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Conductivity and antiferromagnetism of $CaCuO_2$ thin films doped by Sr

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Abstract

The results of electrical and magnetic investigations of epitaxial $Ca_xSr_{1-x}CuO_2$ (CSCO) thin films grown by pulsed laser deposition are presented. The experimental temperature dependence of the CSCO film conductivity at low doping level is well described by the 3-d Mott insulator model over a wide temperature range (4.2–300 K). A deviation from the model with changing of Sr concentration has been observed. The Neel temperature of the films, T_N, was determined by electron paramagnetic resonance technique. The comparison of the obtained T_N value with the one previously obtained for the CSCO powder sample could be caused by oxygen vacancies in the CSCO films. $Nb/Au/Ca_{1-x}Sr_xCuO_2/YBa_2Cu_3O_{7-\delta}$ heterostructures have been fabricated and superconducting current has been observed at low temperatures.

Keywords: Cuprates; Superconductivity; Antiferromagnetic; Electron paramagnetic resonance

1. Introduction

The critical temperature of cuprate superconductors increases with a number of CuO_2 layers in the unit cell [1]. Thus there is a great interest to study the materials with a large number of the CuO_2 layers in the unit cell. The typical example is $Ca_xSr_{1-x}CuO_2$ (CSCO), where CuO_2 planes are divided by Ca atoms sometimes replaced by Sr. This material represents a two-dimensional Heisenberg antiferromagnet with strong interlayer interaction Cu^{2+} at low temperature.

2. Experimental

Epitaxial films of CSCO with $x = 0$, 0.15 and 0.5 were grown on (1 1 0)$NdGaO_3$ substrates by laser ablation at 700–750 °C and 0.3–0.6 mbar of O_2 pressure. The CSCO thin film growth technique is similar to $YBa_2Cu_3O_x$ (YBCO) superconducting films [2]. Typical films thicknesses used are 100–200 nm. Heterostructures Nb/Au/CSCO/YBCO of the areas $A = 10 \times 10$–$50 \times 50\ \mu m^2$ were fabricated by means of photolithography and Ar ion milling. During the processing SiO_2 thin films were used as insulation layers to define the area of the heterostructures [2].

3. Results and discussion

The lattice constants of CSCO films were determined to $a = b = 0.3855$ nm, $c = 0.318$ nm. The c-axis lattice parameter increased to $c = 0.323$ nm for $x = 0.15$.

For the films with the small Sr content $x < 0.5$ temperature dependences of conductivity correspond well to the model of three-dimensional hopping conductivity with the characteristic temperature of $T_0 = (2\text{–}60) \times 10^6$ K determined from the experiments (Fig. 1). If $N(E_f) = 10^{21}$, then the activating energy $E_{hop} = k_B T (T_0/T)^{1/4} = (0.2\text{–}0.5)$ eV, which at $T = 300$ K is smaller than the dielectric gap determined by certain optical methods: $E = 1.5$ eV [3].

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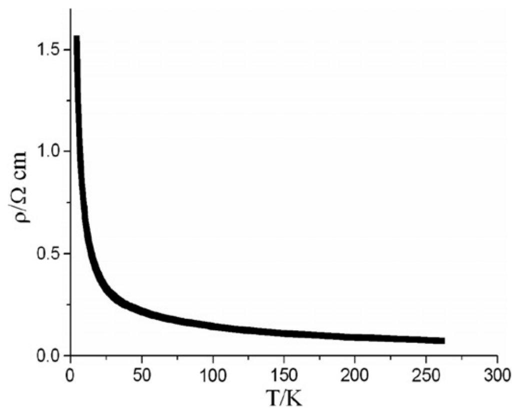

Fig. 1. Temperature dependence of CSCO film resistance $x = 0.15$.

In our thin CSCO films the hopping conductivity is replaced by a $\rho \propto T^{-S}$ dependence at high values of x ($\rho \leqslant 0.01\ \Omega$cm). Early the $\rho \propto T^{-S}$ dependence was observed in CSCO films with $x = 0.3$–0.4 [4] and is typical for disordered electronic systems with high resistance at low temperatures. However no metallic temperature dependence of conductivity has been observed in our experiments at the high doping level ($x \geqslant 0.5$).

In order to determine T_N the EPR spectra of the CSCO films in a temperature range of 80–300 K were carried out. The standard Bruker spectrometer ER 200 (9.56 GHz) with the modulation of the magnetic field at frequency of 100 kHz was used. The concentration of the paramagnetic centers was determined from comparison of the EPR line with the Mn^{2+} of the standard MgO:Mn sample placed in the same cryostat.

For the CSCO film with $x = 0.15$ the copper (Cu^{2+}, $S = 1/2$) line was observed within the measured temperature range near-by a g-factor 2.8. The considerable suppression of the signal with temperature changing (Fig. 2) is related to the paramagnetic–antiferromagnetic transition. Thus the Neel temperature may be determined. There is a small growth of signal absorption within the temperature range from 300 K to 130 K, which is followed by a sharp drop of the signal at paramagnetic–antiferromagnetic transition. The Neel temperature obtained for the two CSCO films is in the range of 90–120 K. Considerable difference in the T_N values from the data obtained by the neutrons scattering of the CSCO powder samples [5] is probably caused by large difference of the oxygen content both in CSCO films and the powder samples.

The number of spins $N_{Cu} \sim 4 \times 10^{15}$ was estimated from EPR line. This value is close to the number of molecules in the $Ca_{0.85}Sr_{0.15}CuO_2$ sample.

Epitaxial multilayer thin film heterostructures of YBCO/CSCO/Au/Nb were fabricated and investigated at low temperatures, where CSCO films are in the antiferromagnetic state. X-ray diffraction technique and AFM microscopy were used to examine crystal structure and surface morphology of the heterostructures. Superconducting current with current density up to 200 A/cm^2 and $I_C R_N \leqslant 200\ \mu$V was observed in the heterostructures with thickness of the CSCO layer up to 50 nm. This fact contradicts to the Bogolubov–De Gennes theory of superconducting proximity effect. From comparison of the properties of the YBCO/CSCO/Au/Nb and YBCO/Au/Nb heterostructures we have found that adding of the antiferromagnetic interlayer increases the $I_C R_N$ product of the junctions by 3–4 times. In addition the period of the modulation of the Josephson current is about ten times smaller in the YBCO/CSCO/Au/Nb heterostructure than in the YBCO/Au/Nb ones.

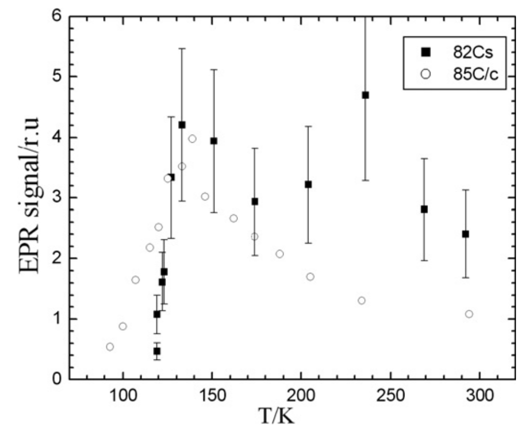

Fig. 2. Temperature dependence EPR amplitude for two CSCO films with $x = 0.15$.

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