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(54) Black oxide-containing coaxial cable and method of making the same

(57) The coaxial cable (10) has a metallic signal-transmitting core (12), a dielectric component (14) which is resistant to temperatures of at least about 1000 degrees C., preferably 1000-1100 degrees C., surrounding the core, and a sheath (16) of stainless steel surrounding the dielectric component and core. The outer surface (20) of the sheath (16) has an adherent protective black oxide layer (22) which comprises chromium oxide, preferably in the form of chromic oxide, with essentially the remainder of the black oxide layer being iron oxide. The stainless steel sheath (16) preferably has about 18-20 weight percent of chromium with essentially the remainder being iron. The black oxide layer (22) is formed on the outer surface (20) of the assembled coaxial cable (18), in accordance with the present method, by passing the coaxial cable through a furnace having a hydrogen-free, wet-nitrogen atmosphere, at a temperature of at least about 1000 degrees C., preferably about 1000-1100 degrees C., and for a residence time in the furnace of about two to about five minutes.

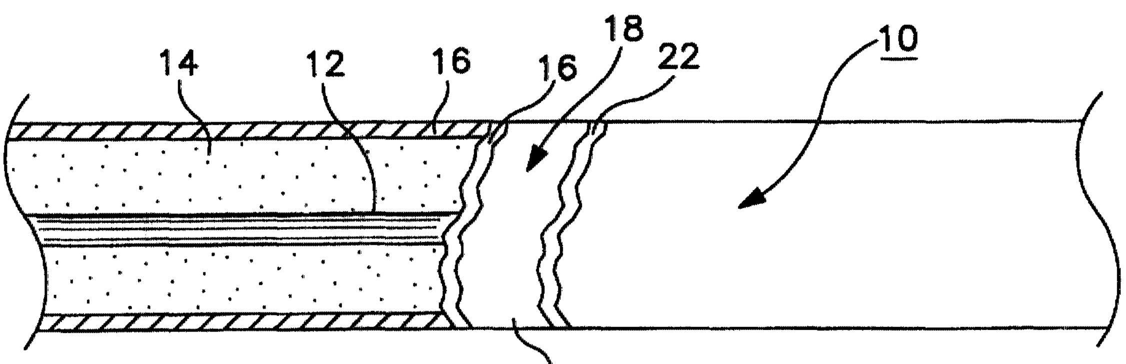

FIG. 1

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Description

[0001] The present invention generally relates to coaxial cables and more particularly to a stainless-steel-sheathed coaxial cable -having a black oxide surface coating and to a method of making the same.

[0002] A substance that absorbs all the radiation of any wavelength falling upon it is known as a black body. Such a body will emit the maximum intensity of radiation for any given temperature. Blackbody surfaces with high emissivity have been used for heat radiation, since no other surface can emit more heat radiation. Such surfaces are in great demand for space applications for coaxial and waveguide transmission lines. In addition to their radiative properties, blackbody surfaces are used as electrostatic discharge bleed-off paths.

[0003] Conventional methods of preparing the external surfaces of transmission lines for blackbody radiation comprise either chemically glazing or ceramically coating the surface. Chemical glazing is usually carried out by first cleaning the surface to be coated, then applying a primer to .the surface and thereafter coating the surface with a black paint. Ceramic coating, generally used for higher temperature applications, is usually carried out by applying a ceramic material such as silicon carbide to the surface.

[0004] However, there are disadvantages with both of these methods. Chemical glazing causes air pollution and the resulting glaze has a low maximum operating temperature as a coating of about 350 degrees F. before it is degraded. Moreover, the coating has limited bending ability. In addition, paint peeling often occurs during and after processing so that the product yield and product durability are low.

[0005] The ceramic coating method results in a hard brittle surface coating which cannot be flexed or bent. This problem limits handling and use of the ceramic coated product. Such product is also subject to damage due to flight-induced vibration in space applications. Moreover, the ceramic coating method is very costly and time consuming.

[0006] Accordingly, there is a need for an improved, low cost, rapid method of imparting a durable, high-temperature-resistant blackbody coating to a coaxial cable. The coating should also be flexible and abrasion resistant.

[0007] The present invention provides a cable and a method as defined in claims 1 and 6 respectively. Preferred features of embodiments of the invention are set out in the dependent claims.

[0008] The method comprises passing an assembled coaxial cable of a specific type through a treating furnace under selected conditions. The cable has a metallic core conductor surrounded by a dielectric capable of resisting degradation at a temperature of at least about 1000 degrees C., preferably about 1000-1100 degrees C. The dielectric and core are surrounded by a stainless steel sheath having a chromium content of at least about 18 weight percent, preferably about 18-20 weight percent, with essentially the remainder of the stainless steel being iron.

