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Sublimation and Hysteretic Transition of the Vortex-Lattice in $Bi_2Sr_2CaCu_2O_8$

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Multiterminal measurements have been made on $Bi_2Sr_2CaCu_2O_8$ crystals to investigate the vortex dimensionality and hysteresis at the fields and temperatures where the first-order transition takes place in the vortex-lattice. A sharp hysteretic transition is seen in transport properties. The data indicate that both resistivity components disappear concurrently, and that the melting and *c*-axis decoupling transitions occur simultaneously at a sublimation transition of the vortex lattice.

The detailed mechanism of the first-order transition (FOT) in high T_c superconductors is yet to be clarified. Some reports [1,2] claim that there are two separate transitions: melting of the vortex lattice into a liquid of vortex lines, and decoupling of the liquid lines into vortex pancakes. Several other studies [3-6] suggest, in contrast, that the two occur together. We have set out in this work to elucidate the nature of the FOT using flux transformer geometry [7] measurements. The data presented below strongly indicate that the two transitions occur simultaneously [8], namely the solid vortex sublimates directly into a gas of vortex pancakes.

$Bi_2Sr_2CaCu_2O_8$ (BSCCO) crystals were cut and cleaved to typical dimensions of 2mm × 300μm × 10μm. Four wires were connected to each of the two cleaved surfaces using silver epoxy annealed at 600°C for 5 minutes (see inset of Fig. 2 for contacts schematic). An ac transport current (72.8 Hz) was applied to the crystal while the resultant voltage was measured using lock-in amplifier techniques. Magnetic field was applied parallel to the crystalline c-axis, and transport measurements were done while sweeping temperature or applied magnetic field.

Figure 1 shows an example of a field sweep for both increasing and decreasing field. A sharp drop in primary voltage $V_p=V_{23}(I_{23})$ (see inset to Fig. 2 for the contact configuration) accompanied by a hysteresis at the top of the transition can be seen. This transition has previously been shown to correspond to the magnetic FOT in BSCCO [9]. The hysteresis (also seen in Fig. 2) is analogous to the one seen in YBCO [10].

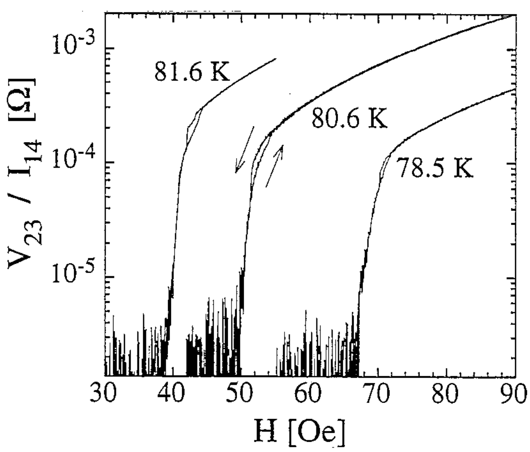

Figure 1. V_{23}/I_{14} at three temperatures as a function of applied field (I = 2 mA for 81.6K and 78.5K curves, and 1.2 mA for the 80.6K curve).

Figure 2 shows both primary V_p and secondary V_s voltages as temperature is changed. The secondary voltage exhibits a remarkable re-entrant behavior. It can be fully explained by current redistribution effects which are controlled by the crystal geometry and temperature dependence of the resistive anisotropy [8].

However the most striking feature of Fig. 2 is the simultaneous decrease of V_p and V_s into the noise at the FOT. The correspondence of the two voltages at the transition means that the vortex lines are

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correlated along the field direction over a lengthscale longer than the sample thickness (10μm). The fact that just above the transition the voltages separate (see Fig. 3) shows that the correlation length drops abruptly above the transition to significantly below the sample thickness. When calculating the resistivity ratios, ρ_{ab}/ρ_c, according to the method of Busch [7] no other marked features which might be attributed to a separate decoupling transition are found. Thus the data suggests that the vortices undergo a sublimation transition transforming from a vortex line solid directly into a vortex pancake gas.

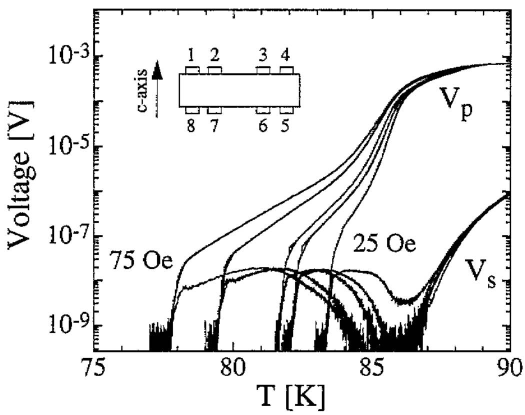

Figure 2. $V_{23}(I_{14})$ and $V_{23}(I_{85})$ as a function of temperature for fields of 25, 35, 40, 60 and 75 Oe, and I = 2 mA. The inset shows the contact configuration.

Figure 3 shows an expanded view of the transition measured with different currents. The current dependence suggests that as the current is lowered the primary and secondary voltages coincide exactly below the transition. The abrupt separation of V_p from V_s above the transition is also seen. Strong nonlinearity below the transition and weak nonlinearity above the transition are observed.

In conclusion, the transport data presented strongly suggests that the vortex lattice sublimates into a vortex gas at the FOT. Hysteresis is apparent in the transition as function of both field and temperature and is asymmetric in form.

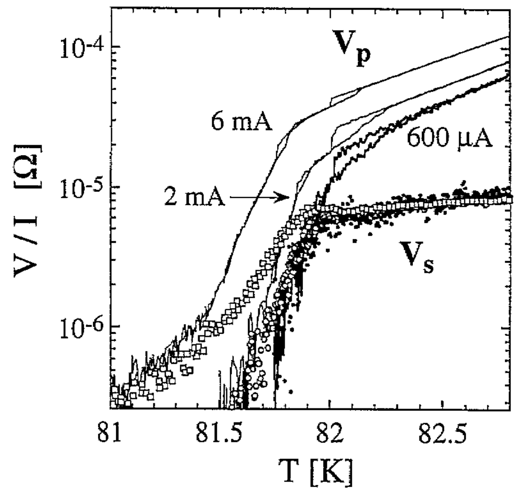

Figure 3. Apparent primary and secondary resistances, V_p/I and V_s/I, at 40 Oe at different currents of 600 μA, 2 mA, and 6 mA. V_p data are shown by solid curves (thick line - 600 μA), and V_s by symbols (□ - 6 mA, o - 2 mA, • - 600 μA).

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