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High-field magnetization of $YBa_2Cu_{3-x}M_xO_7$ (M≡Pb, Sn) at 4.2 K

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Abstract

Magnetization measurements on lead- or tin-doped $YBa_2Cu_3O_7$ have been performed at 4.2 K in magnetic fields up to 29 T. The critical current densities are deduced from the irreversible magnetization and the pinning forces are evaluated. The effect of both lead and tin doping on the critical current density is quite appreciable. In particular, the critical current density of the sample doped with lead is more than twice that of the undoped sample. This effect is thought to be associated with the enhancement of the intergranular coupling of grains through the formation of $BaPbO_3$ phase at the interface of the 123 superconducting phase. The relationship between the critical current density and a micrograph of the tin-doped sample is also discussed.

1. Introduction

Despite the enormous efforts to understand the superconductivity in high-temperature superconductors, the maximum achieved critical current density in bulk polycrystalline samples in high magnetic fields is still low. The intergrain weak-link structure is probably the main obstacle for the potential usage of such materials [1, 2]. In order to improve the electric properties of such materials, the intergranular coupling between the grains has to be strengthened. One seemingly effective way is by doping with appropriate elements [3]. In the present investigation, we report the effect of doping bulk $YBa_2Cu_3O_7$ samples with lead or tin on the microstructure and on the high-field magnetization at 4.2 K in fields up to 29 T.

2. Experimental details

Samples of nominal composition $YBa_2Cu_{3-x}M_xO_7$ (M≡Pb, Sn; $x = 0, 0.05, 0.1, 0.15, 0.2$) were prepared by the usual solid-reaction method. Appropriate mixtures of Y_2O_3, $BaCO_3$, CuO and PbO or SnO_2 of 99.9% purity were calcined at 930 °C for 24 h. The calcined powders were subjected to repeated

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pulverizing and sintering three times and hydrostatically pressed at a pressure of 2000 kg cm^{-1}. After this, they were sintered at 900 °C for 24 h followed by an oxygen absorption treatment at 600 °C for 48 h.

A.c. susceptibility measurements were conducted on all doped samples from liquid nitrogen temperature to room temperature in order to assess the superconducting transition temperature. X-ray diffraction by means of Cu Kα radiation was employed to characterize the phases present in the compound. The composition of the phases was determined by the electron probe microanalysis (EPMA) technique.

High-field magnetization measurements at 4.2 K were performed in the 40 T facility of the University of Amsterdam. Triangular field time profiles were employed with increasing and decreasing field rates of 42 T s^{-1} in measurements up to 11 T, 15 T and 29 T. The samples were heated to room temperature after each pulse in order to remove the trapped flux.

3. Results and discussion

A.c. susceptibility measurements from room temperature down to liquid nitrogen temperature indicate that the superconducting transition temperature of about 91 K of sintered $YB_2Cu_3O_7$ is only little affected by doping with lead or tin.

The phases present in the lead- or tin-doped $YBa_2Cu_3O_7$ were identified by X-ray diffraction (Cu Kα radiation) and EPMA analysis. In the lead-doped samples, it was found that in addition to the principal 123 phase, a new phase $BaPbO_3$ has emerged. In the tin-doped samples, no new phase was found, only some impurity phases like Y_2BaCuO_5 (211) and CuO were detected. The X-ray diffraction patterns and scanning electron microscopy (SEM) micrographs of $YBa_2Cu_{2.9}M_{0.1}O_7$ (M≡Pb and Sn) are shown in Figs. 1 and 2 respectively. It can be seen, that in addition to the 123 phase, some diffraction peaks of $BaPbO_3$ (lead-doped samples) or 211 phase (tin-doped samples) are evident (marked by open circles). The chemical compositions of the phases found in lead-doped $YBa_2Cu_3O_7$ and tin-doped $YBa_2Cu_3O_7$ as assessed by EPMA are given in Tables 1 and 2 respectively. It was shown that tin dissolves largely in the 123 phase and 211 phase, but lead dissolves only slightly in the 123 phase and the rest forms a $BaPbO_3$ phase. This new phase is spread along the grain boundaries of the 123 phase.

