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Magnetic relaxation measurement of infinite layer superconductor $Sr_{0.9}La_{0.1}CuO_2$

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Abstract

The time dependence of irreversible magnetization of grain aligned infinite layer superconductor $Sr_{0.9}La_{0.1}CuO_2$ was measured in temperature range of $2 \text{ K} < T < 30 \text{ K}$ for $H = 0.5$ T, 1.0 T and 1.5 T parallel to *c*-axis. From this, we calculated normalized flux creep rate $S(T) \equiv dlnM/dlnt$ and found that the temperature independent region in *S(T)* is significantly wide in comparision with other cuprate superconductors. Using the method of Maley *et al.*, we also deduce the current density dependence of pinning potential and glassy exponent μ.

Keywords : Relaxation, Normalized flux creep, The method of Maley *et al*

I. Introduction

High-T_c cuprate superconductors are characterized by the high transition temperature and by a common structure element, a CuO_2 plane. In addition to CuO_2 planes, the charge reservoir blocks which supplies the charge carriers were thought to be requisite for superconductivity but the charge reservoir block is believed to reduce the inter layer coupling and the dimensionality of the sample. Because of high transition temperature and reduced dimensionality, the effects of thermal fluctuation are enhanced compared with conventional superconductors. Therefore, high-T_c cuprate superconductors have diverse phases in *H-T* plane. The vortex liquid, vortex solid and their phase boundary are the manifestations of large thermal fluctuations.

The infinite layer superconductors $Sr_{1-x}R_xCuO_2$ (R=La, Sm, Nd and Gd etc.)[1] which has no charge reservoir block, is an advantageous system for investigations of intrinsic properties of cuprate superconductors.

Although infinite layer superconductors can be a profitable reference for experimental investigations, the difficulty in synthesis in high pressure condition limits the research in this field. However, recent report of C. U. Jung *et al.*[2] for the successful synthesis of high quality samples of $Sr_{0.9}La_{0.1}CuO_2$, changes the situation.

In this paper, to understand vortex dynamics and pinning properties of $Sr_{0.9}La_{0.1}CuO_2$, we investigated the time dependence of irreversible magnetization in a temperature $T < 30$ K and obtained the *U(j)* curve from application of the method of Maley *et al.*[4] From the functional form of activation energy for flux creep, we obtained the glassy exponent μ and found that $S(T) \equiv dlnM/dlnt$ is divided in three different regimes.

II. Experiments

The sample which we use is the same as the one used in the high field magnetization measurement. The sample is *c*-axis grain-aligned and the FWHM of the rocking curve of (001) peak is less than 2°. The volume fraction is almost 100 %, judging from the low-field ZFC magnetization. Temperature at half

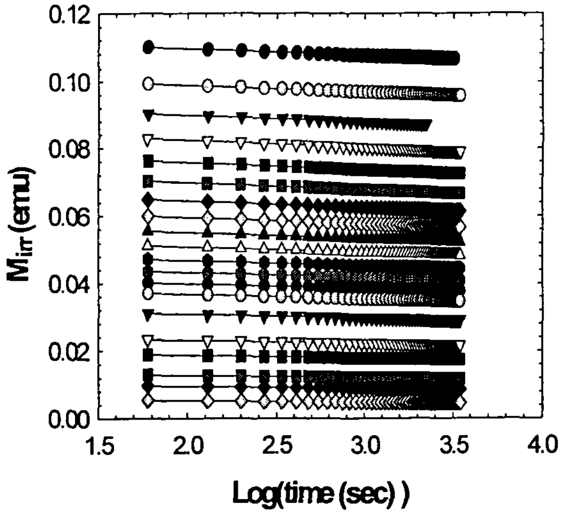

Fig. 1 Time dependence of irreversible magnetization for 1 tesla for flux exit. The time range is up to $10^{3.5}$. the data is well fitted to the logarithmic time dependence. In this measurements, the temperature range is from 2 k to 30 K

diamagnetic signal is 40.5 K and it also shows saturation behavior at low temperature.

The experiments are carried out in commercial SQUID magnetometer (MPMS, Quantum Design Inc.) operating with a 3 cm scan length to minimize the field inhomogeneity effects. First, the temperature is lowered to desired point in ZFC and the magnetic field is increased in the step of 5000 G, establishing the critical state. To differentiate the surface barrier effects, the measurements were done not only in field increasing branch but also in field decreasing one for field up to 1.5 T. In field decreasing branch, data at *H* = 0 T was also measured.

III. Results and discussions

Figure 1 illustrates the irreversible magnetization as a function of time for applied field of 1 T. The time range is from 60 s to 3600 s. In this time range, the data is not deviated from logarithmic time dependence significantly.

