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Pulse magnetization and voltage-current characteristic of $YBa_2Cu_3O_{7-x}$ film

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Abstract. The measurements of $YBa_2Cu_3O_{7-X}$ films magnetization are made at ramp rate of the external magnetic field up to 10^5 T/sec at temperature of liquid nitrogen in fields up to 4 T. The linear dependence of the magnetic moment of films on rate of an external magnetic confirms, that in the large electrical fields down to 1 V/cm the voltage-current characteristic can be described by the flux flow resistance ***Rflow*** and the critical current ***Jflow***, similar to traditional low temperature superconductors: $E = Rflow \cdot (J - Jflow) \cdot \Theta(J - Jflow)$, where Θ is the Heaviside function. The experimental data of pulse magnetization of films of thickness 0,2 microns on substrates Al_2O_3 of size 10 X 10 mm with critical currents higher 10^6 A/cm^2 have allowed to determine field dependence of the critical current and the flux flow resistance. In particular the resistance ***Rflow*** is increased approximately by 3 times for increase of an external field from 0,5 up to 4 T, and the ***Jflow*** values approach the critical currents determined from quasi-stationary magnetization.

Introduction

Volt - ampere characteristic (VAC) of the superconducting material contains information about magnetic flux pinning and character of currents flow in a superconductor. VAC is necessary for analysis of the superconducting material workability, for an estimation of thermal losses of energy, for stability superconducting state in different operating conditions, etc. For example, the form of VAC determines the thermal instability of a superconductor [1]. VAC have formed the basis to find out mechanisms of energy dissipation due to the movement of magnetic flux lines in low temperature superconductors at relative high electrical fields (about 1 mV/cm and above) [2,3]. For these reasons, the experimental researches on VAC of HTS ceramics represent certain interest. In particular, previous researches on VAC and magnetization of porous HTS ceramics of 1-st generation have shown that the electrical field is connected to movement of a magnetic flow on a current carrying network (cluster), which was formed by contacts of superconducting grains. The flux flow resistance (***Rflow***) grows with a field **B** linearly (***Rflow ~ B***) or logarithmically (***Rflow ~ lnB***) in low or high magnetic fields respectively [4, 5]. This behavior ***Rflow*** may be due to the suppression of bulk superconductivity, i.e. a result of the transition from three-dimensional to two-dimensional flow of magnetic flux. The characteristics of Bi-Sr-Ca-Cu-O_PЬ ceramics without pores produced at high pressure support this picture too [6]. Modern 2-G HTS ceramics have high current carrying capacity. And the high bulk density of heat dissipation makes it difficult to carry out measurements of VAC in relatively high electric fields, where a movement of the magnetic flux is developed. Solution of the problem can be pulsed measurements. Indeed, superconductor magnetic moment **M** in the conditions of full magnetization is proportional to the density of flowing currents in the superconductor. The values of these currents **J** are determined by the local values of the electric field **E**, induced by the change of magnetic field **B** in the superconductor. Thus, measuring the dependence of the magnetic moment of a superconductor on the ramp rate of a magnetic field, we can define a relationship between the electric field and electric current in a superconductor that are the parameters of its volt-ampere characteristics.

The purpose of this work is to demonstrate the use of a pulse magnetization for the search parameters of volt-ampere characteristics of a superconductor on the example of the 2-G HTS Y123 ceramics on a dielectric substrate.

Samples and measurement technique

We measured $YBa_2Cu_3O_{7-X}$ coating ceramics of thickness of about 0,2 microns, grown by laser ablation on Al_2O_3 substrates of sizes of 10 x 10 mm and thickness of 0,3 mm. These epitaxial samples had the critical temperature in the range from 85 to 88K and the width of inductive S - N transition about 1K. The samples were placed in the center of solenoid for pulsed magnetic field (Helmholtz coils) located inside of another solenoid of larger size, that was used to create the supporting magnetic field. The pulsed magnetic field ***Bpul*** and the supporting magnetic field ***Bsup*** were oriented perpendicular to the sample surface. Measurements were made at the temperature of liquid nitrogen.

Measurement procedure was as follows.

