Stressed High Temperature Superconducting Films

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Abstract

The goal of the research is to study and describe a new stressed state of High Temperature Superconducting (High-Tc) YBCO Films, to create of SQUIDs (Superconducting Quantum Interference Device) on the bases of these Films with maximal sensitivity. The experimental investigation of the stressed films grown by laser ablation method and its properties, the fabrication of the dc-SQUIDs with maximal sensitivity on the bases of the stressed YBCO films were carried out. The stressed film having the value of the critical current density $J_c = 3 \cdot 10^5$ A/㎠ was the more stable than others.

Key Words : High Temperatute Superconductig Films, laser ablation, stress domain, Coulomb blockade, resistive states, SQUID

1. Introduction

The analysis of the current literature on the questions of superconductor allows us to affirm that the subject of the scientific research is actually necessary for technical application.

The main plans and investigations are to obtain new and more detailed data in the growing of the stressed YBCO films by the laser ablation method, and the mechanism of the critical current suppression at the Coulomb blockade on the interdomain boundaries. The new experimental data of the stressed film properties of the temperature dependence of critical current, the creep, the magnetic permeability depending on the degree of the film stressing would be obtained, and the new data of the stressed domains by the tunneling spectroscopy method was also investigated. The dc-SQUIDs of maximal sensitivity was created on the bases of stressed films. The main application plans are the fabrication of the HTS dc-SQUIDs on the bases of stressed films and the creation of devices of high sensitive medical magnetometers and SQUID microscope.

2. Statement of the problems

A great number of researchers became to work on the good making of a SQUID at ones after the discovery of High-Tc ceramic superconductors at the end of 1986. Bulk ceramic $YBa_2Cu_3O_{7-x}$ (YBCO) RF-SQUIDs were created quite in 1987. These SQUIDs were created on the basis of a weak links Diem bridges that have a cross-section 50×50 μm^2 in the best case. A preparation of them was conjugated with very big difficulties and, in addition, these bridges have collapsed 5~7 thermocycles. So the following works in this direction were focused on the SQUID creation on the basis of the thin High-Tc films. But this problem was proved to be complex one. The point is that the High-Tc films YBCO (precisely they have used most often of the SQUID making), growing by the laser ablation method, have a big range of superconducting and other physical parameters. The epitaxial, single crystalline films have the critical current density about 10^6 A/㎠. The value of the critical current density of the junction is 3 mA at the width of a bridge in 3 ㎛

and the film thickness in 100 nm. In this case the parameter of the dc-SQUID $\beta = 2I_c \cdot L/\Phi_0$ (Φ_0 is a quantum of magnetic flux, L is a inductance of the quantization loop) is equal to 300 for $L=10^{-10}$ H. The value of the parameter β must be about one for the SQUIDs with the high sensitivity. The value of L is determined of the SQUID geometry, and the quantization loop diameter is 20~30 ㎛ usually. This diameter gives for L the value about 10^{-10} H. So, the critical current of junction must be decreased for the decreasing of β. But the film structure is become granular and unstable to the thermocycling at the decreasing of the critical current density up to 10^4 /㎡. At present the creating of the film SQUIDs goes on the whole in the two directions: 1) with using of the step-edge junctions and 2) Bicrystal junctions [1]. These SQUIDs are very complicated for the making and require the expensive and complex equipment. Besides, the High-Tc film on the Bicrystal boundary and step-edge one grows with the low stability to a degenerating.

So, it was proposed by us other way to solve the creating of the film SQUIDs with the high sensitivity. The main idea is to use so called stressed YBCO films. The stressed states in the High-Tc films grown by laser ablation method were found in 1998 [16]. The films in these states have an unordinary temperature dependence of the critical current with the characteristic minimum at 55~57 K intervals. The critical current density of the films in the stressed states is changed over a wide range: from 10^3 to 10^5 A/㎠ at 77 K, moreover the values of the magnetic susceptibility and critical temperature are equal to the values of the single crystalline films [1]. Besides, the stressed films have the high stability to a degenerating. The parameter $\beta = 2I_c \cdot L/\Phi_0$ in the SQUIDs being made on the basis of the stressed films is equal to about one, and the sensitivity of them by magnetic flux is $(2 \cdot 10^{-5} - 6 \cdot 10^{-6})\ \Phi_0/Hz^{1/2}$ [2]. The sensitivity by magnetic field with using of the flux concentrator in 1 ㎟ area is about $5 \cdot 10^{-14}$ $T/Hz^{1/2}$ [3]. This value is in agreement with the sensitivity of the dc-SQUIDs using the step-edge junction and Bicrystal junction.

