Description of Magnetization of High-Temperature Ceramic $YBa_2Cu_3O_{7-x}$ Superconductor with Accounting Crystal Anisotropy

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Abstract
We present the measurements and analytical expressions for the magnetization at T=77 K of the high-temperature ceramic superconductor $YBa_2Cu_3O_{7-x}$. The behaviour of magnetization is studied as a function of external magnetic field. The sample was prepared by the method of solid-state reaction. Magnetization measurements were conducted with ballistic method. Analytical expressions are obtained in Bean's critical state model by taking into account the field H_{c1}. Description of experimental hysteresis of the polycrystal structure of the sample and granule's anisotropy are taken into account as well.

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1. Introduction

In the present work for the description of magnetization hysteresis of high-temperature ceramic $YBa_2Cu_3O_{7-x}$ superconductor the structure of a sample is taken into account.

2. Experimental

The sample was prepared by the method of solid-state reaction. It has cylinder form with diameter 15 mm, height 20 mm, demagnetization factor 0.007, critical temperature (92±1) K. Magnetization measurements were conducted with ballistic method by means of change determination, passing through galvanometer chain while transferring the sample from one measuring coil into another, being connected to meet each other[1].

3. Calculations and results

It is considered as a polycrystal consisting of monocrystals (granules) oriented arbitrarily relative to the external magnetic field H_0.

Average magnetization of $\overline{M}$ polycrystal is determined by:

$$\overline{M} = \int_0^{\pi/2} M(\gamma)\sin\gamma d\gamma \qquad (1)$$

Where M (γ) is the magnetization of granules oriented at $\gamma = \vec{C}\,\hat{}\,\vec{H}$ angle ($\vec{C}$ is the principle axis of a lattice) with respect to magnetic field and sin γdγ is the hit probability of granules in (γ, γ+dγ) interval. According to [2] the dependence of the first H_{c1} critical magnetic field of a granule at γ angle has the form

$$H_{c1}(\gamma) = H_{c1}^{c}(1+\chi\sin^2\gamma)^{-1/2} \qquad (2)$$

Where H_{c1}^{c} is the first critical field of the granules oriented along the external magnetic field χ is the anisotropy parameter. For the $YBa_2Cu_3O_{7-x}$ sample $\chi \approx 25$ [2].

The equation of critical state for the monocrystal oriented at γ angle with respect to H_0 field in axisimmetric case [3], has the form:

$$\frac{dB}{dr} = \frac{4\pi}{c} j_c \qquad (3)$$

Where B is the local magnetic induction, j_c is the critical current density.

For the boundary conditions we have induction equality to equilibrium value at the boundary

$$B(r) = B_{eq}(H_0) \qquad (4)$$

To determine $B_{eq}(H_0)$ dependence, an approximation is used [4]

$$\begin{cases} B_{eq}(H_0) = 0, & H_0 < H_{c1}(\gamma) \\ B_{eq}(H_0) = H_0 - H_s, & H_0 > H_{c1}(\gamma) \end{cases} \qquad (5)$$

Where

$$H_s \equiv H_{c1} - H_b \qquad (6)$$

H_b is the parameter depending on the first critical field

$$H_b = aH_{c1}(\gamma), \quad 0 < a < 1 \qquad (7)$$

The boundary condition (4), with account of (5) takes the form:

$$B(R) = H_0 - H_s \qquad (8)$$

The solution of (3) by boundary condition of (8) gives:

$$B(r) = H_0 - H_s + (4\pi / c) j_c (r - R) \qquad (9)$$

Magnetization of the .granules oriented at γ angle equals to:

$$4\pi M(\gamma) = \langle B(\gamma) \rangle - H_0 \qquad (10)$$

The determine the polycrystal average magnetization $\overline{M}$, account of expressions 4πM(γ) for different values of external magnetic field in (1) gives the following equations for increasing fields:

$$4\pi\overline{M} = K\left\{ -\frac{1}{3}\Omega - aH_{c1}^{ab}\,\mathrm{X}\arcsin\frac{1}{\mathrm{X}} - H_0 \right\}, \quad 0 \le H_0 \le H_{c1}^{ab} \qquad (11).$$

Here and bellow

$$\left[1 - \frac{1}{\chi}(1+\chi)\left(\left(\frac{H_{c1}^{ab}}{H_0}\right)^2 - 1 \right) \right]^{1/2} \equiv g(x) \;,$$

$$\left(\frac{\chi+1}{\chi}\right)^{1/2} \equiv \mathrm{X}, \quad \frac{4\pi}{c} j_C R \equiv \Omega$$

$$\left[\frac{1}{\chi}(1+\chi)\left(\left(\frac{H_{c1}^{ab}}{H_0}\right)^2 - 1 \right) \right]^{1/2} \equiv g_1(x).$$

$$4\pi\overline{M} = K\left\{ \left(-\frac{1}{3}\Omega - H_0\right)(1 - g(x)) + \frac{1}{3}\Omega\, g(x) - (1-a)H_{c1}^{ab}\,\mathrm{X}\arcsin\left(\frac{1}{\mathrm{X}}\cos\arcsin g_1(x)\right) - \right.$$
$$\left. - aH_{c1}^{ab}\,\mathrm{X}\left\{ \arcsin\frac{1}{\mathrm{X}} - \arcsin\left[\frac{1}{\mathrm{X}}\cos\arcsin g_1(x)\right] \right\} \right\},$$

$$H_{c1}^{ab} \le H_0 \le H_{c1}^{c} \qquad (12)$$

$$4\pi\overline{M} = K\left\{ -\frac{1}{3}\Omega - (1-a)H_{c1}^{ab}\,\mathrm{X}\arcsin\frac{1}{\mathrm{X}} \right\}, \qquad H_{c1}^{c} \le H_0 \le H_{0\max} \qquad (13).$$

