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Process for making Tl-Ba-Ca-Cu-O superconductors using thallium vapor

Allen M. Hermann

University of Arkansas, Fayetteville

Zhengzhi Sheng

University of Arkansas, Fayetteville

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Hermann et al.

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- [54] **PROCESS FOR MAKING TL-BA-CA-CU-O SUPERCONDUCTORS USING THALLIUM VAPOR**
- [75] Inventors: **Allen M. Hermann; Zhengzhi Sheng**, both of Fayetteville, Ark.
- [73] Assignee: **University of Arkansas**, Little Rock, Ark.
- [*] Notice: The portion of the term of this patent subsequent to Mar. 5, 2008 has been disclaimed.
- [21] Appl. No.: **735,850**
- [22] Filed: **Jul. 25, 1991**

Related U.S. Application Data

- [62] Division of Ser. No. 236,507, Aug. 25, 1988, Pat. No. 5,082,825.
- [51] Int. Cl.⁵ **C01F 11/02; C01G 3/02; C01G 15/00**
- [52] U.S. Cl. **505/430; 427/62; 505/725; 505/783; 505/472; 505/474; 505/475; 505/492**
- [58] Field of Search **505/1, 783; 501/123; 423/604, 624, 635; 427/62**

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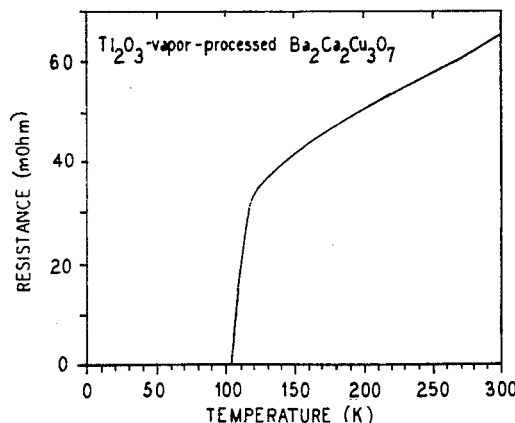
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Primary Examiner—Paul Lieberman
 Assistant Examiner—John Boyd
 Attorney, Agent, or Firm—Hermann Ivester, Hill, Steadman & Simpson

[57] ABSTRACT

A process of making high temperature Tl-based superconductors. The process includes the steps of reacting solid Ba—Ca—Cu-oxides with Tl₂O₃ vapor. The process allows high quality Tl-based superconductors to be easily fabricated.

