Acoustoelectric effect of superconducting $YBa_2Cu_3O_{7-x}$ films

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(Submitted 8 August 1990; resubmitted 15 October 1990)
Pis'ma Zh. Eksp. Teor. Fiz. **52**, 1138–1141 (25 November 1990)

An acoustoelectric effect has been studied in a layered structure consisting of YZ-$LiNbO_3$ and a superconducting $YBa_2Cu_3O_{7-x}$ film. At 300 K the acoustic voltage has a positive sign, i.e., it corresponds to a hole conductivity. At $T \leqslant T_c = 98$ K the acoustic voltage decreases sharply to zero (at 95 K), changes sign, and increases in absolute value to a maximum at $T = 90$ K ($R = 0$). It then decreases to zero at 78–81 K.

Among the effects which accompany the propagation of acoustic waves in a solid the acoustoelectric efffect can be singled out because it is determined by the transfer of the acoustic wave momentum directly to the system of charge carriers. This circumstance makes it worthwhile to study the acoustoelectric effect in high-T_c superconducting materials, where the relaxation processes in the lattice mask the relaxation due to the interaction of sound with the charge carriers during the measurements of the absorption and acoustic velocity.

We have observed an acoustoelectric efffect in $YBa_2Cu_3O_{7-x}$ films of thickness $d = 0.15$–$0.40\ \mu$m, deposited by magnetron sputtering on a polished surface of a YZ-$LiNbO_3$ substrate. The test sample made from a more uniform central part of the film is shown schematically in Fig. 1. A Rayleigh surface acoustic wave (SAW) of frequency 87 MHz and intensity up to 2–3 kW/cm^2 was excited in the substrate. The SAW pulse could be generated by any one of the two interdigital transducers (IDT) mounted on the substrate. The receiving IDT in our case was used to control the amplitude of the acoustic pulse that was transmitted through the sample. The length of the SAW pulses was varied from 1.5 μs to 7 μs and the pulse repetition rate was 50 Hz.

The holder with the substrate and the sample was immersed into a cryostat filled with helium gas. The temperature was controlled in the range 4.2–300 K by a heater which did not produce a magnetic field (within an error better than 0.1 Oe). The electrical resistance of the film was measured by a four-probe method.

Measurements carried out at 300 K showed that activation of a SAW (in the absence of a transport current I_t) led to the appearance of a voltage pulse, and acoustic voltage V_a, at the open contacts of the sample with a time delay long enough for the sound to reach the sample, and to the appearance of an acoustic current video pulse, I_a, of identical shape, when the contacts were short-circuited. The sign of the V_a and I_a pulses suggests that the holes are the charge carriers. Reversal of the propagation direction of the SAW changes the polarity of the pulses. The amplitude of the V_a and I_a pulses depends linearly on the SAW power P_a (Fig. 2). The shape of the pulses and the manner in which it changes as a function of the ratio of the pulse

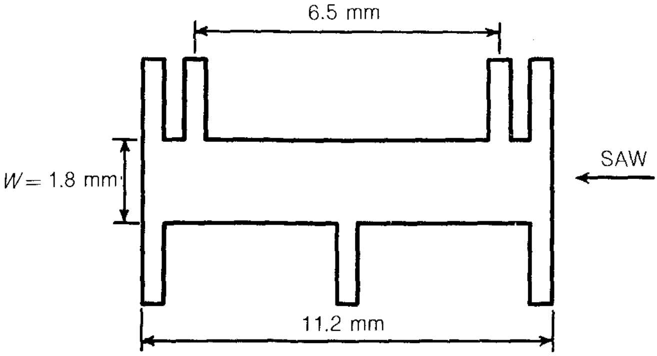

FIG. 1. Schematic diagram of the sample. The film thickness is $d = 0.14\ \mu m$ and the resistivity at $T = 300$ K is $\rho_{300K} = 5.7 \times 10^{-4}\ \Omega \cdot cm$. The surface acoustic wave is propagating along the length of the sample; the SAW aperture is $a = 3$ mm.

