March 14, 1967 D. F. FAIRBANKS 3,309,179

HARD SUPERCONDUCTOR CLAD WITH METAL COATING

Filed May 3, 1963

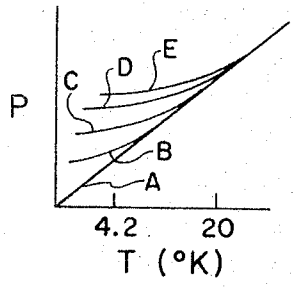


Fig. 1

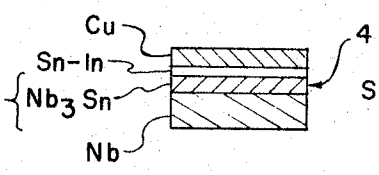


Fig. 2

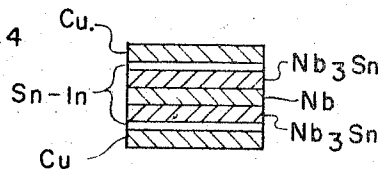


Fig. 2A

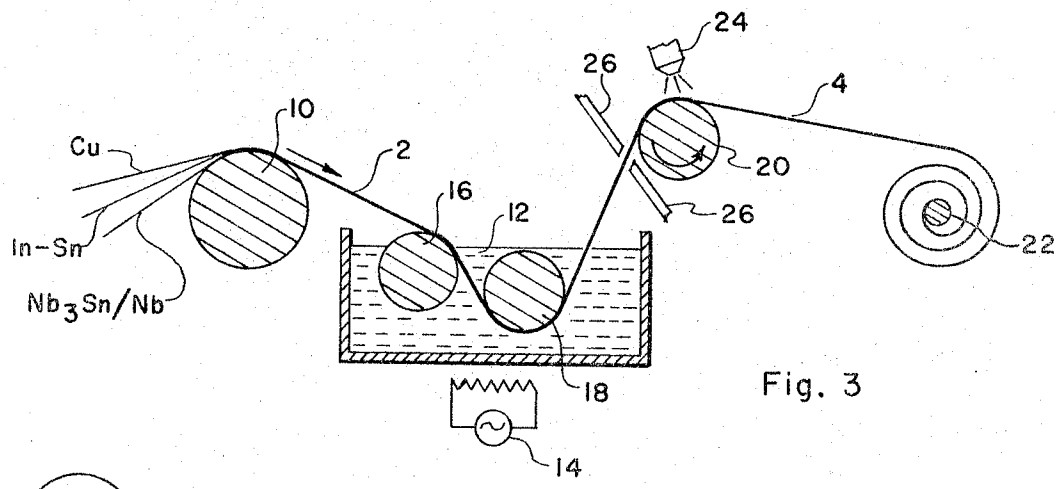


Fig. 3

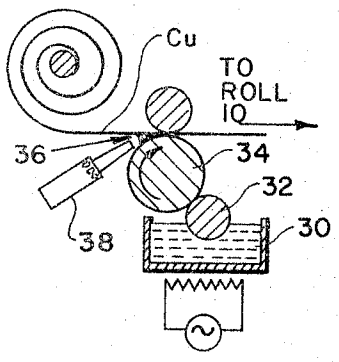


Fig. 4

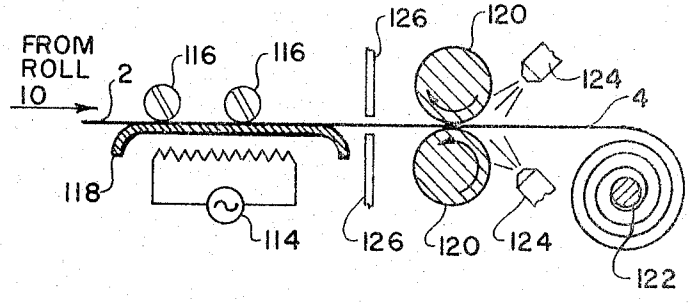


Fig. 5

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United States Patent Office 3,309,179
Patented Mar. 14, 1967

3,309,179
HARD SUPERCONDUCTOR CLAD WITH METAL COATING

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Filed May 3, 1963, Ser. No. 277,899
3 Claims. (Cl. 29—194)

This invention relates to superconductors, and more particularly to alloys known as "hard superconductors," which are used in the manufacture of solenoid coils and the like.