6 Claims, 3 Drawing Sheets



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FIG. 1

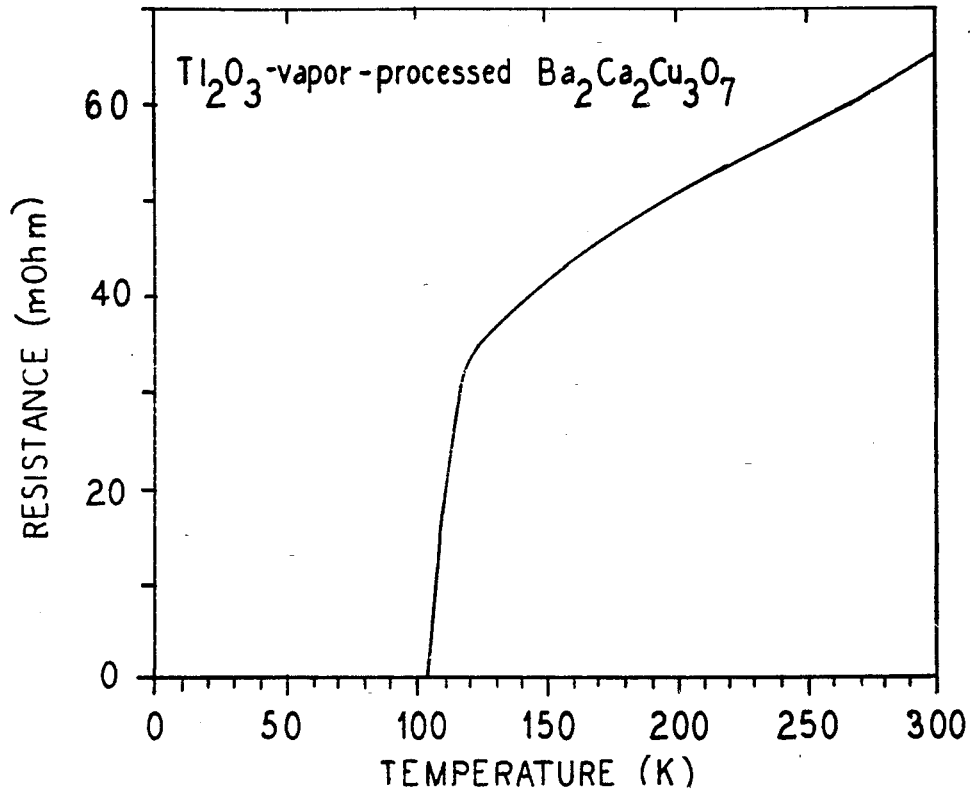


FIG. 2

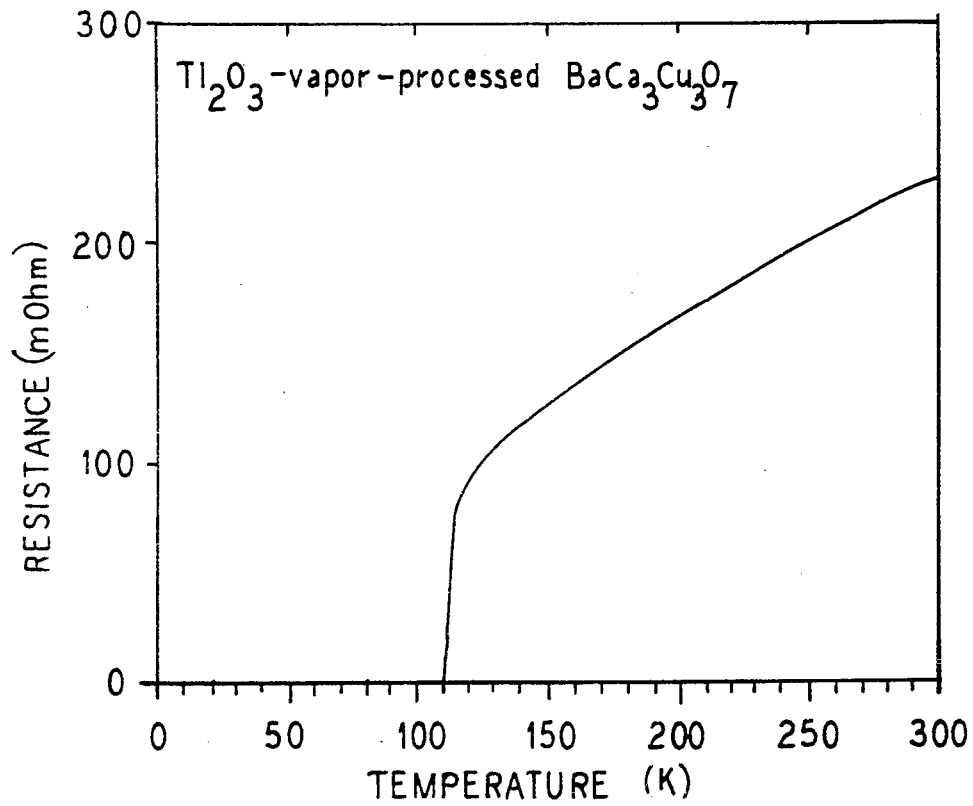


FIG. 3

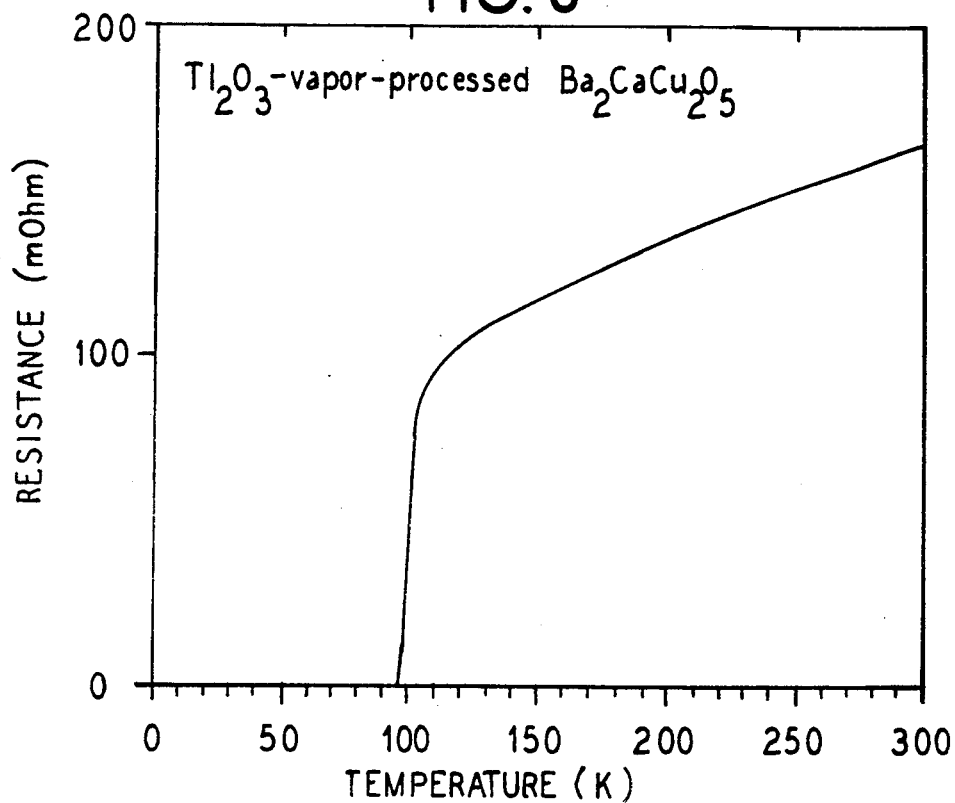


FIG. 4

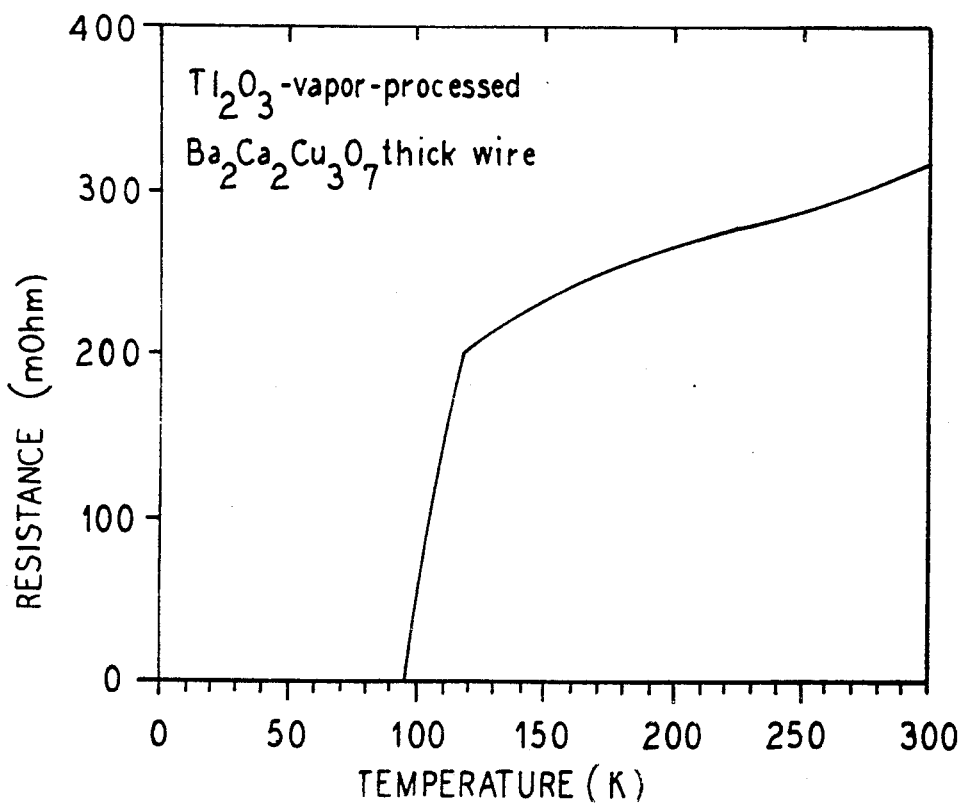


FIG. 5

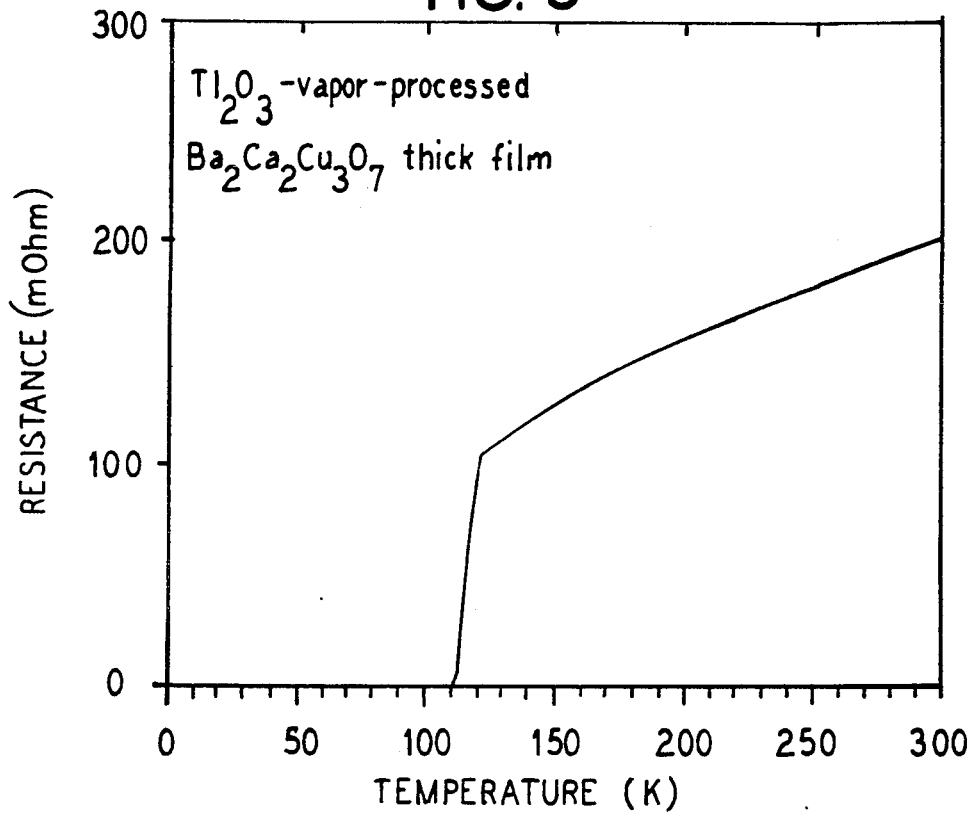
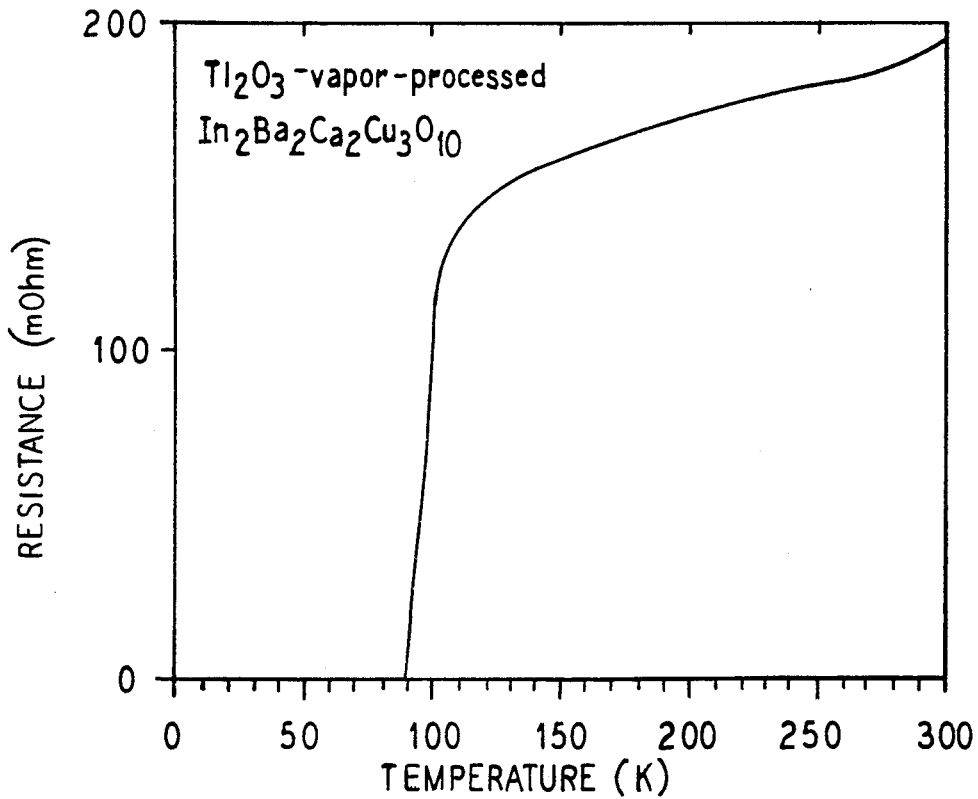


FIG. 6



PROCESS FOR MAKING Tl-Ba-Ca-Cu-O SUPERCONDUCTORS USING THALLIUM VAPOR

This is a division of application Ser. No. 236,507 filed Aug. 25, 1988, now U.S. Pat. No. 5,082,825.

BACKGROUND OF THE INVENTION

The present invention relates generally to high temperature superconductors. More specifically, the present invention relates to the fabrication of the high temperature Tl—Ba—Ca—Cu—O superconductors.

