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Magnetic characteristics of YBCO thin films on sapphire buffered with CeO_2 substrates

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Abstract. Thin films of YBCO covered by protecting CeO_2 overlayer were prepared on CeO_2 buffered Al_2O_3 substrates and their magnetic characteristics were investigated at T>77 K using contactless dc and ac magnetic techniques. The critical current density J_c mesured at 77 K by different techniques was more or about 10^6 A/cm^2 : some difference in results was interpreted as due to the peculiarities of the methods. A non-conventional method was developed to extract the J_c vs T dependence from the ac response signal parameters and for the considered films it was found to be best fitted with a quadratic function of the temperature. The J_c - value decreased nearly two times when perpendicular dc magnetic field B=150 mT was applied.; the time dependence of the trapped field was not pronounced at 77 K and it was less than 3% for 7 10^3 s time interval.

1. Introduction

Sapphire (Al_2O_3) covered by CeO_2 can be considered as a substrate suitable for preparing high quality YBCO thin films with high critical current density J_c and low microwave losses [1,2]. Layered structures deposited on such substrates can be useful as well from practical point of view.In some cases the direct measurement of the current carrying parameters of high temperature superconducting (HTSC) film is not possible and information can be obtained only by measuring the magnetic field of supercurrent, excited inductively in the film. The object of this paper is to investigate magnetic characteristics of YBCO thin films deposited on CeO_2 buffered Al_2O_3 substrate and covered with an additional protecting CeO_2 overlayer.

2. Experimental results and discussion

Sapphire (Al_2O_3) plates with orientation (1102) and dimensions 5mm x 5mm x 0.5 mm were used for preparing HTSC thin films. First the whole surface of the substrate was covered with epitaxial buffer film of CeO_2 with orientation (001) and thickness 60 nm using RF magnetron reactive sputtering from metal target at high substrate temperature [1]. The superconducting films of YBCO with thickness t=140 nm were deposited on such substrates using dc sputtering technique at high pressure of oxygen. As a final step of the procedure the obtained YBCO thin films were covered with a protecting 15 nm thick amorphous CeO_2 layer. The prepared so YBCO thin films were c-oriented and their critical temperatures were 86–88 K.

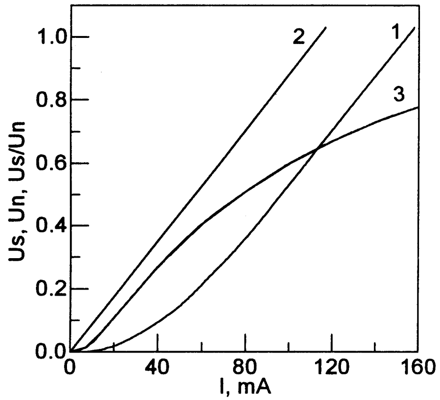

Fig.1.Dependence of the pick-up coil voltages U_s, U_n on the driving coil current amplitude I for YBCO film measured at 77 K (solid line 1) and at 100 K (solid line 2). Curve 3 depicts the behavior of the ratio $N=U_s/U_n$.

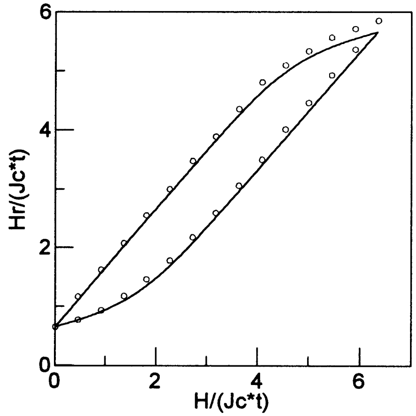

Fig.2. Hysteresis loop measured by Hall probe technique at 77 K for YBCO sample (open circles) and a result of simulation with J_c = 9 10^5 A/cm^2 (solid line), performed on basis of approach developed in [4,5].

Magnetic parameters of YBCO thin films were mainly measured at frequency f=1 kHz using pick-up coil system (method 1) [3]. The small driving and receiving coils were placed coaxially on opposite surfaces of the samples. External dc magnetic field up to 160 mT could be applied perpendicularly or parallel to the film surface. To obtain information on the critical current density J_c in the whole film area some experiments were performed using a spatially uniform ac (method 2, f=1 kHz) or dc (method 3) driving magnetic field and the response signal was registered by a small coil or a miniature Hall sensor.

Dependencies of the pick-up coil voltages U_s, U_n on the driving current amplitude I are shown in Fig.1 for the superconducting (T=77 K) and normal states of the YBCO thin film on Al_20_3 substrate. For elevated values of the current I the curves of the U_s vs I and U_n vs I dependencies are nearly parallel and the "distance" between them depends on J_c–value of the sample. In the same figure the ratio of the response signal amplitudes $N=U_s/U_n$ is shown, which was used later to calculate the temperature dependence of the critical current density. The response signal behavior of the same film obtained at 77 K using spatially uniform ac magnetic field was similar to that described above. Hysteresis loops for this sample was measured using Hall probe technique and the results obtained at 77 K are shown in Fig.2.

