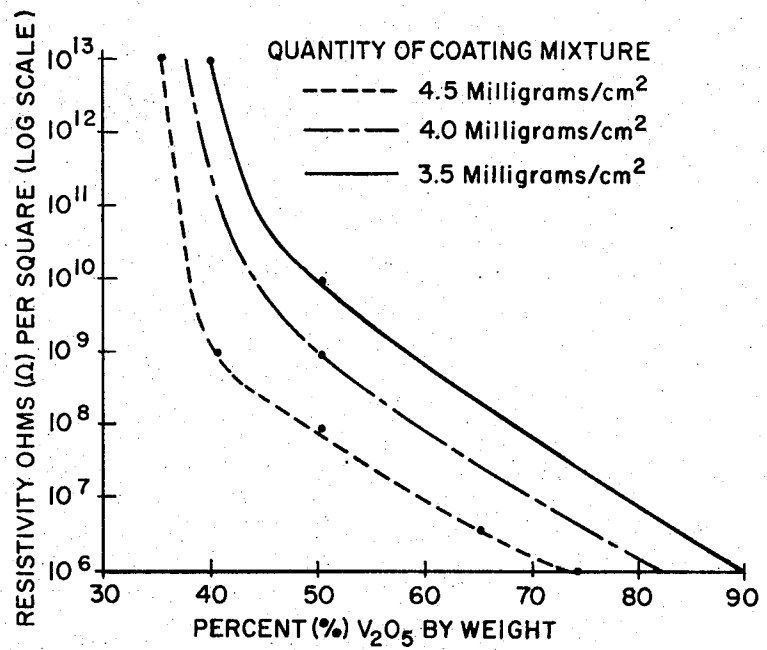


Fig. 2

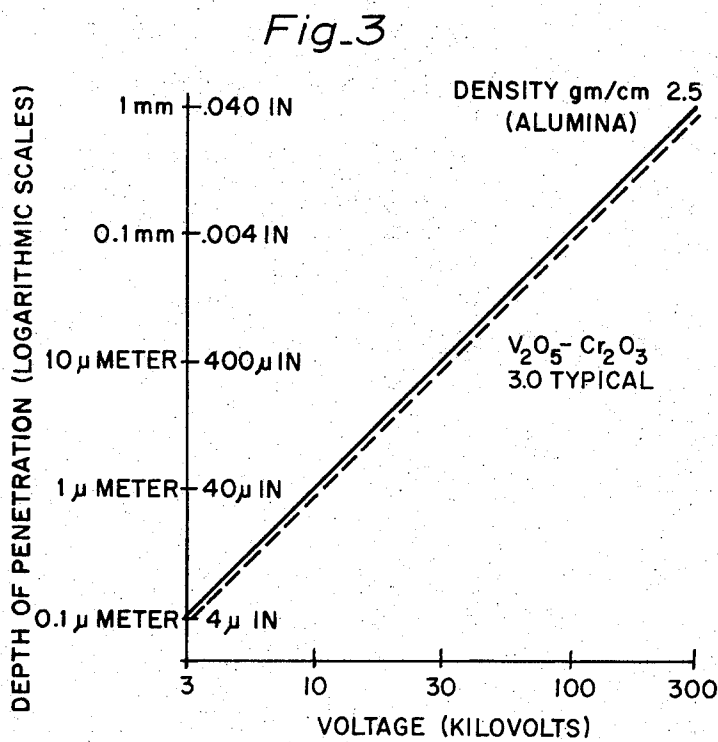


Fig. 3

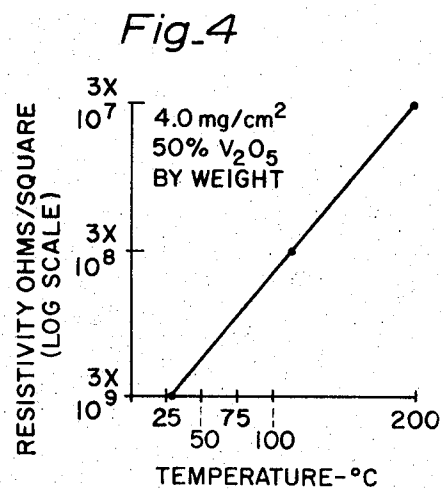


Fig. 4

HIGH VOLTAGE INSULATOR HAVING A THICK FILM RESISTIVE COATING

FIELD OF THE INVENTION

This invention relates to electrical high voltage insulators and, more particularly, to high voltage insulators incorporated as elements of electron discharge tubes.

