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Vortex lattice melting and irreversibility temperatures in $YBa_2Cu_3O_7$

Abstract

The dc I-V characteristic of polycrystalline YBa2Cu3O7-X high temperature superconductors (HTSC) is measured near the transition temperature (Tc). A difference in voltage was found for forward and reverse current directions near Tc. The measured dc voltage showed increased noise near Tc which is related to flicker 1/f noise. The experimental results are explained in terms of melting of the vortex lattice and irreversibility temperature which is observed near the superconducting transition in YBa2Cu3O7-x.

Key Words

High-TC superconductors; Vortex lattice melting; 1/f noise.

In a type-II superconducting material quantized flux lines diffuse for applied magnetic field between H_{C1} and H_{C2}. It was predicted that the flux lines form a triangular lattice[1]. Such lattices has been observed experimentally with neutron scattering[2] and Bitter-pattern technique[3]. When the vortex lattice is two dimensional there can be a melting transition. The vortex lattice melting was observed from the resonance shift of a high-Q ($Q=2\times10^5$) silicon oscillator at 3 kHz in In/InO_x[4]. The high temperature superconductors (HTSC) such as $YBa_2Cu_3O_7$ show strong anisotropy of physical properties[5]. This indicates low dimensional nature of superconductivity in HTSC. Therefore similar vortex lattice melting is expected in HTSC. Magnetization measurements[6] and electrical resistance measurement in magnetic field[7] show signature of vortex lattice melting. The vortex lattice melting has also been studied theoretically[8,9]. In this paper dc I-V characteristic of polycrystalline YBa2Cu3O7-X near the transition temperature (Tc) is reported. A difference in voltage was found for forward and reverse current directions near Tc. The measured dc voltage also showed increased 1/f noise near Tc. The experimental data are explained in terms of melting of the vortex lattice and irreversibility temperature.

Electrical resistance measurement on polycrystalline $YBa_2Cu_3O_7$ was carried by an automated d.c. four terminal technique[10]. This setup is built around a closed cycle refrigerator. The $YBa_2Cu_3O_7$ sample was in the form of rectangular bar having dimension $\sim 1\times2\times11$ mm^3. The sample was characterized as as been discussed elsewhere[11]. The electrical contacts made using silver paste had a resistance of 30 Ohms for the two current leads. The electrical resistance of the sample at 100 K was nearly 0.1 Ohms. The current was varied from 1 mA to 100 mA in steps using a Keithley model 224/2243 programmable current source. The dc voltage was measured using a Keithley model 182 sensitive digital voltmeter. A calibrated type D silicon diode thermometer was used in conjunction with a Leybold model LTC60 temperature controller to control and monitor the temperature of the sample site. The calibrated diode has a standard measurement accuracy of about 1 percent. The measurement was done as the sample was warmed from about 70 K. The HTSC has a superconducting transition (T_c) of 90 K and a width of about 2 K. At each temperature the measurement was done with 1mA, 5 mA, 10 mA, 50 mA and 100 mA of current. For each current value, first the positive polarity of current was given and the voltage was measured. Then the current was made negative with the same value and the voltage was measured again. For each current value 25 voltage readings were averaged to obtain average voltage and its standard deviation (V_{sd}). A systematic difference in voltage was found in the measurement. The difference in voltage which is attributed as due to vortex lattice melting (V_l) is defined as follows:

$$V_l = |V_+| - |V_-| - V_{th} \quad (1)$$

where V_+ and V_- corresponds to positive and negative current, respectively. The stray thermal voltage (V_{th}) was estimated above the T_C. Figure 1 shows the temperature dependence of V_{th} for various current values. It is sen that there is a feature at 83 K which corresponds to the vortex lattice melting. The standard deviations of the measured dc voltage values (V_{sd}) showed the statistics of flicker 1/f noise[12,13]. It was found that low noise voltages occur with high probability whereas high noise voltages occur with low probability as is expected for 1/f noise. At each temperature V_{sd} was averaged further for the ten current values (±1 mA to ±100 mA) to obtain $<V_{sd}>$. Figure 2 shows the temperature dependence of $<V_{sd}>$. It is seen that there is a the peak at 83 K in the 1/f noise can be attributed as due to the vortex lattice melting. Another peak at 89 K in the temperature dependence of $<V_{sd}>$ is also observed which can be due to the irreversibility transition temperature. It is known that near a phase transition there is fluctuation of order parameter and peak in $<V_{sd}>$ is expected at the transition[14]. Therefore, it is concluded that vortex lattice melting and irreversibility temperature appear as two independent transitions.

