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Investigation of stimulated dynamics in strongly anisotropic high-temperature superconductors system Bi–Pb–Sr–Ca–Cu–O

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ABSTRACT

It is used the mechanical method of Abrikosov vortex stimulated dynamics investigation in superconductors. With its help it was studied relaxation phenomena in vortex matter of high-temperature superconductors. It established that pulsed magnetic fields change the course of relaxation processes taking place in vortex matter. The study of the influence of magnetic pulses differing by their durations and amplitudes on vortex system of strongly anisotropic high-temperature superconductors system $Bi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_{10-\delta}$ showed the presence of threshold phenomena. The small duration pulses do not change the course of relaxation processes taking place in vortex matter. When the duration of pulses exceeds some critical value (threshold), then their influence changes the course of relaxation process which is revealed by stepwise change of relaxing mechanical moment τ^{rel}. These investigations showed that the time for formatting of Abrikosov vortex lattice in $Bi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_{10-\delta}$ is of the order of 150 μs which on the order of value exceeds the time necessary for formation of a single vortex observed in isotropic high-temperature superconductor $HoBa_2Cu_3O_{7-\delta}$ and on two orders exceeds the creation time of a single vortex observed in classical type II superconductors.

1. Introduction

The present work is devoted to the experimental investigation of Abrikosov vortex lattice dynamics in strongly anisotropic high-temperature superconductors of Bi–Pb–Sr–Ca–Cu–O system using stimulating pulsed magnetic fields.

Investigation of vortex matter stimulated dynamics in strongly anisotropic high-temperature superconductors is one of important problems both for understanding of fundamental problems connected with strongly anisotropic high-temperature superconductors [1], and from the point of view of their practical applications particularly their behavior in electromagnetic fields and under the current loading [2].

The critical temperature of this class of high-temperature superconductors is so high that they remain superconductive at temperatures when thermal fluctuations play essential role because their energy becomes compared with the elastic energy of vortex and, as well, with the pinning energy [3]. It creates prerequisites for phase transitions. Due to the layered crystal structure and anisotropy, which are characteristic of high-temperature superconductors, it is created conditions for the appearance on B–T diagram (B is magnetic induction, T is temperature) different phases [4–15].

One of fine examples of a phase transition in vortex matter is the 3D three-dimensional transition of Abrikosov vortices in 2D quasi-two-dimensional ones, so-called Pancake vortices. Such phase transition takes place in high-temperature superconductor system $Bi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_{10-\delta}$ [12,13]. During this transition a sharp dissipation energy decrease of moving Abrikosov vortices (almost two orders of value) takes place what in its turn could be related with an essential decrease of pinning force. Further experiments showed out that in the same material the pinning force also sharply increases at the 3D–2D transition (approximately on 300% in value) [15] what makes such materials perspective for technical applications, all the more so that the upper critical field H_{c2} when superconductivity is destroyed could reach 150 T [1]. It is essentially higher as compared with H_{c2} in traditional type II superconductors used currently in practice.

Investigations of Abrikosov vortex lattice dynamics stimulated by alternative and pulsed magnetic fields in high-temperature superconductors could undoubtedly play decisive role from the point of view at their fitness for practical applications in devices under construction operating on the basis of high-temperature superconductivity because frequently alternating and pulsed magnetic fields put limits on the operation of aforementioned devices and such fields, as a rule, appear at their operation. Therefore the investigation of influence of pulsed and alternating magnetic fields on Abrikosov vortex lattice dynamics and relaxation processes occurring in vortex matter is very important.

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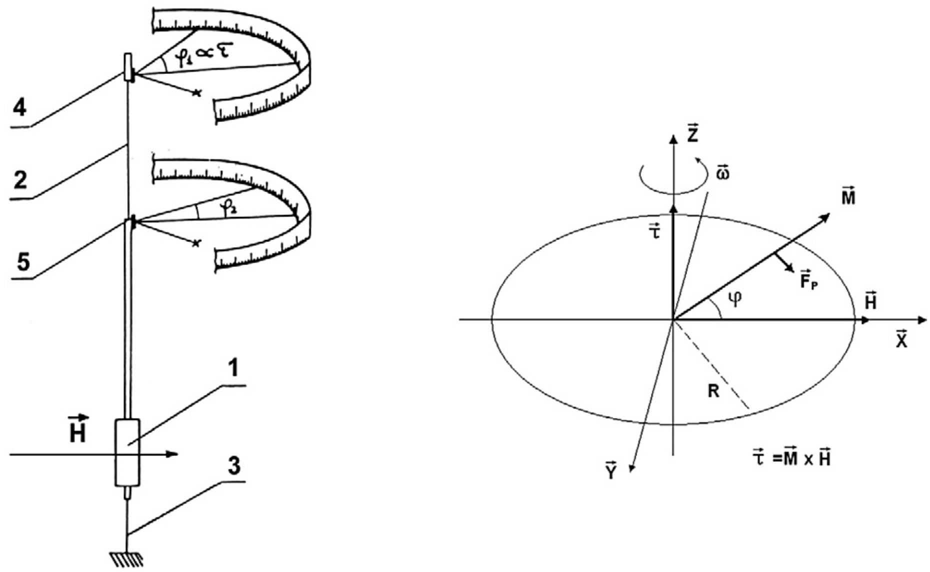

Fig. 1. The schematic diagram and the geometry of the experiment. 1—sample, 2—upper elastic filament, 3—lower filament, 4—leading head, 5—glass road. φ is angle between $\vec{M}$ and $\vec{H}$.

