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Materials Chemistry and Physics 43 (1996) 83–85

MATERIALS CHEMISTRY AND PHYSICS

Materials Science Communication

Comparison of irreversibility lines of silver-sheathed Bi-2223, Tl-1223 and Tl-1234 superconducting tapes

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Received 24 January 1995; revised 5 May 1995; accepted 7 May 1995

Abstract

The irreversibility lines of silver-sheathed $(Bi,Pb)_2Sr_2Ca_2Cu_3O_{10}$ (Bi-2223), $(Tl,Pb,Bi)(Sr,Ba)_2Ca_2Cu_3O_9$ (Tl-1223) and $(Tl,Pb)Sr_2Ca_3Cu_4O_{11}$ (Tl-1234) superconducting tapes were investigated and compared with those of other superconducting systems. We have demonstrated that the shape of the irreversibility lines of Tl-1223 and Tl-1234 superconducting tapes are similar in behavior to those of $YBa_2Cu_3O_7$ (Y-123) and $(Tl,Pb)Sr_2(Ca,Y)Cu_2O_7$ (Tl-1212) systems and better than those of $Tl_2Ba_2Ca_2Cu_3O_{10}$ (Tl-2223) and $(Bi,Pb)_2Sr_2Ca_2Cu_3O_{10}$ (Bi-2223) superconductors. This means that the flux pinning ability of Tl-1223 and Tl-1234 superconducting tapes was stronger than that of Bi-2223 and Tl-2223 superconductors. The possible reason for controlling flux pinning can be attributed to the intrinsic crystal structure difference in the materials.

Keywords: Cuprate superconductors; Flux pinning; Irreversibility lines; High-T_c Superconducting tapes.

1. Introduction

For any high-T_c superconductor, it is possible to draw a line on a temperature versus magnetic field plot containing all the points at which the critical current density (J_c) of the superconducting material goes to zero. This line is known as the irreversibility line. Within the area below the irreversibility line, the material has a finite J_c; above it, the material becomes dissipative. In utility applications, it is vital to keep the fluxons from moving. Therefore, the challenge is to raise the irreversibility line and thereby to achieve higher critical current density at higher magnetic fields and temperatures. The origins of the irreversibility line have been discussed and attributed to either depinning [1] or melting and the glass–liquid transition of the fluxoid lattice [2,3]. From the viewpoint of the energy associated with the state of fluxoids, it has been concluded that the irreversibility line is the depinning line [4]. No matter what the possible reason for controlling the irreversibility line with the common picture is that it is influenced by flux pinning.

In this paper we report on the irreversibility lines of silver-sheathed $(Bi,Pb)_2Sr_2Ca_2Cu_3O_{10}$ (Bi-2223), (Tl, Pb,Bi)$(Sr,Ba)_2Ca_2Cu_3O_9$ (Tl-1223) and $(Tl,Pb)Sr_2Ca_3Cu_4O_{11}$ (Tl-1234) superconducting tapes and compare them with those of other superconductors. Also, we propose an explanation of controlling flux pinning by crystal structure.

2. Experimental

The tape samples used in this study were produced by the powder-in-(Ag) tube method from the starting chemical compositions of $(Bi_{1.81}Pb_{0.4})Sr_{1.98}Ca_{2.2}Cu_{3.01}O_y$ (Bi-2223) [5], $(Tl_{0.6}Pb_{0.2}Bi_{0.2})(Sr_{1.8}Ba_{0.2})Ca_2Cu_3O_y$ (Tl-1223) [6] and $(Tl_{0.7}Pb_{0.3})Ba_2Ca_3Cu_4O_y$ (Tl-1234)

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SSDI 0254-0584(95)01600-Y

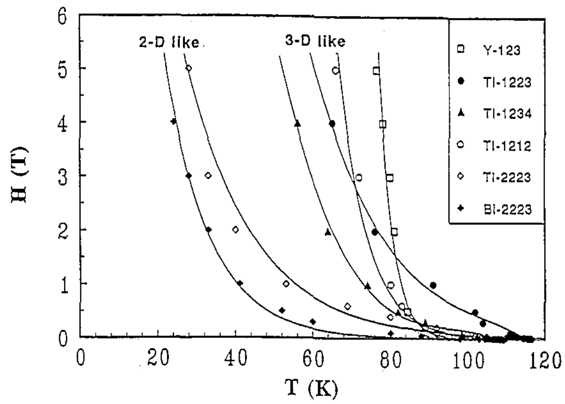

Fig. 1. Irreversibility field (H) as a function of temperature of Y-123, Tl-1223, Tl-1234, Tl-1212, Tl-2223 and Bi-2223.

