A new phase in the vortex solid region in $Bi_2Sr_2CaCuO_8$

Mitsuru Uehara [a,1], Shigeki Nimori [a], Takashi Mochiku [a], Takenori Numazawa [a]

[a] *National Institute for Materials Science, Tsukuba 305-0003 Ibaraki, Japan*

Abstract

The time decay of the zero field cooled diamagnetic magnetization of $Bi_2Sr_2CaCuO_8$ single crystals can be explained in terms of a characteristic relaxation time τ_0, and a mean activation energy E which is proportional to the reciprocal magnetic field. We find that τ_0 becomes extremely long to be around 10 sec at low temperatures below 14K. This low temperature phase in the vortex solid region is also directly confirmed by the ac susceptibility measurements in the ultra low frequency range.

Key words: vortex state; relaxation time; phase transition;

There is continuing interest in the problem of vortex dynamics in high-T_c superconductors due to the first phase transition in which metastable mixed state undergoes transitions to a lower state. A decade ago, we have shown that the concept of mean activation energy leads to coherent results on the mixed state nature in type II superconductors. We have found that the time decay of the zero field cooled diamagnetic magnetization and diamagnetic susceptibility $P \sim M_{zfc}/H$ can be explained in terms of a mean activation energy E which is found to be proportional to the reciprocal magnetic field [1,2]. At high temperatures, penetration rate of vortices into the sample obeys an Arrhenius type equation

$$dP/dt = 1/\tau = 1/\tau_o exp(E/\kappa T) \qquad (1)$$

where τ_0 is minimum relaxation time. E can be separated into two functions, thermal and magnetic components $g(T)$ and $h(H)$, and then described as $E(H,T) = g(T)h(H) = g(T)(H^{-1} - H_0^{-1})$. Where H_0 is a characteristic field depending to vortex state P. In an applied field H_0 penetration of fluxon or nucleation of vortex will occur at an attempt frequency $1/\tau_0$.

In this paper, we report the results of detailed measurements of the magnetic relaxation on single crystals of $Bi_2Sr_2CaCuO_8$ (BSCCO) with different oxygen stoichiometry[3].

The experiments were carried out on two crystals with different oxygen stoichiometry: the over-doped and the optimally doped crystals with $T_c = 86$ K and 92 K, respectively. Decay of the zero field cooled magnetization M_{zfc} have been measured as a function of the applied field and temperature by a SQUID magnetometer in dc magnetic field perpendicularly to $a-b$ plane. We have performed the measurements of relaxation of M_{zfc} at the same level of diamagnetic susceptibility P in various sets of temperature and field.

We have measured simply dP/dt as the penetration rate of vortices into the sample at constant level of $P \sim 0.5$. Fig.1 shows dP/dt versus reciprocal magnetic field $1/H$ in two temperature ranges. These plots give two sets of convergent straight liens intercepting at $H_0 = 0.56$ kG and $1/\tau_0 = 3.0 \times 10^7 s^{-1}$ in high temperature range above 35K (a) and at H_0 =6.1 kG and $1/\tau_0$ =0.18 s^{-1} in low temperature range below 14K (b). In the temperature range 14K $< T <$ 30 K, nonlinear relation is obtained as shown in Fig. 1(a). It suggests that a crossover region exists between two vortex states characterized by two relaxation time τ_0 to have extremely different value from each other. Very similar results are obtained with over-doped crystals.

The function $g(T)$ is determined from the plot

[1] E-mail: UEHARA.Mitsuru@nims.go.jp

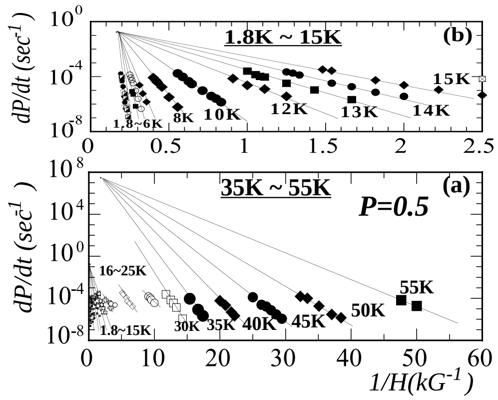

Fig. 1. Penetration rate of vortices dP/dt in optimally doped BSCCO as a function of $1/H$ for P 0.5 in two temperature ranges (a) and (b).

