Local magnetic relaxation in Nd$_{1.65}$Ce$_{0.15}$CuO$_{4.5}$ crystals

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Local magnetic measurements in Nd$_{1.65}$Ce$_{0.15}$CuO$_{4.5}$ crystals show a 'fishtail' anomaly in the magnetization curves together with anomalous relaxation behavior similar to that measured in YBa$_2$Cu$_3$O$_{7-\delta}$ crystals, suggesting a universal flux dynamics in the field range of the fishtail peak.

Magnetic relaxation in high-$T_c$ superconductors is a subject of intensive study [1]. Recently, local magnetic measurements in YBa$_2$Cu$_3$O$_{7-\delta}$ (YBCO) crystals [2] revealed anomalous relaxation behavior in the same field range where the 'fishtail' is observed. In this article we present local magnetic relaxation data in Nd$_{1.65}$Ce$_{0.15}$CuO$_{4.5}$ (NCCO) crystal, demonstrating similar features.

Measurements were performed on a 1.2×0.35×0.02 mm$^3$ NCCO crystal ($T_c \approx 28$ K), using an array of 11 GaAs/AlGaAs Hall sensors with 10×10 $\mu$m$^2$ active area and sensitivity better than 0.1 G. The probes detect the component $B_z$ of the field normal to the surface of the crystal. Temperature stability and resolution were better than 0.01 K. After zero-field-cooling (zfc) the sample from above $T_c$ to the measurement temperature $T$ we measured the full hysteresis loops for all the probes with field parallel to the c-axis of the crystal. The first field for full penetration $H'$ was measured directly by the probe at the center of the sample. After repeating the zfc process, a dc field $H$ was applied parallel to the c-axis and the local induction $B_z$ was measured at different locations as a function of time. These relaxation measurements were repeated after the field was increased by a step $\Delta H > 2H'$ up to the irreversibility field $H_{irr}$. The inset to Figure 1 shows typical hysteresis loops, $m_z = B_z$ vs $H$ at $T = 13$ K for probes located at 13, 33, 53, and 73 $\mu$m.

![Figure 1. Field dependence of the current $j$ at different times (squares) and of the exponent $\mu$ (circles). Inset: Magnetization loops for different probes.](image-url)
from the center of the crystal. Each probe exhibits a clear fishtail behavior with a maximum width at field $H_p \approx 900$ G. The width of the loop is largest at the center of the crystal and decreases towards the edges, as expected from the critical-state model [3].

In Figure 1 we show the time evolution of the current between $t_i = 8$ s and $t_f = 2750$ s, as a function of the applied field. The large relative relaxation of the current, $\Delta j/j$, during the time window of the measurement implies that the dynamics strongly affects the shape of $j(B)$ and the location of the peak. Knowledge of the time and spatial induction distributions enables direct, model independent determination of the activation energy $U(B, j)$ associated with the flux creep [4]: By using the equation for flux motion, $\partial B / \partial t = - \nabla \times (B \times v)$, where the effective vortex velocity $v$ is proportional to $\exp(-U/kT)$, $U$ is derived directly from the raw data. Typical $U$ vs. $j$ data, at 13 K and fields between 240 G and 2900 G, are shown in Figure 2.

In order to quantify the dependence of $U$ on $j$ we use the prediction of the collective creep theory [5] (assuming $j \ll j_c$):

$$U(B, j) = U_c(B)(j/j_c)^\mu$$  \hspace{1cm} (1)

where the positive critical exponent $\mu$ depends on the specific pinning regime. The circles in Figure 1 describe the field dependence of the exponent $\mu$ obtained by fitting Eq. (1) to the experimental data. At low fields $\mu$ changes from about 0.2 to the highest value of more than 1 in agreement with the collective creep theory - these values correspond to the crossover from the single vortex creep regime to the bundle regime [5]. However, at higher fields $\mu$ decreases down to values less than 0.2 and it would imply an inconceivable crossover to a single vortex regime ($\mu = 1/7$) which is expected only for low fields and high values of $j$. Thus, the $\mu$ values at high fields are inconsistent with the collective creep theory. As argued by Abulafia et al. in their measurements of YBCO [2], it is possible to explain this behavior as indicating an elastic-to-plastic creep crossover.

As compared to YBCO, NCCO exhibits smaller $T_c$, larger anisotropy [6], and lower field range for the fishtail anomaly. Moreover, the origin of the fishtail in NCCO and YBCO may be different [7]. Yet, in both cases, similar anomaly in the relaxation is observed in the field range of the fishtail. The connection between these two phenomena requires further investigation.

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REFERENCES