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ZEITSCHRIFT FÜR PHYSIC B-CONDENSED MATTER, vol 64, no. 2, September 1986, Springer International J.G. BEDNORZ; K.A. MÜLLER "Possible High T Superconductivity in the Ba-La-Cu-O system" page 189-193

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CHEMICAL ABSTRACTS, vol. 107, no. 20, November 16, 1987, Columbus, Ohio, USA FUJIKI et al. "Preparation of a High-Tc yttrium-barium-copper-oxygen superconductor using colloidal methods" page 866, column 1, abstract no. 188 711n & Jpn. J. Appl. Phys., Part 2 1987, 26 (7), L1156-L1160

PHYSICAL REVIEW LETTERS, vol. 58, no. 18, may 4, 1987 D.W.MURPHY et al "New Superconducting Cuprate Perovskites" pages 1880-1890

PHYSICAL REVIEW LETTERS, vol 58, no. 16, April 20, 1987 R.J.CAVA et al. "Bulk Superconductivity at 91 K in Single-Phase Oxygen-Deficient Perovskite Ba2 YCu309-8" pages 1676-1679

PHYSICAL REVIEW LETTERS, vol. 58, no. 9, March 2, 1987 P.H.HOR et al. "Superconductivity at 93 K in a New Mixed-Phase Y-Ba-Cu-O Compound System at Anmient Pressure" pages 908-910

Description

This invention pertains to methods for producing a thin layer of superconductive material on a substrate.

From the discovery of superconductivity in 1911 to the recent past, essentially all known superconducting materials were elemental metals (e.g. Hg, the first known superconductor) or metal alloys (e.g. Nb_3Ge, probably the material with the highest transition temperature Tc known prior to 1986).

Recently, superconductivity was discovered in a new class of materials, namely, metal oxides. See J.G. Bednorz and K.A.Muller, Zeitschr. f. Physik B - Condensed Matter, Vol. 64, 189 (1986), which reports superconductivity in lanthanum barium copper oxide.

The latter report stimulated worldwide research activity, which very quickly resulted in further significiant progress. The progress has resulted, inter alia, to date in the discovery that compositions in the Y-Ba-Cu-O system can have superconductive transition temperatures T_c above 77K, the boiling temperature of liquid N_2 (see, for instance, M.K. Wu et al, Physical Review Letters, Vol. 58, March 2, 1987, page 908, and P.H. Hor et al, ibid, page 911). Furthermore, it has resulted in the identification of the material phase that is responsible for the observed high temperature superconductivity, and in the discovery of composition and processing techniques that result in the formation of bulk samples of material that can be substantially single phase material and can have T_c above 90K (see the E.P. Publications 0274421 and 0274407). See also R.J.Cava et al, Physical Review Letters, Vol. 58 (16) pp. 1676-1679 (1987).

The excitement in the scientific and technical community that was created by the recent advances in superconductivity is at least in part due to the potentially immense technological impact of the availability of materials that are superconducting at temperatures that do not require refrigeration with expensive liquid He. Liquid nitrogen is generally considered to be perhaps the most advantageous cryogenic refrigerant, and attainment of superconductivity at liquid nitrogen temperature was a long-sought goal which until very recently appeared almost unreachable.

Although this goal has now been attained, there still exist barriers that have to be overcome before the new oxidic high T_c superconductive materials can be utilized in many technological applications. In particular, techniques for forming high T_c superconductive bodies of technologically significant shape have to be developed. Among the shapes of technological significance are thin layers, frequently patterned, on a non-superconducting substrate.

Prior art metallic superconductors have been prepared in thin layer form by such techniques as vapor deposition and sputtering. Such thin films have found use, for instance, in Josephson junctions and in various detectors.

EP-A-2 77 020 (published 03.08.88; to be considered under Art. 54(3) EPC) discloses a method for forming thin layers of a superconductive material by applying a solution of selected metal-containing components. The solution is applied to a substrate, dried, heated and calcinated in the presence of oxygen to obtain the layers of metal oxide superconductive material.

For a general overview of some potential applications of superconductors see, for instance, B.B. Schwartz and S. Foner, editors, Superconductor Applications: SQUIDS and MACHINES, Plenum Press 1977; and S. Foner and B.B. Schwartz, editors, Superconductor Material Science, Metallurgy, Fabrications, and Applications, Plenum Press 1981. Among the applications are power transmission lines, rotating machinery, and superconductive magnets for e.g., fusion generators, MHD generators, particle accelerators, leviated vehicles, magnetic separation, and energy storage, as well as junction devices and detectors. It is expected that many of the above and other applications of superconductivity would materially benefit if high T_c superconductive material could be used instead of the previously considered relatively low T_c materials.

In particular, the existence of a method for producing thin layers of high T_c superconductive oxide material would likely result in considerable economic benefit. For instance, such a method could be used to produce junction devices and detectors that are operable at higher temperatures than prior art devices, and could perhaps be employed in novel ways, e.g., to interconnect electronic circuits or chips. In particular, a method that can be used to produce superconductive oxide thin films economically and conveniently, without the use of expensive equipment such as vacuum chambers, would be of obvious benefit. Such a method is disclosed below.