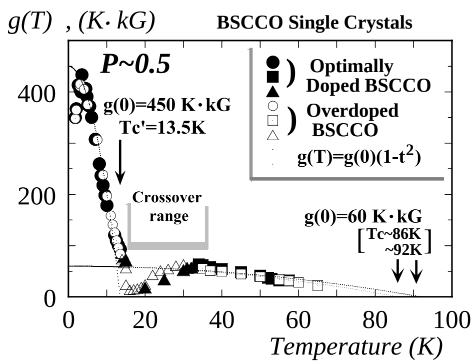

Fig. 2. Temperature dependence of $g(t)$. Decrease of $g(T)$ with decreasing temperature at low temperature come to the crossover from thermal process to quantum tunneling of vortices. Solid lines show the temperature variation of the function $g(t) = g(0)(1 - (T/T_c)^2)$.

of dP/dt versus $1/H$ at various temperatures and then given by $g(T) = -T \cdot dln(\tau/\tau_0)/d(1/H)$. Fig. 2 shows the temperature variation of $g(T)$ for two samples of over-doped and optimally doped crystals for $P \sim 0.5$. It is obvious that a new phase exists in the vortex solid region at low temperature. We have compared the obtained data points to the trial function $g(t) = g(0)(1 - t^2)$ for low and high temperature phases. Where t is the normalized critical temperature corresponding to T_c and T_c' =13.5K for low temperature phase, obtained as a fitting parameter as shown in Fig. 2. We have also found that the values $g(T)$ abruptly decrease below 3K for both samples. This is attributed to the quantum tunneling of vortices as already observed in many systems [1,2].

This new phase in the vortex solid region at low temperature is also directly confirmed by the ac susceptibility measurements. Fig.3 shows the imaginary component of the ac susceptibility χ'' of optimally doped crystal as a function of temperature (a) and frequency (b). Measurements have been performed at remanent states in various frequency and amplitude of the ac field, in the range between 0.05Hz and 1000 Hz and 10 mG to 5.0 G [4].

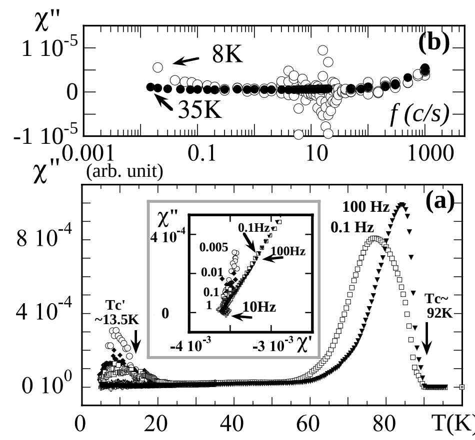

Fig. 3. χ'' of optimally doped BSCCO as a function of temperature (a) and frequency (b). The inset shows χ' versus χ'' plot.

Dissipation peaks at low temperature can be observed only in low frequency range below 1 Hz. A new branch in χ' versus χ'' plot appears at low temperature and in low frequency range as shown in the inset on Fig. 3. It is interesting to note that the values of χ' and χ'' are scattered as like chaotic noise in the range around 10Hz coincide with an attempt frequency $1/\tau_0$ at low temperature below T_c'.

Similar phase transitions in the vortex solid region at low temperatures are observed in other systems [5]. This extreme long relaxation behavior shoud be considered to the general nature in disordered (complex) systems.

References

[1] M. Uehara, B. Barbara, J. Phys. I France **3** (1993) 863.

[2] M. Uehara, T. Numazawa, T. Hirano, B. Barbara, Physica C **235-240** (1994) 2905.

[3] T. Mochiku, K. Hirata, K. Kadowaki, Physica C**235-240** (1994) 523.

[4] S. Nimori, M. Uehara, T. Mochiku, T. Numazawa (these proceedings).

[5] M. Uehara et al., to be published.