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Electrical Transport and Superconductivity in the Au-Bi₂Sr_{1.8}Ca_{1.2}Cu₂O_y Composite System

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We have measured the resistivity ρ of the Au-Bi₂Sr_{1.8}Ca_{1.2}Cu₂O_y composite system with Au volume fraction p_{Au} ranging from 0.00 to 1.00. We find, for the samples with $p_{\text{Au}} \leq 0.4$, that the addition of Au does not disturb the superconducting transition temperature of Bi₂Sr_{1.8}Ca_{1.2}Cu₂O_y. For the samples with $p_{\text{Au}} \geq 0.6$, no zero-resistivity state is observed. The variation of $\rho(300\text{ K})$ with p_{Au} indicates a three-dimensional percolating Au matrix occurring at $p_{\text{Au}} \approx 0.18$.

KEYWORDS: high- T_c superconductor, Bi₂Sr_{1.8}Ca_{1.2}Cu₂O_y, Au addition, electrical resistivity, percolation

§1. Introduction

The electrical-transport and superconducting properties of the high-temperature cuprate superconductors mixed with the noble metals Au and Ag to form superconductor-normal-metal composites have recently been studied.¹⁻⁸⁾ One of the main reasons for this interest is the general belief that the superconducting phase is (almost) undisturbed by the addition of Au or Ag. For example, several groups⁴⁻⁷⁾ have reported that the superconducting transition temperature, T_c , in the Ag-YBa₂Cu₃O₇ composite system is the same as that in silver-free YBa₂Cu₃O₇, even in the presence of a sizeable amount (up to 60% in volume) of Ag. On the other hand, due to the difficulty in preparing single-phased Bi₂Sr₂Ca_{n-1}Cu_nO_y ($n=1, 2$, or 3) compounds, this issue has been much less investigated in the Ag-Bi₂Sr₂Ca_{n-1}Cu_nO_y and Au-Bi₂Sr₂Ca_{n-1}Cu_nO_y composites in the literature. Recently, Maeda *et al.*^{9,10)} reported that the 80-K-superconducting-phase Bi₂(Sr_{1-z}Ca_z)₃Cu₂O_y system can be obtained most easily at $z=0.4$. Motivated by this observation, we have recently successfully fabricated an Ag-Bi₂Sr_{1.8}Ca_{1.2}Cu₂O_y composite system and studied its electrical-transport properties.¹¹⁾ In the present work, we continue study in this direction to investigate the electrical-transport and superconducting properties in the Au-Bi₂Sr_{1.8}Ca_{1.2}Cu₂O_y composite system. Our results are discussed below.

§2. Experimental Method

Composite samples of Au-Bi₂Sr_{1.8}Ca_{1.2}Cu₂O_y were fabricated by the standard solid-state reaction method¹¹⁾ with the Au volume fraction, p_{Au} , ranging from 0.00 to 1.00. The Bi₂Sr_{1.8}Ca_{1.2}Cu₂O_y (hereafter referred to as Bi2:2:1:2) was prepared by mixing and calcining stoichiometric amounts of Bi₂O₃ (99.9% pure), SrCO₃ (99.5% pure), CaCO₃ (99.9% pure), and CuO (99.9% pure) for 16 hours at 790°C. The product obtained was reground and sintered at 835°C for 32 hours in air, with one intermediate grinding and mixing, and finally air-quenched. The product obtained was X-ray pure, and every peak in the diffraction pattern could be indexed.

