

Description**Technical Field**

5 The invention is concerned with articles including a superconductor material, and with the manufacture of such materials and articles.

Background of the Invention

10 On account of superconductor characteristics at temperatures of boiling nitrogen (77 K) and above, materials having one of two recently discovered compound structures show significant and potentially revolutionizing technological promise. Among representatives of the first such structure are compounds in the La-Ba-Cu-O and Y-Ba-Cu-O systems; representative of the second are bismuth-strontium calcium cuprates having representative composition $\text{Bi}_{2-2\delta}\text{Sr}_2\text{Ca}_{0-\delta}\text{Cu}_2\text{O}_{8+\delta}$, with δ in the vicinity of 0.2. In this respect see also, 15 e.g., the paper by M. A. Subramanian et al., "A New High-Temperature Superconductor: $\text{Bi}_2\text{Sr}_{3-x}\text{Ca}_x\text{Cu}_2\text{O}_{8+y}$ ", *Science*, Vol. 239, pp. 1015-1017 (1988).

While many properties of these materials can be studied in sintered polycrystalline samples, it is desirable to provide single crystals of macroscopic dimensions, e.g., for the purpose of determining correlations between structural parameters and superconductor properties. Also, as contemplated superconductor applications include the use of thin, possibly patterned superconductor layers having significant current-carrying capability, and as such capability is likely to be highest in single-crystal material, there is strong interest in epitaxially deposited single-crystal layers, e.g., in switching and logic device technology.

Summary of the Invention

25 The invention provides for the growth (deposition, precipitation) of bismuth-strontium calcium cuprate superconductor material and of other, isostructural superconductor materials such as lead-substituted bismuth-strontium calcium cuprate and thallium-barium calcium cuprate superconductor materials. Preferred growth is in a fluxed melt comprising crystal constituents as solutes, in combination with a flux component which acts 30 as solvent; preferred flux constituents are alkali chlorides such as sodium chloride and potassium chloride. Further preferred is the growth of macroscopic bodies of essentially single-crystal material, such bodies having a preferred diameter which is greater than 2 mm, or which even may equal 3 mm or more. Included in this class of bodies are epitaxially deposited layers. (Essentially single-crystal material may deviate from ideal crystal structure due to irregularities such as stacking faults, for example; such faults are considered as having no 35 significant influence on superconductor transition temperature.)

Brief Description of the Drawing

40 The Figure is a schematic representation of a superconductor quantum interference detector (SQUID), greatly enlarged for the sake of clarity, representing a preferred embodiment of a device in accordance with the invention.

Detailed Description

45 The Figure shows substrate 10, first and second respective superconductor layers 11 and 12 separated by gaps 13 and 14 (typical gap widths being on the order of 1 micrometer), and electrical connections 15 and 16. (For further details with respect to the design and functioning of SQUID devices see, e.g., B. B. Schwartz et al., *Superconductor Application: SQUIDS and Machines*, Plenum Press, New York, 1977.)

50 In accordance with the depicted embodiment of the invention, layers 11 and 12 consist essentially of epitaxially deposited bismuth-strontium calcium cuprate superconductor material and, with respect to the device shown in the Figure, preferred processing in accordance with the invention provides for epitaxial growth of layers 11 and 12 in a fluxed melt on a suitable substrate such as, e.g., a strontium titanate substrate.

Other than to bismuth-strontium calcium cuprate superconductor material, crystal growth in accordance with the invention is applicable to thallium-barium calcium cuprate superconductor material having representative composition $\text{Tl}_2\text{Ba}_2\text{CaCu}_2\text{O}_{8+\delta}$, and to lead-substituted bismuth-strontium calcium cuprate superconductor material having representative composition

55 $\text{Bi}_{2-2-x}\text{Pb}_x\text{Sr}_2\text{Ca}_{0-\delta}\text{Cu}_2\text{O}_{8+\delta}$,
all being isostructural to bismuth-strontium calcium cuprate superconductor material.

