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Establishing of peak effect in YBCO by Nd substitution

D.M. Gokhfeld[a,*], S.V. Semenov[a,b], D.A. Balaev[a,b], I.S. Yakimov[b], A.A. Dubrovskiy[a], K.Yu. Terentyev[a], A.L. Freydman[a], A.A. Krasikov[a], M.I. Petrov[a]

[a] Kirensky Institute of Physics, Krasnoyarsk Science Center SB RAS, Krasnoyarsk 660036, Russia
[b] Siberian Federal University, Krasnoyarsk 660041, Russia

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ABSTRACT

$Y_{0.75}Nd_{0.25}Ba_2Cu_3O_{7-d}$ superconductor has the peak effect with pronounced fishtail feature on magnetization hysteresis. The magnetic field of the peak effect maximum is in ~4 times higher than one of $NdBa_2Cu_3O_{7-d}$. The magnetization hysteresis is tilted anticlockwise due to paramagnetic Nd^{3+} ions occurred on the surface of grains and in the vortex cores.

1. Introduction

Since discovery of high-T_c superconductivity, many works were devoted to optimize transport properties of superconductors. The rare earth element (Re) doping is used to increase the critical current density j_c of $YBa_2Cu_3O_{7-d}$[1]. The Re doping results in crystal defects and improvement of the vortex pinning. Most interest for current applications is the pinning growth especially at high magnetic fields. Such increase of the critical current is typical for the peak effect when j_c becomes to grow with increasing magnetic field H at some field range. The vortex lattice transition [2] can produce the peak effect.

$NdBa_2Cu_3O_{7-d}$ and $EuBa_2Cu_3O_{7-d}$ bulk superconductors exhibit the peak effect [3–5] which manifests itself as fishtail-like feature on the magnetization hysteresis loop $M(H)$. Magnetization loops of $NdBa_2Cu_3O_{7-d}$ and $EuBa_2Cu_3O_{7-d}$ demonstrate the fishtail-like feature at $H < 50$ kOe for $T > 10$ K. In the same time realization of the peak effect in the $YBa_2Cu_3O_{7-d}$ compound is questionable [3]. Previous investigations did not trace the fishtail evolution in the substituted Y(Re)–123 system. In order to advance along this line we search the peak effect in $Y_{0.75}Nd_{0.25}Ba_2Cu_3O_{7-d}$.

2. Material and methods

$Y_{0.75}Nd_{0.25}Ba_2Cu_3O_{7-d}$ was synthesized using the standard solid state reactions technique. The sample was investigated by XRD, transport and magnetic measurements. It was found that the polycrystalline $Y_{0.75}Nd_{0.25}Ba_2Cu_3O_{7-d}$ sample has no additional phases. The critical temperature is 92 K. The average size of grains is about 1 μm. The magnetization loops were measured in the temperature range 4.2–80 K and the magnetic field H range up to 90 kOe using a PPMS-6000 measurement system (Quantum Design).

The extended critical state model (ECSM) was used to analyze the magnetization loops [6–8]. The ECSM accounts contributions to the magnetization loop from the surface and the internal volume of a superconducting sample and it allows to parameterize the magnetization hysteresis with asymmetry relative to the M=0 axis. Using ECSM, several important magnetic parameters could be determined including the penetration field, the irreversibility field, the critical current density and the flux pinning forces.

3. Results and discussion

Fig. 1 shows magnetization hysteresis loops of the sample at different temperatures. The hysteresis loops look to be tilted in the anticlockwise direction. This supports that the total magnetization $M(H)$ is the superposition of a hysteresis loop $M_S(H)$ of the superconducting grains and an additional paramagnetic magnetization $M_P(H)$.

The additional paramagnetic magnetization was accounted firstly to plot $M_S(H)$ from $M(H)$ dependences. This paramagnetic contribution is expressed as $M_P(H)=N\ g\ J\ \mu_B B_J\ (g\ J\ \mu_B H\ k_B^{-1} T^{-1})$, where N is the number of the magnetic ions per unit volume, μ_B is the Bohr magneton, k_B is the Boltzmann constant, g is the Lande's g factor, J is the angular momentum quantum number, and B_J is the Brillouin function. We found that the value of N increases with temperature up to T_c. This supports that the observed paramagnetic contribution is due to Nd^{3+}

* Corresponding author.
E-mail address: gokhfeld@iph.krasn.ru (D.M. Gokhfeld).

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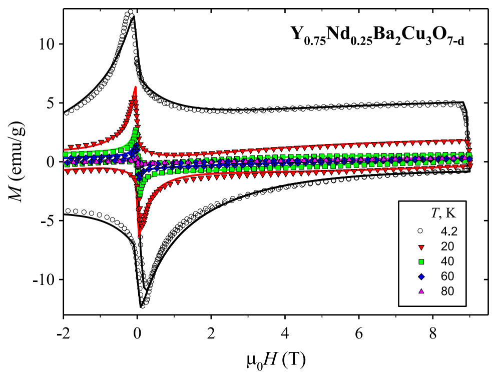

Fig. 1. *M-H* loops of Y(Nd)123. Points – experiment, lines – computed curves.