BACKGROUND OF THE INVENTION

Electrical insulators are used in electrical systems and devices to space apart or support in spaced relationship other elements, usually electrical conductors, which in use are at different electrical potentials or voltages. As the nomenclature "insulator" denotes, the insulator is a very poor conductor of electrical current. Thus electrical discharges or current cannot flow, effectively, between the two elements. Some forms of conventional high voltage insulators are widely known to the ordinary person. One such insulator is that visible on high voltage power lines. In this application, the high voltage wires are mechanically supported to a metal frame or post by means of a porcelain-like body which forms the insulator. Insulators are included as support or spacer elements in high-voltage high-vacuum electron discharge devices, such as electrical switch tubes. In the latter application, and by way of example, an insulator in the shape of a hollow cylinder is used to support apart the anode (collector) and cathode-potential (shield) electrodes of such devices and those electrodes are normally maintained at a voltage difference of 160 kilovolts. Since the elements of the device are in a high-vacuum region, the insulator in this case is nonporous in order to maintain the integrity of the vacuum and is exposed to stray magnetic fields, the importance of which hereinafter becomes apparent.

In many instances, resistive coatings, coatings of material having slight electrical conductivity, are applied to the surface of such insulators in order to eliminate the phenomenon of surface charging and surface charge related discharges. Absent the conductive path provided by the resistive coating, it is possible for electrical charges to accumulate and be stored on the insulator surface much like an electrical capacitor. However when the charge becomes sufficiently large it will discharge or "arc" from the insulator surface to an adjacent element. Often this sudden discharge of stored charge causes damage to both the insulator and adjacent element. By providing a highly resistive coating a path is provided for these charges to bleed off at low current levels to the supported electrodes so that the critical aspects and insulating qualities desired in an insulator are maintained.

A related aspect is that the resistive coating minimizes or has a lower coefficient of secondary emission than the secondary emission coefficient of the bare insulator surface. Typically the coefficient of secondary emission of an insulator such as alumina is greater than one. Hence any electron which bombards the surface of the insulator can knock out one or more additional electrons which, in turn, and particularly in the presence of a magnetic field, reverses direction and strikes the insulator surface, again repeating the process. Such a phenomenon causes undesired heating of and deleteriously affects the insulator. By coating the surface with a material of lower secondary emission

coefficient, the possibility of this type of continuous action is reduced or altogether eliminated.

Previous successful resistive film insulator coatings were usually metals in very thin layers, typically on the order of 30 to 100 Å (Angstroms) or, expressed in inches, 0.12×10^{-6} to 0.4×10^{-6} inches and those coatings were applied by conventional evaporation or sputtering techniques onto the ceramic surface of the insulator. Because the metals possess high bulk conductivity, such films were on the order of less than one atom in thickness in order to provide the very high resistivities approaching the resistivity of a good insulator required in this application. Another alternative is a semi-conducting material which can be used to achieve the high resistivities. However, due to the method of depositions used, the thickness of such material was necessarily on the same order of thickness as the metal coatings. One resistive metal film used on insulator surfaces is titanium, however such thin coatings become discontinuous in high temperature processing leaving insulating gaps, or are too conductive for use in high-voltage high-power applications. Moreover, titanium oxidizes or reduces at the high temperatures encountered in processing of electron discharge devices, depending upon the baking atmosphere, which changes the resistive characteristics in an unpredictable manner. Such an instability makes control of the final product difficult.

Another related aspect is that the thin resistive coatings allowed high energy electrons to reach the main insulator body. Should substantial numbers of high energy electrons penetrate the insulator body, such as in a discharge of accumulated charge, it could destroy the insulator both electrically and mechanically.

