Elastic constant of the vortex lattice in $La_{1.875}Ba_{0.065}Sr_{0.060}CuO_4$

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Abstract

The elastic constant of the vortex lattice is measured in order to estimate the superconducting volume fraction of $La_{1.875}Ba_{0.065}Sr_{0.060}CuO_4$ which undergoes the structural phase transition to the low-temperature orthorhombic (Pccn) phase. The step like change in the elastic constant of c_{44} mode of the vortex lattice is clearly observed below T_c, and the saturated value of the elastic constant of the vortex lattice is 68% of the theoretical result for the full-Meissner state. This experimental result indicates that, probing with the vortex lattice, the superconducting volume fraction seems to be about two over three under the so-called stripe order in the Pccn phase.

Key words: stripe; $La_{2-x-y}Ba_xSr_yCuO_4$; elastic constant

It is well known that $La_{2-x}(Ba,Sr)_xCuO_4$ shows a local minimum of the superconducting transition temperature T_c and shows an anomalous behavior of transport properties around x=0.12. The recent development on this "1/8-problem" is followed from the "stripe model" [1–3]. In the orthorhombic superconducting phase $La_{1.88}Sr_{0.12}CuO_4$, magnetic superlattice peaks are observed by neutron diffraction, while no peaks associated with the charge ordering have been observed [4,5]. In this orthorhombic sample, the superconducting volume fraction is estimated to be over 90% [6]. More recently, in $La_{1.875-x-y}Ba_xSr_yCuO_4$ single crystals which undergo the structural phase transition to the low-temperature orthorhombic (Pccn) phase or to the low-temperature tetragonal phase, the existence of magnetic and charge peaks are confirmed by the elastic neutron scattering [7]. In La-214 system that shows magnetic superlattice peaks and charge peaks are observed, whether or not the superconductivity coexists with the so-called stripe order is a controversial problem.

The purpose of this work is to estimate the superconducting volume fraction in $La_{1.875}Ba_{0.065}Sr_{0.060}CuO_4$ which is in the Pccn phase below 35K using the ultrasonic technique.

Sample used in this work is a single crystal grown by the traveling-solvent-floating-zone (TSFZ) method. The detail of crystal growth is given elsewhere [7]. The magnetization was measured by a SQUID magnetometer. The temperature dependence of the sound velocity V_s was measured by the phase comparison method with the ∼12MHz transverse waves generated by the PZT transducer. All measurements of the temperature dependence of V_s in this study were carried out with decreasing temperature in each magnetic field.

Figure 1 shows the temperature dependence of the magnetization measured in the ZFC condition. The sharp superconducting transition is observed at ${T_c}^{onset}$=7K.

Figure 2 shows the temperature dependence of the elastic constant of c_{44} mode, which is transformed from the measured sound velocity V_s using the relation of $c=\rho {V_s}^2$ (ρ=7.05 g/cm^3). The configuration of the measurement is $\mathbf{k} \parallel [110]_t$, $\mathbf{u} \parallel [001]_t$, and $\mathbf{H} \parallel [110]_t$ in the high-temperature tetragonal (I4/mmm) notation. Under this configuration, elastic waves in the crystal couple with the vortex lattice through an intrinsic pinning mechanism due to the layered crystal strucure of high-T_c superconductors, and in consequence, the c^f_{44} tilt mode of the vortex lattice is detected as an additional component upon the elastic constant of the crystal lattice c^c_{44}. This configuration has a few advan-

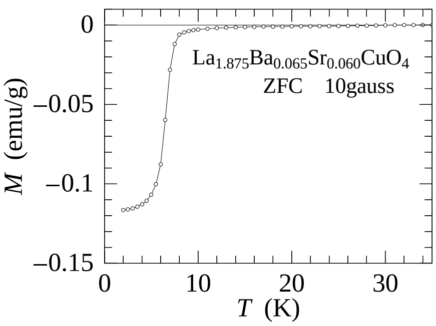

Fig. 1. The temperature dependence of the magnetization in $La_{1.875}Ba_{0.065}Sr_{0.060}CuO_4$.