U.S. patent application Ser. No. 155,247, filed in the name of the inventors, of the present patent application discloses, in part, Tl—Ba—Ca—Cu—O superconductors that were discovered by the present inventors. These Tl—Ba—Ca—Cu—O superconductors have a transition temperature up to and above 120 K., this transition temperature, the inventors of the present patent application believe, is the highest to date among all existing high temperature superconductors.

For useful operation, the transition temperature of a superconductor typically must be at least $\frac{1}{3}$ higher than the temperature of operation. For this reason, the Tl—Ba—Ca—Cu—O system has been called the first real liquid nitrogen temperature superconducting system.

The present existing procedures of preparing Tl-based superconductors involve the mixing of all component elements followed by a final sinter. Since Tl_2O_3 evaporates easily, the quality of the Tl-samples is not easily controlled. In addition, in view of its toxicity, Tl_2O_3 presents an additional set of difficulties during the fabrication of these types of superconductors.

An improved method for making Tl—Ba—Ca—Cu—O superconductors would be desirable for many reasons. Such a process would: (1) allow Tl-based superconductors to be easily constructed in the forms of complex bulk components, wires and fibers, and thick and thin films; (2) minimize the toxicity problem caused by Tl compounds; and (3) provide low cost processing and manufacturability.

Accordingly, there is a need for a new process of making Tl-based high temperature superconductors.