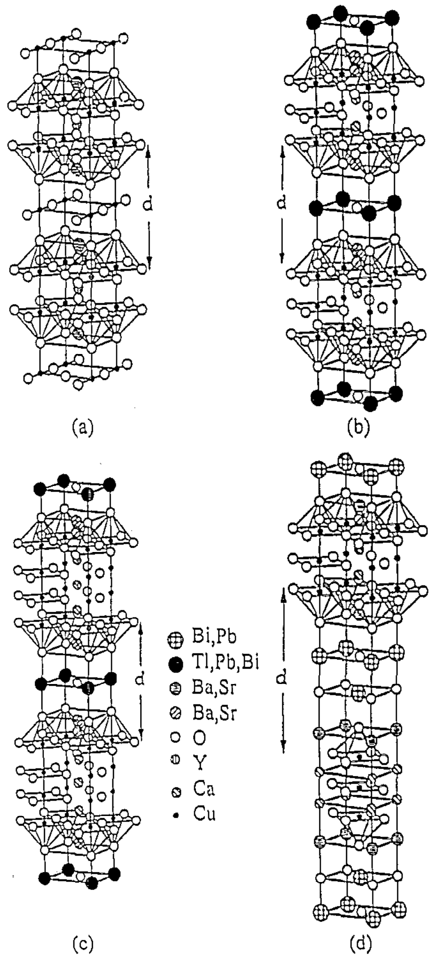

Fig. 2. Representation of the crystal structures of four different types of high-temperature superconductors: (a) Y-123, (b) Tl-1223, (c) Tl-1234 and (d) Bi-2223 which have the interplanar distances (d) between conducting Cu–O sheets of around 8.32 Å, 8.72 Å, 9 Å and 11–12 Å, respectively.

[7], respectively. The Bi-2223 ($T_c = 107$ K), Tl-1223 ($T_c = 118$ K) and Tl-1234 ($T_c = 110$ K) short tapes (with a length of around 3 cm) have the values of transport critical current density (with a criterion of 1 μV cm^{-1}) of 3.2×10^4 A cm^{-2}, 1×10^4 A cm^{-2} and 4×10^3 A cm^{-2}, respectively, at a temperature of 77 K and zero magnetic field. The morphologies of the Bi-2223, Tl-1223 and Tl-1234 tapes were examined by scanning electron microscope (SEM). The grains of Bi-2223 have a large, plate-like shape with a dimension of around 50 μm × 50 μm ($l \times w$), and are well-aligned with the c-axis perpendicular to the tape surface as determined by X-ray diffraction. However, the grains of the Tl-1223 and Tl-1234 tapes are spherical with a diameter of around 3 μm, and are randomly distributed in orientation.

The magnetic measurements have been performed on a superconducting quantum interference device (SQUID) magnetometer (Quantum Design). The magnetic fields were applied normal to the wide planes of the tapes. We measured the magnetization hysteresis loops of ZFC and FC curves to define the irreversibility lines. The Bi-2223, Tl-1223 and Tl-1234 tapes have the dimensions of $0.14 \times 5 \times 5$ mm, $0.14 \times 3.8 \times 5.7$ mm and $0.12 \times 4.5 \times 5.5$ mm, respectively, for this study.

3. Results and discussion

In Fig. 1, we summarize the typical irreversibility lines of $YBa_2Cu_3O_7$ (Y-123) [8], Tl-1223, Tl-1234, $(Tl_{0.5}Pb_{0.5})Sr_2(Ca_{0.8}Y_{0.2})Cu_2O_7$ (Tl-1212) [9], $Tl_2Ba_2Ca_2Cu_3O_{10}$ (Tl-2223) [9] and Bi-2223. The solid symbols represent the irreversibility lines of silver-sheathed Tl-1223, Tl-1234 and Bi-2223 superconducting tapes measured in this work, which are compared with those of other bulk superconducting materials, such as Y-123, Tl-1212 and Tl-2223 (as denoted by open symbols). It seems that these irreversibility lines can be divided into two parts, i.e., 3-D (dimensional) like and 2-D like regions, which will be explained later. Obviously, the irreversibility lines of the Tl-1223 and Tl-1234 superconducting tapes are different from those of the Bi-2223 superconducting tape and the Tl-2223 bulk material. The irreversibility lines of Bi-2223 and Tl-2223 are easily depressed to low temperatures (<40 K) at fields above 1 T. On the other hand, the irreversibility lines at high magnetic field of the Tl-1223 and Tl-1234 superconducting tapes are still in the higher temperature region. In the low field region, the irreversibility line of the Tl-1223 ($T_c = 118$ K) tape is higher than that of the Y-123 ($T_c \sim 95$ K) melt-texture growth (MTG) sample (with the applied magnetic field parallel to the c-axis during the measurement) because of the former having a higher transition temperature. For application at high temperatures, for example at 77 K, the Tl-1223 superconducting tape is a more useful material than other materials. The irreversibility lines for the Tl-1223, Tl-1234 superconducting tapes and the Tl-1212 bulk superconductor are comparable to that of Y-123.

