Vortex phase diagrams of $YBa_2Cu_4O_8$ in $H \parallel c$ and $H \parallel b$

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Abstract

Vortex phase diagram of $YBa_2Cu_4O_8$ has been investigated by means of the AC susceptibility and the DC magnetization. Phase diagram in $H \parallel c$ is very different from Bi2212 and Y123 because the onset field of the magnetization peak increases rapidly as T decreases at temperatures below 40 K. The AC susceptibility and the DC magnetization measurements in $H \parallel b$ reveal that the irreversibility line is almost independent of the applied field (at $\sim$ 40 K). We argue that there must be an additional pinning mechanism in $YBa_2Cu_4O_8$ at temperatures below 40 K compared to Bi2212 and Y123. A possible candidate for pinning centers is a spin density wave which was recently predicted by our group.

Key words: Vortex; Phase diagram; $YBa_2Cu_4O_8$; Single Crystal

1. Introduction

The mixed state of high-T_c cuprates has a fertile feature of vortex phase diagram. So far, the vortex phase diagram has been mainly investigated on $YBa_2Cu_3O_{7-\delta}$ (Y123) [1] and $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212) [2]. There exist the vortex glass and the lattice (or Bragg glass) in vortex solid phase, and the vortex liquid above the melting line. In the preceeding researches, however, the applied field direction for invesitigating the vortex phase diagram is restricted to the c axis. $YBa_2Cu_4O_8$ has an anisotropy parameter $\gamma = 15$ [3]. It is interesting to investigate the vortex phase diagram of $YBa_2Cu_4O_8$ whose anisotropy takes a middle position between $\gamma = 7$ of Y123 and $\gamma = 200$ of Bi2212.

In this paper, we report vortex phase diagrams of $YBa_2Cu_4O_8$ in $H \parallel c$ and $H \parallel b$ investigated by means of the AC susceptibility and the DC magnetization.

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2. Experimental

The Y124 single crystals were grown by a self-flux method under a high-pressure gas mixture of 80% Ar-20% O_2. The starting mixture in a Y_2O_3 crucible was heated at 1140°C for 1 h under 2000 atm and cooled down to 1040°C in 2 days [4]. Samples are YD#1 ($0.3 \times 0.25 \times 0.05$ mm^3, $\sim 20\mu$g) and YD#5 ($\sim 300\mu$g).

The DC magnetization and the AC suseptibility in these samples were measured using a SQUID magnetometer (Quantum Design MPMS-XL).

3. Results and Discussion

As shown in Fig. 1, the melting line is determined by the vortex lattice softening phenomenon in the AC susceptibility. The magnetization curves showed a peak effect as seen in the inset of Fig. 1. In Fig. 1, we also show the peak lines of YD#1 in $H \parallel c$. Peak effect of the curve was reported for Y123 and Bi2212 [1,2]. However, the peak lines of Fig. 1 are quite different from Y123 and Bi2212 because the peak field of YD#1 increases as T decreases. The peak onset line increases rapidly as T decreases from 40 K. We consider that

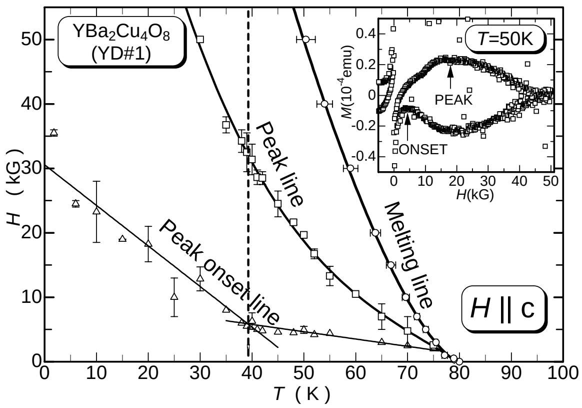

Fig. 1. Vortex phase diagram of $H \parallel c$: the melting line, the peak line, the peak onset line. Inset of the magnetization curve of $YBa_2Cu_4O_8$ at 50 K. Arrows indicate the peak onset and the peak field.