Determination of the critical current density J_c for method 1 was carried out in a model based approach, while for methods 2, 3 the calculations were performed in the approach, developed in [4,5] and describing the penetration of the uniform perpendicular magnetic field into superconducting film. Method 1 gave the highest J_c–value (1.7 10^6 A/cm^2), while the Hall probe technique (method 3) gave the lowest one (9 10^5 A/cm^2). The results of method 2 were close to those of method 3 (10^6 A/cm^2). Divergence in the results could be caused by peculiarities of the considered methods, which differ by duration of measuring time (for methods 1 and 2 it is 10^{-3} s and for method 3 - about 2 10^2 s) and by the field configuration on the film surface. For method 1 the magnetic field penetration starts in the film area, lying just under mean radius of the driving coil. There the magnetic flux lines are nearly parallel to the film surface and are forced to move perpendicularly to the surface. In

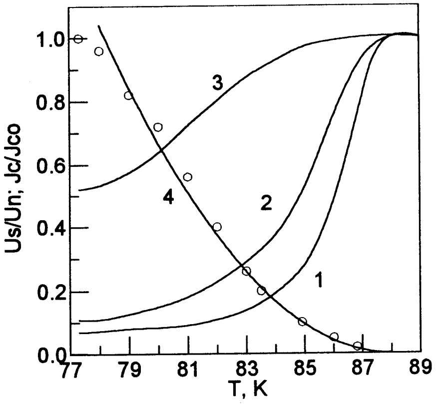

Fig.3. U_s vs T dependencies obtained for the driving current amplitudes 1 mA, 3 mA and 30 mA (curves 1-3, respectively). The circles show the J_c vs T dependence deduced using the procedure described above. Curve 4 is the result of interpolation of $J_c(T)$ by expression $J_c/J_{c0}=0.0104\,(1-(T/T_c))^2$, with T_c =88 K, $J_{c0}=1.7\ 10^6$ A/cm^2.

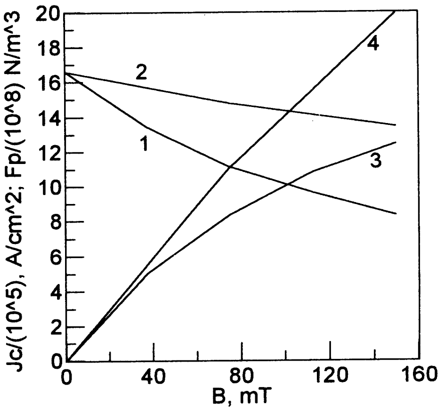

Fig.4. Effect of perpendicular (curves 1, 3) and parallel (curves 2, 4) static magnetic field on the critical current density (curves 1, 2) and the volume pinning force (curves 3,4) in the YBCO samples determined at 77 K.

this case the effects of the surface barrier [6] and the intrinsic pinning of fluxons between CuO_2 planes can be assumed to hinder the field penetration process, leading to increasing of J_c. In the case of methods 2, 3 the penetration process starts from the film edge, where the flux lines are oriented perpendicularly to the surface. The moving conditions of such fluxons are more favorable especially in the case of presence of some weak links serving as channels for fluxon entering into film [7].

The temperature dependencies of the response signal amplitudes, measured using method 1 for several values of the driving current amplitudes I, are shown in Fig. 3. Such experimental data together with the N vs I dependence (see Fig.1) can be used to deduce the temperature dependence of J_c applying the following non-conventional method. If one assumes that the sample is homogeneous and J_c is a constant, independent of the magnetic field,. the parameter N will be a function of the ratio of the critical current density J_c to the driving current amplitude I only. Therefore having an experimental N vs I dependence and the value of the critical current density J_c at some temperature (at 77 K for example), the new J_{c1} -value for another temperature can be found from the new values of the current amplitude I_1 and parameter N_1 (N_1 can be found from fig.3 for required temperatures):

$$J_{c1}=J_c I_1 / I, \qquad (1)$$

where I is found from the known N vs I dependence for the new value of $N=N_1$. The accuracy of the procedure can be supposed to be better for intermediate values of N, where the response signal intensity significantly exceeds the one of the leakage signals and the thermal and magnetic field effects on the spatial homogeneity of the sample properties (which are pronounced near T_c for high values of I) are not so crucial. The temperature dependence of the critical current density, obtained for $0.5 < N < 0.9$ is shown in Fig. 3. The initial part of the dependence can be best fitted with a quadratic function J_c~$(T-T_c)^2$ (which is characteristic for SNS type weak links) and differs from the thermodynamic current behavior $J_c \sim (T-T_c)^{3/2}$ (see for example [8]).

DC magnetic field effect on J_c is shown in Fig.4. Critical current density decreases nearly two times at perpendicular magnetic field $B = 150$ mT, whereas the parallel field influence on J_c is significantly weaker. For the perpendicular field the initial section of J_c vs B dependence is steeper and rather reflects a decrease of the critical current density in some weak links penetrated by magnetic field. Field dependencies of the volume pinning force F_p were also determined for this sample and the results are shown in Fig.4. The pinning force increases with the increasing of B in the considered low field section (a peak value of F_p in YBCO films at 77 K is expected to be observed at field $B > 1$ T).

Time dependence of the trapped magnetic field for considered sample was not very pronounced at 77 K. For example a decreasing of the trapped field recorded by Hall probe technique during $7\ 10^3$ s was less than the error $\Delta B/B = 0.03$ contributed by the time instability of the measuring system parameters.

3. Conclusions

Magnetic characteristics of 140 nm thick YBCO film sandwiched between CeO_2 layers (one of which was the CeO_2 buffer layer on Al_2O_3 substrate) were investigated at $T \geq 77$ K using dc and ac magnetic fields. An non-conventional method was developed to find J_c vs T dependence. It was determined from the temperature dependence of response signal amplitude and could be best fitted by a quadratic function of temperature $(T_c-T)^2$. The critical current density of the film was about 10^6 A/cm^2 at 77 K and its field dependence was not too strong. The time dependence of the trapped field at 77 K was not too pronounced as well, so this layered structure could be considered acceptable for practical applications.

Acknowledgements

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