According to the present invention there is provided a method as defined in claim 1.

We have discovered a convenient method of producing a layer of superconductive metal oxide on a substrate. The method comprises applying, by any appropriate technique (e.g., spraying, dipping, spin-on) a metal-containing precursor solution to the substrate such that a substantially homogeneous metal-containing layer is formed on the substrate. The method further comprises heat treating the layer such that unwanted constituents of the solution that are still present in the layer are removed from the layer, such that the appropriate

superconductive phase is formed in the layer material, and such that, at completion of the heat treatment, the layer material has the appropriate degree of oxidation and is essentially free of chemical constituents that adversely affect ("poison") the superconductive oxide.

Whereas the inventive method is broadly applicable to forming superconductive oxide layers, currently preferred emnbodiments relate to forming cuprate layers. A currently preferred class of cuprates can be represented by the generalized nominal formula $Ba_{2-x}M_{1-y}X_{x+y}Cu_3O_{9-\delta}$, where M is one of Y, Eu, or La, and X is one or more optional element different from Ba and M and selected from the elements of atomic number 57-71, Sc, Ca, and Sr. Typically x + y is in the range 0-1 (with Ba and M being at least 50 atomic % unsubstituted), and $1.5 < \delta < 2.5$. This class of cuprates will be referred to as the Ba-cuprates. For examples of Ba-cuprates see, for instance, D.W. Murphy et al, Physical Review Letters, Vol. 58(18) pp. 1888-1890. In a particular subclass of the Ba-cuprates, $0 \leq x < 0.2$ and $0 \leq y < 0.1$, with M being one or more of Ca, Sr, Y, La, Eu, Lu, and Sc.

Another known class of oxide superconductors has nominal composition $La_{2-x}M_xCuO_{4-\epsilon}$, where M is one or more of divalent metals such as Ba, Sr and Ca, $x \geq 0.05$, and $0 \leq \epsilon \leq 0.5$. This class will be referred to as the La-cuprates.

The inventive method is considered to be applicable to forming a layer of substantially any superconductive oxide on a substrate, including oxides containing alkali metal(s). Cuprates are currently thought to be the most promising class of oxides, and the inventive method can be used to produce unsubstituted cuprates as well as cuprates in which one or more other metals are substituted for part of the copper.

The metal-containing solution can be aqueous or nonaqueous. Typically, the metal ions in the solutions are derived from salts or complexes (including metallo-organic complexes) such a carboxylates or acetylacetonates, or inorganic complexes such as nitrates, of the various metals [Cu, Ba, Y, Eu, etc.]), and the solvent advantageously has a relatively high solubility (typically such that a solution with more than 0.01 molar Cu concentration, preferably greater than 0.1, can be prepared) for the metal-containing compounds. Aqueous solutions frequently need to be acidic, e.g., contain a carboxylic acid or nitric acid. In an exemplary embodiment, the solvent (before concentration) is 1:1 H_2O and acetic acid, and the metal salts are the metal acetates. In another exemplary embodiment the solvent is chloroform, toluene or other appropriate organic solvent, and the metal precursors are metallo-organic complexes of the relevant metals, for instance, carboxylate (e.g., butyrate or ethylhexanoate) complexes of the relevant metals. In general, the complexes of the different metals should be mutually compatible, the complexes should be soluble in a solvent that is suitable for spincoating, spraying, or other application techniques, the solution should form homogeneous, continuous films, and the solution should decompose cleanly, e.g., leave no residual carbon.

The solution is applied to the substrate by any appropriate technique. The solution may be hot relative to the substrate or vice versa. For instance, in one embodiment the aqueous solution is at about 100 °C and the substrate is substantially at room temperature. In another embodiment the substrate is relatively hot, and the relatively cold solution is applied by spraying. In other embodiments the solution and the substrate are at substantially the same temperature, e.g., room temperature. The substrate frequently has a relatively plane surface to which the solution is applied, but this is not a requirement. For instance, the substrate may be a filamentary body, or may have any other non-planar shape. However, the substrate material (or, more precisely, the surface of the substrate) has to be compatible with the superconductive oxide, as will be discussed in detail below.

After formation of the substantially homogeneous metal-containing layer on the substrate, the substrate/layer combination is heat treated. One aspect of the heat treatment is the removal of unwanted constituents from the layer material. By this is meant the removal of those constituents that are not desired to be present in the superconductive layer material. The removal may comprise pyrolysis of some constituents (e.g., organic ions such as CH_3COO^-) and/or evaporation. Exemplarily, the removal of the unwanted constituents is attained by heating to a temperature in the range 250-450 °C, but removal at higher temperatures may be required for some films.

A further aspect of the heat treatment is the transformation of the layer material into the phase that is associated with superconductivity. Frequently, this requires the formation of microcrystals, since the as-deposited layer typically is amorphous, whereas a definite crystal structure is associated with the superconductive phase. For instance, in at least some Ba-cuprates the high temperature ($T_c > 77K$) superconductive phase has a quasi-perovskite structure. The formation of the superconductive phase typically requires heating of the layer to a temperature in the range 600-950 °C, even as high as 1000 °C.