For decreasing fields:

$$4\pi\overline{M} = K\left(1-\frac{H_{0\,\max}-H_0}{2\Omega}\right)\left(\frac{1}{3}H_{0\,\max}-\frac{2}{3}\Omega-\frac{1}{3}H_0\right)-K\left\{(1-a)H_{c1}^{ab}\mathrm{X}\arcsin\frac{1}{\mathrm{X}}+\frac{1}{3}\Omega\right\}\quad \widetilde{H}_0 \le H_0 \le H_{0\,\max} \qquad (14).$$

$$4\pi\overline{M} = K\left\{\left(\frac{1}{3}\Omega - H_0\right)(1-g(x))+\frac{1}{3}\Omega\, g(x) + aH_{c1}^{ab}\, X\left\{\arcsin\frac{1}{X}-\arcsin\left[\frac{1}{X}\cos\ \arcsin\ g_1(x)\right]\right\}-\right.$$

$$\left.-(1-a)X\, H_{c1}^{ab}\arcsin\left[\frac{1}{X}\cos\arcsin g_1(x)\right]\right\}\qquad H_{c1}^{ab} \le H_0 < \widetilde{H}_0 \qquad (15).$$

$$4\pi\overline{M} = K\left\{\frac{1}{3}\Omega + aH_{c1}^{ab} X\arcsin\frac{1}{X} - H_0\right\},\qquad 0 \le H_0 \le H_{c1}^{ab} \qquad (16)$$

Where

$$\widetilde{H}_0 = H_{0\ \max} - 2\Omega \qquad (17).$$

H_{c1}^{ab} Denotes the first critical field of the granules oriented perpendicularly with respect to the external field, K is the coefficient connected with the imperfect behaviour of Meissner effect and it is determined in the linear region of hysteresis by $4\pi M/H_0$ relation, which, for our sample equals to 0.33. $H_{0\ \max}$ =320 Oe and $\frac{4\pi}{c} j_c R = 50$ Oe, $H_{c1}^{ab} = 50$ Oe parameters in equations (11-16) are selected on the basis of experimental data [5].

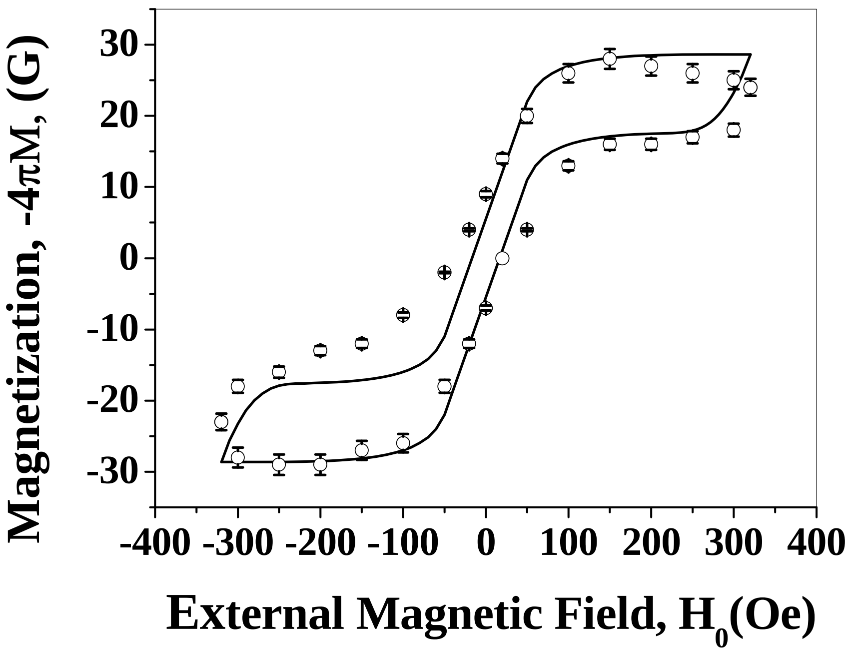

Fig. 1. the dependence of magnetization on external magnetic field: symbols – experimental data; solid line – theoretical results.

The fig. 1. Presents experimental (symbols) and theoretical (line) results, where the values of a parameter are taken as equal to zero.

4. Conclusions

Good agreement between theoretical loop and experimental data allows us to conclude that while describing magnetic properties of high-temperature ceramic superconductor obtained by solid state reaction, one should take into account the anisotropy of the granules.

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