It has been found advantageous to coat superconductive wire with a coating of copper or other material of low thermal and electrical resistance before winding it into high field magnetic solenoids. The presence of the copper permits the wire to carry currents which would be expected on the basis of tests on short samples of the wire. Without it, the currents are considerably less; e.g., one-half of short-sample test values. Probably, the effect of copper is mainly due to its low electrical resistivity and its consequent ability to pass current around sections of the wire which may temporarily go normal. The bypassing of the current in this manner minimizes local heat production in the coil and reduces variations in the magnetic field. In addition the presence of copper is helpful in speeding the removal of heat from the winding to its surroundings.

The present invention seeks to achieve the benefits of such coating on Nb_3Sn superconducting wires and ribbons of the type disclosed in the copending application of Allen and Stauffer, S.N. 133,653, filed Aug. 24, 1961, and now abandoned and in the copending application of Allen, Das and Stauffer, S.N. 245,239, filed Dec. 17, 1962, now Patent No. 3,218,693. However, it should be understood that the invention is also applicable to various other elongated superconductors in the form of wire, ribbon, plate and other regular shapes, as described, for instance, in the copending application of Saur, S.N. 208,925, filed July 10, 1962, and now Patent No. 3,252,832, and in Aviation Week and Space Technology Magazine, Oct. 9, 1961, p. 84. In these references, an outer coating of Nb_3Sn is formed on a substrate of refractory metal, as a decomposition coating in the last case and as a diffusion coating in the others. The exposed position of the Nb_3Sn layer militates against the use of conventional extrusion or drawing processes for cladding the Nb_3Sn with copper; the brittle Nb_3Sn layer might be damaged in such processes. As noted in the above copending application of Saur, the coating may comprise hard superconductor alloys other than Nb_3Sn, such as Nb_3Al, V_3Ga and V_3Si. The present invention is also applicable to such variations.

It is an object of the present invention to provide a technique of preparing superconductors clad with a heat dissipating and electric current-bypassing coating, without resort to excessive compression of the superconductor.

It is a more specific object of the invention to provide a ribbon superconductor comprising a niobium base with an Nb_3Sn coating and an outer layer of copper or other high conductivity substitutes, bonded to the outer surface of the Nb_3Sn via a thin bond metal layer which is compatible with the Nb_3Sn layer.

These and other objects of the invention will in part be obvious and will in part appear hereinafter.

The invention accordingly comprises the process involving the several steps and the relation and order of one or more of such steps with respect to each of the others, and the resulting product, which are exemplified in the following detailed disclosure and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in connection with the accompanying drawings wherein:

FIG. 1 is a graph illustrating the considerations which govern the choice of methods of forming a heat and current dissipating layer;

FIG. 2 is a cross-section of a superconductive ribbon made according to the present invention;

FIG. 2A is a variation of FIG. 2 wherein the current carrying capacity is increased by the use of multiple superconductive layers;

FIG. 3 is a schematic diagram of one embodiment of the cladding process of the invention showing the application of conventional elements of apparatus;

FIG. 4 is a schematic diagram showing a variation of part of the process of FIG. 3; and

FIG. 5 is a schematic diagram showing a variation of another part of the process of FIG. 3.

The metal of choice for the heat and current dissipating layer is copper. However, in accord with the present invention, because of their excellent conductivities at cryogenic temperatures, tungsten or cadmium may be used in similar fashion. Other metals which may be used are aluminum, indium, silver, lead, tin and sodium. In each case the pure element should be used. Generally, the superconductor will be used at liquid helium temperature where the electrical and thermal resistivities of the pure metals are lower than those of their respective alloys.

As noted above, conventional extrusion and cladding processes are not suitable for applying the copper layer, due to the brittle nature of the superconducting layer. Electroplating avoids the danger of damaging the superconducting layer, but tends to contaminate the copper layer. The effect of contaminants is shown in the graph of FIG. 1 wherein Curve A is the resistivity curve of pure copper and curves B, C, D, E indicate the effect of contaminants and alloying elements.

