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Composite materials on high-T_c superconductors and $BaPbO_3$, Ag basis

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Abstract

The preparation, processing and characterization of the composite materials on high-T_c superconductor (HTSC) basis, $YBa_2Cu_3O_7$/Ag and $Y_{0.75}Lu_{0.25}Ba_2Cu_3O_7/BaPbO_3$, is reported. The initial components $YBa_2Cu_3O_7$ and $BaPbO_3$ were prepared by the standard solid state reaction technique. The microstructures of the samples were observed by scanning electron microscopy, whilst the XRD paterns of the composites HTSC+Ag and HTSC+$BaPbO_3$ revealed the 123 superconducting phase and the Ag or $BaPbO_3$ structure. The chemical compositions of the powders and the interface zone were found by employing energy dispersive spectrometry. The resistive and magnetic measurements of the composites indicated the transition temperature 93.5 K. Application of such composite materials in the construction of a superconducting fault current limiter model is reported. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Composite high-T_c superconductors; Superconducting fault current limiter

1. Introduction

A superconducting fault current limiter (SFCL) is one of the most promising applications of ceramic high-T_c superconductors (HTSCs). The discovery of high-T_c superconductivity in copper-oxides resulted in an increased interest for SFCL devices, because the high-transition temperature of HTSCs (90–120 K) allows for the use of liquid nitrogen for freezing the active elements (superconductors) of such devices. A number of studies of SFCLs on HTSC materials basis appeared since1987, see Refs. [1–5] and the references listed there.

Composite materials on HTSC basis are known to be suitable for use as active elements of SFCLs, because they possess improved mechanical and physical properties, overload capability, etc. The important requirement to non-superconducting component of a HTSC based composite is the absence of chemical interaction with HTSC. Among a number of possible materials for HTSC based composites, Ag seems to be the most attractive [6]. On the other hand, the use of metal-oxides, such as $BaPbO_3$, is also promising [7]. In the present paper reported are results regarding preparation, processing and characterization of $YBa_2Cu_3O_7$/Ag and

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$Y_{0.75}Lu_{0.25}Ba_2Cu_3O_7/BaPbO_3$ composites, for fabricating components for electrical applications.

2. $YBa_2Cu_3O_7$/Ag composites

$YBa_2Cu_3O_7$ was synthesized from Y_2O_3, BaO_2, and CuO at 900–925°C. The use of BaO_2, instead of the $BaCO_3$ in the solid state reaction technique, allowed for the improvement of the homogeneity of the HTSC and the decrease of sintering time (30 h). $YBa_2Cu_3O_7$/Ag composites were prepared from $YBa_2Cu_3O_7$ powder and ultra-dispersed Ag. The powders of the initial components were carefully mixed and pressed as pellets. Then the composites $YBa_2Cu_3O_7$/Ag, with volume contents of Ag up to 33 vol%, were synthesized at 925°C for 8 h.

The XRD pattern of the composites reflected the 123 superconducting phase and the silver, while small additions of the $YBa_2Cu_3O_5$ phase were also detected, as it can be seen from Fig. 1.

The microstructure of samples with 33 vol% of Ag was observed by scanning electron microscopy (SEM), a typical micrograph is presented in Fig. 2. The interface boundaries are not so clear, indicating that the YBCO powder was mixed with the silver powder creating an interface zone. The chemical composition of both the powder and the interface zone was obtained by employing energy dispersive spectrometry (EDS). According to the EDS analysis, all the elements of the YBCO powder were present, as well as the silver in the interface, but a certain amount of Ca was also detected. The EDS spectrum of both the YBCO

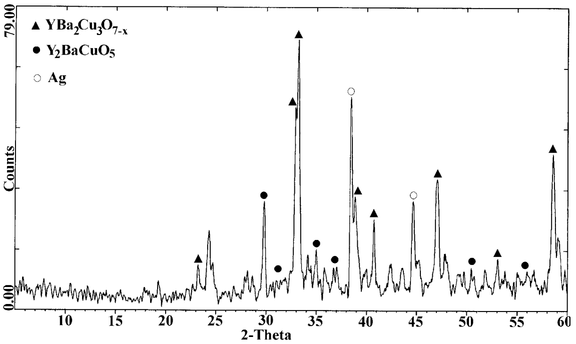
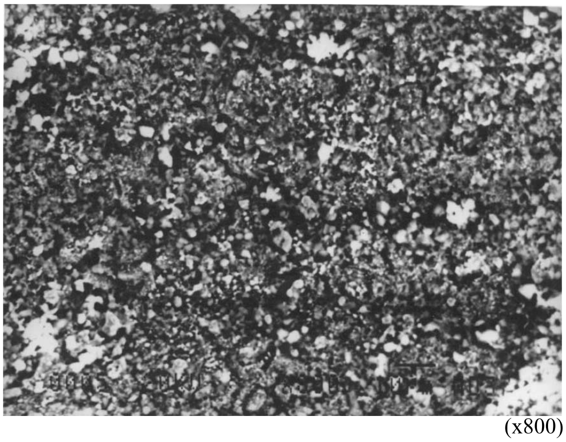


Fig. 1. XRD pattern of YBCO/Ag composite.