Crystal growth in accordance with the invention may be initiated by spontaneous nucleation in a body of molten material; alternatively, growth may be on a seed or substrate. Substrate material is chosen for chemical compatibility with material to be deposited and, in the case of preferred, essentially single-crystal growth, seed or substrate material is chosen crystallographically compatible with material to be grown. Quite generally, whether growth produces single-crystal or polycrystalline material, and whether growth is epitaxial, by pulling from a melt, or by directional cooling, growth involves cooling so as to produce supersaturation or undercooling of the melt with respect to the solute to be precipitated, such supersaturation being at least in the vicinity of a surface or in region where precipitation is desired. In many instances, desired growth conditions result from gradual cooling of a melt over-all; alternatively, with melt temperature held constant on average, a temperature gradient can be produced, e.g., as a somewhat colder substrate is dipped into a melt.

While, for the preparation of a melt, use of a platinum crucible may be optimal, ceramic crucibles such as, e.g., high-purity alumina crucibles can also be used. A desired melt or body of molten material can be produced by conventional mixing of oxide ingredients, followed by melting at a temperature typically lying in a preferred range from 750 C to 900 C. Preferred crystal growth temperatures are in a range from 650 C to 800 C.

Preferred melts comprise a solute component representing 10 to 50 weight percent of the melt, a preferred amount of at least 50 weight percent of the remainder being sodium chloride, potassium chloride, or a mixture of sodium chloride and potassium chloride. A complementary portion of at most 50 weight percent of the remainder may include other alkali halides such as, e.g., rubidium chloride, and small amounts of other chlorides and fluorides.

The composition of deposited layers is relatively insensitive to the constitution of the solute component of a melt, with the relative amount of bismuth being somewhat sensitive, however, in that growth from a severely bismuth-deficient melt tends to favor a semiconductor phase over the desired superconductor phase. Considered as favorable is excess oxygen as introduced, e.g., by adding sodium oxide to a melt based on a sodium chloride flux - such addition having been found to favor regular growth of crystals from the melt. And, finally, care is indicated in preventing undue loss of bismuth by evaporation from the melt.

In device manufacture in accordance with the invention, crystal growth may be used in conjunction with other processing steps such as, e.g., the manufacture of substrates, the deposition of semiconductor layers, and the patterning of semiconductor as well as of superconductor layers by selective removal of deposited layer material. Available, for patterning, are a variety of methods including ion milling, as well as photolithographic methods as involving pattern generation and development in a sensitive layer, followed by pattern transfer by chemical means.

Example 1

Commercially obtained oxide powders were mixed in the following approximate amounts: 3 g CuO, 2.7837 g SrCO₃, 1.3972 g Ca(OH)₂, and 4.3931 g Bi₂O₃. The mixture was placed in an oven at a temperature of approximately 700 C; oven temperature was then raised to approximately 800 C and held there for approximately 1 hour for prereaction of the mixture. After cooling, the resulting body was ground into a powder, and the powder was mixed with sodium chloride in a ratio of 1 : 4 by weight. The resulting mixture was placed in a platinum crucible and turned into a melt by heating to a temperature of approximately 850 C. After holding at this temperature for approximately 1 hour, the melt was allowed to cool to a temperature of approximately 760 C at a rate of approximately 2 C per hour, resulting in the formation of crystals in the form of platelets and bars at the surface of the melt. Platelets had a surface area greater than 1 cm², and bars were several millimeters long, with a width greater than 1 mm and a thickness of several micrometers. These crystals were separated mechanically from the solidified melt, and adherent salt remnants were removed from the crystals by washing in water. Other solvents suitable for washing include acetonitrile (methyl cyanide, CH₃CN).