OBJECTS OF THE INVENTION

Accordingly, it is an object of the invention to provide a high voltage electrical insulator with a novel resistive coating for an electron discharge device.

It is an additional object of the invention to provide a resistive coating for a high voltage insulator of an electron discharge device that both prevents accumulation of electrical charges on the insulator surface and protects the insulator surface from high energy electrons.

It is a still further object of the invention to provide a high voltage electrical insulator of an electron discharge device which does not accumulate electrical charges on its surface and which does not crack under bombardment by high energy electrons.

In accordance with the invention, a resistive coating is applied to the inner surface of a hollow cylindrical high voltage electrical insulator, suitably aluminum oxide, which possesses an electrical resistivity on the order of between 3×10^8 and 10^{13} ohms per square at 75°F. and having a thickness sufficient to prevent substantial electron penetration at the voltage levels encountered, such as at least 0.0001-inch in thickness at 30 kilovolts. Suitably, the resistive coating is a continuous layer of resistive material. Further, in accordance with the invention, the resistive material comprises a mixture of vanadium-oxide and chromium-oxide. In the manufacture of the novel insulator of the invention, vanadium-pentoxide (V_2O_5) and chromium-sesquioxide (Cr_2O_3) powders, 100 grams each, are mixed

together in a liquid suspension to form a slurry and in this form the resistive mixture is sprayed onto the surface of the insulator to a depth of 0.002-inch or the depth formed by evenly spraying a quantity of 70 milliliters over a surface area of 2000 square centimeters. The entire assembly is baked in a wet hydrogen atmosphere dew point of +80°F at a temperature of 1550°C for 30 minutes to fuse the mixture to the ceramic surface. The resistive coating is of the desired thickness and resistivity with which to prevent substantial electron penetration of the insulator and is of the desired resistivity with which to gradually bleed off charges.

The foregoing objects of the invention, together with additional objects and advantages of same, and equivalent and substituent elements for the elements of the invention, together with the method of making and using the invention, are better understood from a consideration of the detailed description of a preferred embodiment of the invention which follows, taken together with the figures of the drawings.

DESCRIPTION OF DRAWINGS

In the drawings:

FIG. 1 illustrates a preferred embodiment of an insulator of the invention;

FIG. 2 illustrates graphically the resistivity of a preferred coating material, vanadium-pentoxide chrome-oxide, plotted as a function of the composition and thickness of that preferred resistive material as applied to said insulator;

FIG. 3 illustrates graphically the theoretical electron penetration of materials of various density as a function of voltage; and

FIG. 4 illustrates the change in resistivity as a function of temperature of one specific example of the preferred resistive material.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 shows a hollow cylindrical shaped insulator 1, suitably of aluminum oxide ceramic material. In this geometry the cylinder is used for support and separation between the collector and shield electrodes found in an electron discharge device denoted switch tube, such as that made available by Litton Industries, Electron Tube Division, San Carlos, Calif. under the designation of L-5033, and in that application on the order of 10 inches in radius and 10 inches in length. A coating of resistive material 3 is included on the inner surface of insulator 1. In the preferred embodiment, the resistive coating is fused to the alumina ceramic, as hereinafter becomes apparent, and comprises a mixture of vanadium-oxide and chromium-oxide in the preferred ratio by weight of 50 to 50 percent and is of a thickness of 0.002-inch to operate at fields of between 30 kilovolts to 100 kilovolts.

The embodiment of FIG. 1 is manufactured by obtaining first a clean ceramic material of the desired shape, such as the cylinder of FIG. 1. The ceramic cylinder is mounted for rotation in a glass lathe in order to receive a spray coating solution.