length and the time it takes the sound to pass through the sample behave normally for a pulsed acoustoelectric efffect.[1]

The dependence R/R_{300K} of V_a and I_a is shown in Fig. 3. With a decrease in the temperature, the resistance R decreases linearly to the point at which the superconducting transition occurs. At $T = 170–220$ K we see a change in the slope of the linear dependence of $R/R_{300K}(T)$, which was indicated previously in a $YBa_2Cu_3O_{7-x}$ single crystal[2] and which was attributed in Ref. 2 to the phase transition. A diffuse maximum of V_a and I_a was observed in this temperature interval.

In the region of the superconducting transition, which at the level (0.1–0.9) R_{300K} occurs in the temperature interval $T = 92–96$ K for the test sample, we see a sharp decrease in the amplitude of the acoustic voltage and acoustic current pulses to

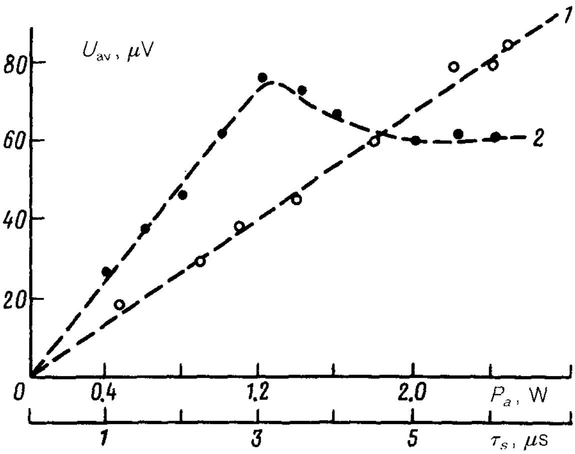

FIG. 2. The acoustic voltage V_a at $T = 300$ K versus (1) the SAW power, P_a, W (O) and (2) the length τ of the SAW pulses, μs (●).