SUMMARY OF THE INVENTION

The present invention provides a new process for making Tl-based superconductors. The process includes the step of reacting vapor phase Tl_2O_3 and solid Ba—Ca—Cu-oxides. Pursuant to the method of the present invention the Tl-based superconductors are produced in approximately two steps. The first step is the preparation of Ba—Ca—Cu-oxides; and the second step is the processing of the Ba—Ca—Cu-oxides by the use of Tl_2O_3 vapor to form high quality Tl-based superconductors. Pursuant to the present invention, the method of making Tl-based superconductors is simplified and only requires the manufacture of Ba—Ca—Cu-oxides and a final Tl_2O_3 vapor phase treatment.

Accordingly, an advantage of the present invention is that it provides a method which can easily produce Tl-based superconductors.

A further advantage of the present invention is to provide high quality Tl-based superconductors.

A still further advantage of the present invention is that it provides a method which can make Tl-based superconductors in the forms of bulk materials, wires or fibers, thick and thin films.

Furthermore, an advantage of the present invention is that certain elements can be added into the precursor Ba—Ca—Cu-oxides to satisfy specific needs for various applications.

An additional advantage of the present invention is that the Ba—Ca—Cu-oxides can be made in the recrystalline form of a melt.

Still another advantage of the present invention is that Tl_2O_3 -vapor-processing can be carried out in closed containers.

Yet another advantage of the present invention is that it provides a method of making Tl-based superconductors which minimizes contamination by Tl compounds.

Additional advantages and features of the present invention are described in and will be apparent from, the detailed description of the presently preferred embodiments and the drawings.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 illustrates the relationship of electrical resistance versus temperature for a Tl_2O_3 -vapor-processed $Ba_2Ca_2Cu_3O_7$ sample made pursuant to the method of the present invention.

FIG. 2 illustrates the relationship of electrical resistance versus temperature for a Tl_2O_3 -vapor-processed $BaCa_2Cu_3O_7$ sample made pursuant to the method of the present invention.

FIG. 3 illustrates the relationship of electrical resistance versus temperature for a Tl_2O_3 -vapor-processed $Ba_2CaCu_2O_5$ sample made pursuant to the method of the present invention.

FIG. 4 illustrates resistance-temperature dependence for a Tl_2O_3 -vapor-processed $Ba_2Ca_2Cu_3O_7$ thick wire sample made pursuant to the method of the present invention.

FIG. 5 illustrates resistance-temperature dependence for a Tl_2O_3 -vapor-processed $Ba_2Ca_2Cu_3O_7$ recrystallized thick film sample made pursuant to the method of the present invention.

FIG. 6 illustrates resistance as a function of temperature for a Tl_2O_3 -vapor-processed $In_2Ba_2Ca_2Cu_3O_{10}$ sample made pursuant to the present invention.

DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EMBODIMENTS

The present invention provides a method for making high quality Tl—Ba—Ca—Cu—O superconductors. The present invention is based on reactions between vapor phase Tl_2O_3 and solid Ba—Ca—Cu-oxides. The fabrication procedure for the making Tl—Ba—Ca—Cu—O superconductors according to the present invention can be divided into two steps: (1) preparation of Ba—Ca—Cu-oxides; and (2) Tl_2O_3 -vapor-processing of the Ba—Ca—Cu-oxides to form Tl—Ba—Ca—Cu—O superconductors. The present invention simplifies the fabrication of Tl—Ba—Ca—Cu-oxides to the fabrication of Ba—Ca—Cu-oxides, and minimizes problems caused by the toxicity and volatility of Tl compounds. The present invention allows high quality Tl-based superconductors to be easily made in the forms of complex bulk components, wires and fibers, and thick and thin films, and provides low cost processing and manufacturability of Tl-based superconductors.

Pursuant to the method of the present invention, first Ba—Ca—Cu-oxides are produced. Preferably compounds, the Ba—Ca—Cu-oxides are produced by grinding and mixing one of the following groups of: $BaCO_3$, CaO , CuO ; $BaCO_3$, $CaCO_3$, CuO ; BaO_2 , CaO_2 , CuO ; or

BaO₂, CaO, CuO. In a preferred embodiment, the molar ratio is 2:2:3, respectively, of the components. In an embodiment, the molar ratio of BaCO₃, CaO, CuO is 1:3:3.

Preferably, after the grinding and mixing the powder is heated. Preferably the powder is heated to approximately 925° C. for approximately 24 to about 48 hours with intermediate grindings.

In an embodiment the resultant powder has the following nominal composition:



wherein: $0 < X < 100$; and $0 < y < 100$.

In an embodiment, the powder is then pressed into a pellet.

After the powder is prepared, or pressed into a pellet, it can then be reacted with Tl₂O₃ vapor. The Tl₂O₃ vapor can be produced by heating Tl₂O₃ with the Ba—Ca—Cu-oxides or heating any Tl-containing compound that can form Tl₂O₃ vapor upon being heated to, for example, approximately 900° C.

In an embodiment, prior to being reacted with Tl₂O₃ vapor, the powder is mixed with a compound chosen from the group consisting of: Tl₂O₃, MgO, AgO, K₂O, Na₂O, ZrO₂, In₂O₃, HgO, Bi₂O₃, and KCl. The resultant mixture is then reacted with Tl₂O₃ vapor.

