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Magnetization loop and critical current of porous Bi-based HTS

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Abstract

The magnetization of porous $Bi_{1.8}Pb_{0.3}Sr_2Ca_2Cu_3O_x$ has been investigated. The experimental magnetization hysteretic loops of $M(H)$ were described in the frames of Val'kov–Khrustalev model developed for type II granular superconductors.

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1. Introduction

High-temperature superconductors (HTSs) having a foam structure [1,2] are objects of fundamental interest connecting with the study of transport and magnetic properties in disorder media with fractal dimensions [3]. The high specific surface of foam makes porous HTSs attractive for practical application. Influence of porosity of HTS on critical current is unclear. The only article [4] concerning this matter can be referred, when critical state in superconducting single-crystalline $YBa_2Cu_3O_7$ foam is considered.

2. Experimental

The standard ceramics method is employed to prepare the porous $Bi_{1.8}Pb_{0.3}Sr_2Ca_2Cu_3O_x$ (BPSCCO), except for the final annealing. The time of synthesis was ~400 h. The decomposition of calcium carbonate realizes during the final annealing stage. The excess pressure of carbon dioxide results in an increase of the material volume.

The density ρ of the porous material equals 2.26 g/cm^3 (38% from theoretical one for BPSCCO). The SEM images show that the porous BPSCCO has flakes-like microstructure formed by the chaotic oriented crystallites [2,3]. The crystallites have thickness ~2 μm and width ~10–20 μm.

To derive the effect of porosity on magnetic properties, bulk BPSCCO was prepared from the initial porous BPSCCO by the standard technique. For this dense HTS, ρ equals 95% from theoretical one of BPSCCO.

The temperature of zero resistivity ($\leqslant 1$ μΩm cm) of porous and dense BPSCCO equals 107 K.

Measurements of magnetic field dependences of magnetization $M(H)$ in fields up to 60 kOe have been performed using the vibrating sample magnetometer with the superconducting solenoid. The specimens have the cylindrical form with height ~4 mm and diameter ~0.7 mm. The mass of sample is 0.0179 g for porous BPSCCO and 0.0264 g for dense BPSCCO. The applied magnetic field was parallel to the axis of symmetry of the cylinder sample.

3. Results and discussion

Fig. 1 presents $M(H)$ dependences of porous BPSCCO with low density and dense BPSCCO measured at liquid

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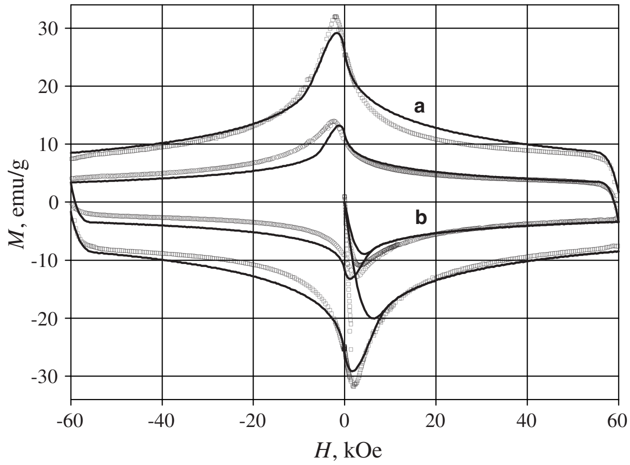

Fig. 1. Experimental $M(H)$ dependences of (a) porous BPSCCO and (b) dense BPSCCO—points. Solid lines are the results of computer simulation of $M(H)$ dependence using theory [7].

helium temperature. It is clearly seen that the shape of this dependences is similar, but the absolute value of diamagnetic response is higher in case of porous superconducting material (2.4 times in units emu/g and 1.63 times in units emu).