the peak onset point indicates the phase boundary between the vortex lattice (or Bragg glass) and the disordered vortex solid. As discussed by Giamarchi and Le Doussal [5], the disorder transition line can be estimated by using a Lindemann criterion. The disordering transition line in Y123 is well explained by $B_{dis}(T) \simeq B_{dis}(0)(T^s_{dp}/T)^{10/3} \exp[(2c/3)(T/T^s_{dp})^3]$ in the temperature range above the single vortex depinning temperature T^s_{dp} (c is constant of order unity). Since the peak lines of Fig. 1 are extremely different from this theory, we consider that there must be additional pinning sources in $YBa_2Cu_4O_8$.

In Fig. 2(a), we show the AC susceptibility measurements at different fields in $H \parallel b$. M'_{ac} shows a rather linear temperature dependence at higher temperatures while there is a break point at a lower temperature. The break point was not observed in the AC susceptibility of $YBa_2Cu_4O_8$ in $H \parallel c$. As shown in Fig. 2(b), we determine the irreversibility temperature from the magnetization hysteresis with respect to temperature and show the irreversibility line in Fig. 2(c). As seen in the figure, it is remarkable to note that the midpoint of M'_{ac} follows the irreversibility line excellently. The field-independent feature of the irreversibility line near 40 K suggests that the vortex pinning becomes strong at temperatures below the irreversibility line. In Fig. 2(c), we also show the melting line determined by the onset of the AC susceptibility and the break point in M'_{ac} in $H \parallel b$. The break point is also independent of the applied field at ~ 30 K.

In conclusion, we have obtained vortex phase diagrams of $YBa_2Cu_4O_8$ in $H \parallel c$ as well as $H \parallel b$. The phase diagram in $H \parallel c$ is not easily understood from the difference in the anisotropies in Y123 and Bi2212. We argue that there must be an additional pinning mechanism in $YBa_2Cu_4O_8$ at temperatures below 40 K. A possible candidate for pinning centers is a spin

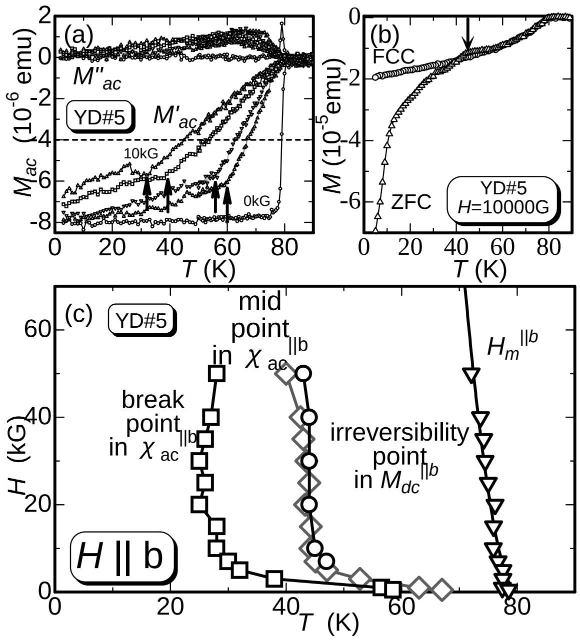

Fig. 2. (a) AC susceptibility of $H \parallel b$: 10 kG, 7 kG, 3 kG, 1 kG, 0 kG. Dashed line is a middle point at -8×10^{-6}emu. Arrows indicate the break points. (b) DC magnetization of $H \parallel b$ at 10000 G. The arrow indicates the irreversibility point. (c) Vortex phase diagram of $YBa_2Cu_4O_8$ in $H \parallel b$: the melting line $H^{\parallel b}_m$, the irreversibility line, the middle points, the break points.

density wave below 40 K which is recently predicted by our group [6].

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