LARGE MAGNETIC FIELD INDUCED FLUCTUATION EFFECT IN SUPERCONDUCTING $\text{Bi}_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$ TAPE

Qiang Li and M. Suenaga

Material Science Division, Brookhaven National Laboratory, Upton, NY 11973

BNL--47891

DE92 041314

T. Hikata and K. Sato

Osaka Research Laboratories, Sumitomo Electric Industries. Ltd.

1-1-3 Shimaya, Konohana, Osaka, 554 Japan

Abstract--We present our study on the magnetic field induced fluctuation effect in a highly textured $\text{Bi}_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$ tape, based on the magnetization measurement. Extremely large induced excess diamagnetism in high fields was observed at temperatures down to 75 K. In weak fields, fluctuation significantly reduces the diamagnetism of this system just below T_c . The role of this large extended fluctuation effect played in the application of Bi-based superconductor family is discussed.

fields. On the other hand, the fluctuation induces deficient diamagnetism for low fields.

II. EXPERIMENTS

The specimen used for this study is a $40 \times 3 \times 0.1 \text{ mm}^3$ highly c-axis-oriented $\text{Bi}(2:2:2:3)$ thin tape, made by K. Sato, et. al.,⁴ which has a T_c of 107.5 K, with a transition width of 2.6 K, and is able to carry more than 30,000 A/cm² transport critical current at 77 K and zero field. The magnetization measurements of this tape was carried in a Quantum Design SQUID magnetometer, in magnetic fields always applied parallel to the c-axis. Background signals and normal-state magnetization were carefully subtracted.^{1,2} The data shown in Fig. 1 are of typical magnetization of $\text{Bi}(2:2:2:3)$, plotted as a function of temperature taken at 1000, 10000, and 50000 Oe.

I. INTRODUCTION

Superconducting cuprates have layered structures, with short superconducting coherence lengths ($\xi \sim \text{nm}$). These characteristics result in very pronounced fluctuation effects.^{1,2} Since the thermodynamic fluctuation is intrinsic to electronic structure of superconducting materials, it automatically sets a theoretical limit to practical applications. To evaluate the extent of this fluctuation effect on various properties of high- T_c superconductors, particularly in magnetic fields, is the motivation of our work presented in this paper.

Unfortunately, there is no theory available as to correctly describe the mixed state of quasi two-dimensional superconductors with the consideration of fluctuation effects. Thus, it is not practically feasible to give an accurate calculation of the fluctuation effects on various properties of high- T_c superconductors in magnetic fields well below T_c . However, based on our studies of superconducting $\text{Bi}_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$ [$\text{Bi}(2:2:2:3)$], a good estimation of the effects of the fluctuation could be made on some of the superconducting properties. Our approach is to compare the experimental measured magnetization with the calculated magnetization following the Hao-Clem model³ and using the value of Ginzburg-Landau parameter κ and $H_c(T)$ which are determined by application of this model in the temperature region where the fluctuation is insignificant. The result indicated large excess diamagnetic moments, which are induced by the fluctuations, in high

III. RESULTS AND DISCUSSIONS

The theoretical basis of this work is the Hao-Clem variational model, which is an anisotropic Ginzburg-Landau theory, and covers entire field region between H_{c1} and H_{c2} . In our previous study, we have demonstrated that the Hao-Clem model is applicable in describing the mixed state of $\text{Bi}(2:2:2:3)$, except in the strong fluctuation region.^{1,2} The fluctuation effects result in the diverging behavior of Ginzburg-Landau parameter κ near T_c , and a cross-over of various $4\pi M$ -versus- T curves at different fields.¹ By using the procedure described in Ref. 1, we obtained the thermodynamic parameters (for instance, $\kappa = 170$, mean-field $T_c = 110.08 \text{ K}$, $dH_{c2}/dT = -3.68 \text{ T/K}$ near T_c) of superconducting $\text{Bi}(2:2:2:3)$, which excludes the fluctuation effects.

By using these derived parameters and Eq. 20 of Ref. 3, together with $4\pi M = B - H$, we calculated the theoretical magnetization $4\pi M$ as a function of temperature at various fixed fields. The solid lines, shown in Fig. 1, are three typical calculated curves of $4\pi M$ -versus- T at 1000, 10000,

MASTER

and 50000 Oe, which would simply represent the theoretical expectation of magnetization of Bi(2:2:2:3) system if no fluctuation is involved. The fluctuation effect is clearly displayed by the difference between the experimental data and the calculated lines without fluctuation. Strong excess diamagnetism is induced at 50000 Oe, while diamagnetism is reduced at 1000 Oe.

Fig. 1 Temperature dependence of magnetization data (open circles) of Bi(2:2:2:3) in various fields parallel to the c-axis, where the solid lines are theoretical curves calculated by non-fluctuation Hao-Clem model.