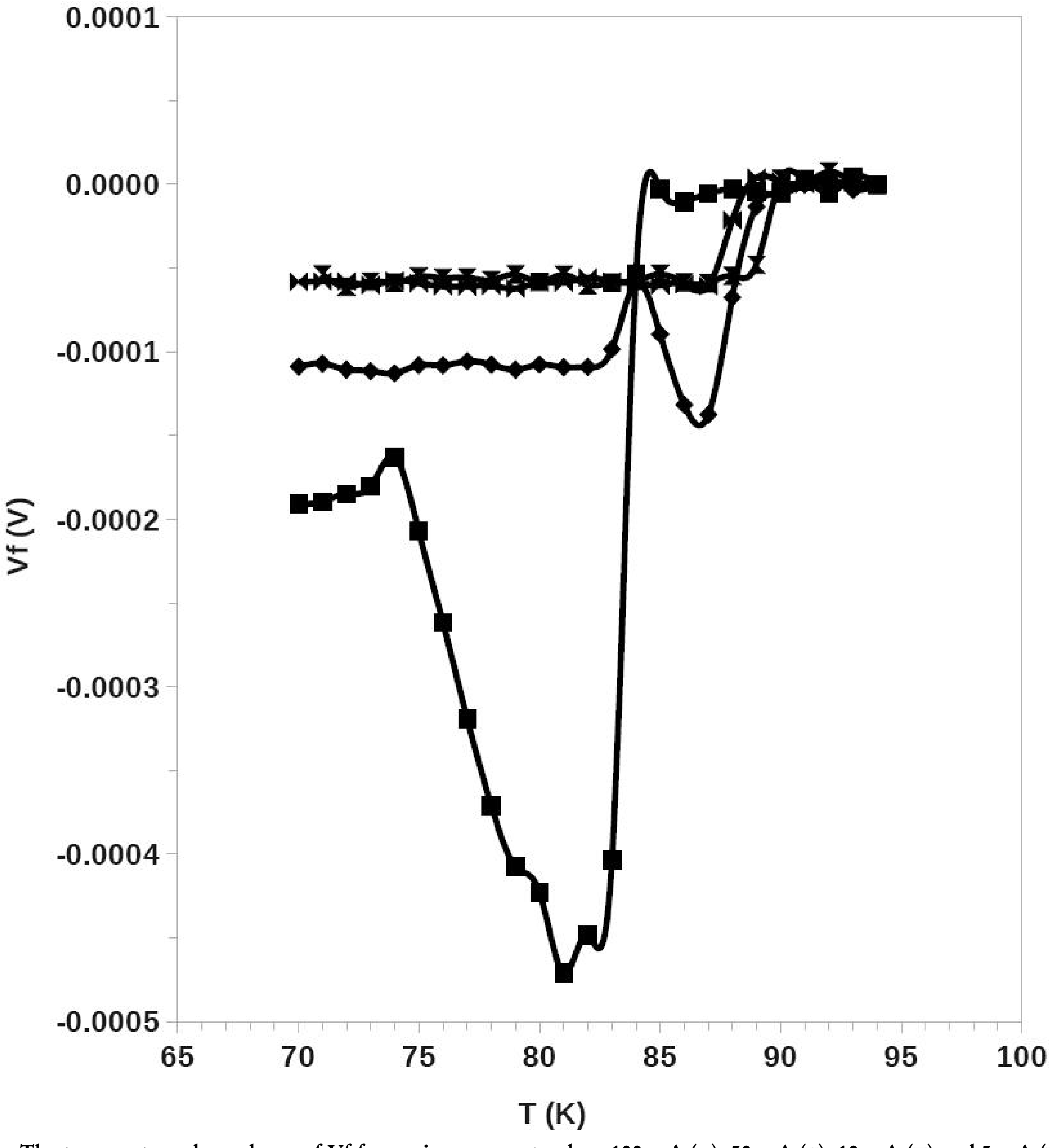

Figure 1 : The temperature dependence of Vf for various current values 100 mA (■), 50 mA (♦), 10 mA (⋈) and 5 mA (⧗). The solid lines through the data is to guide the eye.

