Thermally activated flux flow in FeSe$_{0.5}$Te$_{0.5}$ superconducting single crystal

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Abstract. The current–voltage ($J$-$E$) isotherms of single crystal FeSe$_{0.5}$Te$_{0.5}$ sample have been measured at several temperatures near the transition temperature ($T_c$) and under applied magnetic fields ($H$). A power law ($E \sim J^\beta$) has been used to fit the data and evaluate the activation energy $U_o(T)$ using $\beta = U_o/k_BT$. At low current density ($J \ll J_c$), the initial behaviour is associated with thermally activated flux flow (TAFF) while at $J \gg J_c$ vortex flux flow (FF) behavior is expected. The effects of applied magnetic field on FF and TAFF also been investigated. We found that $U_o(FF)$ was reduced with by about an order of magnitude in magnetic fields as low as ~1.5 Tesla -the reduction in $U_o(TAFF)$ is even faster than in $U_o(FF)$- hence reflecting the low pinning nature (defects, vacancies etc.) of FeSe$_{0.5}$Te$_{0.5}$ superconductor.

1. Introduction
The vanishing electrical resistance and diamagnetism below $T_c$ is one of the main characteristics of superconductor. In superconductors, current transports occur with no energy loss for the currents lower than the critical current ($J_c$). However, it also depends on the temperature and the applied magnetic field. But in type-II superconductors, as the applied magnetic field increases above certain critical field $H_{c1}$, the vortex state complicates the picture. The vortex motion activated thermal energy may lead to “flux flow resistance” which could cause the energy dissipation.

Transport studies and dissipative properties in type II superconductors are usually limited to the region near $T_c$. Flux creep and vortex motion close to $T_c$ can be explained using the Kim-Anderson model [1, 2], if the pinning potential was taken into account. Vortex dynamics, the irreversibility line and a vortex glass transition have been studied in high temperature superconductors [1,3-7]. From $(I-V)$ measurements of thin films and single crystals high $T_c$ superconductors several researchers suggested the continuous vortex glasses transition at temperatures below $T_c$. Fisher et al. suggested a scaling behaviour for the $(I-V)$ curves obtained at various temperatures close to $T_c$ [8-10] and Koch et al. [9] showed experimentally the first evidence for the continuous vortex glass transition at temperatures below $T_c$ by scaling the nonlinear $(I-V)$ curves in YBCO thin films. Similar results have been found in YBCO single crystal by Gammel et al. [11]. Sun et al. [4] have suggested a power-law relation as $V = aI^\beta$ to describe the $(I-V)$ curves. Where the exponent $\beta$ is related to the pinning barrier $U_o$. Based on the status of vertices the mixed state in type II superconductor contains different regimes; thermal activated flux flow regime (TAFF), flux creep regime (FC) and flux flow regime (FF) according to status of vortices. Although there is no clear-cut distinction between each regime, the variations of the current density with temperature is used as a guide in this respect [12]. The newly discovered Fe-based superconductors have an intermediate transition temperature where thermal fluctuations are in between
conventional and high Tc superconductors. Hence, it will be interesting to investigate the effects of thermally activated flux flow on various transport properties of these new materials. These properties are strongly influenced by the dynamic behaviour of vortices in the superconductor and can be studied by measuring the current–voltage curves [11,13].

In this paper, we report our (I-V) isotherms of single crystal FeSe0.5Te0.5 near Tc (~14.5K) in the presence of applied magnetic field. We discuss our results in terms of the power law form, then present the variation of the activation energies Uo (pinning potential barrier) with temperature.

2. Experimental Details

High purity (≥99.99 %) elements Fe, Se and Te have been used in 1:0.5:0.5 atomic ratios to prepare FeSe0.5Te0.5. The elements were grinded, pressed and sealed in a quartz tube partially filled with Argon gas. The tube was annealed at 500 °C for 2 hours and then at 1070 °C for 24 hours. The temperature was reduced at a rate of 4°C/h to 700°C and kept for 5 hours, then reduced to 400°C, at kept and annealed 2 hours, then furnace cooled to room temperature. Four-probe (dc) technique was used to measure the current-voltage (I-V) characteristics using Lake Shore 7507 measuring system. Keithley 220 constant current source has been used to supply the current, and the voltage was measured using Keithley 2182 nano-voltmeter. The sample was cooled in a closed cycle cryostat (Advanced Research Systems) and the temperature was controlled using Lake Shore 340 temperature controller.

3. Results and discussions

From x-ray diffraction pattern for FeSe0.5Te0.5 single crystal, the structure of the sample is a tetragonal structure with cell parameters a = 3.797 Å, b = 3.797 Å and c = 5.984 Å. The lattice parameters are agreeing with the published data.

(I-V) isotherms of single crystal FeSe0.5Te0.5 have been measured at two different values of magnetic field B=0T and B=1.5T. Figure 1 (a) and (b) shows a representative (I-V) isotherms of the sample at magnetic field B=0T and B=1.5T respectively. The data is presented on a log-log graph that simplify evaluating the exponent α in the power-law behaviour V = αIβ where α is a constant, β = Uo/kBT and Uo is the pinning barrier [4-6]. The exponent β is calculated from the slope of linear part of the (I-V) isotherms obtained at H=0T and 1.5T and was used to evaluate the activation energies Uo(TAFF) and Uo(FF). The activation energy is essentially the pinning barrier provided by defects and pinning centres in the sample. The results are presented in Figure 2 (a) and (b) as a variation of 1/T for both TAFF and FF regimes at H=0T and H=1.5T. Thermal activated flux flow (TAFF) occurs near 1μV, while flux flow (FF) regime is at much higher voltage. The figures reveal that as the temperature decreases below Tc, Uo continuously increases. The increase in TAFF regime is much faster than in FF regime. In other words, the gradual increase in exponent follow gradual increase in the pinning barrier with decreasing temperature. The exponent β approaches unity (Ohmic behaviour) near Tc. The deviation from Ohmic behaviour occurs at a non-linear temperature Tinf ~ 14.2K, which is about 0.3K below the Tc (~14.5K). The pinning potential at H=1.5T for both cases drops to about one tenth of its initial value obtained at H=0T. Above Tc the exponents β~1.4, for both regimes; which illustrates that the I-V curves are nonlinear material is still not in the normal state. Fluctuations and thermal effects near critical temperature may cause such deviations and pose limitations for Sun et al. model.
Figure 1. Selected (I-V) isotherms for single crystal FeSe$_{0.5}$Te$_{0.5}$ (a) at B = 0T and (b) at B = 1.5T around its corresponding superconducting transition temperature.

Figure 2. The pinning potential $U_o$ obtained for H=0T (a) and for H=1.5T (b) are presented as variations with temperature in both thermally activated flux flow (TAFF) and flux flow (FF) regions.
4. Conclusion

Current-voltage isotherms of the single crystal FeSe$_{0.5}$Te$_{0.5}$ exhibit a power law behaviour in both regimes namely, TAFF and flux flow. The exponents $\beta$ obtained of (from- TAFF and flux flow (FF) regime are found to decreases linearly as $T$ increases. The pinning barrier $U_0$ for TAFF is about 0.85eV and for FF is about 0.11eV. Both energy barriers decrease by about an order of magnitude in 1.5T. These values indicate that the pinning forces are relatively week in FeSe$_{0.5}$Te$_{0.5}$ single crystals.

Acknowledgments

We would like to acknowledge the support of King Fahd University of Petroleum & Minerals for this work. This project has been funded by NSTIP under project number 11-ADV1631-04.

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