Fig. 2 shows the difference between experimental data ($4\pi M^{\text{expt}}$) and the values calculated from the non-fluctuation Hao-Clem model for magnetization ($4\pi M^{\text{theo}}$), plotted against temperature. At temperatures higher than mean-field $T_c(H)$, Fluctuation simply induces diamagnetic moments for all fields, because of the contribution by the

fluctuating Cooper pair density.² Above T_c , this induced diamagnetic moments increases as field increasing so that the diamagnetic susceptibility remains relatively unchanged. As also observed by others, this fluctuation is quite pronounced up to 160 K. The same phenomena manifests the excess conductivity above T_c .

Fig. 2 The difference between experimental data ($4\pi M^{\text{expt}}$) and the values calculated from non-fluctuation theory ($4\pi M^{\text{theo}}$), plotted against temperature

Below $T_c(H)$, Fluctuation shows different behavior depending on the intensity of magnetic fields. High magnetic fields (approximately over 10000 Oe) induce excess diamagnetic moments, as illustrated in Fig. 2. The data taken at 50000 Oe shows that this field-induced-fluctuation effect extends to 75 K. The mechanism for high field fluctuation is mostly the fluctuation of order parameter, and the reduction of dimensionality by high magnetic fields enhance the effect of fluctuation of order parameter.^{2,5} Since this fluctuation is basically from the fluctuating order parameter, a dissipation should exist even though temperature is below $T_c(H)$. The question of the practical importance is how much the observed fluctuation in the order parameter contributes to low in-field critical current density J_c of Bi-oxides at temperatures above 77 K. From the fact that the value of J_c at 77 K, reported so far, is very low at even 1 Tesla field parallel to the c-axis, it is likely the critical current limitation for this family of superconductors is due to weak pinning sites for the vortex lines. However, the fluctuation may set the upper limits for the useful J_c even if the pinning strength is improved drastically by some treatments such as heavy ion irradiation. This is due to the fact this phenomena of fluctuation is intrinsic to quasi two-dimensional electronic system, unlike the flux pinning which depends on the defects in the

materials.

In low magnetic fields, fluctuation reduces the diamagnetism, as displayed by the data taken at 1000 Oe. L. Bulaevskii, et al⁶ show that fluctuation of vortices in layered high- T_c superconductors is the main reason for the reduction of diamagnetism at low fields, because of the extra entropy contribution to the free energy due to thermal distortions of vortices. The reduction of diamagnetism for Bi(2:2:2:3) was observed at temperatures down to 90 K, at fields as low as 200 Oe, within the experimental accuracy. Therefore, even at low fields, the vortices, which are presented in Bi-based superconductors, could give rise to dissipation and persistent-current decay, which is a significant factor need to be taken into account for development of superconducting electronics.

IV. CONCLUSIONS

The degree of the excess, or the reduced diamagnetism in superconducting Bi(2:2:2:3) due to the fluctuations has been studied based on the magnetization measurements and application of Hao-Clem model. At high fields, fluctuation of superconducting order parameter induces diamagnetic moments down to 75 K. At weak fields, the positional fluctuation of vortices is responsible for the reduction of diamagnetism down to 90 K. All these fluctuation could cause dissipation which is not favorable for the most of applications based on Bi(2:2:2:3) materials.

ACKNOWLEDGEMENTS

This work was supported by the U.S. Department of Energy, Division of Materials Sciences, Office of Basic Sciences, under Contract No. DE-AC02-76CH00016.

REFERENCES

- [1] Q. Li, M. Suenaga, J. Gohng, D. K. Finnemore, T. Hikata, and K. Sato, "Reversible magnetic properties of c-axis-oriented superconducting $\text{Bi}_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$," Phys. Rev. B (rapid communication), Aug. 1992. (in press).
- [2] Q. Li, M. Suenaga, T. Hikata, and K. Sato, "Two-dimensional fluctuations in the magnetization of $\text{Bi}_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$," Phys. Rev. B (rapid communication), Sept. 1992. (in press).
- [3] Z. Hao, J. R. Clem, M. W. McElfresh, L. Civale, A. P. Malozemoff, and F. Holtzberg, "Model for the reversible magnetization of high κ type-II superconductors: Application to high- T_c superconductors," Phys. Rev. B, 43, pp. 2844-2852, Feb. 1991.
- [4] K. Sato, et. al., "High J_c silver-sheathed Bi-based superconducting wires," IEEE Trans. Mag. 27, pp. 1231-1238 (1991).
- [5] Z. Tesanovic, L. Xing, L. Bulaevskii, Q. Li, and M. Suenaga, "Critical fluctuations in the thermodynamics of quasi-two-dimensional type-II superconductors," (submitted to Phys. Rev. Lett.)
- [6] L. Bulaevskii, M. Ledvij, and V. G. Kogan, "Fluctuations of vortices in layered high T_c superconductors," Phys. Rev. Lett., 68, pp. 3773-3776, June 1992.

END

**DATE
FILMED**

12 / 8 / 92