[0009] In a preferred embodiment of the invention, the cable is treated in the furnace in a hydrogen-free, wet nitrogen atmosphere at at least about 1000 degrees C., preferably 1000-1100 degrees C., which is a temperature which does not degrade the dielectric. The residence time in the furnace is sufficient to form the desired blackbody coating in the form of a black oxide layer on the exterior surface of the stainless steel sheath. Thus, the residence time is usually from about two to about five minutes. The wet nitrogen is introduced into the furnace from a storage container where it is maintained at a pressure of about 20 p.s.i. The nitrogen is bubbled through a water chamber and mixed with air prior to introduction into the furnace.

[0010] The treated black oxide layer-containing coaxial cable is then passed from the furnace and cooled to ambient temperature. The black oxide layer is adherent to the underlying surface of the stainless steel sheath and is relatively thin and flexible, but also is abrasion resistant and thermally stable at high temperatures and in normally corrosive atmospheres. It comprises chromium oxide, preferably as chromic oxide. The remainder of the black oxide layer essentially comprises iron oxide. It has an emissivity value which is close to that exhibited by the previously known chemical glazing and ceramic coatings.

[0011] Various other features of the method of the present invention and the coaxial cable produced thereby are set forth in the following detailed description and accompanying drawings in which:

FIG. 1 is a schematic side elevation, partly broken away and partly in cross-section, of a preferred embodiment of the coaxial cable of the present invention, showing the black oxide coating formed on the exterior of the cable by the method of the present invention; and

FIG. 2 is a schematic side elevation of the furnace and conveyor assembly used in a preferred embodiment of the method of the present invention.

[0012] Now referring particularly to FIG. 1 of the drawings, a preferred embodiment of the coaxial cable of the present invention is schematically depicted therein. Thus, elongated, semi-flexible, generally tubular coaxial cable 10 is shown which comprises a central metallic transmission wire 12 running the length thereof and completely surrounded by a dielectric component 14, such as silicon dioxide, having suitable electrical characteristics, as well as a resistance to thermal degradation at up to at least about 1000 degrees C. and preferably up to about 1100 degrees C. Dielectric component 14 is completely surrounded by an outer tubular sheath 16 of stainless steel having a chromium content of at least about 18 weight percent, preferably about 18-20 weight percent or more. Essentially the remainder of the stainless steel is iron, with preferably not more than minor quantities of other metals.

[0013] Wire 12, dielectric component 14 and sheath 16 form an assembled coaxial cable 18 which is passed into, and heat treated in, the furnace employed in the present method to form coaxial cable 10 which, after treatment in accordance with the present method, includes an adherent blackbody on the exterior surface 20 of sheath 16 in the form of a black oxide layer 22 comprising chromium oxide, which may also contain iron oxide. The chromium oxide may be in the form of chromic oxide.

[0014] The method of the present invention can be carried out in any suitable heat treating equipment, such as that depicted in FIG. 2. FIG. 2 shows a furnace 24, such as a Watkins-Johnson conventional belt furnace having an input end 26 and an opposite output end 28 through which coaxial cable 18 is drawn by a wire (not shown) in order to form the desired black oxide layer on cable 18 which then becomes cable 10. In FIG. 2, cable 18 is shown passing from a cable input reel 30 and cable straightener 32 upstream from furnace 24 to and through furnace 24 and downstream thereof to a cable take-up reel 34 as cable 10 after production of the black oxide layer 22 thereon.

[0015] While in furnace 24, cable 18 is subjected to a black-oxide-forming temperature of at least about 1000 degrees C. in a hydrogen-free, wet nitrogen atmosphere. The wet nitrogen atmosphere as used in the present method is achieved by drawing nitrogen from storage containers where it is maintained at a pressure of about 20 p.s.i. and bubbling it through a water chamber before introduction into the furnace 24. In the furnace, the wet nitrogen is intermixed with air to some extent, since both ends of the furnace are open to atmosphere.

[0016] While in furnace 24, cable 18 does not contact any surface, so that the black oxide layer 22 formed thereon is uniform in thickness and extends over the entire exterior surface 20 of sheath 16. The residence time of cable 18 while in furnace 24 will vary, depending on the actual temperature employed in the furnace and the thickness of layer 22 which is desired, and also the concentration of chromium in sheath 16. However, normally the residence time for cable 18 in furnace 24 is from about two to about five minutes, resulting from a transit speed of either one foot per minute or two feet per minute through a furnace hot zone of approximately four to five feet in length.