At least in some embodiments of the invention the heat treatment conditions have an effect on the crystal orientation in the superconductive film. For instance, treating a film formed from metallo-organics at a relatively high temperature frequently

favors the growth of crystallites with the c-axis normal to the film plane, whereas treating such a film at a relatively low temperature frequently favors random orientation of the crystallites. For films of nominal (final) composition $YBa_2Cu_3O_7$ the heat treatment typically comprises a soak (exemplarily in the range 1 minute to 5 hours) in an oxygen-containing atmosphere at a temperature in the approximate range 820-1000 °C, with c-axis orientation typically favored for soak temperatures of about 950 °C and above.

A third aspect of the heat treatment is the incorporation of oxygen into the layer material. It is known that at least some of the oxides of interest herein (e.g., at least some Ba-cuprates) lose oxygen at relatively high temperatures, and can take up oxygen from the ambient at intermediate temperatures. Therefore, the layer material typically is oxygen deficient at the completion of the above referred to transformation step, and the layer is advantageously maintained in an O_2-containing atmosphere at an intermediate temperature (typically in the range 300-500 °C) for a time sufficient to result in the attainment of the desired oxygen concentration in the layer material. Slow cooling through the relevant temperature range of course can also accomplish this objective.

The superconductive oxides of interest herein frequently have a bulk superconductive transition temperature $T_c > 77K$. Recently there have also been reports that indications of superconductivity have been detected in a Ba-cuprate at temperatures above 200K, as high as 240K. Some workers have even expressed a belief that a room temperature oxide superconductor will soon be discovered. Since the inventive method is broadly applicable to superconductive oxides, we contemplate its use in conjunction with superconductive oxides having bulk $T_c > 200K$, 240K, or even room temperature, should such oxides be found. Superconductive layers produced by the inventive method typically have a transition onset temperature of at least 77K and possibly even greater than about 240K.

Thin superconductive layers according to the invention can advantageously be used in a variety of apparatus. For instance, they can be patterned by photolithographic and other methods so as to provide interconnects between electronic components or subsystems, or to form detectors or devices such as SQUIDS and other weak link devices. They can, for instance, also be deposited on a filamentary substrate so as to produce a relatively flexible superconductive "wire".

Apparatus comprising a superconductive layer according to the invention typically comprises electrical current source means and means responsive to an electrical current, both connected to the superconductive layer.

The inventive method can, economically and without the use of expensive equipment, produce large area thin layers of superconductive oxide material. It is expected that these characteristics of the novel method will assist in finding widespread use for the novel superconductive oxides.

Brief Description of the Drawings

FIG. 1 is a flow chart showing major steps of a process according to the invention; and

FIG. 2 schematically depicts a patterned inventive superconductive layer on a substrate.

Detailed Description of Some Embodiments

Figure 1 schematically presents some process steps of an exemplary embodiment of the inventive process which will now be discussed in more detail. The solution is prepared by dissolving appropriate amounts of metal-containing compounds (e.g., metal acetates such as copper-, barium-, and yttrium acetate) in a solvent such as 1:1 glacial acetic acid and water at approximately 100 °C. As will be appreciated by those skilled in the art, the amounts of the metal-containing compounds are chosen such that the metal ions are present in the solution in the desired molar ratios. This need not necessarily be the same molar ratio that is considered to be optimal in the corresponding bulk superconductive oxide. In one particular embodiment the solution is maintained at about 100 °C and allowed to evaporate until the Cu concentration in the solution is about 0.3 molar. The (hot) solution is then applied to a compatible substrate (e.g., a MgO wafer) by a standard technique (e.g., spin-on), resulting in the formation of a homogeneous (exemplarily transparent and glassy) layer on the substrate.

In another exemplary embodiment, stoichiometric amounts of metallo-organic complexes (e.g., ethylhexanoates such as those of Y, Ba, and Cu) are dissolved in chloroform at room temperature, and the resulting metal-containing solution is spin-coated at room temperature onto a ZrO_2 substrate, resulting in formation of a homogeneous layer on the substrate.

The substrate/layer combination is then heated so as to remove unwanted constituents (e.g., H_2O, acetic acid, CO_2). It is generally advantageous (although not obligatory) to raise the layer temperature slowly (e.g., 10-50 °C/hour) so as to avoid damage to the film. Typically the removal can be accomplished at temperatures up to about 450 °C, although in some cases a higher temperature may be advantageously used. The removal step may be carried out in air, in any other appropriate atmosphere, or in a vacuum. Frequently, some oxida-

tion of the layer material takes place during this step. The details of the removal step generally will depend on the nature of the unwanted constituents. Completion of the step can be verified by any appropriate technique, e.g., thermogravimetric or mass spectrographic analysis.