The coating solution is prepared by mixing together amounts of chromium-sesquioxide and vanadium-pentoxide in a lacquer solution. One suitable lacquer solution uses the following ingredients: Ethyl Cellulose

Type N-200, 168 CPS, 48.8 percent; Ethoxyl, Socal 25, a petroleum solvent such as available from the Standard Oil Company; reagent grade Methyl Isobutyl Ketone and Beckocite solution which contains a resin such as P458A-60 available from the Reichold Chemical Company. Twelve hundred milliliters or 60 percent by volume Socal 25 is mixed together in a glass jar with 800 milliliters 40 percent volume Methyl Isobutyl Ketone, and 30 grams Ethyl Cellulose and 2 ½ grams Beckocite solution, and the mixture is rotated on a milling or rolling unit until the Ethyl Cellulose is completely dissolved. This provides a fast drying lacquer solution. Next, 100 grams of chromium-sesquioxide (Cr_2O_3) of mesh size 230 or smaller, and 100 grams of vanadium-pentoxide (V_2O_5) of mesh size 100 or smaller, is mixed together in a glass jar with 260 milliliters of the lacquer previously prepared as described. The glass jar is capped and preferably rotated on a rolling unit to render the mixture homogenous.

Preferably the viscosity of the coating solution should be of 24° Baume. Should the viscosity be too great, a thinner consisting of 60 percent solvent No. 25, or other compatible equivalent, and 40 percent Methyl Isobutyl Ketone can be added until the viscosity is reduced to the preferred figure.

Approximately 70 milliliters of the coating solution is transferred into an air brush jar and the air brush is mounted to a traveler on the lathe so that it moves into and out along the axis of the ceramic cylinder.

Upon operation of the lathe, the cylinder rotates at approximately 125 revolutions per minute while the nitrogen supply for the air brush is operated and adjusted to 12 PSI. As the cylinder rotates, the air brush travels longitudinally at approximately 12 inches per minute along the axis of the cylinder and sprays the contents of the jar on the inner walls of the insulator. This continues until the entire 70 milliliter coating is consumed. A sample can be removed and checked with an optic depth micrometer so that the thickness of the coating at this stage appears to be about 0.0002-inch thick. The insulator cylinder is then removed and hydrogen fired at 1550°C. for 30 minutes at a dew point of +80°F. Subsequently the insulator is placed in an air furnace maintained at a temperature of 40°C. for a period of 2 hours. By firing, the lacquer is burned off and the ceramic powders form a ceramic mixture of elements or "glaze" which diffuse into the aluminum-oxide. The resultant resistivity should measure between 30,000 megohms (3×10^{10}) to 60,000 megohms (6×10^{10}) per square.

The hollow cylindrical insulator of FIG. 1 is normally included in an electron discharge switch tube in which a collector electrode at one electric potential protrudes through one end of the cylinder and a shield electrode maintained at a different electrical potential protrudes through the front end of the cylinder so that both of these metal elements are within the hollow of the cylinder. The ceramic insulator itself forms a wall for the tube and is exposed to the ambient air along its external surface while its inner surface is maintained in vacuum with the other electron tube elements. Because both elements are located within the hollow of the cylinder, it is necessary to coat only the inner surface. Thus, in that instance electrical charges can drift or

bleed through the resistive coating off of the insulator to one or the other of those elements. Likewise any high energy electrons that may travel toward the cylinder wall and strike the resistive coating would not penetrate through to the alumina ceramic of the insulator. It is apparent that in other applications and with other types of insulators it may be necessary to coat merely the outer surface of the insulator or both the inner and outer surface and, depending upon the particular requirements of the electrical system with which the insulator is arranged, it may be necessary to coat only some portion of the insulator surface. The resistive coating thus is found to provide the desired degree of resistivity between 10^9 and 10^{13} ohms per square with which to allow electrical charges to bleed off the insulator. Concurrently in obtaining resistances in this range the resultant film layer is "thick"; that is, between 0.001-inch and 0.003-inch in thickness, and is essentially continuous over the coated areas of the insulator. Thus it is found that high energy electrons of between 3,000 and 100,000 electron volts either do not penetrate through this film or in penetrating the film give up substantial portions of their kinetic energy so as to avoid the release of such energy on the aluminum oxide ceramic insulator itself which could otherwise result in cracking the insulator. In the specific example given for a resistive film that has been found desirable and suitable to meet this requirement, the combination of the vanadium-pentoxide and chromium-oxide in the specific mixture of 50 percent by weight vanadium-oxide and 50 percent by weight of chromium-sesquioxide deposited to a depth of 4.0 milligrams per square centimeter, or 0.001-0.002 inch, serves that purpose.