According to the present invention a very thin layer of metallic solder is interleaved between the superconducting and copper layers and the cladding is accomplished by heating the flux to its melting point. The solder is selected as an alloy of low melting point and good electrical conductivity at liquid helium temperature. The material designated for this purpose in the present invention is the eutectic mixture of tin and indium, a commercially available solder having a melting point of about 120° C. Further, this material has been discovered to be superconductive at liquid helium temperatures and low external magnetic fields up to 2 kilogauss, a factor which enhances its suitability for present purposes.

FIG. 2 shows a cross-section of ribbon assembly **20** after the copper cladding is completed in accordance with the new method described below. The copper layer is bonded to the Nb_3Sn layer via a thin layer of tin-indium eutectic. It has been found by experiments that a eutectic composition of tin-indium alloy in contact with the Nb_3Sn layer will not adversely affect its superconductivity. It is believed that the alloy can be varied to as much as from 15:85 to 95:5 of tin to indium with similar results. It is also believed that a similar range of tin-lead alloys can be used. It should be noted that a eutectic composition of tin-indium offers a lower melting point than the above-suggested alternates and that it is desirable to work at the lowest possible temperatures to avoid contaminating the Nb_3Sn while working in atmosphere. Whatever solder is used, the temperature must be kept low enough to avoid excess formation of copper alloys which are poor heat and electrical conductors compared to copper. Where cadmium or tungsten are used in lieu of copper, the choice of solders is wider since these metals

are less reactive with tin (in the solder or in the Nb_3Sn layer) than is copper.

FIG. 2A shows a variation of FIG. 2 wherein the original superconductive ribbon has Nb_3Sn coatings on both sides and copper is clad on both sides in accord with the present invention.

Copper clad ribbon, shown in FIGS. 2 and 2A can be wound into a magnet without further treatment. However, it is preferred, in each instance, to first coat the entire ribbon with a conventional dielectric insulation. When the magnet is put into a cryogenic bath the current will be carried entirely by the Nb_3Sn layers. If small sections of the Nb_3Sn layer return temporarily to normal state conduction of electric current, the copper layers in intimate contact therewith will allow current to bypass these sections and will minimize resistance heating since copper has a very low resistivity at cryogenic temperatures and a substantial cross-section in the arrangement shown. The resistance heating which does occur is dissipated by the excellent thermal conductivity of the copper. When a section of ribbon goes normal, the copper dissipates the resistance heat in a manner tending to avoid extreme localization of temperature rise in the ribbon with consequent destruction of the ribbon at the overheated locality. The copper or other metallic foil used should be soft, annealed metal with a thickness of .0005 to .001 inch. For simplicity, only the method shown in FIG. 2 for cladding the ribbon is described below.

Referring now to FIG. 5 there is shown a variation of some of the apparatus in FIG. 3. The foil assembly **2** is passed between a stainless steel shelf **118** and rollers **116**, where it is heated by heater **118** to the melting point of the flux and then passed through driven rollers **120** to a wind-up roll **122**. The minimum spacing between rollers **120** is equal to the thickness of the foil assembly **2**, less the average thickness of the solder layer, and the maximum spacing is the thickness of the foil assembly **2**, plus about 10%. Thus, a gentle compression is applied to the foil assembly **2** to spread the solder and drive out included gases without damaging the Nb_3Sn layer. Water cooling jets **124** and shields **126**, similar to those of FIG. 3, are also provided.

Since certain changes may be made in the above process without departing from the scope of the invention herein involved, it is intended that all matter contained in the above description, and shown in the accompanying drawings, shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. An article of manufacture comprising a ribbon with a central flat layer of niobium having opposed outer faces, two thin layers of Nb_3Sn compound overlaying the outer faces of the niobium ribbon and being secured thereto by intermetallic bonding, two thin layers of an electrically conductive tin base solder metal which has a melting point no greater than that of tin overlaying the outer faces of Nb_3Sn and secured thereto by an intermetallic bond and two thin layers of copper overlaying the outer faces of the solder and secured thereto by an intermetallic bond.

2. The article of claim **1** wherein the solder metal is an alloy selected from the group consisting of tin-indium where the tin varies from 15–95% and tin-lead where the tin varies from 15–95%.

3. The article of claim **1** wherein the solder metal is a eutectic mixture of tin and indium.

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