1. Big solenoid creates long (about 0,1 sec) pulse relatively slowly changing supporting magnetic field ***Bsup***
2. At the time when the maximum value ***Bsup*** was achieved, the discharge of a capacitor battery at the Helmholtz coils was carried out. Several oscillations of pulsed magnetic field ***Bpul*** are monitored during the time up to 30 μsec.
3. EMF signals of two measuring coils are registered. One coil by a diameter of 1 mm is placed at the center of a sample; the second coil by a diameter of 19 mm is placed in a plane of symmetry of Helmholtz coils, so that the difference between the signals of the two measuring coils is directly related to the currents circulating in the sample.
4. After this the maximum value (amplitude) of the supporting magnetic field ***Bsup***, and/or amplitude and/or direction of pulsed magnetic field ***Bpul***, and/or sample are changed and the measurements are repeated again from step 1.

The rate of change of magnetic field ***dBpul/dt*** achieves a value of about 10^5 T/sec for the voltage of the condenser battery ***Uc*** = 350 V and the diameter of the Helmholtz coils 16 mm. Such magnetic pulse induces electric field above 1 V/cm in a sample size of 10 mm.

As a result we can make measurements of the magnetization of samples in magnetic fields up to 4 T at induction of electric fields up to 1V/cm by changing the parameters of pulse magnetic fields ***Bpul*** and ***Bsup***. Initial results are obtained in the form of EMF signals of two measuring coils as a function of time ***t*** at the various values of the supporting magnetic field ***Bsup***, capacitance of the battery ***C*** and its primary voltage ***Uc***.

Results and discussion

The subsequent integration of EMF signals of measuring coils gives us the rapidly changing in time component of the external magnetic field ***Bpul(t)*** and the difference between ***Bpul(t)*** and field ***Bo(t)*** in the center of the sample ***Bpul(t) - Bo(t) = M(t)*** , i.e. magnetic field of currents induced in the sample. The signals ***Bpul(t)*** and ***M(t)*** for the sample **S4** in a magnetic field ***Bsup*** = 0,3 T and for pulse parameters ***C*** = 10 mF and ***Uc*** = 350 V are presented in Fig. 1A.

Quick and full change of magnetizing of the sample accompanies each change of direction of change of the magnetic field. The same data are presented in the form of dependence ***M*** from the value ***Bpul*** in figure 1B and give us the hysteresis loop of full magnetizing of the sample for different amplitudes ***Bpul*** (various rates of the magnetic field ***dB/dt***), i.e. for different levels of electric field ***E*** in the

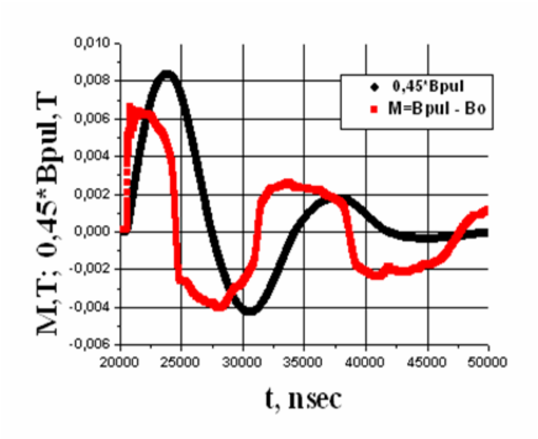

Fig. 1A. Time dependence ***Bsup*** and ***M*** for the sample **S4** in supporting field ***Bsup***=0,3 T.

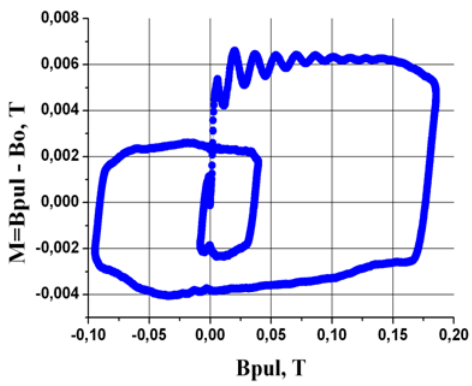

Fig. 1B. The dependence ***M*** on ***Bpul*** for the sample **S4** in supporting field ***Bsup***=0,3 T.

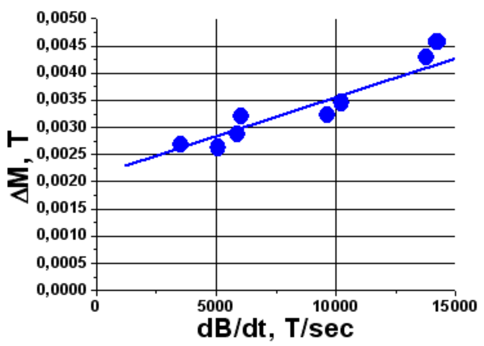

Fig. 2. Dependence ***ΔM*** from the ***dB/dt*** for the sample **S4** in the field ***Bsup*** = 0,75 T