Obviously, as is brought out in the graphical evaluation of the characteristics of this material presented in FIG. 2, a range of permissible variations in the specific composition of that resistive compound are available. Thus the solid curve in FIG. 2 represents a deposit of 3.5 milligrams per centimeter square, or 0.0014-inch of resistive compound. The dashed line represents a layer thickness of 4.5 milligrams per centimeter square, or 0.0018-inch, and the dash-dot curve represents a layer thickness of 4.0 milligrams per centimeter square, or 0.0016-inch. Each of the foregoing curves defines the resistivity of the material as a percentage by weight of vanadium-pentoxide. Basically it is believed that a thickness of 3.5 milligrams per centimeter square, or 0.0014-inch, represents a minimum desirable thickness for the resistive layer of the invention. Thus for a composition containing between 35 and 40 percent vanadium-pentoxide the resistivity of the material varies between 10^{13} and 10^9 ohms per square, respectively. For the 4.0 milligrams per square centimeter thick layer, this same range of resistivity is obtained by approximately the range of 37 to 50 percent vanadium-pentoxide and at the 4.5 milligrams per centimeter square thickness layer the corresponding range of resistivity is obtained by a percentage mixture containing between 40 and 58 percent vanadium pentoxide.

Basically it can be seen that the resistive mixture should comprise at most 70 percent by weight vanadium-pentoxide and minimally 30 percent vanadium-pentoxide in order to obtain the requisite resistivity and thickness.

The theoretical depth of penetration of electrons for various materials as a function of voltage is graphically illustrated in FIG. 3. Thus at a voltage of 100 kilovolts, alumina, aluminum oxide, of density 2.5 grams per cubic centimeter, must possess a thickness of approximately 0.004-inch to capture the electron and prevent penetration. At 30 kilovolts only a thickness of near 0.400×10^{-6} inches (0.0004-inch) is required. The density of the vanadium-pentoxide chromium-sesquioxide ceramic mixture (50 percent by weight of each compound) is perhaps about 3 grams per cubic centimeter or near that of alumina. As is apparent from the graph, exposure to electrons having energy from 100 kilovolts maximum should be on the order of 0.002-inch in thickness. Thus the coating protects the insulator from electron penetration.

Obviously, as the thickness of the resistive layer is increased to prevent penetration by electrons, the layer resistivity decreases. The resistivity must remain high, i.e. low enough to permit electrons or other charge to bleed off slowly, yet high enough so that the insulator retains its fundamental characteristic as an electrical insulator and suitably in the range of 3×10^8 to 10^{13} ohms per square. To continue to increase the thickness of the resistive coating of presently used resistive coatings would serve to reduce the resistivity of the coating to unacceptably low levels. With the vanadium-pentoxide chromium-sesquioxide composition both properties of desired thickness and resistivity are obtained.

Obviously, while the sintered ceramic mixture of vanadium-pentoxide (V_2O_5) and chromium-sesquioxide (Cr_2O_3) has been found to be a suitable resistive material for the practice of the invention, it is apparent that other or equivalent materials are apparent to those skilled in the art or may be found in accordance with the teachings presented herein.

One such additional mixture would appear to be vanadium-pentoxide, titanium-dioxide, and chromium-sesquioxide mixtures in suitable portions, as well as other mixtures of chromium-oxide and titanium-dioxide.

The vanadium-pentoxide chromium-sesquioxide resistive layer possesses, additionally, thermistor characteristics. In other words, the material changes its resistivity with changes in temperature. This additional characteristic, while not necessary desired in all insulator applications, is useful with the insulator of FIG. 1 in its particular application. As noted by the curve in FIG. 4, which is for a 4.0 milligrams per square centimeter coating of a vanadium-pentoxide chromium-oxide mixture in the proportion by weight of 50 percent of vanadium-pentoxide and 50 percent chromium-oxide, the resistivity in ohms per square is plotted on a logarithmic scale as the function of temperature in degrees centimeter. Thus, as indicated at approximately 25°C ., the resistivity is 3×10^9 ohms per square. At approximately 112°C . the resistivity drops in order of magnitude to 3×10^8 ohms per square.