By way of example and not limitation, examples of the of the present invention process of making high quality Tl—Ca—Ba—Cu—O superconductors will now be given.

EXAMPLE 1

A. The following reagents were utilized:

1. Tl₂O₃,
2. CaO,
3. BaCO₃,
4. CuO.

B. The following procedure was followed:

1. A mixture of a two molar portion of BaCO₃, a two molar portion of CaO, and a three molar portion of CuO was ground with an agate mortar and pestle heated in air at 925° C. for more than 24 hours (with several intermediate grindings) to obtain a uniform black Ba₂Ca₂Cu₃O₇ powder.
2. The resulting Ba₂Ca₂Cu₃O₇ powder was completely ground, and pressed into a pellet.
3. The pellet was heated at about 925° C. in a tube furnace for about 10 minutes.
4. The heated pellet was then taken out of the furnace and cooled in air to room temperature.
5. A small amount (approximately 0.1 to about 0.2 gm) of Tl₂O₃ was put in a platinum boat, and the platinum boat was placed in a quartz boat.
6. The cooled pellet was placed over the platinum boat.
7. The quartz boat, containing the platinum boat, was placed into a tube furnace which had been heated to about 900° C., and was heated for about 3 minutes in flowing oxygen.
8. The sample was then furnace-cooled to room temperature in flowing oxygen, the sample was then taken out of the furnace.

The samples prepared by this procedure formed a layer of superconductive compounds on their bottom surface, which had an onset temperature of above 120 k. and a zero resistance temperature of above 100 k. FIG. 1 illustrates the resistance as a function of temperature

for a Tl₂O₃-vapor-processed Ba₂Ca₂Cu₃O₇ sample made pursuant to this example. This sample reaches zero resistance at 104 k. FIG. 4 illustrates comparable behavior for a Ba₂, Ca₂, Cu₃O₇ thick wire as a precursor made by a similar procedure.

EXAMPLE 2

A. The following reagents were utilized:

1. Tl₂O₃,
2. CaO,
3. BaCO₃,
4. CuO.

B. The following procedure was followed:

1. A mixture of a one molar portion of BaCO₃, a three molar portion of CaO, and a three molar portion of CuO was ground with an agate mortar and pestle, heated in air at 925° C. for more than 24 hours (with several intermediate grindings) to obtain a uniform black BaCa₃Cu₃O₇ powder.
2. The resulting BaCa₃Cu₃O₇ powder was completely ground, and pressed into a pellet.
3. The pellet was heated at approximately 925° C. in a tube furnace for about 10 minutes.
4. The heated pellet was then taken out of the furnace and cooled in air to room temperature.
5. A small amount (approximately 0.1 to about 0.2 gm) of Tl₂O₃ was placed in a platinum boat, and the platinum boat was then placed in a quartz boat.
6. The cooled pellet was placed over the platinum boat.
7. The quartz boat was put into the tube furnace which had been heated to about 900° C., and was heated for about 3 minutes in flowing oxygen.
8. The sample was then furnace-cooled to room temperature in flowing oxygen, and the sample was then taken out of the furnace.

The samples prepared by this procedure formed a layer of superconductive compounds on their bottom surface, which had an onset temperature of above 120 K., a midpoint of about 110 K., and a zero resistance temperature of above 100 K. FIG. 2 illustrates resistance as a function of temperature for a Tl₂O₃-vapor-processed BaCa₃Cu₃O₇ sample prepared pursuant to this example. This sample reaches zero resistance at 110 K. FIG. 3 illustrates comparable behavior for a Ba₂-CaCu₂O₅ precursor similarly prepared.

EXAMPLE 3

A. The following reagents were utilized:

1. Tl₂O₃,
2. CaCO₃,
3. BaCO₃,
4. CuO.

B. The following procedure was followed:

1. A mixture of a two molar portion of BaCO₃, a two molar portion of CaCO₃, and a three molar portion of CuO was ground with an agate mortar and pestle, heated in air at approximately 925° C. for more than 24 hours (with several intermediate grindings) to obtain a uniform black Ba₂Ca₂Cu₃O₇ powder.
2. The resulting Ba₂Ca₂Cu₃O₇ powder was completely ground, and pressed into a pellet.
3. The pellet was heated at approximately 925° C. in a tube furnace for about 10 minutes.
4. The heated pellet was then taken out of the furnace and cooled in air to room temperature.

5. A small amount (approximately 0.1 to about 0.2 gm) of Tl_2O_3 was put in a platinum boat, and the platinum boat was placed in a quartz boat.
6. The cooled pellet was placed over the platinum boat.
7. The quartz boat was put into the tube furnace which had been heated to approximately $900^\circ C.$, and was heated for about 5 minutes in flowing oxygen.
8. The sample was then furnace-cooled to room temperature in flowing oxygen, and was then removed from the furnace.