[0017] Although stainless steel with a larger concentration than 20 weight percent of chromium, for example, up to 36 weight percent or more, can be successfully employed in the present method, such stainless steel is normally more expensive and less flexible than stainless steel having 18-20 weight percent of chromium and may require a longer residence time in furnace 24 to fully develop the black oxide layer 22 thereon. Therefore, for most purposes stainless steel with 18-20 weight percent chromium is employed in the present method.

[0018] Cable 10, which is the patentable product produced by the present method, has suitable blackbody characteristics, including an emissivity value which is not less than 0.7, due to black oxide layer 22. Layer 22 is tenaciously adherent to sheath 16 and is thermally stable at elevated temperatures. It also has sufficient flexibility so that cable 10 substantially retains its semi-flexible character and therefore can be rolled up on take-up reel 34 and successfully employed in a number of applications, including space applications. Cable 10 therefore has superior properties when compared to conventional coaxial cables, particularly in applications where high heat emissivity is desired.

[0019] The following specific examples illustrate certain features of the method and coaxial cable of the present invention.

EXAMPLE I

[0020] A coaxial cable meeting the characteristics set forth above and employing silicon dioxide as the dielectric component thereof and a stainless steel sheath known in the art as stainless steel 304L is treated in accordance with the previously described method of the present invention. Stainless steel 304L has the following concentrations, by weight percent of constituents: chromium -- 18-20; carbon -- 0.03; manganese -- 2 max.; nickel -- 8-12; phosphorus -- 0.045 max.; silicon -- 1 max; sulfur -- 0.03 max; remainder -- iron.

[0021] The furnace is a Watkins/Johnson belt furnace utilizing the auxiliary equipment set forth in FIG. 2 of the drawings, and in which the treating conditions are as follows:

> atmosphere = wet nitrogen, with no hydrogen present, prepared by drawing nitrogen from storage containers at a pressure of about 20 p.s.i. and bubbling it through a water chamber before introducing the gas into the furnace at atmospheric pressure.
> temperature = 1000 degrees C.
> residence time in the furnace = two minutes.

[0022] The black oxide layer formed on the exterior of the stainless steel sheath comprises chromium oxide, substantially the remainder of said layer being iron oxide. The layer is uniform, adherent, flexible and temperature stable at temperatures up to at least 900° F.

[0023] The finished coaxial cable therefore has superior blackbody properties.

EXAMPLE II

[0024] A coaxial cable substantially identical to the coaxial cable of Example I is used, except that the stainless steel sheath has a chromium concentration of about 36 weight percent. The treating conditions in the furnace of Example I are the same as in Example I, except as follows:

furnace residence time = five minutes.
furnace temperature = 1100 degrees C.

[0025] The finished treated cable has the same characteristics as the finished treated cable of Example I, except for a somewhat decreased flexibility for the black oxide layer and the sheath, and except for the fact that the black oxide layer is essentially chromium oxide.

EXAMPLE III

[0026] The coaxial cable being heat treated in Example III is the same as that of Example I and the treating conditions in the furnace are the same as in Example I, except as follows:

the furnace temperature is 1050 degrees C.
the furnace residence time for the cable is three minutes.

[0027] The finished cable containing the black oxide layer thereon has substantially the same characteristics as the finished cable of Example I.

Claims

1. A coaxial cable comprising a metallic signal-transmitting core, a dielectric component which is heat resistant to temperatures above about 1000 degrees C. surrounding and insulating the core, and a stainless steel sheath surrounding and shielding the dielectric component and core, **characterized by** the sheath having an adherent protective outer black oxide layer comprising chromium oxide.

2. The coaxial cable of claim 1 wherein the dielectric component is heat resistant to temperatures of up to about 1100 degrees C. and completely surrounds the core, and wherein the sheath completely surrounds the dielectric component.

3. The coaxial cable of claim 1 or claim 2 wherein the stainless steel of the sheath has at least about 18 percent by weight of chromium and wherein the dielectric component comprises silicon dioxide.

4. The coaxial cable of any one of claims 1-3 wherein the stainless steel of the sheath has about 18-20 percent by weight of chromium, with essentially the remainder of the stainless steel being iron.

5. The coaxial cable of any one of claims 1-4 wherein the chromium oxide of the black oxide layer mainly comprises chromic oxide, with essentially the remainder of the black oxide layer being iron oxide.

