Available online at www.sciencedirect.com
ScienceDirect
Physica C 460–462 (2007) 1311–1312
PHYSICA C
www.elsevier.com/locate/physc

Crossover from S–I–S to S–F–S junctions in composites $Y_{3/4}Lu_{1/4}Ba_2Cu_3O_7 + Y_3(Al_{1-x}Fe_x)_5O_{12}$

S.I. Popkov *, D.A. Balaev, K.A. Shaihutdinov, M.I. Petrov

Kirensky Intitute of Physics, Krasnoyarsk 660036, Russia

Available online 2 April 2007

Abstract

The transport properties of the two phases composites based on $Y_{3/4}Lu_{1/4}Ba_2Cu_3O_7$ (YBCO) and $Y_3(Al_{1-x}Fe_x)_5O_{12}$ ($x = 0.0 \ldots 1.0$) have been studied to investigate the effect of magnetic ordering in garnet on superconducting properties of the composites. The composites represent network of Josephson junctions where the non-superconducting ingredient (garnet) acts as barriers separating YBCO grains. It is found that magneto-active ions (Fe) in garnet are responsible for an additional suppression of Josephson coupling in the composites. At some critical concentration of Fe atoms full suppression of super current is observed in a temperature range from T_C of YBCO grains down to the characteristic temperature T_m. This behavior is attributed to the interaction of super current carriers with spins of Fe atoms located in the barriers. The crossover from S–I–S (S – superconductor, I – insulator) to S–F–S (F – ferrimagnet) junctions is observed in the composites $Y_{3/4}Lu_{1/4}Ba_2Cu_3O_7 + Y_3(Al_{1-x}Fe_x)_5O_{12}$ with x increase.

Keywords: S–F–S structures; High-T_C superconductors

1. Introduction

Josephson structures with magnetic ordering in the barrier separating superconductors (S) are under intensive investigation both theoretically [1] and experimentally [2]. In Ref. [3] we have studied the effect of magnetic ordering in the insulating (I) component $Y_3Fe_5O_{12}$ of the composite $YBaCuO + Y_3Fe_5O_{12}$ on its transport properties. The composites represent a network of Josephson junctions where the non-superconducting component acts as barriers separating YBCO grains [3]. Here we report on experimental study of transport properties of composites $YBCO + Y_3(Al_{1-x}Fe_x)_5O_{12}$ with various x from 0 to 1.

2. Experimental

Series of the substituted garnets $Y_3(Al_{1-x}Fe_x)_5O_{12}$ with $x = 0.0$, 0.003, 0.025, 0.05, 0.1, 0.15, 0.3, 0.4, 0.6, 0.8, 1.0 was synthesized using solid state reaction technique at temperatures 1200–1400 °C for 200 h. The X-ray diffraction patterns of the compounds obtained show only reflections corresponding to the garnet structure. The lattice constant grows linearly with increase in the aluminum content. Magnetic measurements showed that the samples with $x = 1.0$, 0.8 are ferrimagnets. The values of the saturation magnetization and magnetic moment per iron ion coincide with the data of [4]. The magnetic properties of samples with $0.1 < x < 0.8$ demonstrate a superposition of ferrimagnetism and paramagnetism. At $x \leqslant 0.1$ the $Y_3(Al_{1-x}Fe_x)_5O_{12}$ compounds are paramagnets.

The composites with 92.5 vol.% of $Y_{1/4}Lu_{1/4}Ba_2Cu_3O_7$ (YBCO) and 7.5 vol.% of garnet $Y_3(Al_{1-x}Fe_x)_5O_{12}$ (GR) have been prepared by fast backing technique [3]. The current–voltage characteristics (CVCs) and temperature dependences of resistance $R(T)$ have been measured by standard four-probe technique. Analysis of structural, transport, and magnetic properties of the composites have shown absence of chemical interaction between YBCO and garnets. We designate the composites as $S + GR(Fe_x)$,

* Corresponding author. Tel.: +7 3912 43 26 35; fax: +7 3912 43 89 23.
E-mail address: volk80iph@yandex.ru (S.I. Popkov).

0921-4534/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.physc.2007.03.348

where x is the concentration of iron in the compound $Y_3(Al_{1-x}Fe_x)_5O_{12}$.

3. Results and discussions

Fig. 1 shows $R(T)$ dependences of some composites at different values of a transport current j. A sharp drop of resistance at T_C (onset of transition) corresponds to transition of YBCO grains in the composites. The $R(T)$ below T_{C1} (offset of transition of YBCO grains, Fig. 1) is caused by transition of network of Josephson junctions in the composites. For composites with Fe concentration in garnet up to $x = 0.1$ the increase of x result in decrease of "zero resistance" temperature T_{C0}. Growth of bias current affects on form of $R(T)$ dependence and shifts T_{C0} to low temperatures, Fig. 1d. Such a behavior is typical for a network of Josephson junctions and has been observed for granular superconductors [3].

