Anomalies in the Temperature Dependence of the Local Magnetization in $YBa_2Cu_3O_{7-\delta}$ and $Nd_{1.85}Ce_{0.15}CuO_{4-\delta}$ Crystals

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Local magnetic measurements as a function of temperature ($m_H(T)$) in $Nd_{1.85}Ce_{0.15}CuO_{4-d}$ (NCCO) and untwinned $YBa_2Cu_3O_{7-\delta}$ (YBCO) crystals reveal an abrupt increase in the local magnetization at a field dependent temperature, in a certain field range. Both crystals also exhibit a pronounced kink in their local magnetization vs field ($m_T(H)$) curves. However, while in YBCO the anomalies in $m_T(H)$ and $m_H(T)$ curves occur along the same line in the field-temperature plane, in NCCO the (B,T) locations of the anomalies do not coincide. In both crystals the anomalies in $m_T(H)$ are identified as signifying vortex solid-solid disorder induced transition. However, we show that the anomalies in $m_H(T)$, although associated with the vortex solid-solid transition, do not necessarily indicate the location of the transition.

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1. INTRODUCTION

Two distinct vortex solid phases, characterized as quasi-ordered and highly disordered vortex solids, have been identified in $Bi_2Sr_2CaCu_2O_{8+\delta}$ (BSCCO),[1] $Nd_{1.85}Ce_{0.15}CuO_{4-d}$ (NCCO),[2] and untwinned $YBa_2Cu_3O_{7-\delta}$ (YBCO) crystals.[3,4] In magnetization *vs* field ($m_T(H)$) measurements, this vortex phase transition is indicated by a sharp anomalous feature (onset[1,2] or a kink[3]) associated with the second magnetization peak. The line $B_{ss}(T)$ describing the location of these anomalies in the field-temperature phase diagram divides the vortex solid phase into two regions characterized by weak and strong pinning. It is expected that by sweeping the temperature at a

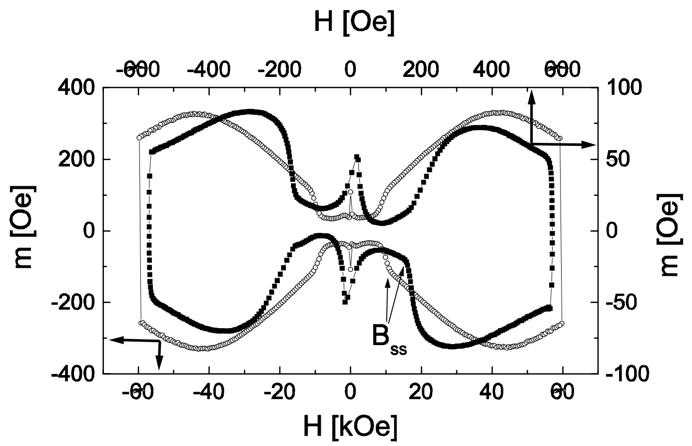

Fig. 1. Local magnetization $m_T(H)$ for $YBa_2Cu_3O_{7-\delta}$ at T = 55 K (open circles) and $Nd_{1.85}Ce_{0.15}CuO_{4-d}$ at T= 17 K (solid squares). The arrows indicate the vortex solid-solid transition field B_{ss}.

constant field, the magnetization $m_H(T)$ will also show some anomaly on crossing the transition line $B_{ss}(T)$. We have carried out measurements of $m_T(H)$ and $m_H(T)$ in two HTS crystals: NCCO and untwinned YBCO. In both crystals $m_H(T)$ reveals an abrupt increase in the local magnetization at a field-dependent temperature $T_k(B)$. However, while in YBCO $T_k(B)$ overlaps with $B_{ss}(T)$ as expected, in NCCO $T_k(B)$ lies above the transition line $B_{ss}(T)$. In this paper we describe these results and explain the discrepancy found in NCCO.

2. EXPERIMENTAL

The transition temperatures of the 0.5 x 0.3 x 0.02 mm^3 untwinned YBCO crystal[5] and the 1.2 x 0.35 x 0.02 mm^3 NCCO crystal[6] are 93 and 23 K, respectively. An array of 11 Hall sensors[7] is in direct contact with the surface of the crystal. The active area of each sensor was 10 x 10 μm^2, separated by 10 μm.

Figure 1 shows typical $m_T(H)$ data for YBCO (open circles) and NCCO (solid squares) at 55 K and 17 K, respectively. Both crystals exhibit a pronounced peak effect associated with the vortex solid-solid phase transition. The transition fields $B_{ss}(T)$ (marked by arrows in Figure 1) are plotted in Figure 2 (solid symbols) for YBCO and NCCO, respectively.[8]

Figure 3 and the inset to this figure show typical $m_H(T)$ data for NCCO

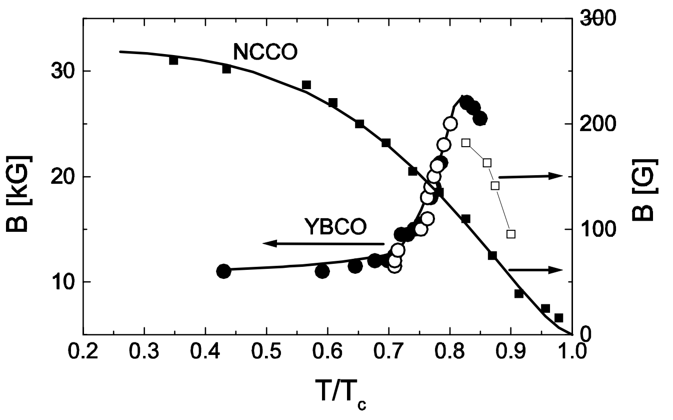

Fig. 2. Temperature dependence of the vortex solid-solid transition field B_{ss} for $YBa_2Cu_3O_{7-\delta}$ (circles) and $Nd_{1.85}Ce_{0.15}CuO_{4-d}$ (squares). Solid and open symbols indicate field values derived from m_T(H) and m_H(T), respectively.