6. A method of forming an adherent protective black oxide layer mainly comprising chromium oxide on the outer surface of a coaxial cable having an outer sheath of stainless steel, which method comprises the steps of:

   a) passing an assembled coaxial cable into a treating furnace, the cable having a metallic signal-transmitting core surrounded by a dielectric component which is temperature resistant to above about 1000 degrees C., the dielectric component being sheathed in an outer jacket of stainless steel having a chromium concentration of at least about 18 percent by weight, the furnace having a treating temperature of at least about 1000 degrees C. and also having a hydrogen-free, wet-nitrogen-containing atmosphere;
   b) maintaining the cable in the furnace for a residence time sufficient to form an adherent protective black oxide layer comprising chromium oxide on the outer surface of the stainless steel sheath; and
   c) thereafter removing the black-oxide-layer-containing coaxial cable from the furnace and cooling the coaxial cable to ambient temperature.

7. The method of claim 6 wherein the residence time is about two to about five minutes and wherein the cooling is carried out in air.

8. The method of claim 6 or claim 7 wherein the temperature in the furnace is about 1000-1100 degrees C., wherein the dielectric component is heat resistant to the furnace temperature and wherein the wet nitrogen is produced by bubbling nitrogen through a water chamber.

9. The method of any one of claims 6-8 wherein the stainless steel has about 18-20 weight percent of chromium, with essentially the remainder of the stainless steel being iron.

10. The method of any one of claims 6-9 wherein the chromium oxide in the black oxide layer consists essentially of chromic oxide.

11. The method of claim 10 wherein essentially the remainder of the black oxide layer is iron oxide.

12. The method of any one of claims 6-11 wherein the dielectric component comprises silicon dioxide.

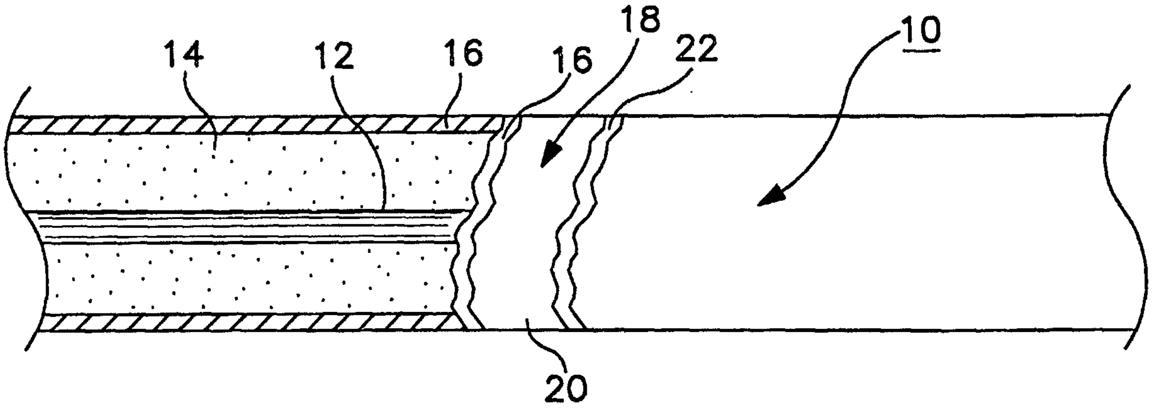

FIG. 1

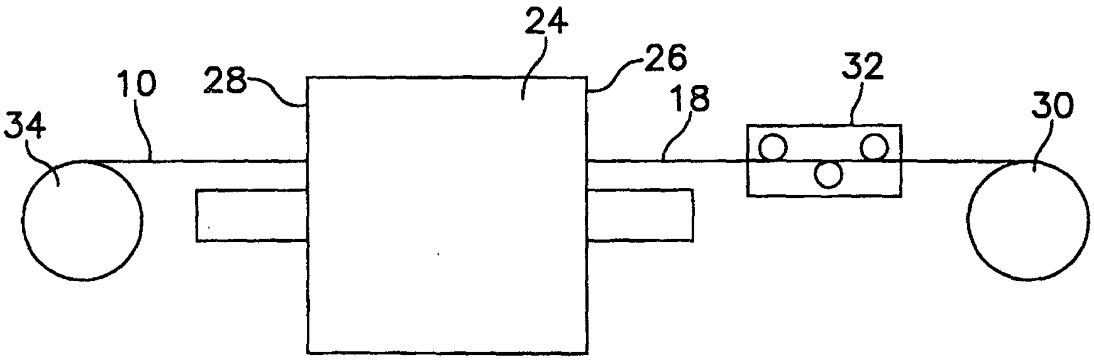

FIG. 2