Transformation of the layer material into the superconductive phase typically requires heating of the layer material to a relatively high temperature for a period of time effective to result in transformation of at least a substantial portion (preferably essentially complete transformation) of the layer material. The degree of transformation can be monitored by any appropriate technique, e.g., X-ray diffraction or polarized light microscopy, as well as by determination of the superconductive properties, as will be apparent to those skilled in the art. The time required to complete the transformation depends strongly on the temperature, with lower temperatures corresponding to longer times. For various reasons (e.g., possible interaction of the layer material with the substrate) it may be desirable to carry out the transformation at a relatively low temperature, and/or to limit the time at the highest temperature. This may, for instance, be achieved by a multistep process (in which part of the transformation is carried out at one or more lower temperatures), or by means of flash heating (of all or part) of the layer. Such flash heating can be carried out with, for instance, a high intensity lamp or a laser. The transformation step is advantageously carried out in an oxygen-containing atmosphere (e.g., air, O_2 at ambient or elevated pressure) so as to limit the loss of oxygen from the layer material.

Subsequent to the transformation treatment it will frequently be advantageous to subject the layer material to an oxygenation treatment, since the oxygen concentration in the as-transformed layer material typically is lower than is optimal in the bulk material of equivalent composition. Oxygenation can be accomplished, for instance, by maintaining the layer in contact with an appropriate oxygen-containing atmosphere (e.g., air, O_2 at ambient or higher pressure) at an appropriate intermediate temperature (e.g., 400 °C) until the desired oxygen concentration is reached.

The above described processing steps are exemplary only, and other heat treatment schedules may also be advantageously used. For instance, the previously referred to film formed by a metallo-organic spin-on process can be heat treated by ramping the temperature to about 950-1000 °C in 1-5 hours, soaking the film at a temperature in that range for about 1-10 minutes, ramping the temperature to about 400-450 °C in about 0.5 - 2 hours, soaking at a temperature in that range for about 2 - 24 hours, followed by a furnace cool to about room temperature, all in an oxygen atmosphere.

As will be appreciated by those skilled in the art, the details of the above described process may frequently be optimized by observing the effect of changes of process parameters on the superconductive properties of the film. It may thus be possible that in some cases optimal operating conditions may be found outside of the typical ranges indicated herein.

It will also be appreciated that, since a single application of the inventive method typically results in a superconductive film of approximate thickness in the range 0.5 - 1 μm (the exact thickness typically depends on such factors as the metal concentration in the solution, the viscosity of the solution, and the application conditions such as the spinning rpm), it may at times be advantageous to apply a layer of metal-containing solution over an already formed superconductive layer, and to subject the combination to a further heat- and/or oxygenation treatment. Repeated application of the inventive technique thus can produce superconductive films of any desired thickness (typically less than about 5 μm) if this thickness cannot be obtained by a single application. Two or more applications of the inventive method may also result in improved critical current density of the resulting film since a film formed by a single application may comprise current-limiting cracks.

It has been found that the nature of the substrate has a significant effect on the properties of the layer on the substrate, and choice of a substrate that is compatible with a given superconductive layer material is a significant aspect of the inventive method. A "compatible" substrate herein is a substrate which does not substantially interact with the layer material during the heat treatment in a superconductivity-affecting manner. By way of example, some Ba-cuprate layers have been found to be substantially compatible with MgO substrates as well as ZrO_2 and $SrTiO_3$ substrates at many of the heat treatment conditions described herein, but were found to react to some degree (and are therefore not properly compatible) with SiO_2 substrates under the same conditions. Al_2O_3 has an intermediate degree of incompatibility and may be acceptable under some circumstances. These Ba-cuprate layers are also compatible with Au and Ag. Therefore, it may be possible to interpose an appropriate (Au or Ag, or one of the above compatible oxide) passivation layer (possibly together with one or more other layers that may serve different functions, e.g., prevent diffusion of Ag or Au into the substrate, or enhance adhesion) between a substrate and the superconductive layer thereon, to prevent poisoning of the layer material. Those skilled in the art will appreciate that under some conditions, e.g., flash heating, some substrates that

are non-compatible with a given layer material under other heat treatment conditions (e.g., furnace heating) may have acceptable compatibility.

The above description of the method is exemplary only, and those skilled in the art will readily be able to determine the conditions that are advantageously used for a given substrate/superconductive layer combination.

FIG. 2 schematically depicts a (patterned) superconductive layer 22 on a substrate 21. Although not shown, a barrier layer (e.g., Au, Ag or MgO) can be interposed between 21 and 22. Patterning of 22 can be accomplished by any appropriate technique, e.g., photolithography in conjunction with wet or dry etching, laser ablation, or ion implantation.

Example 1: A superconductive layer of nominal composition $Ba_2YCu_3O_7$ was prepared as follows: 0.9538g of $BaCO_3$ 0.2729g of Y_2O_3, and 0.8120g of basic copper carbonate (which has been assayed and found to contain 56.74 weight % Cu) was added to 100 ml of 1:1 glacial acetic acid and H_2O. The mixture was refluxed for about 16 hours to give a clear blue solution, without visible residue. The solution was then boiled down to a volume of about 25 ml. After ascertaining that the solution was of proper concentration (by spinning hot solution onto room temperature quartz discs at 2000 rpm for 50 seconds; the concentration was deemed right if the spun on layers showed neither radial streaks nor were speckled but were even, pale blue films) the hot solution was spun under the same conditions onto a 1 cm x 1 cm x 1 mm MgO crystal at room temperature. The substrate/layer combination was then heated in air from room temperature to 100°C at 200°C/hour, and from 100°C to 400°C at 20°C/hour. The combination was then heated to 750°C for 1 hour, to 800°C for two hours, and 830°C for 30 minutes, furnace cooled (about 30 minutes) to 400°C, held at 400°C for 15 minutes, then cooled to room temperature in 98066.5 Pascals (1 at.) of flowing O_2. The superconductive properties of the film were determined by measuring the resistance as a function of temperature by a standard 4-point probe technique. The layer was found to have a transition onset temperature of about 85K.

