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STUDY OF COMPOSITES CONSISTING OF HIGH-T_c SUPERCONDUCTOR AND FINE MAGNETIC PARTICLES

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The composite systems as a mixture of fine magnetic particles of Fe_3O_4 and superconducting powder such as $Bi_{1.8}Pb_{0.2}Sr_2Ca_2Cu_3O_{10+x}$ were prepared. The influence of internal magnetic field (generated by magnetic particles) on the superconducting properties of prepared composites were studied as a function of concentration of magnetic particles and their magnetic state. The observed data both of the shielding and the Meissner effect were compared with corresponding linear combination of pure signals of magnetite and superconductor, respectively. The large differences were observed for demagnetized samples. It means that result must be discussed in the frame of the distribution of internal magnetic field created by the magnetic particles.

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1. Introduction

The magnetic flux exclusion properties of superconducting material are strongly affected by the presence of magnetic field larger than lower critical field. As an applied field rises above H_{c1}, magnetic flux penetrates into the body of the sample, reducing the amount of excluded flux. In our previous paper [1] the influence of internal magnetic field on the superconducting properties of composites consisting of a mixture of superconducting $YBa_2Cu_3O_{7-x}$ and ferrimagnetic Fe_3O_4 powder. The experimental data have shown that even very small magnetic particles admixture is high enough for a significant Meissner effect disturbance. Flippen [2] studied magnetic flux exclusion properties of composites of magnetic CrO_2 and superconducting $YBa_2Cu_3O_{7-x}$ powder. It was shown that the magnetic state of magnetic material affects flux exclusion of superconducting material. Our aim in this paper was to study the flux exclusion properties of composite material made up of high-T_c superconducting $Bi_{1.8}Pb_{0.2}Sr_2Ca_2Cu_3O_{10+x}$ and fine magnetic particles Fe_3O_4 traditionally used in magnetic fluid technology.

2. Experimental

The samples of high-T_c superconducting powder oxide with nominal composition of $Bi_{1.8}Pb_{0.2}Sr_2Ca_2Cu_3O_{10+x}$ were prepared by common powder metallurgical method from Bi, Pb, and Cu oxides, and Sr and Ca carbonates. Typical size of particles was about 10–15 μm. For more details of preparation conditions see [3]. The estimated values for T_c and $\mu_0 H_{c1}$ were 108 K and 40 mT, respectively. The magnetic particles Fe_3O_4 (mean diameter D_v = 10 nm and standard deviation $\sigma = 0.22$) were prepared by the well known precipitate technique. The samples of composites were made by thoroughly mixed appropriate masses of powders of high-T_c materials and magnetite in a nonreactive fluid such as ethanol, followed by evaporating fluid and pressing at constant pressure p = 10 kbar finally. We used four samples with 0.2, 0.5, 1, and 2% of mass concentration of magnetite, respectively. All prepared samples were measured at two defined magnetic states — demagnetized and magnetized at external magnetic field $\mu_0 H$ = 4 T at 200 K. The magnetization was measured by a vibrating sample magnetometer in the temperature range 4.2 to 120 K. The sample was cooled in zero field to 4.2 K, then small magnetic field of $\mu_0 H$ = 2 mT was applied and the temperature dependence of the magnetization of the sample was measured up to 120 K (zero field curve, ZFC). This curve corresponds to the shielding effect. Subsequently, the temperature dependence of the magnetization of the sample was measured in the same magnetic field in the temperature range 120 to 4.2 K (field curve, FC). This measuring of the flux exclusion corresponds to a true Meissner effect.

3. Results and discussion

Figure 1 shows ZFC and FC curves for pure pressed magnetite and superconducting oxide used in the experiments.

Figure 2 represents ZFC and FC curves for two mass concentrations of magnetite for demagnetized and magnetized state. The addition of magnetite causes the shift of both the flux exclusions (the Meissner effect) and shielding effect. We can see that this change increases with increasing mass concentration and is larger for magnetized samples. The influence of mass concentration of magnetic particles on the shielding and the Meissner effects for demagnetized and magnetized samples are illustrated in Figs. 3 and 4 respectively. For illustration we compared our experimental results of composites with the simple linear combination of the corresponding signals of pure magnetite and superconducting material.

From these figures it is evident that the differences between measured and calculated values are very small for demagnetized samples while significant differences are observed for magnetized samples for both the Meissner and shielding effects. It means that in demagnetized samples the adding of small concentration of magnetic particles creates the internal fields (lower than H_{c1}) that are so low to influence the superconducting properties and their only effect is the shift of the curves to higher values. In our previous work we have studied the flux exclusion properties of YBaCuO — magnetite composites [1]. The obtained results showed that approximation of effective medium theory is not suitable for such system.