All high-T_c superconducting cuprates contain the mutual parallel copper–oxygen planes perpendicular to the c-axis, which are recognized to be responsible for superconductivity. However, such planes are commonly separated by non-superconducting layers which may have either metallic, semiconducting or even insulating behavior. The superconducting currents are hindered when passing through these non-superconducting layers along the c-axis. Therefore, the interlayer coupling between copper–oxygen planes is a major factor in controlling the intrinsic flux pinning of the cuprate materials.

Both Tl-2223 and Bi-2223 superconductors have double Tl–O or Bi–O layers in the crystal structures, which are thought to be insulating [10]; therefore, the superconductive order-parameter between the superconducting Cu–O layers is considered to be very small which may lead these materials to have a 2-D like character [11,12]. In the cases of Tl-1212, Tl-1223, Tl-1234 and Y-123, the materials have only one insulating layer (e.g., Tl-O layer in the Tl-1212, Tl-1223 and Tl-1234) or metallic layer (e.g., Cu–O chain in Y-123) along the c-axis. In Fig. 2 we show the representation of the crystal structures of four different types of high-temperature superconductors: (a) Y-123, (b) Tl-1223, (c) Tl-1234 and (d) Bi-2223, which have the interplanar distances (d) between conducting Cu–O sheets of around 8.32 Å, 8.72 Å, 9 Å and 11–12 Å, respectively. Therefore, the insulating or metallic region in Tl-1212, Tl-1223, Tl-1234 and Y-123 (8–9 Å) is much thinner than in those of Tl-2223 and Bi-2223 (11–12 Å). Consequently, the strong interlayer coupling may enhance the ability of flux pinning and lead to a 3-D like character in the Tl-1212, Tl-1223, Tl-1234 and Y-123 materials. According to the crystal structure of the high-T_c cuprates, the Y-123 material is the least anisotropic, followed by Tl-1212, Tl-1223 and Tl-1234 with one insulating layer along the c-axis. The Tl-2223 and Bi-2223 superconductors are highly anisotropic because the materials have two insulating layers between conducting copper–oxygen planes along the c-axis. We propose that the distribution of the irreversibility lines of high-T_c cuprates is the result of the anisotropy of the materials. Moreover, it is worth pointing out that the structures of the Tl-1212, Tl-1223 and Tl-1234 superconductors have two, three and four copper–oxygen planes in the half unit cell, respectively, along the c-axis. However, there is no significant difference in the irreversibility lines of the materials with a higher number of copper–oxygen layers in the crystal structure. This means that the irreversibility line is not necessarily raised with increasing number of copper–oxygen layers.

4. Conclusions

In summary, we have pointed out the relationship between the irreversibility lines and crystal structures of the Bi-2223, Tl-1223, Tl-1234 tapes and the Tl-1212, Tl-2223 and Y-123 bulk materials. The materials, such as Tl-1212, Tl-1223, Tl-1234 and Y-123, with the 3-D like (i.e., less anisotropic) behavior have steeper irreversibility lines than those of 2-D like materials (such as Bi-2223 and Tl-2223). This means that the high-T_c cuprates with the 3-D like behavior have a high intrinsic flux pinning ability. Moreover, the irreversibility line can not be moved to higher temperatures at a fixed temperature in the materials with a higher number of conducting copper–oxygen planes (e.g. in the case of Tl-1212, Tl-1223 and Tl-1234).

Acknowledgements

We would like to thank the Materials Research Laboratories, Industrial Technology Research Institute of the Republic of China, for the support in the experiments.

References

[1] Y. Yeshurun and A.P. Malozemolf, *Phys. Rev. Lett.*, *60* (1988) 2202.
[2] R.G. Beck, D.E. Farrell, J.P. Rice, D.M. Ginsberg and V.G. Kogan, *Phys. Rev. Lett.*, *88* (1992) 1594.
[3] M.P.A. Fisher, *Phys. Rev. Lett.*, *62* (1989) 1416.
[4] T. Matsushita, *Physica C*, *214* (1993) 100.
[5] D.S. Shy, H.W. Lee and R.S. Liu, *Mater. Res. Soc. Symp. Proc.*, *290* (1994) 23.
[6] R.S. Liu, S.F. Wu, D.S. Shy, C.H. Tai, S.F. Hu and D.A. Jefferson, *Chin. J. Phys.*, *31* (1993) 951.
[7] R.S. Liu and S.F. Wu, unpublished.
[8] Y. Dai, Z. Liu, H. Chen, C. Wei, H. Peng, X. Long, Q. Peng, S. Zhou, Z. Qi and Y. Wu, *Chin. J. Low Temp. Phys.*, *15* (1993) 405.
[9] R.S. Liu, D.N. Zheng and A.M. Campbell, unpublished.
[10] T. Hasegawa and K. Kitazawa, *Jpn. J. Appl. Phys.*, *29* (1990) L434.
[11] P.H. Kes, J. Aarts, V.M. Vinokur and C.J. van der Beck, *Phys. Rev. Lett.*, 64 (1990) 1063.
[12] J.R. Chem, *Phys. Rev. B*, *43* (1991) 7837.