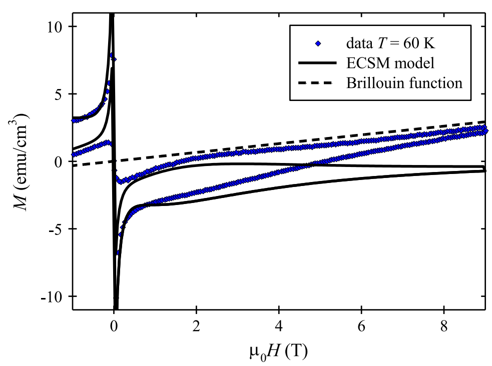

Fig. 2. Superconducting M_S and paramagnetic M_P magnetizations. Points – experimental loop tilted in the clockwise direction, lines – computed curves.

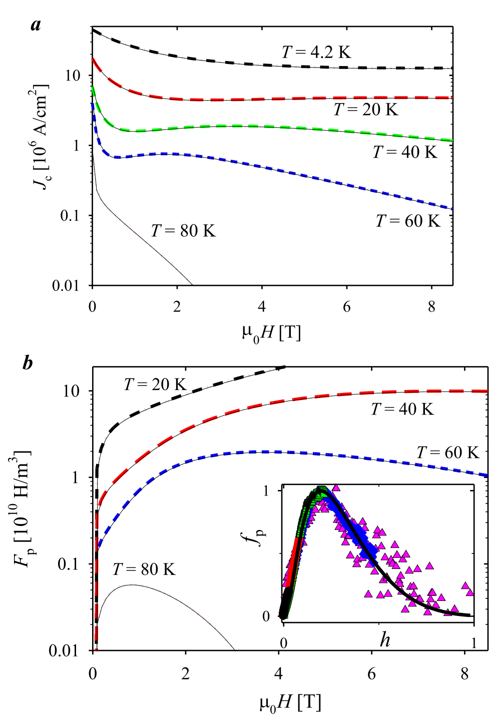

Fig. 3. Magnetic field dependence of the intragrain critical current density (a) and the pinning force (b). Insert of Fig. 3b demonstrates scaling of the $F_p(H)$ dependencies. Solid line is a $f_p(h)$ curve calculated by ECSM.

ions occurred on the grain surface and in the normal cores of Abrikosov vortices. At low T and H most Nd^{3+} ions are screened by the superconducting bulk.

The magnetization hysteresis loops of superconducting grains demonstrate the second peak. The peak effect is good observable at temperature range 20–60 K. The $M_S(H)$ loops were fitted by ECSM. The dependence of j_c on H was suggested to be the product of a decreasing function and a step function. The decreasing function describes the evolution of j_c from H=0 to H=H_{c2} and it has different decrease rates at low and high magnetic fields [9]. A step function describes the transition between states with different j_c. Detailed description of ECSM application to the magnetization hysteresis with the second peak will be presented later. The fitting curves $M(H)$ =$M_S(H)$+$M_P(H)$ are shown on Fig. 2 (lines).

The field dependences of the intragranular critical current density $j_c(H)$ are presented on Fig. 3a. The dependences of the pinning force density on the applied magnetic field $F_p(H)$ were determined as $F_p(H)$ =$\mu_0 H J_c(H)$ (Fig. 3b). The $F_p(H)$ dependencies demonstrate that the maximal pinning field H_{2p} of $Y_{0.75}Nd_{0.25}Ba_2Cu_3O_{7-d}$ is higher than H_{2p} of $NdBa_2Cu_3O_{7-d}$, e.g. H_{2p}=38 kOe for Y(Nd)–123 though $H_{2p}\approx$10 kOe for Nd-123 at T=60 K. As Figs. 3a, 3b demonstrate the peak effect is governed by temperature. Both the peak width and the maximum field H_{2p} is increased as decreased temperature such that the second peak becomes much smoothed. The second peak height is drastically decreased for loops at T=80 K.

Scaling of the normalized vortex pinning force f_p=F_p/F_{pmax} is observed as a function of reduced field h=H/H_{irr} at all temperatures, here F_{pmax} is the maximal pinning force at given T, H_{irr} is the irreversibility field at given T. The scaling plot is shown in the insert on Fig. 3b, a solid line on this graph is the $f_p(h)$ curve calculated by ECSM. It is seen that the $f_p(h)$ dependences scale satisfactory that gives an evidence of the vortex lattice transition [2,10].

4. Conclusion

The $Y_{0.75}Nd_{0.25}Ba_2Cu_3O_{7-d}$ compound was synthesized with the aim to examine the peak effect (fishtail) on the magnetization hysteresis. It was found that Nd doping of Y123 results in appearance of the peak effect with the maximum at $\mu_0 H < 10$ T at temperatures 40–80 K whereas pure $YBa_2Cu_3O_{7-d}$ does not demonstrate the peak effect under these conditions. The peak field, the peak width and the peak height are decreased as temperature increases. Additional paramagnetic contribution observed on the $M(H)$ dependences is due to Nd^{3+} ions occurred on the grain surface and in the vortex cores.

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