The magnetization curves of sintered $YBa_2Cu_{2.95}M_{0.05}O_7$ (M≡Pb, Sn, Cu) at 4.2 K are shown in Fig. 3. The Bean model [4] was used to determine the critical current density according to the formula $J_c = \Delta M/Vd$ where ΔM is the difference between the magnetic moments of the field-up and field-down curves, V is the volume of each doped sample and d an effective thickness of the samples.

It was found that among the doped samples the critical current density of the samples with composition $YBa_2Cu_{2.95}M_{0.05}O_7$ (M≡Pb, Sn) is higher than that of the more heavily doped ones. When x is larger than 0.05 in

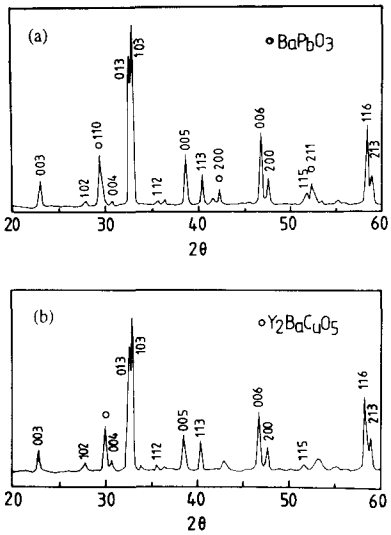


Fig. 1. X-ray diffraction patterns of $YBa_2Cu_{2.9}M_{0.1}O_7$ (M≡Pb (a), Sn (b)). Diffraction peaks resulting from $BaPbO_3$ and 211 phase are marked by open circles.

$YBa_2Cu_{3-x}M_xO_7$ (M≡Pb, Sn), the critical current density decreases gradually with increase of the dopants, but is still higher than that of the undoped one. To compare the effect of the various dopants, the field dependence of the critical current density (J_c) for the three samples ($YBa_2Cu_{2.95}M_{0.05}O_7$, M≡Pb, Sn, Cu) is shown in Fig. 4. It can be seen that, although the magnetizations of these samples decrease gradually with increasing applied magnetic field, the critical current densities of both lead- and tin-doped YBCO are still higher than those of the undoped sample in all magnetic fields applied. In particular, the critical current density of the sample doped with lead is approximately two times higher than that of the undoped sample. This is because the dopant lead forms a stable compound $BaPbO_3$ along the interfaces of the superconducting 123 phases, which is a good electrical conductor [5]. Its presence may strengthen the intergranular coupling of grains and improve the intergrain weak-link structure in these sintered materials. For the tin-doped sample, it is very interesting that its critical current density decreases less strongly with the increasing magnetic field applied. This means that in higher magnetic fields, tin doping is more effective than lead doping for increasing the critical current density of YBCO. This probably is to be associated with the solution of tin in the 123 phase and pinning by finely dispersed 211 particles in the 123 phase.

The volume density of the pinning force F_p can be deduced from the critical current density by means of the formula $F_p = J_c \times B$ where B is the external magnetic field. The field dependence of the pinning force of $YBa_2Cu_{2.95}M_{0.05}O_7$ (M≡Pb, Sn, Cu) is shown in Fig. 5. From this figure, it can be noticed that the pinning forces in the samples doped with lead or tin are superior to that in the undoped sample. It is also clear that the

