Physica B 194–196 (1994) 1887–1888
North-Holland

PHYSICA B

FLUX PINNING AND THE IRREVERSIBILITY LINE IN $Bi_2Sr_2CaCu_2O_8$ SINGLE CRYSTALS

A.A. El-Abbar, J.R. Owers-Bradley, K.J. Maxwell, J. Lees and P.J. King
Department of Physics, University of Nottingham, Nottingham, NG7 2RD, UK.
G. Balakrishnan and D.Mck Paul
Department of Physics, University of Warwick, Coventry, CV4 7AL, UK.

Measurements of the ac-susceptibility have been used to investigate the irreversibility line (IL) for a $Bi_2Sr_2CaCu_2O_8$ single crystal. The activation energy, U_0, determined from the frequency dependence of the ac-susceptibility, can be related to the IL if one employs the model of thermally activated flux creep. This correlation is clearly demonstrated by the observation of a kink in the IL and the existence of two regions in the $U_0(H)$ curve. These results show that for the magnetic field strengths considered in this work, the IL is a depinning line marking a crossover from flux creep to flux flow regimes.

1. INTRODUCTION

The irreversibility line(IL) is one of the many interesting phenomena observed in high temperature superconductors the existence of which indicates the importance of flux line motion in determining transport and magnetic properties. Many investigations have shown that the flux creep in high T_c superconductors is a giant effect compared to low T_c superconductors. These large thermal effects have been attributed to the small pinning energies and high working temperature. In general, introducing more pinning centres results in a shift of the IL to higher temperatures and fields which indicates that the IL is a depinning line arising from thermally activated flux processes.

2. EXPERIMENTAL DETAILS

In this paper flux pinning and the IL have been studied by measuring ac-susceptibility. The measurements were made by using a standard mutual inductance technique. The dc field of up to 1 Tesla was provided by a superconducting solenoid. The $Bi_2Sr_2CaCu_2O_8$ single crystals were grown by the floating zone method using an infrared image furnace. Rods of polycrystalline BSCCO(2212) were zoned at a rate of 0.5 mm/h. When cleaved, the processed rods yielded single crystal platelets with the c-axis perpendicular to the plane of the platelets. The sample crystal chosen for susceptibility measurements had approximate dimensions of $3\times1\times0.1$ mm^3.

3. RESULTS AND DISCUSSION

We measured the temperature dependence of χ'' at various ac-fields strengths ($1\mu T$ - 0.5 mT) and frequencies (10Hz - 10KHz) and dc fields up to 1T. The ac-field direction was parallel to the c-axis and since the sample used in this work is a thin platelet the susceptibility data were corrected for demagnetisation effects using a demagnetising factor of 0.9. From the onset of the deviation in χ'' from zero at the smallest applied field we define the transition temperature, T_c=91.4 K.

Peaks in χ'' are observed which shift to lower temperatures as the applied ac-field increases. We take the peak position $T_p(H)$ as an indication of a crossover from irreversible ($T < T_p$) to reversible ($T > T_p$) magnetic regimes and hence $T_p(H)$ defines the IL. The ILs also shift to higher temperatures and fields as the frequency increases. Yeshurun and Malozemoff[1] have shown that the IL can be explained by Anderson-Kim model of thermally activated flux creep. According to this model, the activation energy U_0

SSDI 0921-4526(93)1575-7

is related to the hopping frequency of the flux lines over the pinning centres by an Arrhenius formula and the IL may be written as:

$$1 - t \sim H^q \quad (1)$$

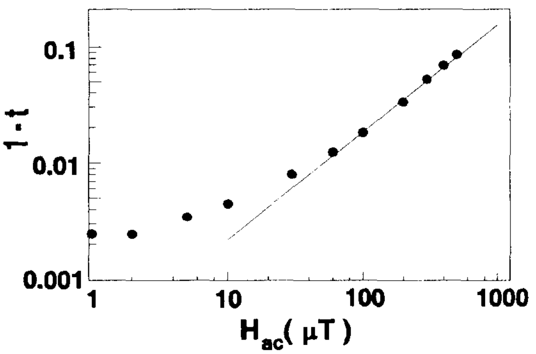

Figure 1 *1-t vs H_{ac} at 1kHz with no applied dc field. The line is a fit to eq(1) with q=0.59.*

where $t=T_p/T_c$. For $H_{dc}=0$, the data for ac fields > 20 μT can be fitted to eq.(1) with q=0.59. For low fields the data deviate from this power law and finally becomes field independent at very small fields, as seen in fig.1. This change in behaviour in the IL marks a crossover between two regimes in the ac magnetic field dependence. There are also two regions in the ac+dc IL as indicated by a change in slope at 300mT. The values of q for the low field and high field regions are 0.67 and 0.22 respectively.

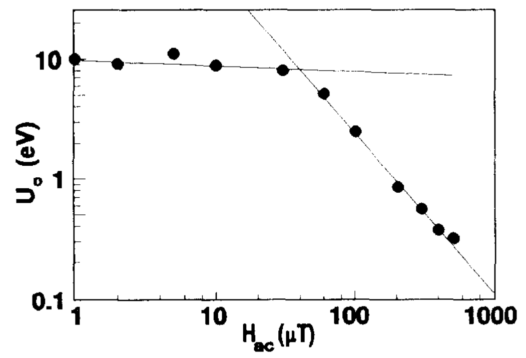

Figure 2 *Activation energy as a function of H_{ac}.*

From the frequency dependence of the IL's we obtain U_0. The existence of two regions in the dependence of U_0 on H_{ac} is clearly demonstrated in fig.2. The data for H>20 μT can be fitted to the power law $U_0 \sim H^{-\alpha}$ with $\alpha = 0.13$. For H<20 μT the activation energy is high($\sim$ 10 eV) and almost field independent. We note that the IL starts deviating from the power law at about the same field at which $U_0(H)$ crosses over from the scaling law behaviour to the field independent regime. Similar behaviour is found in the dc-field dependence of U_0 where the data for H_{dc}<200mT can be fitted to the $U_0 \sim H^{-\alpha}$ law with $\alpha = 0.64$. Again the change in behaviour in the ac+dc IL occurs at a field close to the crossover field in the U_0 vs H_{dc} line. Many workers, including ourselves[2], have reported different values for α and q for a variety of samples and ac and dc fields and so it is clear that they are not universal. They are sensitive to the pinning mechanism as noted by Matsushita et al[3] who considered the weak flux pinning case.

4. CONCLUSIONS

Using ac-susceptibility measurements we have studied the irreversibility line and the activation energy of a BSCCO(2212) single crystal. We find that there are two regimes of behaviour as a function of the applied ac and dc magnetic fields indicated by both a deviation from power law of the IL and by a change in slope of the activation energy vs H curve. This fact suggests that at the temperatures and fields considered in this work thermally activated flux creep is the origin of the irreversibility line.

REFERENCES

1. Y. Yeshurun and A. P. Malozemoff, Phys. Rev. Lett. **60** , 2202 (1988) .
2. A. El-Abbar, P. J. King, K. J. Maxwell, J. R. Owers-Bradley, and W. B. Roys, Physica **C198**, 81 (1992).
3. T. Matsushita, T. Fujiyoshi, K. Toko, and K. Yamafuji, Appl. Phys. Lett. **56**, 2039 (1990).