Figure 2(a) is the normalized creep rate *S(T)* for flux exit. The difference between flux entry and flux exit is small and regarded as within experimental errors. Thus, we consider only the flux exit data. Figure 2(a) is divided by three regimes. First, below 10 K, the creep rate increases in temperature. This region is conventional Anderson-Kim region in which normalized creep rate *S(T)* is proportional to temperature. Between 10 K and T^* = 22 K (17 K, 15 K) for *H* = 0.5 T (1.0 T, 1.5 T), *S(T)* shows plateaus which is wide in comparison with other cuprate

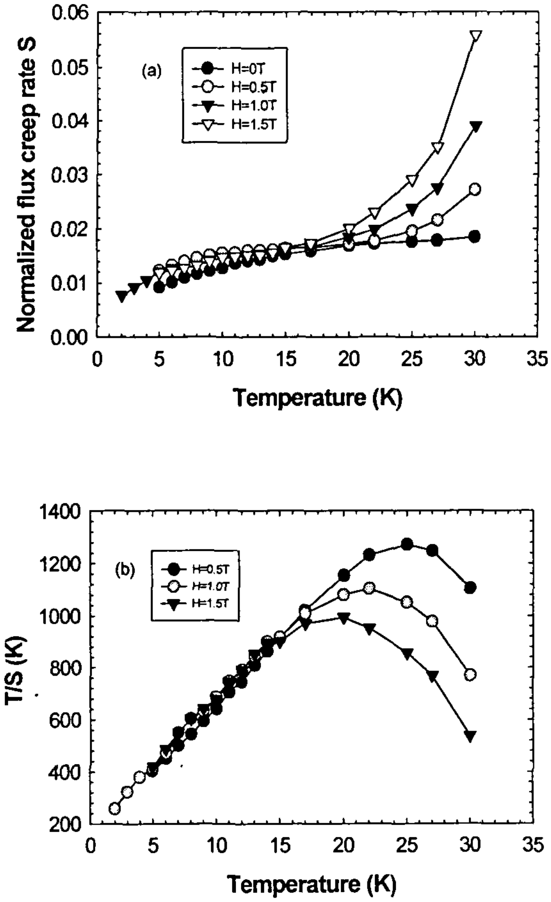

Fig. 2.(a) Normalized flux creep rate *S(T)* for flux exit. This data is divided by three regimes. Below 10 K, creep rate increases and Between 10 K and T^*, plateaus exist. Above T^*, creep rate increases again. (b) Teperature divided by normalized creep rate *T/S*. Linear increase in *T/S* becomes wider with magnetic field. Up to T^*, the data is well described by the collective creep theory. There is no quantum creep even at T = 2K . Above T^*, slope of *T/S* changes.

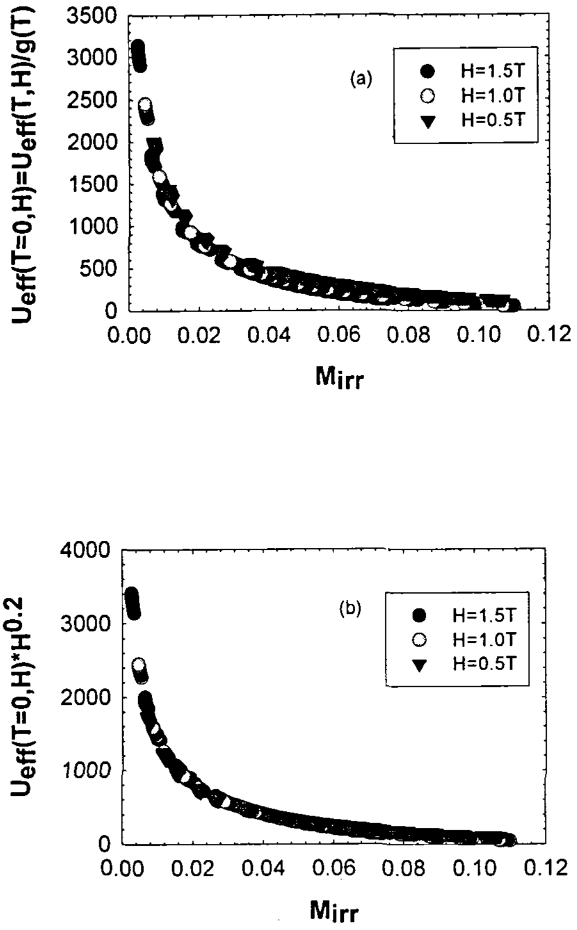

Fig. 3.(a) Current density dependence of the effective activation energy for flux creep which is constructed by the method of Maley *et al.* and its extensions. We used the temperature dependence of $g(T) = 1 - (T/T_{irr})^2$ (b) The data of (a) scaled by $H^{0.2}$

superconductors. The smaller the strength of the field is, the larger the plateau is. Above T^*, $S(T)$ increases again.

