Defects-induced thermal instability in YBCO films in microwave field

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Abstract

The heat instability induced by linear defects is assumed to enhance the remarkable difference between microwave properties of YBCO single crystals and thin films due to extended strain fields near out-of-plane edge dislocations. We have shown theoretically and confirmed experimentally that a single dislocation can not have a strong effect on the surafce resistance R_s, but dislocation arrays, which were observed experimentally, can induce the thermal instability, if edge dislocations in the arrays are spaced closer than the heat relaxation length. Ordered dislocation structures provide much higher local temperature perturbation than randomly distributed dislocations.

Key words: heat instability; epitaxial thin films; microwave properties

1. Theory

In spite of a great number of works on microwave surface resistance in HTS compounds a physical nature of the losses is far from a full comprehension yet. Several approaches are usually used to explain anomalous behavior of the surface impedance of the films. The first one is based on the $d_{x^2-y^2}$ symmetry of superconducting order parameter [1,2]. The second approach considers HTS materials as inhomogeneous superconductors with weak links between crystallites [3]. One more approach involves observed strong influence of oxygen stoichiometry on the temperature behavior of surface resistance [4]. The present work is aimed to investigate a possible thermal instability, which can develop in the films at high microwave power. Linear defects are considered as a possible intrinsic source of the instability.

The analysis of thermal conductivity equation for the superconducting film carrying dissipative microwave current in the cylindrical heat removal model [5] has shown that the thermal instability can develop in the film when the characteristic dimension of the initial discontinuity is comparable with the heat relaxation length λ_h:

$$\lambda_h = \sqrt{K^{-1} \cdot (\partial f(T)/\partial T)|_{T_0}}. \qquad (1)$$

Here K is the film thermal conductivity, $f(T)$ is the heat balance function, that is the difference between heat removal and heat generation. λ_h has been estimated in the chosen model for typical values of parameters to be about 50 nm. Such rather large value is just 4 times higher than the size of a normal phase region near a single dislocation [6]. A dislocation array in a boundary between domains in a quasi-single-crystal film may contain much larger number of closely spaced dislocations, which can be considered as a single dis-

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continuity.

On the other hand, the heat generation in a normal phase region near a dislocation (or array) must be strong enough. Considering 2D heat balance for the stationary problem, the local overheating ΔT due to a single discontinuity is estimated as:

$$\Delta T \approx \frac{\rho_n j^2 L d}{4\pi K}. \qquad (2)$$

Here ρ_n is the normal state resistivity of the film, j is the microwave current density, L is the linear characteristic size of discontinuity, d is the film thickness. Of course, ρ_n in the defect region is not known exactly, but it for sure exceeds $10^{-5}\Omega\cdot$m. Then, for $j \approx 3\cdot 10^6$ A/cm^2 the local temperature increase near a single dislocation $\Delta T \approx 0.1$ - 1.0 K. This is not sufficient to induce a heat instability, but ΔT linearly depends on L. This means that a single dislocation can not have strong effect, but dislocation array observed experimentally [7], spaced closer than λ_h, can induce the thermal instability.

2. Experiment

A set of samples has been prepared to confirm the above considerations. $YBa_2Cu_3O_{7-\delta}$ (YBCO) films were deposited over CeO_2 buffer layer onto sapphire substrates by magnetron sputtering. To achieve just very small difference between the samples, parameters of YBCO deposition (substrate temperature of about 750°, magnetron power, oxygen pressure, time of deposition) were absolutely the same. The only difference between the samples was in the substrate temperature during preparation of the CeO_2 sublayer. The difference was controlled by X-ray diffraction (00l)-peaks were checked). Lower quality of the buffer layer (produced at lower lemperature) resulted in a slightly wider X-ray peaks both for CeO_2 and for YBCO. That is larger number of substrate induced dislocations as well as smaller domain size in the YBCO could be expected. High resolution electron microscopy confirmed this.

The experimentally measured temerature dependencies of the surface resistance for the set of YBCO epitaxial films with slightly different defect structure are shown in Fig. 1. Mesurements were performed at the high frequency of 135 GHz, where the law $R_s \propto \omega^2$ is not more valid and R_s for pure Cu is only slightly higher than R_s of YBCO in superconducting state. As it was expected, the onset superconducting transition temeprature as well as low temperature behavior (down from 70 K) were found to be almost the same for all the samples. But the width of the transition, that is $R_s(T)$ near T_c, changes with samples. We suggest that this difference confirms the existence of heat instability induced by linear defects.

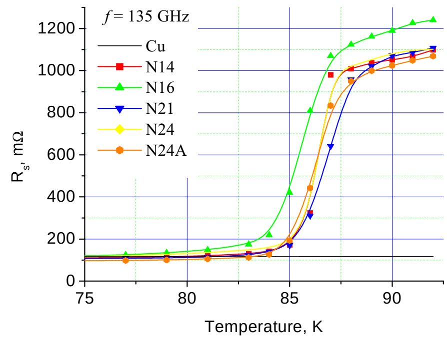

Fig. 1. Experimentally measured temerature dependence of the surface resistance for the series of YBCO epitaxial films with slightly different defect structure.

3. Conclusion

Out-of-plane edge dislocations play a remarkable role in the value and temperature behavior of the microwave surface resistance of highly biaxially oriented epitaxial YBCO films. The effect of linear defects is the most significant just below the superconducting transition. Dislocation arrays in the low-angle domain boundaries could be a source of an initial thermal fluctuation, but single dislocations can not have essential influence.

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