sample. The ripples in the beginning all curves **M(B)** are caused, probably, noise pulse connecting a capacitor battery. The width of the loop of a magnetic hysteresis ***ΔM*** has the lineal increase (with a precision of 10 - 20%) with the growth ***dB/dt***, that is with increasing electric field ***E*** in the sample (see Fig. 2.). This relationship between ***ΔM*** and ***dB/dt*** gives us an opportunity to estimate the slope of the linear plot ***σm= dΔM/d(dB/dt)*** and ***ΔMflow*** as extrapolation of linear part of the curve to the value ***dB/dt=0***. It is obvious that the values ***σm*** and ***ΔMflow*** differ from the parameters of volt - ampere characteristics namely the flux flow conductivity ***σflow*** and the critical current ***Jflow*** only by constant coefficients, which are determined by the details of the experiment (the sample geometry, the placement of sensors, the nature of the current flow, and others). Thus, the dependence ***σm*** and ***ΔMflow*** on the value of the magnetic field ***Bsup*** gives us the field dependence of the flux flow conductivity ***σflow*** and critical current ***Jflow*** in the measured sample. Figure 3 shows ***ΔMflow*** and width of the curve of magnetization in quasi-stationary magnetic field (***ΔMqs)*** for the sample **S4** as a function of the external field.

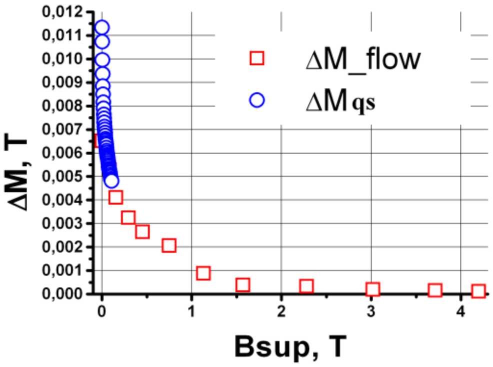

Fig. 3. ***ΔMflow*** and ***ΔMqs*** vs. ***Bsup*** for the sample **S4**

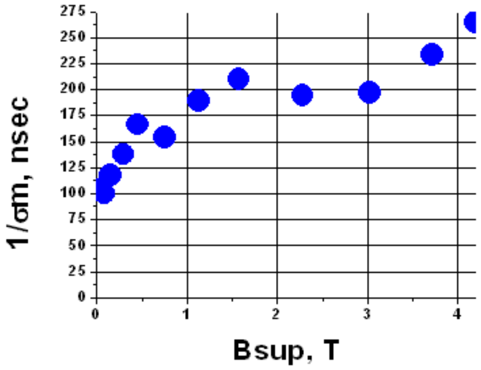

Fig. 4. ***1/σm*** vs. ***Bsup*** for the sample **S4**

We can see that the result of quasi-stationary magnetization (***ΔMqs)*** coincides with those for pulsed magnetization ***ΔMflow***. Width of the magnetization loop ***ΔMqs*** more than 0,01 T corresponds to the value of the current, circulating in the sample over 25 A, i.e. the critical current density is over 10^6 A/cm^2. In figure 4 the field dependence of the inverse ***σm*** (***1/σm*** is proportional to flux flow resistivity ***Rflow***) for the same sample is presented. A weakly increasing resistivity with increasing field is observed.

Conclusions

The experimental results show that pulsed magnetization allows estimating the parameters of volt-ampere characteristics of 2-G HTS ceramics on a dielectric substrate. In particular, it was shown on YBCO samples of thickness of about 0,2 microns, obtained by laser ablation on Al_2O_3 substrates of 10X10 mm^2 size and 0,3 mm thickness mm the following.

1. The form of volt-ampere characteristics of the 2-G HTS $YBa2Cu3O7_{-X}$ ceramics in the range of 10 - 500 mV/cm is close to linear, that is has the form similar to the current-voltage characteristic of low-temperature superconductors.
2. The results of the pulse magnetization (***ΔMflow***) correspond to the results for quasi-stationary magnetization (***ΔMqs***) of 2-G HTS ceramics.
3. The effective flux flow resistance ***Rflow*** weakly depends on the value of the magnetic field similarly to the case of low-temperature superconductors. This behavior of ***Rflow*** may be related with the motion of the vortices of the magnetic flux in granular films along grain boundaries or other reasons. The investigation of mechanisms of dissipation in the HTS ceramics needs a more detailed study of the flux flow.

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