3. Stressed YBCO film

To grow high quality thin YBCO films by laser ablation method we must understand, first of all, processes going on the substrate surface at the absorption of laser pulses. Our experiments have showed that the power density of the laser radiation $W_{pc} = 2{,}5 \cdot 10^8$ W/㎠ is boundary one. The cluster mechanism of the particle break-off from substrate YBCO is realized at $W_p > W_{pc}$, which is changed on the drop mechanism at $W_p < W_{pc}$. We are developed a theory of the cluster and drop mechanisms [4].

The stressed YBCO films have been deposited by laser ablation method. As a substrate we used single-crystal plates of $LaAlO_3$ (100), and used a pulsed Nd:YAG laser (wavelength λ = 1.06 ㎛, pulse length τ =20 ns, repetition race =12 Hz). The substrate temperature was adjusted at temperature in the range 810~840℃, and the oxygen partial pressure in the vacuum chamber was about 0.1~0.6 mbar during the deposition. The power density of laser radiation on the target surface varied from 310^8 W/㎠ to 810^8 W/㎠. The studied films were made in the shape of long strips of width about 10~40 ㎛ by means of focused ultraviolet laser beam. The critical current was measured by a four-probe method. The 1 ㎶ criterion was used for the critical current.

The stressed states of growing HTS YBCO films arise at the rapid rate of cooling [5]. A main cause of arising of the mechanical stress in the films is a difference of parameters of the YBCO structure and substrate material. This difference of the YBCO and $LaAlO_3$ crystals are equal to about 1 %. At the rapid rate of cooling about 1.5~2.5 deg./s the mechanical stresses in the film were not able to relax and they are frozen in the superconducting material. Dependences of the critical current density in accordance with time of the holding in the furnace at different cooling rates are shown in Fig. 1.

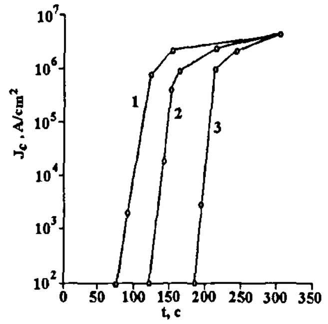

Fig. 1. Dependences of critical current density Jc vs. time of holding in furnace at different cooling rates. [(1) 2.5 deg./s, (2) 2.2 deg./s, (3) 1.6 deg./s)].

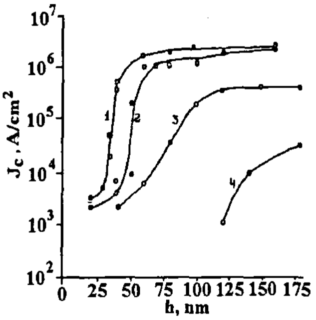

Fig. 2. Dependences of critical current density Jc vs. thickness of films at different hardening time: 1) 300 sec, 2) 180 sec, 3) 90 sec, 4) 80 sec.

The stress degree of films depends on the thickness of them (see Fig.2). The stressed HTS films by the tunneling microscopy indicates that film structure consists of stress domains. We have measured tunnel I-V characteristics between a film and a needle of the scanning microscope [6]. A boundary between domains has a deformation potential well, in which an electron may by localized. Therefore, the tunnel I-V characteristics was taken place of peaks. Fig. 3 is the typical I-V characteristics of it.

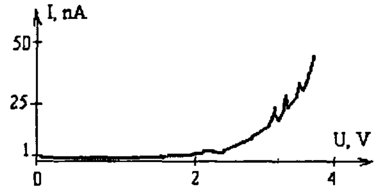

Fig. 3. Typical tunnel I-V characteristics

In Fig. 4 coordinates of dots on the scan, where the I-V characteristics have peaks as in Fig. 3 are shown.

