Charge Ordering and Anomalous Elastic Properties of Cuprates Superconductors

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Abstract

In cuprates superconductors (as polycrystal and single crystal samples) unusual hysteretic temperature behavior of elastic properties is frequently observed. In this work from the uniform point of view detailed analysis this abnormal temperature behavior of elastic properties is given. It is shown that the hysteretic temperature dependencies of elastic properties of $YBa_2Cu_3O_{7-\delta}$ crystal are strongly anisotropic and are connected to the hysteretic behavior of the C_{3333} modulus while the C_{1111} and C_{2222} moduli have no such dependence. The analysis of the elastic constant tensor on the basis of a microscopic model has allowed to draw a conclusion, that the hysteretic behavior of the C_{3333} modulus of $YBa_2Cu_3O_{7-\delta}$ crystal is caused by temperature dependent renormalization of constants of interaction of apex oxygen atoms with copper atoms and are connected apparently to the formation of charge ordering.

Key words: superconductivity; elastic properties; charge ordering;

Already the first investigations of high temperature superconductors have revealed a variety of essential features in the temperature dependencies of velocity $v(T)$ and attenuation $\alpha(T)$ of ultrasound. Surprising there was that at heating and cooling of a sample the temperature dependencies of velocity (attenuation) did not coincide. A distinct thermal hysteresis was observed between 60 and 230 K. Further investigations have shown that the hysteretic behavior of $v(T)$ is observed for all isostructural series (RE)$Ba_2Cu_3O_{7-\delta}$, (RE)$Ba_2Cu_4O_8$ and also for the Bi Pb, Tl, $Ba_xK_{1-x}BiO_3$ [1], MgB_2 [2] HTSC compounds and the hysteretic behavior of $v(T)$ was observed as for polycrystal and for single crystal samples [3,4]. Earlier we offered a phenomenological model describing hysteretic temperature behavior of elastic constants of HTSC single crystals [5]. However the microscopic mechanism resulting in so anomalous temperature behavior of velocity of ultrasound and essential distinction in elastic properties of polycrystal and single crystal samples of HTSC compounds remains obscure till now.

To develop a detailed microscopic model of hysteretic behavior of ultrasonic velocity and to analyze temperature dependencies of ultrasonic wave velocity in polycrystal materials we must know the components of elastic tensor which have anomalous temperature dependence. First of all I have shown that the experimental results of [3] are consistent with results [4] quantitatively in the assumption, that anomalous temperature dependence the elastic modulus C_{3333} has only. I have calculated resonant frequencies of a sample at deformation of a torsion and compression in view of inertia of cross movement of elements of a sample (for more details see [6]). The calculated temperature dependencies are depicted in Figs. 1, 2. For all investigated orientations calculated and experimental dependencies are in excellent agreement. I pay attention, that for the orientation $\mathbf{u}\|\mathbf{c}, \mathbf{k} \perp \mathbf{c}$ a strong temperature dependence of ω(T) is caused by excitation of bending oscillations of a sample which natural frequency is determined by the $C_{3333}(T)$ module. Having expressed a tensor of elastic moduli as a

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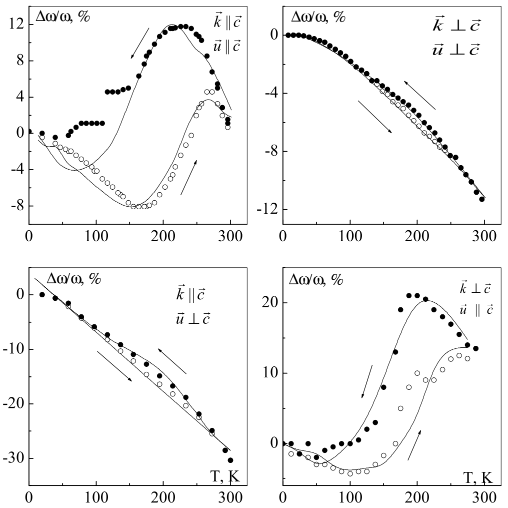

Fig. 1. Temperature dependencies of the relative resonant frequency $(\omega(T)-\omega(T_0))/\omega(T_0)$ of oscillations of a single crystal sample for various orientations of the wave vector and the vector of displacement of a ultrasonic wave . Lines represent simulations; points are experimental results [4]; the direction of change of temperature is shown by arrows

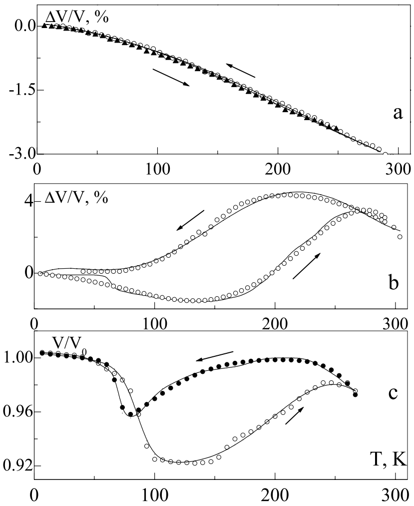

Fig. 2. Temperature dependencies of the relative velocity of ultrasound $((v(T)-v(T_0))/v(T_0)$ (a,b) and $V(T)/v(T_0)$ (c) in $YBa_2Cu_3O_{7-\delta}$ polycrystal samples. Lines represent simulations; points are experimental results [9]: a - for dense, small crystal grains sample; b - textured sample; c - sample with relatively large crystal grains ($\sim 50\mu m$); the direction of change of temperature is shown by arrows

function of constants of pair interactions of atoms in $YBa_2Cu_3O_{7-\delta}$ crystal it can be shown that the abnormal temperature behavior of the elastic modulus C_{3333} is caused by change with temperature of force constants of the apical oxygen atoms. In used approach the modulus C_{3333} is determined by the interaction of apex oxygen atoms with copper and barium atoms but as abnormal temperature behavior of the elastic moduli C_{1111}, C_{2222} is not observed, a sole opportunity is the temperature renormalization of the O(4) oxygen - copper force constants. The given conclusion is consistent with experimental results [7] (also references in it) in which features in dynamics of O (4), O(1) oxygen atoms in $YBa_2Cu_3O_{7-\delta}$ were observed also. For a more detailed study of the dynamics of oxygen atoms I calculated this effect within the framework of model [5] and compared it with the recently obtained experimental results [8]. It is very interesting that the temperature interval in which incoherent lattice fluctuations exceeds thermal coincides with the interval in which hysteretic behavior of speed of ultrasound is observed. And the temperature of formation of charge ordering $T_1^* \approx 200K$ corresponds to the temperature of opening of a hysteresis loop.

The analysis performed shows that observed experimentally incoherent lattice fluctuations in $YBa_2Cu_3O_{7-\delta}$ crystals may be caused by particular dynamics of oxygen atoms and that the hysteretic behavior of the C_{3333} elastic modulus may be attributed to the formation of charge ordering at temperatures $T < 200K$.

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