Example 2: A superconductive layer of nominal composition $Ba_2EuCu_3O_7$ was prepared substantially as described in Example 1, except that 0.4252 g of Eu_2O_3 was substituted for Y_2O_3. The resulting layer was found to have a transition onset temperature of about 75K.

Example 3: A superconductive film of nominal composition $YBa_2Cu_3O_7$ was prepared as follows: 1.35×10^{-3} mol Y(2-ethylhexanoate)$_3$ 2.7×10^{-3} mol Ba(2-ethylhexanoate)$_2$, and 4.05×10^{-3} mol Cu(2-ethylhexanoate)$_2$ were dissolved in 10.5g (7 ml) chloroform at room temperature (the ethylhexanoates were prepared substantially as described by G. M. Vest et al in the Materials Research Society Proceedings, Symposium L: Defect Properties and Properties of High-Technology Nonmetallic Materials, Boston, Massachusetts, December 2-4, 1985, Y.Chen et al, editors, pp. 35-42). The resulting solution was spin-coated onto a MgO substrate (2000 rpm, 60 s), the coated substrate placed into a standard tube furnace, with oxygen flowing through the furnace tube, and the furnace temperature ramped up to about 990°C in 2 hours. Next, the sample was soaked at 990°C for 3 minutes, the furnace temperature was ramped down to about 450°C in about 30 minutes, the sample soaked at 450°C for 8 hours, followed by a furnace cool to room temperature. The resulting black ceramic film was about 0.5 μm thick, had predominantly c-axis orientation perpendicular to the film plane, an onset T_c of about 89K, with T_c - (R = 0) of about 77K.

Example 4:

A superconductive film having a thickness of about 1 μm was produced by forming a 0.5 μm thick film substantially as described in Example 3, spin-coating a layer of the metal-containing solution onto the film, and repeating the heat treatment. The resulting film had predominantly c-axis orientation and onset T_c of about 89K.

Example 5:

A metal-containing solution was spun onto a MgO substrate substantially as described in Example 3. The coated substrate was placed into the tube furnace and, under O_2 at ambient pressure, the temperature was ramped to 850°C for 1 hour and the sample was soaked at that temperature for 1 hour. The temperature was then ramped to 400°C (30 minutes), and the sample soaked at that temperature for 8 hours, followed by a furnace cool to room temperature. The thus produced 0.5 μm $YBa_2Cu_3O_{9-\delta}$ (δ about 2.1) film consisted or randomly oriented grains, and had an onset T_c of about 91K.

Example 6:

A superconductive film of nominal composition $NdBa_2Cu_3O_7$ was produced substantially as described in Example 4, except that Nd(2-ethylhexanoate)$_3$ was substituted for the Y(2-ethylhexanoate)$_3$. The resulting film has predominantly c-axis orientation normal to the film plane and onset T_c of about 89K.

Example 7:

A superconductive film of nominal composition $YBa_2Cu_3O_7$ was produced substantially as described in Example 4, except that Cu(isobutyrate)$_2$ is substituted for the Cu(2-ethylhexanoate)$_2$. The resulting film has essentially the same properties as the film of Example 4.

Examples 8-13:

Superconductive films are formed substantially as described in Examples 1 and 4, respectively, except that the substrate is strontium titanate, Ag-coated (0.5 μm evaporated Ag) SiO_2, and Ag-coated oxidized Si, respectively.

Example 14:

A patterned superconductive film is formed by producing a film substantially as described in Example 4, followed by patterning by means of laser ablation.

Example 15:

A superconductive body is formed by coating a 0.5 mm diameter Ag wire with a metal-containing solution prepared substantially as described in Example 1, and by heat treating the coated wire, also as described in that example.

Claims

1. Method of producing a superconductive metal-containing oxide layer on a surface of a substrate, the method comprising
a) applying a metal-containing precursor solution to the surface of the substrate such that a substantially homogeneous metal-containing layer results, and
b) heating at least a part of the layer in the presence of oxygen such that at least a substantial portion of the material in the part of the layer is transformed into a metal oxide superconductive material;
wherein step b) comprises heating the layer to a first temperature in the range 250-450 °C such that the unwanted constituents are substantially removed from the layer, further comprises heating the layer to a second temperature in the range 600-1000 °C for a period sufficient to result in transformation of at least a substantial portion of the layer material into a phase that is associated with superconductivity; and still further comprises cooling the layer to a third temperature in the range 300-500 °C and contacting the layer with an oxygen-containing atmosphere such that effective oxygenation of the layer material results.