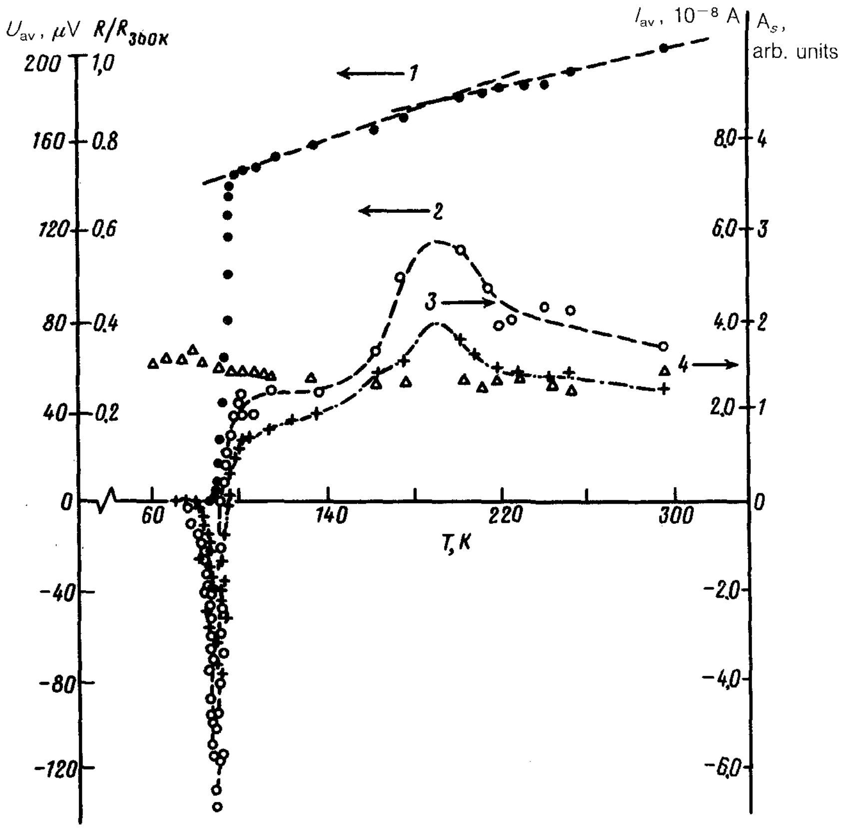

FIG. 3. Temperature dependence. 1—R/R_{300K}, a 10 μA transport current flows through the film (●); 2—acoustic voltage, V_a (O); 3—acoustic current, I_a (+); 2, 3—the SAW intensity is 2 kW/cm^2 and no transport current flows through the sample; 4—the amplitudes of SAW pulses, A_s taken from the receiving IDT (▽).

zero (near 95 K) and then a reversal of their polarity and an increase in absolute value to a peak which occurs at $T = 90$ K, followed by a decrease to zero at $T = 78$–81 K. It should be noted that the results can be reproduced well, and that there is no noticeable hysteresis (the temperature varies at the rate $T \sim 0.3$ K/min). Qualitatively similar results were also obtained for the other three films. The amplitude of the SAW pulse at the receiving IDT was virtually constant over the entire temperature interval under investigation (curve 4 in Fig. 3, A_s).

Since the high-T_c superconductivity mechanism (and acoustoelectronic coupling mechanism) of Y–Ba–Cu–O materials has not yet been determined, we will restrict the analysis to short comments.

The measured voltage is in fact of an acoustoelectronic nature; above T_c it retains more or less a constant value and below T_c it decreases rapidly to zero.

1. Let us first consider the temperature region $T > T_c$. The sign V_a shows that at

$T > T_c$ the principal carriers are the holes, in agreement with the available indirect data and data on the Hall effect. The measured value of the acoustic voltage, however, is larger by more than an order of magnitude than the value found from the estimates based on the known mechanisms. This difference is, in our view, attributable to the stratification of the structure.

2. An abrupt change in the region of V_a at $T < T_c$ so far has not been explained. The behavior of V_a is very similar to the behavior of the Hall voltage in superconducting $Bi_2CaSr_2Cu_2O_x$ single crystals, which was observed in Ref. 3 and which was explained there in terms of the thermally stimulated vortex creep. Since we have used polycrystalline films, such processes should be ruled out, and a further study should be carried out. Similar features in the behavior of the Hall effect in $YBa_2Cu_3O_{7-x}$, however, were attributed in Ref. 4 to the particular structural features of the band near the Fermi level. Various structural features of the bands have been frequently invoked in order to explain the acoustic absorption anomalies at $T < T_c$ (Ref. 5). A study carried out by Mueller *et al.*[6] is worth noting. In this study it was concluded, on the basis of measurements of an rf component of the magnetic field which accompanies the acoustic wave, that the characteristic features in the acoustoelectronic interaction are the result of a ferroelectric phase transition. According to Mueller *et al.*,[6] the excitonic superconductivity mechanism is active in $YBa_2Cu_3O_{7-x}$. This circumstance may also account for the peculiar behavior of acoustoelectronic effects.

[1]G. Weinreich, Phys. Rev. **104**, 321 (1956).
[2]Ya. V. Kopelevich, V. V. Lemanov, and P. P. Syrnikov, Fiz. Tverd. Tela **30**, 3186 (1988) [Sov. Phys. Solid State **30**, 1835 (1988)].
[3]S. N. Artemenko, I. G. Gorlova, and Yu. I. Latyshev, Pis'ma Zh. Eksp. Teor. Fiz. **49**, 352 (1989) [JETP Lett. **49**, 403 (1989)].
[4]H. L. Stormer, A. F. Y. Levi *et al.*, Phys. Rev. B**38**, 2472 (1988).
[5]K. Fossheim and T. Laegreid, IBM J. Res. Develop. **33**, 365 (1989).
[6]V. Mueller, C. Hucho *et al.*, Sol. St. Commun. **72**, 997 (1989).

Translated by S. J. Amoretty