The samples prepared by this procedure formed a layer of superconductive compounds on their bottom surface, which have an onset temperature of above 120 K., a midpoint of about 110 K., and a zero resistance temperature of above 100 K.

EXAMPLE 4

- A. The following reagents were utilized:
 1. Tl_2O_3 ,
 2. CaO,
 3. $BaCO_3$,
 4. CuO.
- B. The following procedure was followed:
 1. A mixture of a two molar portion of $BaCO_3$, a two molar portion of CaO, and a three molar portion of CuO was ground with an agate mortar and pestle, heated in air at $925^\circ C.$ for more than 24 hours (with several intermediate grindings) to obtain a uniform black $Ba_2Ca_2Cu_3O_7$ powder.
 2. The resulting $Ba_2Ca_2Cu_3O_7$ powder was placed on a platinum substrate which was put in a quartz boat, and was heated in a tube furnace at approximately 950° to about $1000^\circ C.$ for 3-5 minutes in flowing oxygen.
 3. The quartz boat was then taken out of the furnace. The $Ba_2Ca_2Cu_3O_7$ powder had melted completely, forming a layer of recrystalline Ba—Ca—Cu—O.
 4. A small amount (approximately 0.1 to about 0.2 gm) of Tl_2O_3 put in a platinum boat, and the platinum boat was placed in a quartz boat.
 5. The platinum substrate was put over the platinum boat with the molten Ba—Ca—Cu—O facing downward.
 6. The quartz boat was put into the tube furnace which had been heated to about $900^\circ C.$, and was heated for about 3 minutes in flowing oxygen.
 7. The sample was then furnace-cooled to room temperature in flowing oxygen, and was then taken out of the furnace.

A Tl_2O_3 -vapor-processed $Ba_2Ca_2Cu_3O_7$ thick film was produced that was superconducting. FIG. 5 illustrates resistance as a function of temperature for a Tl_2O_3 -vapor-processed $Ba_2Ca_2Cu_3O_7$ recrystallized thick film created pursuant to this example. The film had an onset temperature of above 120 K. and reached zero resistance at about 111 K.

This experiment also shows that thin film Ti—Ca—Ba—Cu—O superconductors can be made using the Tl_2O_3 vapor process with appropriately deposited Ca—Ba—Cu—O precursor thin films. These thin films can be produced by depositing a thin-film of Ca—Ba—Cu—O precursor utilizing known techniques of physical vapor deposition. These techniques include, inter alia, sputtering, evaporation, ablation, electrodeposition, electroless deposition, and chemical vapor deposition. After the thin film of Ca—Ba—Cu—O is

produced, it can then be reacted with Tl_2O_3 vapor, for example, by placing Tl_2O_3 in a boat under or near the precursor and heating the boat.

EXAMPLE 5

- A. The following reagents were utilized:
 1. Tl_2O_3 ,
 2. In_2O_3 ,
 3. CaO,
 4. $BaCO_3$,
 5. CuO.
- B. The following procedure was followed:
 1. A mixture of two molar portion of $BaCO_3$, a two molar portion of CaO, and a three molar portion of CuO was ground with an agate mortar and pestle, heated in air at approximately $925^\circ C.$ for more than 24 hours (with several intermediate grindings) to obtain a uniform black $Ba_2Ca_2Cu_3O_7$ powder.
 2. A one molar portion of the resulting $Ba_2Ca_2Cu_3O_7$ powder was mixed with a one molar portion of In_2O_3 , and was completely ground and pressed into a pellet.
 3. The pellet was heated in a tube furnace at about $900^\circ C.$ in flowing oxygen for about 3 minutes, and was then removed from the furnace.
 4. A small amount (approximately 0.1 to about 0.2 gm) of Tl_2O_3 was put in a platinum boat, and the platinum boat was put in a quartz boat.
 5. The $In_2Ba_2Ca_2Cu_3O_7$ pellet was put over the platinum boat.
 6. The quartz boat was then put into the tube furnace which had been heated to approximately $900^\circ C.$, and was heated for about 3 minutes in flowing oxygen.
 7. The sample was then furnace-cooled to room temperature in flowing oxygen, and was then removed from the furnace.

The bottom surface of the Tl_2O_3 -vapor-processed $In_2Ba_2Ca_2Cu_3O_7$ sample constructed pursuant to this method was found to be superconducting. FIG. 6 illustrates resistance as a function of temperature for a Tl_2O_3 -vapor-processed $In_2Ba_2Ca_2Cu_3O_7$ sample, made pursuant to this example, which had an onset temperature about 120 K., and reached zero resistance at 89 K.

EXAMPLE 6

- A. The following reagents were utilized:
 1. Tl_2O_3 ,
 2. CaO,
 3. $BaCO_3$,
 4. CuO.
- B. The following procedure was followed:
 1. A mixture of a two molar portion of $BaCO_3$, a two molar portion of CaO, and a three molar portion of CuO was ground with an mortar and pestle heated in air at $925^\circ C.$ for more than 24 hours (with several intermediate grindings) to obtain a uniform black $Ba_2Ca_2Cu_3O_7$ powder.
 2. The resulting $Ba_2Ca_2Cu_3O_7$ powder was completely ground, and pressed into a pellet.
 3. The pellet was heated in a tube furnace at approximately $925^\circ C.$ for about 5 minutes.
 4. The pellet was then taken out of the furnace and cooled in air to room temperature.
 5. A small amount (approximately 0.1 to about 0.2 gm) of Tl_2O_3 was put in a platinum boat, and the

platinum boat and cooled pellet were put in a gold container.