and YBCO, respectively. Each figure exhibits several curves at the indicated fields. Note the abrupt increase in the local magnetization at field-dependent temperatures $T_k(B)$ marked by arrows. These anomalies are observed in a limited field range: 11 kOe < H < 25 kOe for YBCO and H < 270 Oe for NCCO. The temperatures $T_k(B)$ are plotted in Figure 2 (open symbols) for YBCO and NCCO, respectively. Apparently, for YBCO the line $T_k(B)$ defined by the anomalies in $m_H(T)$ coincide with the line $B_{ss}(T)$ defined by the anomalies in $m_T(H)$. However, these lines are markedly different for NCCO.

3. DISCUSSION

As it is clear from Figures 2 and 3, the local magnetization *vs* temperature in YBCO exhibits the abrupt increase only in the field range, corresponding to the increasing branch of $B_{ss}(T)$. Crossing this branch by raising temperature at a constant field corresponds to a phase transition from a disordered vortex state with relatively high persistent current to a quasi-ordered state with low current. This phase transition is accompanied by a burst of flux lines penetrating the sample; this is manifested by an abrupt increase in the magnetization. For fields larger than 25 kG or smaller than 11 kG,

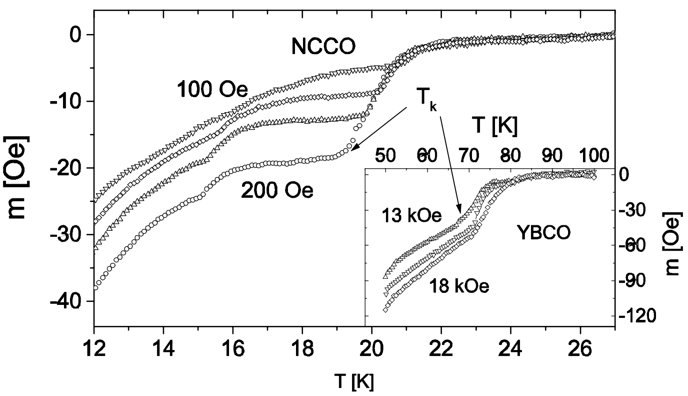

Fig. 3. Typical m_H(T) data for $Nd_{1.85}Ce_{0.15}CuO_{4-d}$ at H = 100,150,175, and 200 Oe and $YBa_2Cu_3O_{7-\delta}$ at H = 13, 16, and 18 kOe (inset). The transition temperatures T_k are marked by arrows.

raising temperature does not lead to crossing of the $B_{ss}(T)$ line and thus no sign of a phase transition is observed in $m_H(T)$ measurements.

In NCCO, B_{ss} decreases with temperature.[2,3] Thus, crossing the $B_{ss}(T)$ line by raising temperature at a constant field corresponds to a phase transition from a quasi-ordered state with low persistent current to a disordered vortex state with relatively high current. In this case, flux should be expelled from the sample, i.e. move in opposite direction to the Lorentz force. Since this process is inhibited, the induction profile within the sample, and consequently the persistent current j, are "frozen", and the magnetization $m_H(T)$ is constant, similarly to what is obtained in standard field-cooled measurements. Only when a high enough temperature is reached at which the persistent current $j_T(H)$ is smaller than the frozen value of $j_H(T)$, flux can enter the sample. This is manifested by a change in the slope of $m_H(T)$. This explanation is further illustrated in Figure 4 in which $m_T(H)$ curves (solid circles) are mapped onto the $m_H(T)$ curve (open squares) in NCCO. The two curves coincide up to the transition temperature after which $m_H(T)$ freezes and lies above the data mapped from $m_T(H)$. Only when $m_H(T) = m_T(H)$ flux can enter and the two data sets coincide again. We conclude that although the anomalies in $m_H(T)$ are associated with the vortex solid-solid phase transition, their location does not necessarily indicate the location of the transition.

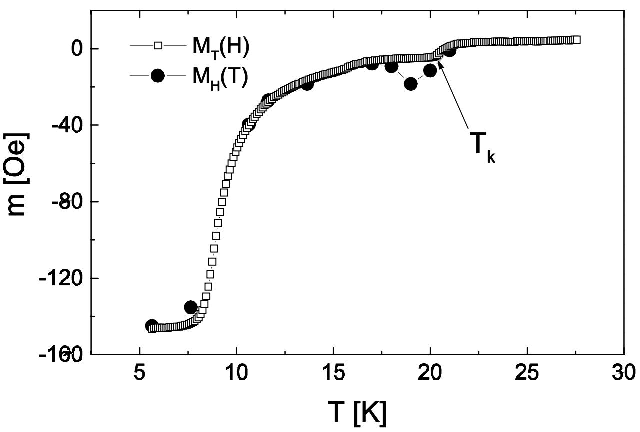

Fig. 4. The magnetization data m_T(H) (solid circles) mapped onto the m_H(T) curve (open circles) in NCCO for H = 150 Oe.

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8. Note that B_{ss} in NCCO is defined as the onset of the second peak (See Ref. 2) whereas in YBCO it is defined as the location of the kink (See Ref. 3).