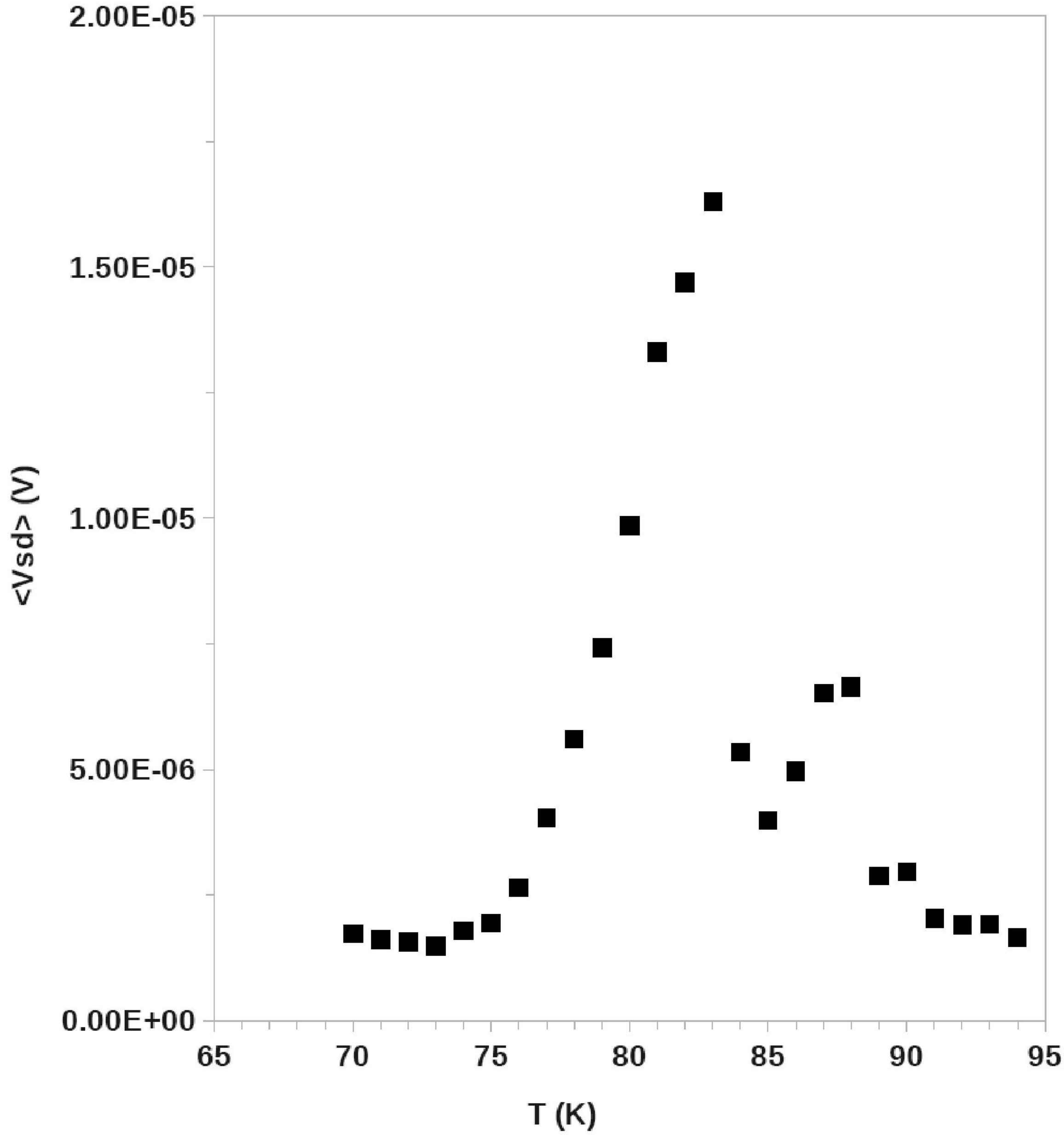

Figure 2 : The <Vsd> as a function of temperature. The increased noise giving rise to peaks at 83 K and 88 K corresponds to vortex lattice melting transition and irreversibility transition temperatures, respectively.

In conclusion, dc I-V measurements have been carried out on YBa2Cu3O7-x in the temperature range 70-95 K. Signature of vortex lattice melting has been observed in the dc I-V characteristic. The temperature dependence of 1/f noise shows a peaks at 83 K and 88 K which corresponds to vortex lattice melting transition and irreversibility transition temperatures, respectively.

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