(x800)

Fig. 2. SEM micrograph of the interface zone of $YBa_2Cu_3O_7$/Ag composite (33 vol% Ag).

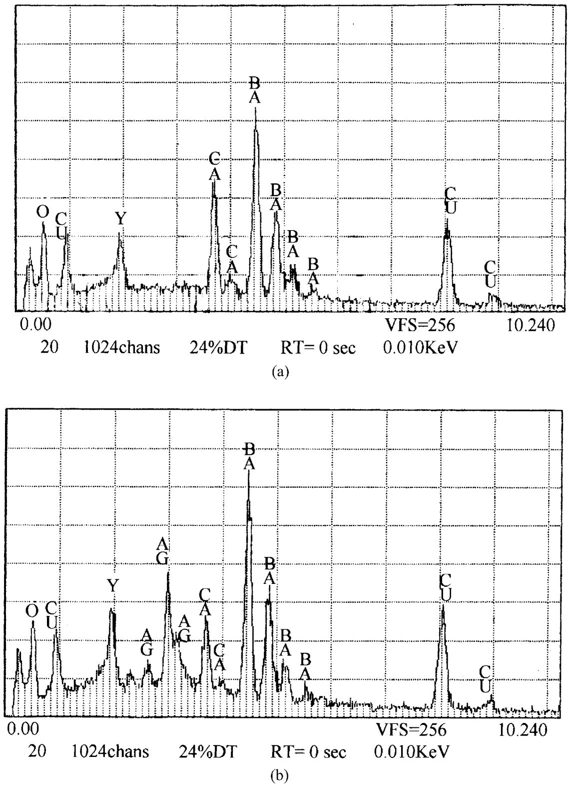


Fig. 3. EDS spectrum of (a) the YBCO powder and (b) the interface zone of $YBa_2Cu_3O_7$/Ag composite (33 vol% Ag).

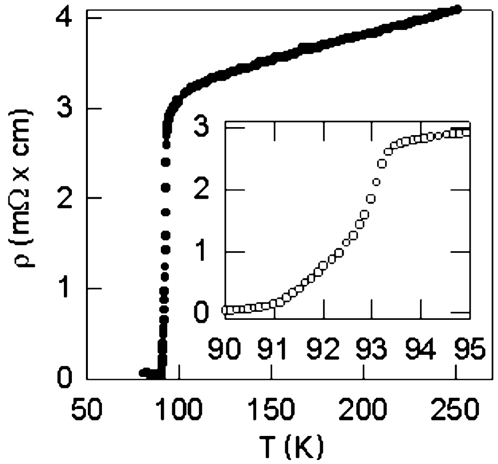


Fig. 4. DC temperature dependence of resistivity of $YBa_2Cu_3O_7$/Ag composite (33 vol% Ag).

powder and the interface zone are presented in Fig. 3(a) and (b), respectively.

In Fig. 4 the DC temperature dependence of resistivity, of the composite with 33 vol% Ag is shown. The critical temperature, $T_c = 93.5$ K almost coincides with that determined by magnetic measurements and with the T_c of the initial $YBa_2Cu_3O_7$ powder. The 'zero resistance' transition temperature was equal to 90.2 K.

Fig. 5 presents current–voltage characteristic (CVC) of the sample with 33 vol% Ag, measured by the DC four probe technique at stationary power conditions. The critical current density, J_c at 77 K, determined by the 1 μV/cm criterion, was 30 A/cm^2. Such low values of J_c may be attributed to the effect of weak links between HTSC crystallites [7]. Note that, the sample shows a good overload capability, i.e. transport currents 50 times more than critical value at stationary conditions, which makes such $YBa_2Cu_3O_7$/Ag composite materials proper for SFCL devices.

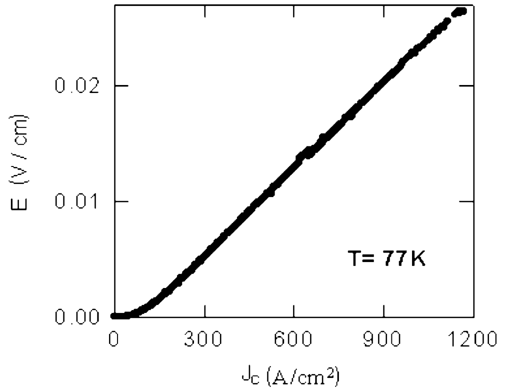


Fig. 5. CVC at 77 K of $YBa_2Cu_3O_7$/Ag composite (33 vol% Ag).