2. Method of claim 1, comprising selecting the precursor solution and the conditions of b) such that the metal oxide superconductive material has nominal composition $Ba_{2-x}M_{1-y}X_{x+y}Cu_3O_{9-\delta}$, where M is selected from the group consisting of Y, Eu, and La, and X is an optional component different from Ba, Y, Eu and La and selected from the group consisting of the elements of atomic number 57-71, Sc, Ca and Sr, with $0 \leq x + y \leq 1$, $1.5 < \delta < 2.5$, and Ba and M being at least 50 atomic % unsubstituted.

3. Method of claim 1 or 2, comprising selecting a precursor solution that comprises Cu, Ba, and Y, with the Cu-concentration in the precursor solution being at least about 0.01 molar.

4. Method of claim 1, comprising forming the precursor solution by dissolving a copper-containing compound in an acidic aqueous medium, and wherein the temperature of the precursor solution that is being applied to the substrate is greater than the substrate temperature.

5. Method of claim 1 or 2, comprising maintaining the layer in contact with an oxygen-containing atmosphere during substantially all of step b).

6. Method of claim 1 or 2, comprising providing a substrate, with at least a part of the surface of the substrate consisting of a material that is substantially inert during b) with respect to oxygen and with respect to the layer material.

7. Method of claim 6, comprising selecting the substrate from the group consisting of MgO, ZrO_2, and $SrTiO_3$.

8. Method of claim 1 or 2, comprising providing a substrate comprising a first substrate material and a barrier layer on at least part of the first substrate material.

9. Method of claim 8, comprising selecting a barrier layer that consists substantially of material selected from the group consisting of Au, Ag, MgO, ZrO_2, and $SrTiO_3$.

10. Method of claim 1 or 2, comprising selecting a substrate that is a filamentary body.

11. Method of claim 1 or 2, wherein a) comprises spraying the precursor solution onto the major

surface, with the temperature of the substrate being substantially higher than the temperature of the precursor solution.

12. Method of claim 1 or 2, wherein the precursor solution is formed by dissolving one or more metallo-organic compounds in an organic solvent.

13. Method of claim 12, wherein the precursor solution is formed by dissolving at least one metallo-organic compound selected from the group consisting of the ethylhexanoates and the butyrates, and wherein the solvent is chloroform or toluene.

14. Method of claim 13, comprising dissolving at least one metallo-organic compound selected from the group consisting of copper ethylhexanoate, copper isobutyrate, barium ethylhexanoate, and barium isobutyrate, and wherein b) comprises heating the layer to a temperature in the range 820-1000 °C.

Revendications

1. Procédé pour produire une couche d'oxyde supraconducteur contenant des métaux sur une surface d'un substrat, ce procédé comprenant :

a) l'application sur la surface du substrat d'une solution de précurseur contenant des métaux, de façon à former une couche contenant des métaux et pratiquement homogène, et

b) le chauffage d'au moins une partie de la couche en présence d'oxygène, de façon qu'au moins une partie notable du matériau de cette partie de la couche soit transformée en un matériau supraconducteur consistant en oxyde métallique;

dans lequel l'étape b) comprend le chauffage de la couche jusqu'à une première température dans la plage de 250-450 °C, de façon que les constituants indésirables soient pratiquement éliminés de la couche, elle comprend en outre le chauffage de la couche à une seconde température dans la plage de 600-1000 °C pendant une durée suffisante pour provoquer la transformation d'au moins une partie notable du matériau de la couche, pour donner une phase qui est associée à la supraconductivité; et elle comprend en outre le refroidissement de la couche jusqu'à une troisième température dans la plage de 300-500 °C, et la mise en contact de la couche avec une atmosphère contenant de l'oxygène, de façon qu'il se produise une oxygénation effective du matériau de la couche.

2. Procédé selon la revendication 1, comprenant la sélection de la solution de précurseur et des conditions de l'étape b) de façon que le matériau supraconducteur consistant en oxyde métallique ait la composition nominale $Ba_{2-x}M_{1-y}X_{x+y}Cu_3O_{9-\delta}$, dans laquelle M est sélectionné dans le groupe qui comprend Y, Eu et La, et X est un composant que l'on peut choisir, qui est différent de Ba, Y, Eu et La, et qui est sélectionné dans le groupe comprenant les éléments ayant des numéros atomiques 57-71, Sc, Ca et Sr, avec $0 \leq x + y \leq 1$, $1,5 \leq \delta < 2,5$, et Ba et M étant non substitués dans un pourcentage atomique d'au moins 50%.

3. Procédé selon la revendication 1 ou 2, comprenant la sélection d'une solution de précurseur qui comprend Cu, Ba et Y, la concentration molaire de Cu dans la solution de précurseur étant d'au moins environ 0,01.

4. Procédé selon la revendication 1, comprenant la formation de la solution de précurseur par dissolution d'un composé contenant du cuivre dans un milieu aqueux acide, et dans lequel la température de la solution de précurseur qui est appliquée au substrat est supérieure à la température du substrat.