At investigation of Abrikosov vortex lattice stimulated dynamics on the external permanent magnetic fields, applied to HTSC and creating vortex lattice, is imposed a weak alternative or pulsed magnetic field, causing the motion of vortex continuum. This, in its turn, leads to a change of relaxation processes taking place in the vortex matter [8,9].

Consequently, the study of these problems could result in the understanding of energy dissipation mechanisms arising at the motion of vortex matter inside a superconductor. Investigation of these problems is of current concern from the practical view because it makes it possible to establish of applicability limits of technical devices constructed and created on the basis of high-temperature superconductors.

2. Experimental

For investigation it was used currentless mechanical method of Abrikosov vortex stimulated dynamics study by magnetic pulses revealing relaxation phenomena in vortex matter described in work [16]. This method is a development of currentless mechanical method of pinning investigations [17,18] and is based on pinning forces countermoments measurements and viscous friction, acting on a axially symmetrical superconducting sample in an outer (transverse) magnetic field. Countermoments of pinning forces and of viscous friction, acting on a superconductive sample from quantized vortex lines side (Abrikosov vortices) are defined by the way as it was described in works [19,20]. The sensitivity of the method accordingly work [21], is equivalent to 10^{-8} V cm^{-1} in the method of V–A characteristics.

The high-temperature superconducting samples of $Bi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_{10-\delta}$ system were prepared by the standard solid state reaction method. Samples were made cylindrical with height $L = 12$ mm and diameter $d = 1.2$ mm. Their critical temperature was $T_c = 107$ K. The investigated samples were isotropic what was established by mechanical moment τ measurements appearing $H > H_{c1}$ with the penetration of Abrikosov vortices into a freely suspended on a thin elastic thread superconducting sample. The appearance of such moment $\tau = MH\sin\alpha$, characteristic for anisotropic superconductors, is related with penetrating Abrikosov vortices and the mean magnetic moment $\vec{M}$ of a sample which could deviate on angle α from the direction of outer magnetic field $\vec{H}$. In superconducting anisotropic samples it is presented energetically favorable directions for the arrangement of emerging (penetrating) vortex lines which in their turn are fastened by pinning centers creating aforementioned moment τ. The lack of τ moment is characteristic for isotropic and investigated by us samples, no matter magnetic field value and its previous orientation with respect to $\vec{H}$ in the axial symmetry plane. Pulsed magnetic fields were created by Helmholtz coils. The value of pulsed magnetic fields was changed in $\Delta h = 2$–200 Oe limits.

In experiments it was used both single and continuous pulsed with repetition frequency ν from 2.5 s^{-1} to 500 s^{-1}. The duration Δx of pulses was changed from 0.5 to 500 μs. Magnetic pulse could be directed both parallel ($\Delta h \parallel H$) and perpendicularly ($\Delta h \perp H$) to applied steady magnetic field $\vec{H}$, creating mixed state of superconducting sample. The standard pulsed generator and amplifier were used to feed Helmholtz coils. The current strength in coils reached up to 40–50 A. Samples were high-temperature superconductors of $HoBa_2Cu_3O_{7-\delta}$ system placed in the center between Helmholtz coils.

The principal set-up of experiment is shown in Fig. 1 [19,20]. In experiments it is measured the rotation angle φ_2 of sample depending on the angle of rotation of a torsion head φ_1, transmitting the rotation to a sample by means of suspension having the torsion stiffness $K \approx 4 \times 10^{-8}$ N m, which can be replaced when necessary by a less stiff or stiffer one.

The measurements were carried out at a constant speed of rotation of the torsion head, making $\omega_1 = 1.8 \times 10^{-2}$ rad/s. Angles of rotation φ_1 and φ_2 were determined with an accuracy of $\pm 4.6 \times 10^{-3}$ and $\pm 2.3 \times 10^{-3}$ rad, respectively. The uniformity of the magnetic field's strength along a sample was below $\Delta H/H = 10^{-3}$.

To avoid effects, connected with the frozen magnetic fluxes, the lower part of the cryostat with the sample was put into a special cylindrical Permalloy screen, reducing the Earth magnetic field by the factor of 1200. After a sample was cooled by liquid nitrogen to the superconducting state, the screen was removed, a magnetic field of necessary intensity H was applied and the φ_2 (φ_1) dependences were measured. To carry out measurements at different values of H, the sample was brought to the normal state by heat-