3. $Y_{0.75}Lu_{0.25}Ba_2Cu_3O_7/BaPbO_3$ composites

The $BaPbO_3$, as a non-superconducting component of the composites, was sintered from BaO_2 and PbO at 880°C for 20 h. The $Y_{0.75}Lu_{0.25}Ba_2Cu_3O_7$ powder was prepared by the standard solid state reaction technique. The $Y_{0.75}Lu_{0.25}Ba_2Cu_3O_7/BaPbO_3$ composites were produced by using the following procedure. The composite components were well mixed, with additional milling of the powders, in an agate mortar and then pressed into pellets. The pellets were put into pre-heated dies and then heated in a furnace to 950°C, kept at this temperature for 5 min. Subsequently, they were normalized in another furnace for 6 h at 400°C and slowly cooled to room temperature. The XRD patterns of the composites exhibit 123-phase and perovskite structure only. The onset temperature of the resistive transition for the composites was 93.5 K, which almost coincides with that obtained from magnetic measurements. The zero resistance transition temperature depends on the $BaPbO_3$ content.

The CVCs of the compounds were measured, while the critical current measurements of the $Y_{0.75}Lu_{0.25}Ba_2Cu_3O_7/BaPbO_3$ are reported in Ref. [7]. Fig. 6 shows an example of CVC of a composite with 7.5 vol% $BaPbO_3$ at 4.2 K, measured by the DC four probe technique at fixed current conditions. Its shape was fully reproducible at any current scanning velocity, indicating, therefore, that self-heating effects were avoided. The CVC is characterized by a sharp transition from low to high resistivity at some value of scanning current, accompanied by hysteresis [8]. Such a behavior is very advantageous for SFCL devices.

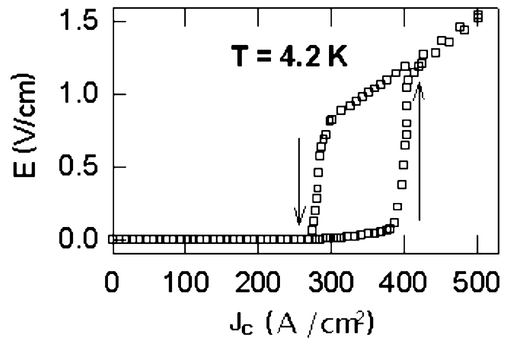


Fig. 6. CVC at 4.2 K of $Y_{0.75}Lu_{0.25}Ba_2Cu_3O_7/BaPbO_3$ (7.5 vol% BaPbO3, arrows indicate current scanning direction).

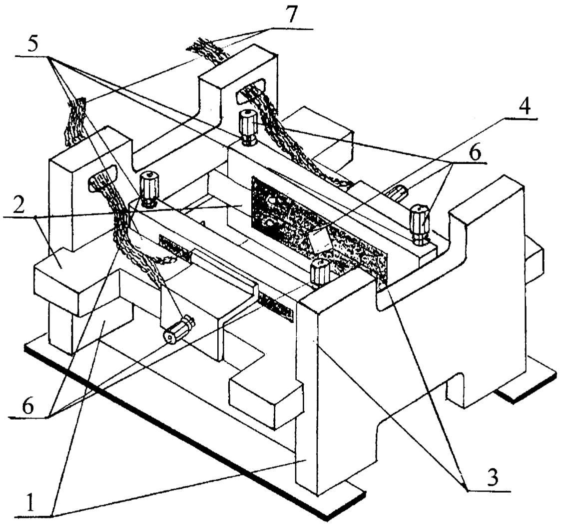


Fig. 7. A schematic diagram of the circuit of the high-temperature SFCL model, 1: insulating plate, 2: floating current leads holders, 3: massive copper current leads, 4: groove N3 for the active HTSC element, 5: springs securing the holdings down of the detail N3 to the active HTSC element, 6: adjusting screws, 7: flexible output electrodes.

4. Applications

The superconducting composite materials produced were used as HTSC elements for a SFCL model, constructed by the authors [9]. Note that, such materials, showing CVC hysteresis peculiarities, are close to ideal for this device, since they indicate an abrupt transition from low- to high-resistivity ($\Delta T \cong 0$).

In the ideal SFCL, the ballast resistance (superconductor) is equal to zero for current $I \leqslant I_c$, where I_c is the critical value for the superconducting element, and it ‘switches on’ when $I > I_c$, limiting, therefore, the current to a safe level. A schematic diagram of the SFCL model is presented in Fig. 7. The HTSC element was inserted between copper floating holders and immersed into liquid nitrogen bath. The contact resistance obtained was about 6 $\mu\Omega \times \mathrm{cm}^2$ at 77 K [9].

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