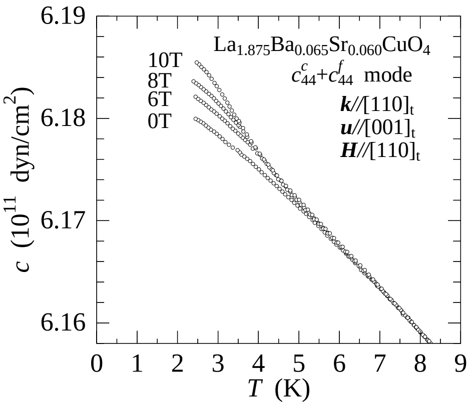

Fig. 2. The temperature dependence of the elastic constant (c_{44} transverse mode) under several magnetic fields in $La_{1.875}Ba_{0.065}Sr_{0.060}CuO_4$.

tages in the investigation of the superconducting volume fraction. The first is that the elastic constant of the crystal lattice c^c_{44} has no anomaly at the superconducting transition temperature and has no magnetic field dependence. The second is that, in type II superconductors, the theoretical result of the c^f_{44} tilt mode of the vortex lattice $H^2/4\pi$ is calculated by the thermodynamics [8]. This means that the obtained result is independent on the structure of the vortex lattice. The last is that the superconducting transition temperature is hardly changed by the magnetic field, because of a large anisotropy of the superconductivity. Evidently from fig.2, the contribution of the vortex lattice appears below 7K which coincides with the onset temperature of the magnetization. In order to extract the contribution of the vortex lattice, c_{44} in 0T is subtracted from that in each magnetic field, and we obtain $\Delta c^f_{44}(H,T) = c_{44}(H,T) - c_{44}(0,T)$.

Figure 3 shows the temperature dependence of the obtained elastic constant of the vortex lattice Δc^f_{44} in 6, 8, 10T. As decreasing temperature, Δc^f_{44} begins to increase at 7K, shows a drastic increase below 4K, and saturates at the lowest temperature. The inset of fig.3 shows the magnetic field dependence of the saturated

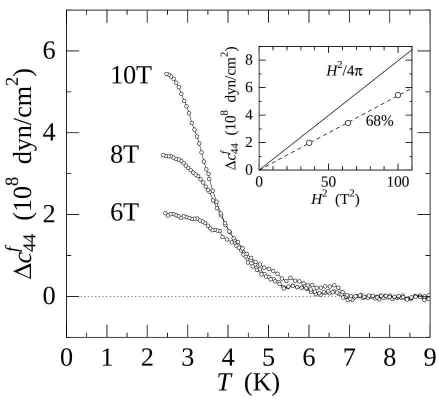

Fig. 3. The temperature dependence of the subtracted elastic constant of the vortex lattice Δc^f_{44} in 6, 8, 10T. The inset shows the magnetic field dependence of the saturated value of the elestic constant. The solid line denotes the theoretical result for the full-Meissner state. The dashed line is the result of the fitting to the measurement data.

value of Δc^f_{44}. The solid line denotes the theoretical result of the c^f_{44} tilt mode, $H^2/4\pi$.

By estimating the ratio of the measured value to the theoretical result for the fll-Meissner state, the superconducting volume fraction is able to be deduced. Because the flux line does not couple with the crystal lattice in the normal state region, and the Δc^f_{44} is in proportion to the volume of the superconducting region. The measurement data is well fitted by the theoretical line $V \times H^2/4\pi$ (the dashed line in the inset of fig.3). From this analysis, we obtain the value V=0.68. This result indicates that the superconducting volume fraction is 68% in $La_{1.875}Ba_{0.065}Sr_{0.060}CuO_4$. It thus appears that, probing with the vortex lattice, the superconductivity is partially destroyed but the superconducting volume fraction has a finite value, about two over three under the so-called stripe order in the Pccn phase. The measurement on the sample of the low-temperature tetragonal structure is in progress.

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