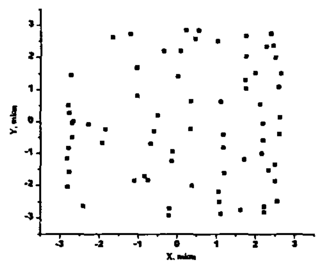

Fig. 4. Coordinates of dots with tunnel I-V characteristics of domain boundaries.

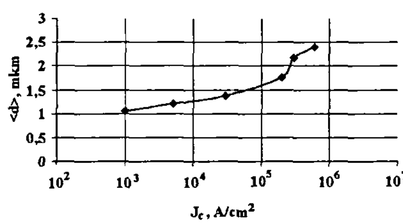

Fig. 5. The dependence of an average size of domain vs. critical current density Jc.

It was seen from Fig. 5 that average size of domain increases at increasing of critical current density, i.e. at decreasing of stress power. The distance between two neighboring dots apparently is a size of domain. In Fig. 5, dependence of an average size of domain in accordance with critical current density is shown.

The stressed HTS YBCO films have unusual temperature dependence of the critical current density. In the temperature interval of 55~57 *K* it has the minimum [7]. In Fig. 6 the typical temperature dependence of the critical current density is shown.

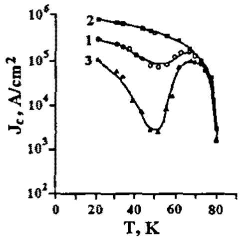

Fig. 6. Typical temperature dependence of critical current density for stressed HTS YBCO film at different number of thermocycles n (1: n=0, 2: n=70, 3: n=140).

This unusual behavior of the curve of temperature dependence of the critical current density is explained with the Coulomb blockade on the domain boundaries, where electrons are localized. These domain boundaries are like a Josephson junction of an unknown type.

4. Conclusions

It has shown that the stressed films were more stable to the thermocycling than the films with the granular structure. The stressed HTS YBCO films have unusual temperature dependence of the critical current density. The dc-SQUIDs was fabricated with maximal sensitivity on the bases of the stressed YBCO films. The stressed films having the value of the critical current density $J_c = 3 \cdot 10^5$ A/㎠ were the more stable. These films were carried out more than 500 thermocycles.

Acknowledgements

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References

[1] K.N.Yugay, G.M.Seropjan, A.A.Skutin, K.K. Yugay. "Superconducting properties of YBCO thin films at thermocycling", Low Temp. Phys., Vol.23, p.281, 1997

[2] E.A.Kanev, A.B.Muravjev, K.K.Yugay, K.N.Yugay, G.M.Seropjan, S.A.Sjichev. "HTS film dc-SQUID: measurement of its asymmetry and sensitivity", Vestnik Omsk Univer., No.1, p.30, 2000

[3] Patent No. 2104939 (Russia). Yugay K.N., Skutin A.A., Muravjev A.B., Sjichev S.A., Yugay K.K. "Superconducting Quantum Interference Device and method of its making", 1999.

[4] A.V.Demin, O.L.Kurnjavko, A.B.Muravjev, WA. A.Skutin, K.K.Yugay, K.N.Yugay, G.M.Seropjan, S.A.Sjichev., "Temperature dependence of the critical current of the HTS films growing by laser ablation method", Vestnik Omsk Univer., No.3, p.37. 1998

[5] A.B.Muravjev, G.M.Seropjan, K.K.Yugay, K.N.Yugay. "HTS stressed YBCO films growing by laser ablation method", Vestnik Omsk Univer., No. 4, p.25. 2000

[6] K.N.Yugay, K.V.Konovalenko, A.B.Muravjev, G.M.Seropjan, Sjichev S.A. "Studying of stressed states of YBCO films by tunnel spectroscopy method", Vestnik Omsk Univer., No.3, p.21. 2002

[7] A.B.Muravjev, G.M.Seropjan, K.K.Yugay, K.N.Yugay. "Growing of HTS YBCO films and their properties. Proc. of Sensor Microelectronics Institute of SB RAS Microsensors", p.242, 2000