In a high energy electron environment where the resistive coating is or may be constantly bombarded by high energy electrons which release large amounts of kinetic energy, this kinetic energy appears physically in the form of heat and this, in turn, raises the temperature of the thick film resistive layer. In that event, the

resistivity of the layer drops, or as otherwise termed, the layer becomes more electrically conductive. In that event, any charges induced on the insulator are dissipated more quickly; hence the thermistor effect in this application provides a self-protective physical mechanism.

An additional aspect of the invention resides in the texture of the resistive coating. The vanadium-pentoxide and chromium-sesquioxide powders introduced in the mixture as previously described are of a mesh size of between 100 and 300 mesh. This provides a "rough" surface, as measured by a conventional stylus profilometer, of 250 to 400 microinches, root mean square (RMS) roughness. Due to surface roughness the possibility of secondary electron emission from the resistive layer itself is minimized.

It is believed that the foregoing description of a preferred embodiment clearly explains how to make and use the invention. However, it is expressly understood that the details as have been presented in connection with that description are illustrative and are not intended to limit the scope of the invention in any way, since numerous modifications of the invention become apparent to those skilled in the art upon reading this specification. Accordingly, our invention is to be broadly construed within the spirit and scope of the appended claims.

We claim:

1. An electrical insulator for spacing apart two different elements of an electron discharge device and having at least two spaced locations on its surface for contacting, respectively, two different elements of said electron discharge device comprising a hollow cylindrical body of electrically insulative ceramic material adapted to receive therewithin a first electrode element which protrudes thereinto through one end of said body and adapted to receive therewithin a second electrode element which protrudes thereinto through the opposed end of said body and a resistive coating fused to the inner surface of said body and covering the inner surface area thereof including said two locations; said resistive coating having a resistance of between 3×10^8 and 10^{13} ohms per square at a temperature of 75° F.

and having a thickness of at least 0.001-inch.

2. The invention as defined in claim 1 wherein said ceramic body comprises aluminum oxide and wherein said resistive coating comprises a fired mixture of vanadium-pentoxide and chromium-sesquioxide powders.

3. The invention as defined in claim 2 wherein said vanadium-pentoxide comprises between 30 and 70 percent by weight of the weight of said resistive material and said chromium-sesquioxide comprises the remainder.

4. The invention as defined in claim 3 wherein said vanadium-pentoxide and chromium-sesquioxide comprise in original form a powder having a mesh size of between 100 and 300 so as to provide a rough surface, as measured by a stylus profilometer, of 250 to 400 microinches, root-mean-square roughness.

5. The invention as defined in claim 2 wherein said vanadium-pentoxide comprises 50 percent by weight of said resistive coating and said chromium-sesquioxide the remainder, and wherein said thickness of said coating is 0.002-inch.

6. An electrical insulator for an electron discharge device which comprises a hollow cylindrical body of ceramic material adapted to receive therewithin a first electrode which protrudes thereinto through one end of said body and adapted to receive therewithin a second electrode which protrudes thereinto through the opposed end of said body and a thick-film, fired-on sintered ceramic electrically resistive coating in a continuous layer over the inner surface of said cylindrical body for providing a resistance of 3×10^8 to 10^{13} ohms per square so as to prevent the accumulation of electrical charges on said insulator and having a thickness of at least 0.001-inch for preventing penetration of high energy electrons to the surface of the insulator body.

7. The invention as defined in claim 6 wherein said fired ceramic coating comprises vanadium-pentoxide and chromium-sesquioxide powders.

8. The invention as defined in claim 6 wherein said coating has a surface roughness of between 250 to 400 microinches, root-mean-square, as measured by a stylus profilometer.

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