6. The gold container, was sealed so that the platinum boat and pellet were sealed in oxygen, was put into a tube furnace which had been heated to approximately 900° C., and was heated for about 10 minutes.
7. The gold container was then furnace-cooled to room temperature, and was removed from the furnace.
8. The gold container was opened, and the sample taken out.

This example produced a Tl₂O₃-vapor-processed sample that formed a layer of superconducting compounds on its surface, which had an onset temperature of above 120 K. and a zero resistance temperature of above 100 K.

EXAMPLE 7

A. The following reagents were utilized:

1. Tl₂O₃,
2. CaO,
3. BaCO₃,
4. CuO.

B. The following procedure was followed:

1. A mixture of a two molar portion of BaCO₃, a two molar portion of CaO, and a three molar portion of CuO was ground with an agate mortar and pestle, heated in air at approximately 925° C. (with several intermediate grindings) to obtain a uniform black Ba₂Ca₂Cu₃O₇ powder.
2. The resulting Ba₂Ca₂Cu₃O₇ powder was mixed with Tl₂O₃ in a molar ratio of 1:1, and was completely ground and pressed into a pellet.
3. The pellet was heated at approximately 925° C. in a tube furnace for approximately 4 hours. The sample could have been heated for a longer time however.
4. The heated pellet was then taken out of the furnace and cooled in air to room temperature. The resultant pellet was found to have a semiconductor behavior.
5. A small amount (approximately 0.1 to about 0.2 gm) of Tl₂O₃ was put in a platinum boat, and the platinum boat was put in a quartz boat.
6. The resultant pellet was put over the platinum boat.
7. The quartz boat was then put into the tube furnace which had been heated to approximately 900° C., and was heated for about 3 minutes in flowing oxygen.
8. The sample was then furnace-cooled to room temperature in flowing oxygen, and was then removed from the furnace.

The resulting Tl₂O₃-vapor-processed sample, produced by this example, had a superconducting behavior, and had an onset temperature of above 120 K., and a zero resistance temperature of above 100 K.

It should be understood that various changes and modifications to the presently preferred embodiments described herein will be apparent to those skilled in the art. Such changes and modifications can be made without departing from the spirit and scope of the present invention and without diminishing its attendant advantages. It is therefore intended that such changes and modifications be covered by the appended claims.

We claim:

1. A method for making high temperature superconductors, comprising the steps of:

- a. preparing Ba—Ca—Cu-oxides; and thereafter
- b. reacting Tl₂O₃ vapor and solid Ba—Ca—Cu-oxides to form Tl—Ba—Ca—Cu—O superconductors.

2. The method of claim 1 wherein the Ba—Ca—Cu-oxides are created from a mixture of compounds selected from the group consisting of: BaCO₃, CaO, and CuO; BaCO₃, CaCO₃ and CuO; BaO₂, CaO, and CuO; and BaO₂, CaO₂, and CuO.

3. The method of claim 1 wherein the Tl₂O₃ vapor is created by heating a Tl-containing compound.

4. A method for making high temperature superconductors comprising the steps of:

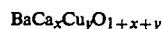
- a. grinding a mixture of a compound selected from the group consisting of CaCO₃, CaO, a compound selected from the group consisting of BaCO₃ and BaO₂, and CuO and heating the ground mixture to obtain a uniform black Ba—Ca—Cu—O powder;
- b. pressing the resulting Ba—Ca—Cu—O powder into a pellet;
- c. heating the pellet;
- d. allowing the pellet to cool;
- e. placing the pellet near an amount of Tl₂O₃;
- f. making the pellet into a wire shape;
- g. heating the wire shape and Tl₂O₃ so that at least a portion of the Tl₂O₃ vaporizes; and
- h. allowing the resultant product to cool.

5. A method for making thin-film Tl—Ca—Ba—Cu—O superconductors comprising the steps of:

- a. depositing a thin-film of Ca—Ba—Cu—O precursor utilizing physical vapor deposition;
- b. placing Tl₂O₃ in a platinum boat under or near the precursor thin film;
- c. heating the platinum boat and precursor film in flowing O₂; and
- d. cooling the film and platinum boat.

6. A method for making high temperature superconductors, comprising the steps of:

- a. preparing Ba—Ca—Cu-oxides; and thereafter
- b. reacting Tl₂O₃ vapor and solid Ba—Ca—Cu-oxides having a nominal composition substantially represented by the formula:



wherein:

$$0 < x < 100; \text{ and } 0.01 < y < 100$$

to form Tl—Ba—Ca—Cu—O superconductors.

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