5. Procédé selon la revendication 1 ou 2, comprenant le maintien de la couche en contact avec une atmosphère contenant de l'oxygène pendant pratiquement la totalité de l'étape b).

6. Procédé selon la revendication 1 ou 2, comprenant l'opération qui consiste à fournir un substrat, et une partie au moins de la surface du substrat consiste en un matériau qui est pratiquement inerte pendant l'étape b), vis-à-vis de l'oxygène et vis-à-vis du matériau de la couche.

7. Procédé selon la revendication 6, comprenant la sélection du substrat dans le groupe qui comprend MgO, ZrO_2, et $SrTiO_3$.

8. Procédé selon la revendication 1 ou 2, comprenant l'opération qui consiste à fournir un substrat qui est constitué par un premier matériau de substrat et par une couche de barrière sur au moins une partie du premier matériau de substrat.

9. Procédé selon la revendication 8, comprenant la sélection d'une couche de barrière qui consiste pratiquement en un matériau sélec-

tionné dans le groupe comprenant Au, Ag, MgO, ZrO_2, et $SrTiO_3$.

10. Procédé selon la revendication 1 ou 2, comprenant la sélection d'un substrat qui consiste en un corps sous forme de filaments.

11. Procédé selon la revendication 1 ou 2, dans lequel l'étape a) comprend la pulvérisation de la solution de précurseur sur la surface principale, dans une condition dans laquelle la température du substrat est notablement supérieure à la température de la solution de précurseur.

12. Procédé selon la revendication 1 ou 2, dans lequel on forme la solution de précurseur en dissolvant un ou plusieurs composés organométalliques dans un solvant organique.

13. Procédé selon la revendication 12, dans lequel on forme la solution de précurseur en dissolvant au moins un composé organométallique sélectionné dans le groupe qui comprend les éthylhexanoates et les butyrates, et dans lequel le solvant consiste en chloroforme ou en toluène.

14. Procédé selon la revendication 13, comprenant la dissolution d'au moins un composé organométallique sélectionné dans le groupe qui comprend l'éthylhexanoate de cuivre, l'isobutyrate de cuivre, l'éthylhexanoate de baryum et l'isobutyrate de baryum, et dans lequel l'étape b) comprend le chauffage de la couche jusqu'à une température dans la plage de 820-1000 ° C.

Patentansprüche

1. Verfahren zur Herstellung einer supra leitenden Metall-enthaltenden Oxidschicht auf einer Oberfläche eines Substrats mit den Schritten:

a) Aufbringen einer Metall-enthaltenden Vorläuferlösung auf die Oberfläche des Substrats, derart, daß sich eine im wesentlichen homogene, Metall-enthaltende Schicht ergibt, und

b) Erhitzen wenigstens eines Teils der Schicht in Gegenwart von Sauerstoff, derart, daß wenigstens ein wesentlicher Teil des Materials in dem Teil der Schicht in ein supra leitendes Metall-Oxidmaterial umgewandelt wird, wobei

der Schritt b) umfaßt:

Erhitzen der Schicht auf eine erste Temperatur im Bereich von 250 bis 450 ° C, derart, daß die unerwünschten Bestandteilen im wesentlichen aus der Schicht entfernt werden, ferner

Erhitzen der Schicht auf eine zweite Temperatur im Bereich von 600 bis 1000 ° C für eine Zeitdauer, die ausreicht, um zu einer Umwandlung wenigstens eines wesentlichen Teils des Schichtmaterials in eine Phase zu ergeben, der Supraleitfähigkeit zugeordnet ist, und

Abkühlen der Schicht auf eine dritte Temperatur im Bereich von 300 bis 500 ° C sowie in Kontaktbringen der Schicht mit einer Sauerstoff-enthaltenden Athmosphäre, derart, daß sich eine wirksame Oxidation des Schichtmaterials ergibt.

2. Verfahren nach Anspruch 1,
bei der die Vorläuferlösung und die Bedingungen des Schrittes b) derart gewählt sind, daß das supra leitende Metall-Oxidmaterial eine nominelle Zusammensetzung $Ba_{2-x}M_{1-y}X_{x-y}Cu_3O_{9-\delta}$, wobei M gewählt ist aus der aus Y, Eu und La bestehenden Gruppe und X eine wahlfreie, von Ba, Y, Eu und La verschiedene Komponente gewählt aus der Gruppe, die aus den Elementen der Ordnungszahlen 57 bis 71, Sc, Ca und Sr mit $0 \leq x + y < 1$, $1,5 < \delta < 2,5$, und Ba und M wenigstens 50 Atomprozent unsubstituiert sind.

3. Verfahren nach Anspruch 1 oder 2,
bei dem eine Vorläuferlösung gewählt ist, die Cu, Ba und Y umfaßt, wobei die Cu-Konzentration in der Vorläuferlösung wenigstens etwa 0,01 Molar ist.

4. Verfahren nach Anspruch 1,
bei dem die Vorläuferlösung durch Auflösen einer Kupfer-enthaltenden Verbindung in einem sauren wässrigen Medium hergestellt wird und bei dem die Temperatur der Vorläuferlösung, die auf das Substrat aufgebracht wird, größer als die Substrattemperatur ist.