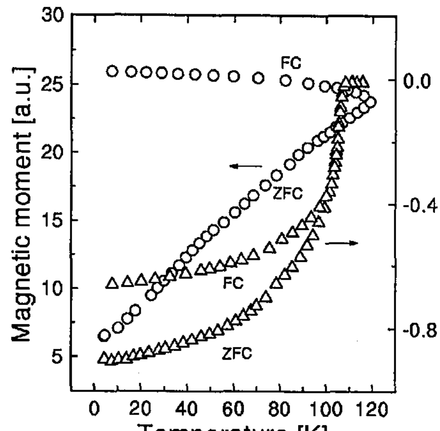

Fig. 1

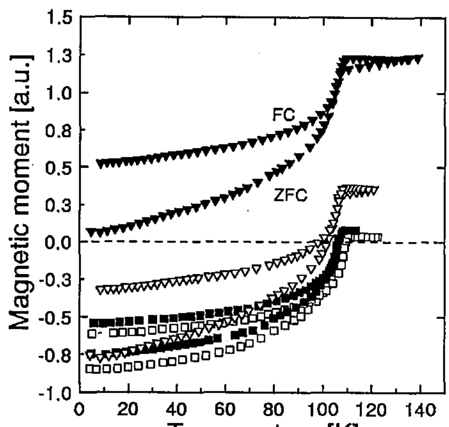

Fig. 2

Fig. 1. ZFC and FC curves at $\mu_0 H = 2$ mT for pure magnetite powder (circles) and for $Bi_{1.8}Pb_{0.2}Sr_2Ca_2Cu_3O_{10+x}$ powder (triangles).
Fig. 2. ZFC and FC curves at $\mu_0 H = 2$ mT for two mass concentrations (0.2% Fe_3O_4 — squares and 2% Fe_3O_4 — triangles, respectively), for demagnetized samples (open symbols) and samples magnetized at external magnetic field $\mu_0 H = 4$ T (solid symbols).

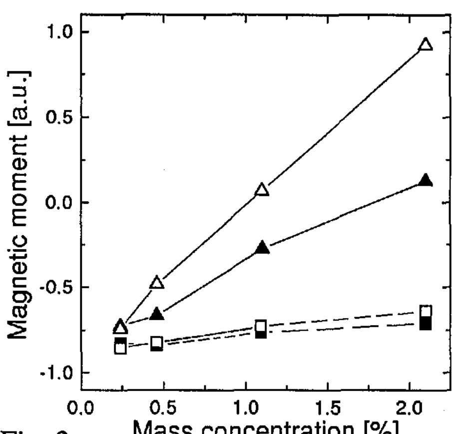

Fig. 3

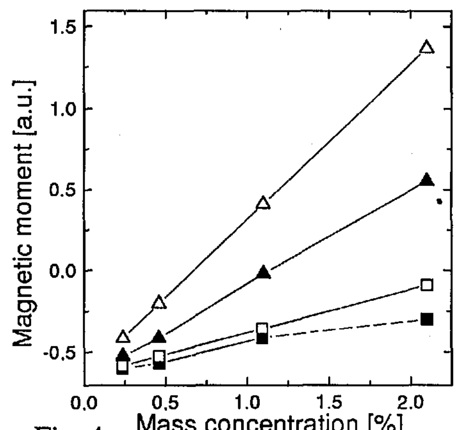

Fig. 4

Fig. 3. The shielding effect as a function of mass concentration of magnetite particles at 25 K (squares — demagnetized samples, triangles — magnetized at $\mu_0 H = 4$ T, solid and open symbols denote measured and calculated values, respectively).
Fig. 4. The Meissner effect as a function of mass concentration of magnetite particles at 25 K (squares — demagnetized samples, triangles — magnetized at $\mu_0 H = 4$ T, solid and open symbols denote measured and calculated values, respectively).

When we assume, for example, that system of magnetic particles in a composite can be considered as a system of randomly positioned magnetic dipoles with density n, with Gaussian distribution of the internal magnetic field [4]

$$P(\boldsymbol{H}) = \frac{1}{2\delta\sqrt{\pi}} \exp\left(-\frac{H^2}{4\delta^2}\right), \tag{1}$$

with Gaussian spread

$$\delta = \sqrt{\frac{4\pi p^2 n}{9a^3}}, \qquad p = \frac{4}{3}\pi a^3 M_s, \qquad n = \frac{\varphi}{\left(\frac{4}{3}\pi a^3\right)}, \tag{2}$$

dependent on the magnetic particles with diameter a, their magnetic moment p, and saturation magnetization M_s, and use the experimental data for superconducting and magnetic material ($M_s = 0.4$ T and $\mu_0 H_{c1} = 0.04$ T), it is possible to show that even a very small concentration of magnetic particles with volume concentration $\varphi > 0.0074$ (it corresponds to 0.9% mass concentration) is enough for influence of the Meissner and shielding effects. From Figs. 3 and 4 we can see that from demagnetized samples the measured values of shielding and Meissner effect for concentration smaller than 0.9% correspond to calculated values taken from linear combination of signals of pure magnetite and superconducting material. For higher concentrations we observed deviations from calculated values. For magnetized samples internal magnetic field created by magnetite obviously influences superconducting state of superconductor. It means that this magnetic field may penetrate into the body of superconducting material and subsequently change the superconducting properties. We conclude that detailed consideration including distribution of internal magnetic field is needed for the explanation of the experimental results. This will be the subject of our future work.

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