Energy-dispersive spectroscopic analysis (EDS) showed no detectable levels of sodium or of chlorine in the crystals. Crystals were characterized by X-ray diffraction, and they were found to have an orthorhombic subcell with dimensions 0.5414 x 0.5418 x 3.089 nanometers, and an incommensurable superlattice. Crystals were screened for superconductivity by monitoring their field-dependent microwave absorption near zero magnetic field. Onset of absorption was at a temperature of approximately 115 K, and there was a sharp increase in absorption at a temperature of approximately 90 K. At all temperatures, microwave absorption was anisotropic and greatest with the magnetic field in the direction of the crystallographic c-axis. Superconductivity was further confirmed by resistivity and susceptibility measurements. Zero resistance was achieved at a temperature of approximately 80 K.

The effect of increasing the measuring current was studied over the range from 1 to 100 A/cm² (calculated on the basis of sample cross section); the transition temperature was found to shift by less than 1 K over this range (as is indicative of high critical current density).

Example 2

Crystal growth as described above in Example 1 was carried out with potassium chloride as flux material instead of sodium chloride. Grown crystals had essentially the same morphology and physical properties.

Example 3

Crystal growth as described above in Example 1 was carried out with a 50-50 mole percent (eutectic) mixture of sodium-potassium chloride as flux material instead of sodium chloride alone. Grown crystals had essentially the same morphology and physical properties.

Claims

1. A method for making a device including a body of bismuth-strontium calcium cuprate, lead-substituted bismuth strontium calcium cuprate, or thallium-barium calcium cuprate superconductor material, said method comprising cooling a melt at least locally, said melt comprising constituents of said material,
CHARACTERIZED IN THAT said melt further comprises a flux component comprising at least one fluxing agent selected from the group consisting of sodium chloride and potassium chloride.
2. The method of claim 1 in which said at least one fluxing agent constitutes an amount by weight of 50 percent or greater of the portion of said melt exclusive of said constituents.
3. The method of claim 1 in which said constituents represent 10 to 50 percent by weight of said melt.
4. The method of claim 1 in which said flux component comprises sodium chloride.
5. The method of claim 1 in which said flux component comprises potassium chloride.
6. The method of claim 1 in which said flux component comprises sodium chloride and potassium chloride.
7. The method of claim 1 in which cooling is to a temperature in the range from 650 C to 800 C.
8. The method of claim 1 in which preparation of said melt comprises heating to a temperature in the range from 750 C to 900 C.
9. The method of claim 1 in which remnant salt is removed from said body by washing.
10. The method of claim 9 in which washing is with water.
11. An article of manufacture comprising a body of bismuth-strontium calcium cuprate, lead-substituted bismuth strontium calcium cuprate, or thallium-barium calcium cuprate superconductor material, said body being in essentially single-crystal form and having, at least at some manufacturing stage, a diameter which is greater than 2 mm.
12. The article of claim 11 in which said body is an epitaxial layer on a substrate.

Patentansprüche

1. Verfahren zum Herstellen eines Bauelements, welches einen Körper aus Wismuth-Strontium-Calcium-Kuprat, bleisubstituiertem Wismuth-Strontium-Calcium-Kuprat oder Thallium-Barium-Calcium-Kuprat als Supraleitermaterial enthält, wobei das Verfahren das zumindest lokale Abkühlen einer Schmelze umfaßt, welche Bestandteile des Materials beinhaltet, dadurch gekennzeichnet, daß die Schmelze weiterhin eine Flußkomponente enthält, die mindestens ein Flußmittel umfaßt, welches aus der Gruppe ausgewählt ist, die aus Natriumchlorid und Kaliumchlorid besteht.
2. Verfahren nach Anspruch 1, bei dem das mindestens eine Flußmittel einen Gewichtsanteil von 50 Prozent oder mehr des Schmelze-

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CHARACTERIZED IN THAT said melt further comprises a flux component comprising at least one fluxing agent selected from the group consisting of sodium chloride and potassium chloride.
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2. Verfahren nach Anspruch 1, bei dem das mindestens eine Flußmittel einen Gewichtsanteil von 50 Prozent oder mehr des Schmelze-



nanteils ohne die Bestandteile darstellt.