As the Fe concentration x in the garnet exceeds 0.15 an additional feature appears on the $R(T)$ curves. In the temperature range T_m–T_{C1} R does not depend on the transport current. In this temperature range the $R(T)$ curves prolong semiconducting-like behavior which takes place above T_C [3]. Resistance of the composites growths with decrease of temperature due to insulating layers (formed by garnet) between YBCO crystallites. Below T_m the $R(T,j)$ dependences become current-dependent which is typical for Josephson junction network. Independence of R on j is manifestation of full destruction of Josephson coupling in the range T_m–T_{C1}. Similar effect have been observed on low-T_C Nb/Al/Gd/Al/Nb junctions [2]. When Cooper pairs tunnel through the non-superconducting barrier interaction of pair spin with magnetic moments of Fe ions takes place which result in destroying of Cooper pairs. In the high temperature region the pair breaking mechanism predominates over the Josephson coupling. When the temperature decreases the Josephson coupling energy growths and below the characteristic temperature T_m the Josephson coupling prevails the pair breaking mechanism. Fig. 2 shows the width of temperature interval T_{C1}–T_m in which complete suppression of the Josephson coupling is observed as a function of the Fe content in the garnet. Monotonous growth of this temperature interval is observed starting from $x =$ 0.15.

The influence of growth of transport current on $R(T)$ curves (including shift of T_{C0} values) of composites becomes more pronounced for samples containing high concentrations of the Fe in the garnet. This additionally points out suppression of Josephson coupling in composites below T_m with the increase of Fe concentration barriers between the YBCO crystallites.

Thus, we have observed the crossover from S–I–S (I – insulator) to S–F–S (F – ferrimagnet) junctions in the composites $Y_{3/4}Lu_{1/4}Ba_2Cu_3O_7 + Y_3(Al_{1-x}Fe_x)_5O_{12}$ with increase of Fe concentration in garnet.

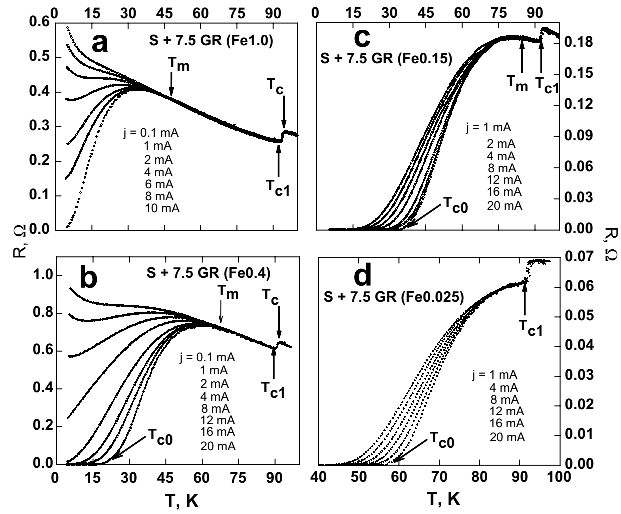

Fig. 1. The temperature dependences of resistance for composites, where $x = 1.0$; 0.15; 0.4; 0.025 at different values of transport current.

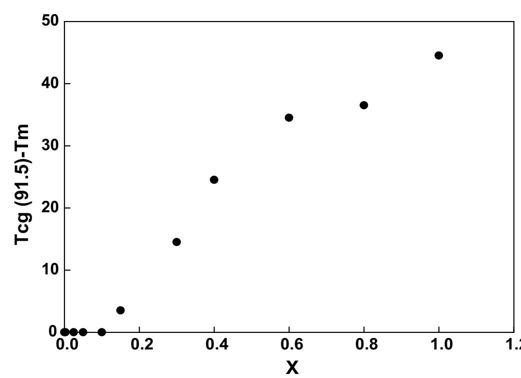

Fig. 2. The width of temperature interval T_{C1}–T_m as a function of Fe content in $Y_3(Al_{1-x}Fe_x)_5O_{12}$ for the composites 92.5 vol.% YBCO + 7.5 vol.% $Y_3(Al_{1-x}Fe_x)_5O_{12}$.

Acknowledgement

This work is supported by Lavrent'evs competition of young scientists of SB RAS, project N52, integration project of SB RAS N3.4, program "Quantum macrophysics" of RAS N 3.4, and in part by Russian Science Support Foundation.

References

[1] Yu.A. Izumov, Yu.N. Proshin, M.G. Khusainov, Phys.-Uspehi 45 (2002) 109.
[2] O. Bourgeois, P. Gandit, A. Sulpice, et al., Phys. Rev. B 63 (2002) 064517.
[3] M.I. Petrov, D.A. Balaev, K.A. Shaikhutdinov, K.S. Aleksandrov, Supercond. Sci. Technol. 14 (2001) 798.
[4] M.A. Gillio, S. Geller, Phys. Rev. 110 (1958) 73.