Vortex Glass Transition of the Josephson Vortex System in LSCO Crystals

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Abstract

Electrical resistivity has been measured under magnetic fields parallel to the CuO_2 planes in LSCO single crystals, where Josephson vortices form in the region between the CuO_2 planes. In the crystals over the wide Sr content from the under-dope to the over-dope the vortex glass melting transition is observed in the field range of 1T-17.5T. The glass transition lines strongly depend on the anisotropy of the system, that is, it is suppressed to the low field in the under-doped crystal with large anisotropic parameter. The Josephson vortex glass transition is discussed in terms of the anisotropic parameter.

Key words: Vortex glass transition; Josephson vortex; LSCO system;

The research of the vortex matter in the mixed state has been intensively made in the Y-Ba-Cu-O and Bi-Sr-Ca-Cu-O systems for $H\|c$-axis. Recently properties of the Josephson vortex system have begun to be studied in both systems. Josephson vortex is formed by the Josephson current between the CuO_2 planes and its behavior is expected to be quite different from the vortex system which appears for $H\|c$-axis. The vortex phase diagram for $H\|c$-axis shows a wide variety by the anisotropy but has not been researched in the intermediate region of the anisotropy such as the La-Sr-Cu-O system. In the present paper the phase transition of the Josephson vortex system is studied on $La_{2-x}Sr_xCuO_4$ single crystals.

The measured samples from the under-doped to the over-doped region with x=0.08, 0.14 and 0.18 are prepared and are synthesized by the Traveling Solvent Floating Zone method [1]. After the growth the samples are annealed at $900-950^{o}$C in flowing O_2 and then quenched to the room temperature. The anisotropic parameter $\gamma(=\xi_{ab}/\xi_c)$ of the samples with x=0.08, 0.14 and 0.1 is γ=50, 13, and 10 and the superconducting transition temperature is T_c=25.9K, 38.4K and 34.8K, respectively. The transition width is small below 1K. In these samples the first order transition of the vortex system has been observed for $H\|c$-axis [2]. The resistivity is measured by a conventional dc four-probe method in the magnetic fields between 1T and 17.5T. The samples are set on the sample holder with a rotational mechanism in which the angle step is 0.01^{o} and the condition of $H\|ab$-plane is determined as the position of the minimum resistivity in the angular dependence $\rho(\phi=0)$ in the ac-plane. The current is always perpendicular to the magnetic fields.

Fig. 1 shows the temperature dependences of the resistivity of the sample with x=0.08 at $\phi=0$. These do not show the resistivity jump related with the first order vortex lattice melting transition which is observed in the YBCO [3] and BSCCO [4] etc. but continuously decreases in all magnetic fields. This suggests that the phase transition in the vortex system is the second order. Actually its temperature dependence in the low resistivity region obeys $\rho(T)=\rho_0(T-T_g)^s$ which is

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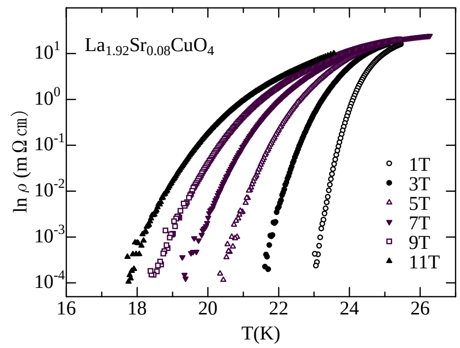

Fig. 1. Temperature dependences of the resistivity in the sample with x=0.08 at various magnetic fields.

predicted in the vortex glass transition [5]. The temperature dependences of the inverse of the temperature differentiation of the resistivity on the basis of this equation are given in Fig.2, where the data at H=1T, 7T and 11T are plotted. In the all fields linear temperature dependences are clearly seen in the low resistivity regions. According to the vortex glass theory these results indicate that the second order phase transition from the vortex liquid to the vortex glass phase occurs and similar results are observed in the other samples with x=0.14 and 0.18. In Fig. 2 the cross point of the linear line by the experimental data with the temperature axis is the glass transition temperature $T_{\rm g}$ and the gradient corresponds to the critical exponent s. Thus it is concluded that the transition observed in the Josephson vortex system of La-Sr-Cu-O is the second order vortex glass one. The critical exponent is roughly independent of the magnetic fields in each sample. It takes s=5-7 in all samples and its value is also consistent with the theoretical prediction [5].

The phase diagram of the present system is summarized in Fig. 3, where the horizontal axis is the reduced temperature. The phase transitions increase rapidly with decreasing temperatures which originate from the relatively small anisotropy. The γ values are almost the same between the samples with x=0.14 and 0.18. On the other hand the transition curve is strongly suppressed to the low fields in the sample with x=0.08 with large anisotropic parameter. The effect of thermal fluctuation becomes more and more conspicuous with increase of the anisotropy through the Ginzburg number. It is interpreted that the thermal fluctuation due to the large anisotropy of this sample is effective to the Josephson vortex system. The Josephson vortex transition shows a similar behavior to that in the vortex system for $H \| c$-axis to the change of the anisotropy and the anisotropy is also important in the determination of the Josephson vortex phase diagram.

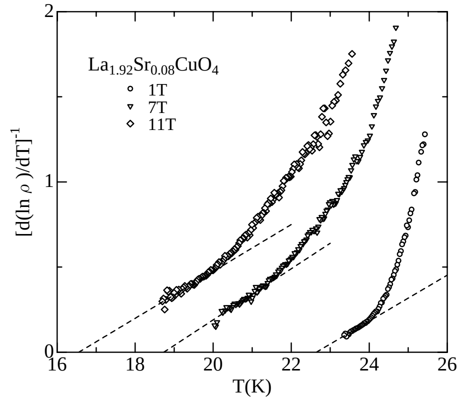

Fig. 2. Temperature dependences of the inverse of the temperature differentiation of the resistivity. In the low field region linear relation is seen in this plot.

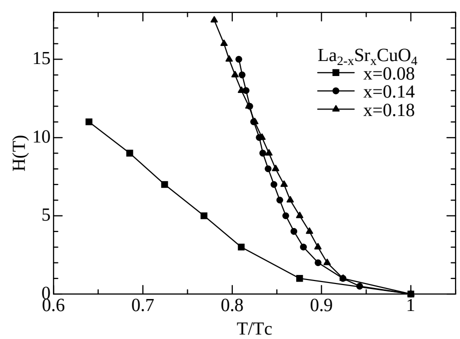

Fig. 3. Josephson vortex phase diagram in the La-Sr-Cu-O system.

To summarize the phase transition of the Josephson vortex system is studied in the La-Sr-Cu-O system by the resistivity measurements. It is made clear that the all samples from the under-doped to the over-doped region show the second order vortex glass transition and the temperature dependences of the transition are basically explained by the effect of the thermal fluctuation to the Josephson vortex system. The anisotropy is an important parameter in the determination of the phase diagram as well as that for $H \| c$-axis.

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