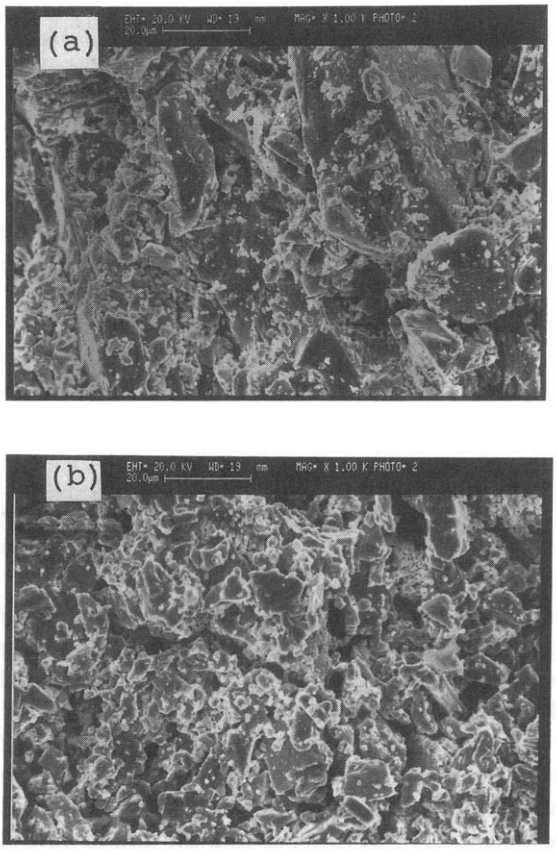


Fig. 2. Scanning electron microscopy images of $YBa_2Cu_{2.9}M_{0.1}O_7$ (M≡Pb (a), Sn(b)).

TABLE 1

Chemical compositions of the phases in lead-doped $YBa_2Cu_3O_7$

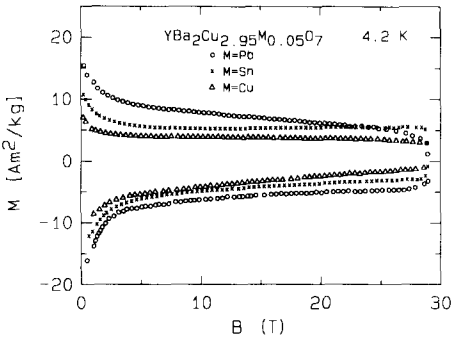
Composition (at.%)					Identified phase
O	Cu	Ba	Pb	Y	
57.38	22.50	14.18	0.06	5.90	123
60.00	0.90	20.37	14.07	4.66	$BaPbO_3$

magnetic field at which the pinning force reaches a maximum is higher for lead- or tin-doped YBCO than for undoped. Especially for the tin-doped sample, it would appear that up to 30 T no maximum is reached, indicating that the upper critical field B_{c2} is far above this field value. The critical current density in the tin-doped sample may even become higher than in the lead-doped sample if higher magnetic fields are applied than those in the present study.

TABLE 2

Chemical compositions of the phases in tin-doped $YBa_2Cu_3O_7$

Composition (at.%)					Identified phase
O	Cu	Ba	Sn	Y	
55.62	22.24	15.61	0.47	6.06	123
55.01	43.86	0.86	0.22	0.06	CuO
57.05	12.68	11.60	0.02	18.66	211



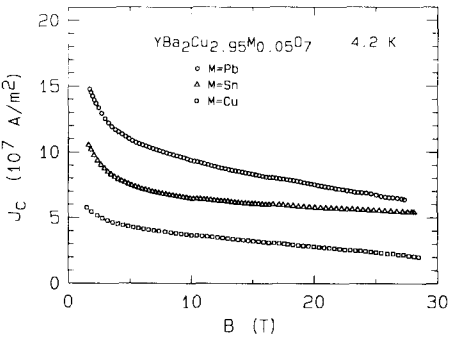


Fig. 3. Magnetization curves of sintered $YBa_2Cu_{2.95}M_{0.05}O_7$ (M≡Pb, Sn, Cu) at 4.2 K.

Fig. 4. Field dependence of the critical current densities in sintered $YBa_2Cu_{2.95}M_{0.05}O_7$ (M≡Pb, Sn, Cu) at 4.2 K.

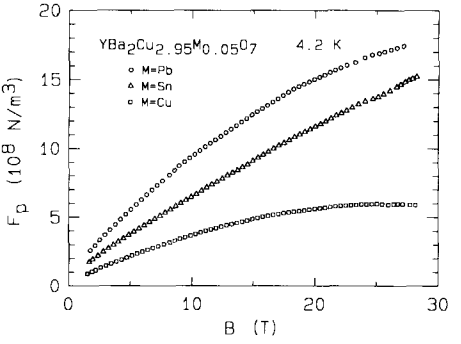


Fig. 5. Field dependence of the pinning forces in sintered $YBa_2Cu_{2.95}M_{0.05}O_7$ (M≡Pb, Sn, Cu) at 4.2 K.

Acknowledgments

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