# Scaling Behavior of the C-axis $E$-$J$ Characteristics for Bi:2212 Single Crystal

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**Abstract**

The c-axis isothermal $E$-$J$ curves of Bi:2212 single crystal in different fields have been investigated. All of the isothermal $E$-$J$ curves under the same magnetic field collapse onto two curves, suggesting the occurrence of a vortex-glass transition. The relevant critical exponents are extracted. When field exceeds 0.1T, crossover from 3D to 2D appears.

*Key words:* Scaling; Vortex Glass;$I$-$V$ curves

## 1. Introduction

It is now well established that in high temperature superconductors (HTS) the mixed states is divided into a vortex liquid phase and a vortex solid. In systems with strong disorder, the solid phase is a vortex glass (VG)[1], while for clean sample, it is an ordered Abirkosov lattice. One of the interesting features of HTS is the scaling of $E$-$J$ curves and many experimental results show strong support to the VG theory [2,3]. In this paper we report the successful scaling of $E$-$J$ curves along c-axis of a Bi2212 single crystal, demonstrating the existence of the c-axis VG transition at well-defined temperatures.

## 2. Experiments

BSCCO-2212 crystals were grown by a large temperature gradient self-flux method. Lithographically patterned gold contact pads were sputtered on opposing faces of a $50\times130\times1\mu$m crystal for 4-point measurements. The sample showed sharp transition at ~87.5K.

The c-axis $I$-$V$ characteristics have been measured at different temperatures for different magnetic fields ($H//$c). A set of those curves measured at 0.04T is shown in Fig. 1.

## 3. Scaling Behavior of Isothermal $E$-$J$ Curves

The dc $E$-$J$ characteristics for a D-dimensional sample should be scaled as

$$E\xi_G^{Z+1} \sim \widetilde{\varepsilon}_{\pm}(J\xi_G^{D-1}). \tag{1}$$

where $\widetilde{\varepsilon}_{\pm}(J\xi_G^{D-1})$ is an appropriate scaling function for temperatures above (+) and below (-) $T_{\rm G}$, $\xi_{\rm G}$ is the coherence length, which diverges at the temperature $T_{\rm G}$, $\xi_{\rm G} \sim |T - T_{\rm G}|^{-\nu}$ and $z$ is the usual dynamic critical exponent.

The scaling function, $\widetilde{\varepsilon}_{+}(x)$, goes to a constant as $x{\equiv}J/J_0{\to}0$, implying a linear resistivity, which vanishes as

$$\rho_l \sim (T - T_G)^{\nu(z+2-D)}. \tag{2}$$

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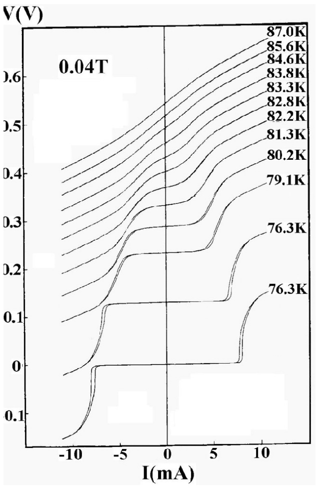


Fig. 1. A set of $I$-$V$ curves measured in 0.04T field along the c-direction.

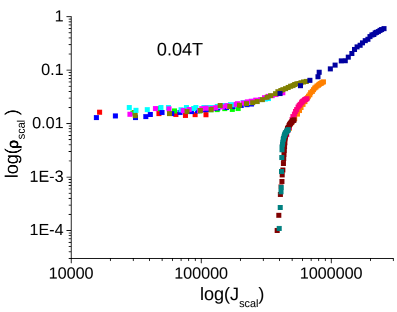


Fig. 2. Scaling of the $E$-$J$ isotherms at $H_{//}$=0.04T.

The scaling function, $\widetilde{\varepsilon}_{-}(x)$ vanish as $x \rightarrow 0$, so that $\rho_l$=0.

The above scaling formulae are universal and if VG melting transition occurs with a current along c-axis at a defined temperature all isothermal $E$-$J$ curves of different temperatures for a magnetic field should be scaled appropriately onto two different curvature lines. Considering that there is hysteresis in some of the $E$-$J$ curves, which is actually the signature of Josephson behavior, only the decreasing current branch is used for the scaling. Based on the equation (1), we scale all data by the two functions: the scaled resistance $\rho_{\mathrm{scale}}=E/J|T-T_{\mathrm{G}}|^{\nu(z+2-D)}$ and the scaled current density $J_{\mathrm{scale}}=J/|T-T_{\mathrm{G}}|^{\nu(D-1)}$. The measured curves showing in Fig. 1 are then scaled accordingly and re-plotted in Fig. 2. It can be seen clearly that all of the $E$-$J$ isothermal curves collapse nicely onto two positive ($T>T_{\mathrm{G}}$) and negative ($T<T_{\mathrm{G}}$) curvature curves.

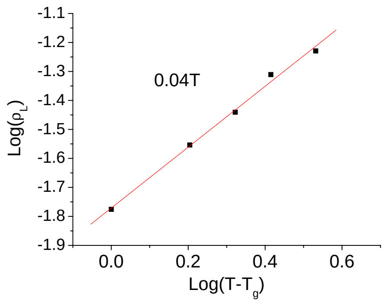


Fig. 3. The relation between the small current resistivity and the temperature ($T$-$T_{\mathrm{G}}$).

In order to exam the equation (2), we also analyze the temperature dependence of the linear resistivity with small currents. Fig. 3 displays the relation between $\rho_{\mathrm{L}}$ and $T$-$T_{\mathrm{G}}$ in 0.04T magnet field.

The extracted scaling parameters (VG transition temperature $T_G$, dynamic critical exponent $z$ and critical exponent $\nu$) for 0.04T are 81.2K, 5.00, 0.25 respectively, and those for 0.1T are 77.5K, 5.3, 0.34. For 0.04T this system belongs to 3D system. However, for 0.1T the system dimension becomes 2.5. This suggests that the higher the magnetic fields, the stronger the interaction between vortex lines and the softer the vortex line, leading to a crossover from 3D to 2D behavior above the field between 0.04T and 0.1T.

## 4. Conclusion

We have observed the c-axis vortex-glass transition in Bi2212 single crystal. After proper scaling, all isothermal $E$-$J$ curves collapse onto two curves. At low magnetic fields the system has 3D behavior and the 2D behavior shows up when the external magnetic fields beyond 0.1T.

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