3. Verfahren nach Anspruch 1,
bei dem die Bestandteile 10 bis 50 Gewichtsprozent der Schmelze darstellen.
- 5 4. Verfahren nach Anspruch 1,
bei dem die Flußkomponente Natriumchlorid aufweist.
- 10 5. Verfahren nach Anspruch 1,
bei dem die Flußkomponente Kaliumchlorid aufweist.
- 15 6. Verfahren nach Anspruch 1,
bei dem die Flußkomponente Natriumchlorid und Kaliumchlorid aufweist.
7. Verfahren nach Anspruch 1,
bei dem das Abkühlen auf eine Temperatur im Bereich von 650 C bis 800 C erfolgt.
- 20 8. Verfahren nach Anspruch 1,
bei dem die Bereitstellung der Schmelze ein Erwärmen auf eine Temperatur im Bereich von 750 C bis 900 C umfaßt.
9. Verfahren nach Anspruch 1,
bei dem Restsatz von dem Körper durch Abwaschen entfernt wird.
- 25 10. Verfahren nach Anspruch 9,
bei dem das Waschen mit Wasser erfolgt.
- 30 11. Fertigungsartikel, umfassend einen Körper aus Wismuth-Strontium-Calcium-Kuprat-, bleisubstituiertem Wismuth-Strontium-Calcium-Kuprat- oder Thallium-Barium-Calcium-Kuprat-Supraleitermaterial, wobei der Körper im wesentlichen Einkristallform besitzt und zumindest in irgendeiner Fertigungsstufe einen Durchmesser besitzt, der größer als 2 mm ist.
12. Artikel nach Anspruch 11,
bei dem der Körper eine epitaktische Schicht auf einem Substrat ist.

35 Revendications

1. Un procédé de fabrication d'un dispositif comprenant un élément constitué par un matériau supraconducteur consistant en cuprate de calcium et de bismuthstrontium, en cuprate de calcium et de bismuth-strontium avec substitution de plomb, ou- en cuprate de calcium et de thallium-baryum, ce procédé comprenant le refroidissement d'un bain en fusion, au moins de façon locale, et le bain en fusion contenant des constituants du matériau précité,
CARACTERISE EN CE QUE le bain en fusion contient en outre un composant de type fondant qui comprend au moins un agent ayant une fonction de fondant qui est sélectionné dans le groupe qui comprend le chlorure de sodium et le chlorure de potassium.
- 40 2. Le procédé de la revendication 1, dans lequel le ou les agents ayant une fonction de fondant représentent une proportion de 50% en masse, ou plus, de la partie du bain en fusion autre que les constituants précités.
- 45 3. Le procédé de la revendication 1, dans lequel les constituants précités représentent de 10 à 50% en masse du bain en fusion.
- 50 4. Le procédé de la revendication 1, dans lequel le composant de type fondant consiste en chlorure de sodium.
- 55 5. Le procédé de la revendication 1, dans lequel le composant de type fondant consiste en chlorure de potassium.
6. Le procédé de la revendication 1, dans lequel le composant de type fondant consiste en chlorure de so-



dium et en chlorure de potassium.

7. Le procédé de la revendication 1, dans lequel le refroidissement est effectué jusqu'à une température dans la plage de 650 à 800°C.
8. Le procédé de la revendication 1, dans lequel la préparation du bain en fusion comprend un chauffage jusqu'à une température dans la plage de 750°C à 900°C.
9. Le procédé de la revendication 1, dans lequel on enlève par lavage le sel restant sur l'élément précité.
10. Le procédé de la revendication 9, dans lequel le lavage est effectué avec de l'eau.
11. Un article manufacturé constitué par un élément en matériau supraconducteur consistant en cuprate de calcium et de bismuth-strontium, en cuprate de calcium et de bismuth-strontium avec substitution de plomb, ou en cuprate de calcium et de thallium-baryum, cet élément étant sous forme pratiquement monocristalline, et ayant, au moins à un certain stade de fabrication, un diamètre qui est supérieur à 2 mm.
12. L'article de la revendication 11, dans lequel l'élément précité consiste en une couche épitaxiale sur un substrat.