Figure 2(b) is the temperature divided by normalized creep rate. Below T^*, the data increases linearly in temperature and above T^*, the data begin to decrease. The linear increase in temperature is consistent with the collective creep model where $T/S=U_0+k_BT/ln\ (1+t/t_0)$. From the data, U_0 is estimated to about 175 K which is the same order of magnitude with those of other cuprates. An exceptional feature in Figure 2(b) is that T/S is proportional to temperature even at T = 2 K in our measurements. In other cuprates, the quantum tunneling of vortices in low temperature reduces the T/S at a certain temperature[5]. Compared with the data of $YBa_2Cu_3O_{7-\delta}$ film[6] in which the effect of quantum creep shows up to high temperature, the quantum creep dose not appear down to 2 K.

The absolute value of normalized creep rate is smaller than that of $YBa_2Cu_3O_{7-\delta}$. In $YBa_2Cu_3O_{7-\delta}$, S in the plateau is about 0.022~0.026[7] but in $Sr_{0.9}La_{0.1}CuO_2$, S is about 0.014. Combined with the data of current density[2], which is the same order of magnitude of those of other cuprates, we reach the conclusion that the pinning is effective in $Sr_{0.9}La_{0.1}CuO_2$. The small creep rate may originate from more isotropic nature of this compound.

According to Maley *et al.*, the effective pinning energy is given by

$$U_{eff}(M_{irr}) = T\left(A - \ln\left|\frac{\partial M_{irr}(t)}{\partial t}\right|\right) \qquad (1)$$

where $A \equiv ln(B\omega a/\pi d)$. ω is the attempt frequency, a hopping distance and d the average grain size. Figure 3(a) is the Maley's construction of the effective activation energy for flux pinning. Since our data covers large temperature range, temperature factor[8] $g(T) = 1-(T/T_{irr})^2$ should be included. Without $g(T)$, data is deviated from the single curve in high temperature. This is because the prefactor in $U(j)=U_0(j_c/j)^{\mu}$ is temperature dependent. The A is 20 in $Sr_{0.9}La_{0.1}CuO_2$, whereas A of $YBa_2Cu_3O_{7-\delta}$ is 18.

Figure 3(b) shows the U_{eff} data scaled by $H^{0.2}$, where H is measured in Tesla. This suggests the activation energy is $H^{-0.2}$ power law dependent. The exponent is, however, different from -0.9 of $La_{1.86}Sr_{0.14}CuO_4$[8] and -1.1 of $HgBa_2Ca_2Cu_3O_{8+\delta}$[9]. The meaning of this value is unclear until now.

We calculate the glassy exponent μ from Figure 3(a). To find out the exponent, we first determined the linear region in log-log plot. The linear region in $U(j)$ in log-log plot is almost coincident with the plateaus in $S(T)$, which is a reasonable consequence in collective creep theory because in the collective creep theory, power law dependence of $U(j)$ is assumed and from this, the interpolation formula is derived.

The exponent μ is 0.95, 1.11 and 1.23 for $H = 0.5$ T, 1.0 T and 1.5 T, respectively. Since the $U_{eff}(j)$ weakly depends on the $g(T)$, we try to adapt different approach. First, we apply the original Maley analysis and then we adjust the $g(T)$ to a single curve. Below 17 K, the curve is fitted into single curve with no temperature factor, e.g., $g(T) = 1$. The glassy exponent is 0.96±0.02 for all field strength in linear $U(j)$ region in log-log plot.

The value of glassy exponent μ in above analysis is less than 1.5 which is the upper limit which the collective pinning theory predicts. Based on not only normalized creep rate $S(T)$ but also the effective activation energy for flux pinning $U_{eff}(j)$, we can identify the plateaus in $S(T)$ and linear $U(j)$ in log-log plot as the collective pinning dominated regions. Below and above this region, $U_{eff}(j)$ is deviated from power law behavior and $S(T)$ shows the increases in temperature.

IV. Conclusions

In summary, magnetic relaxation on $Sr_{0.9}La_{0.1}CuO_2$ reveals both energy scale and current dependence of activation energy for flux pinning. The energy for flux pinning is about 175 K which is the same order of magnitude with other cuprates in Anderson-Kim region. Both $S(T)$ and $U_{eff}(j)$ are divided into three regions. Below 10K which is the Anderson-Kim region, $S(T)$ increases in temperature and $U_{eff}(j)$ increases linearly in current density. Between 10K and T^*, $S(T)$ shows plateaus and $U_{eff}(j)$ has a power law dependence. Finally, above T^*, $S(T)$ increases again and $U_{eff}(j)$ is deviated from the power law dependence. Even at $T = 2$K, there is no signal of quantum tunneling of vortices. This behavior is different from that of other cuprates of which data show quantum relaxation up to high temperature. The value of normalized creep rate is 0.014 which is distinguished feature of $Sr_{0.9}La_{0.1}CuO_2$ system. Comparing with about 0.022~0.026 of $YBa_2Cu_3O_{7-\delta}$, this is much smaller than other cuprates. The measured value of μ is about 1 and we found that μ depends on $g(T)$.

Acknowledgments

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