In the Bean approximation to the critical state [5], the critical current densities can be estimated from the magnetization data as [6] $J_c = 30\Delta M/2R$, where J_c is measured in A/cm^2, $\Delta M = M^+ - M^-$ (in emu/cm^3) is the width of the magnetization hysteresis loop at a certain magnetic field, R is the radius of the cylinder sample (in cm). The obtained zero field values of J_c are 260 kA/cm^2 for porous BPSCCO and is 1.63 times smaller, 160 kA/cm^2 for dense BPSCCO. However, the given approach does not take into account the granular structure of HTSs. Application of a more appropriate model appears to give some different results. The approach [7] is an extension of the critical state theory for the case of granular bulk HTS. The model [7] allows us to draw the hysteretic loops in a broad magnetic field range. Model considers the penetration of magnetic field in the crystallites having form of a cylinder. The general expression for performing $M(H)$ calculation in [7] is

$$4\pi M(H) = -H + (1-P)\mu_n H + \frac{2}{R_0^2}\int_0^\infty \varphi(R)\,\mathrm{d}R \int_0^R rB(r)\,\mathrm{d}r, \tag{1}$$

where P is the fraction of the superconductor concentrated in the superconducting grains, μ_n is the magnetic permeability of the intergranular material, $\varphi(R)$ is the distribution density of the superconducting granules, and $B(r)$ is the dependence of the magnetic induction on the radius. The main fitting parameter in model [7] is the average crystallite radius R and critical current density J_c, which determines $B(r)$. A new form of dependence of J_c on the magnetic induction B is employed in model [7] also. This dependence is characterized by the presence of two magnetic induction scales determined by the parameters B_1 and B_0. These scales demarcate regions with different rates of decrease of J_c. The dependence $J_c(B)$ has the following form [7]:

$$J_c(B) = J_c(0)\left[\frac{1+Q(B/B_1)}{1+B/B_1} + \left(\frac{B}{B_0}\right)^{\gamma}\right]^{-1}, \tag{2}$$

where parameters Q and γ determine the rates of variations of J_c for the scales B_1 and B_0 correspondingly.

The real crystallites of BPSCCO have a form of plates. Therefore one should modify model [7] to consider the penetration of the field in the randomly oriented flat crystallites. It will be the task of future investigation. However, we do not expect a remarkable difference of the magnetization picture.

The pores do not contribute to the magnetization of the sample. We accept P equals the density of the material normalized on the theoretical density of BPSCCO. Consequently, $P = 0.38$ for porous BPSCCO and $P = 0.95$ for dense BPSCCO. Two parameters are left in the model: J_c and R. The experimental magnetization curves are described using the same value of $J_c = 2150$ kA/cm^2 and $R = 21$ μm for porous BPSCCO and $R = 13$ μm for dense BPSCCO. The solid lines in Fig. 1 are the results of computer simulation of $M(H)$ dependences in frames of model [7]. A satisfactory agreement between the experimental and theoretical $M(H)$ curves is achieved. If we calculate $M(H)$ using larger J_c for case of porous BPSCCO than dense BPSCCO, the agreement with the experiment becomes worse.

The grain boundaries limit the critical current density of polycrystalline HTSs [8–10]. Especially, remarkable influence of grain boundaries on the critical current density is obtained from the transport measurements j_c. But roles of grain boundaries in porous HTSs are negligible [2,4]. However, j_c of porous BPSCCO is relatively small. Determination of j_c by using the criterion 1 μV cm gives 2–100 A/cm^2 at 4.2 K [3]. These values are smaller than the ones for bulk polycrystalline BPSCCO (~100 A/cm^2). There is supposed to be two reasons for decreasing of j_c: the reduced effective area of current flowing in porous HTS and the much smaller number of percolation paths in the foam in comparison with the dense HTS. We suppose that the high porosity of HTS does not lead to the enhancement of the magnetic critical current density J_c instead of the broader magnetization curve of porous BPSCCO than one of dense BPSCCO. This suggestion is in contradiction with the prediction of the Bean model. Thus the observed enhancement of the diamagnetic response should be explained by other reasons except increasing of J_c, e.g. larger size of the crystallites in porous BPSCCO.

4. Conclusion

We investigated and compared the magnetization curves of porous BPSCCO and the dense one. The experimental magnetization hysteretic loops of $M(H)$ were described in the frames of Val'kov–Khrustalev model [7] developed for type II granular superconductors. The increasing of magnetic critical current density J_c is not found in the porous BPSCCO. Contrarily, growth of the porosity is accompanied by the decreasing of the number of percolation paths that reduces the transport critical current density j_c. Discovered enhancement of the diamagnetic response in porous HTSs is very attractive for practical applications, e.g. superconductor bearings and levitators.

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