5. Verfahren nach Anspruch 1 oder 2,
bei dem die Schicht während im wesentlichen des gesamten Schrittes b) in Kontakt mit einer Sauerstoff-enthaltenden Athmosphäre gehalten wird.

6. Verfahren nach Anspruch 1 oder 2,
bei dem ein Substrat verwendet wird, von dem wenigstens ein Teil seiner Oberfläche aus einem Material besteht, das während des Schrittes b) mit wesentlichen inert mit Bezug auf Sauerstoff und mit Bezug auf das Schichtmaterial ist.

7. Verfahren nach Anspruch 6,

bei dem das Substrat aus der Gruppe ausgewählt wird, die aus MgO, ZrO_2 und $SrTiO_3$ besteht.

8. Verfahren nach Anspruch 1 oder 2, bei dem ein Substrat verwendet wird, das ein erstes Substratmaterial und eine Sperrschicht auf wenigstens einem Teil des ersten Substratmaterials umfaßt.

9. Verfahren nach Anspruch 8, bei dem eine Sperrschicht gewählt wird, die im wesentlichen aus einem Material besteht, das aus der aus Au, Ag, MgO, ZrO_2 und $SrTiO_3$ bestehenden Gruppe gewählt wird.

10. Verfahren nach Anspruch 1 oder 2, bei dem ein Substrat gewählt wird, das ein fadenförmiger Körper ist.

11. Verfahren nach Anspruch 1 oder 2, bei dem der Schritt a) das Aufsprühen der Vorläuferlösung auf die Hauptfläche umfaßt, wobei die Temperatur des Substrats wesentlich höher als die Temperatur der Vorläuferlösung ist.

12. Verfahren nach Anspruch 1 oder 2, bei dem die Vorläuferlösung durch Lösen von einer oder mehreren Metallorganischen Verbindungen in einem organischen Lösungsmittel hergestellt wird.

13. Verfahren nach Anspruch 12, bei dem die Vorläuferlösung durch Lösen wenigstens einer Metall-organischen Verbindung hergestellt wird, die aus der aus den Ethylhexanoaten und den Butyraten bestehenden Gruppe gewählt wird und bei dem das Lösungsmittel Chloroform oder Toluol ist.

14. Verfahren nach Anspruch 13, bei dem wenigstens eine Metall-organische Verbindung gelöst wird, die aus der aus Kupfer-Ethylhexanoat, Kupfer-Isobutyrat, Barium-Ethylhexanoat und Barium-Isobutyrat bestehenden Gruppe gewählt ist und bei dem der Schritt b) das Erhitzen der Schicht auf eine Temperatur im Bereich von 820 bis 1000° C umfaßt.

FIG. 1

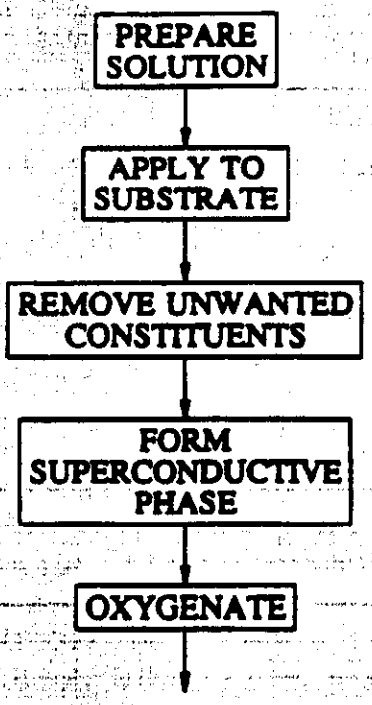
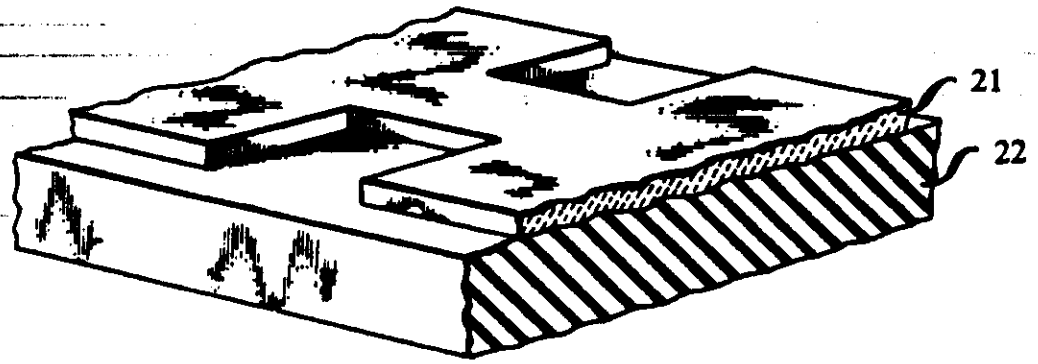

PREPARE SOLUTION
APPLY TO SUBSTRATE
REMOVE UNWANTED CONSTITUENTS
FORM SUPERCONDUCTIVE PHASE
OXYGENATE

FIG. 2


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