Powders (≈ 100 mesh) of these presintered Bi2:2:1:2 were thoroughly mixed with Au powders (99.99% pure, 325 mesh) of appropriate proportions, where densities of 4.95 and 19.3 g/cm³ for Bi2:2:1:2 and Au, respectively, were used. The mixtures were pelletized and sintered at 810°C for 18 hours in air, and were finally air-quenched. The structures of the composites were studied by powder X-ray diffraction. Two sets of peaks were observed, corresponding to the Bi2:2:1:2 phase and Au. Three typical examples of the θ - 2θ diffraction patterns with $p_{\text{Au}}=0.00, 0.15, 0.20, 0.30$, and 0.40, respectively, are shown in Fig. 1. DC resistances were measured by the standard four-

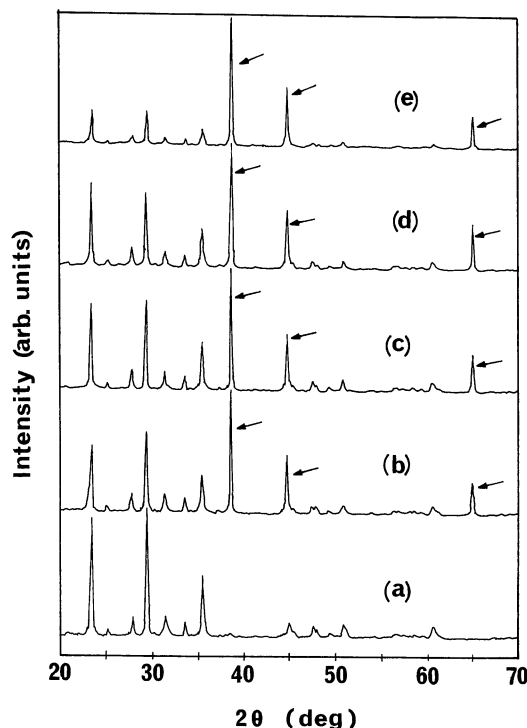


Fig. 1. Powder X-ray diffraction patterns of a (a) pure Bi₂Sr_{1.8}Ca_{1.2}Cu₂O_y sample and four Au-Bi₂Sr_{1.8}Ca_{1.2}Cu₂O_y composites with $p_{\text{Au}}=0.15$ (b), 0.20 (c), 0.30 (d) and 0.40 (e), respectively. The arrows in (b)-(e) indicate the three strongest peaks of Au, which implies that Au is present as a segregated phase.

probe technique. The electrical contacts were made with silver paste. A silicon diode thermometer was used as the temperature sensor.

§3. Results and Discussion

Figure 2 shows the normalized resistivity, $\rho(T)/\rho(300\text{ K})$, as a function of temperature for five Au-Bi₂:2:1:2 composites (from bottom to top) with $p_{\text{Au}}=0.00, 0.25, 0.50, 0.60,$ and 0.75 , respectively. Clearly, $\rho(T)/\rho(300\text{ K})$ for all samples varies approximately linearly with temperature above 100 K. Furthermore, no resistivity drop at 110 K characteristic of the Bi₂Sr₂Ca₂Cu₃O_y phase is observed, indicating good controllability in sample fabrica-

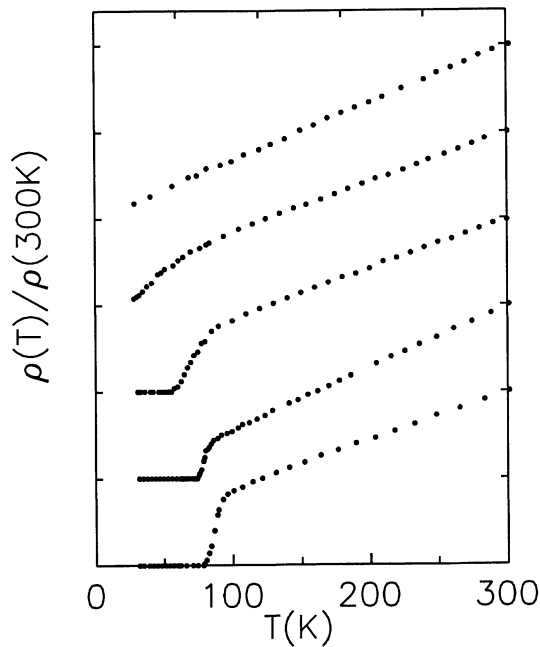


Fig. 2. Normalized resistivity $\rho(T)/\rho(300\text{ K})$ as a function of temperature for five Au-Bi₂Sr_{1.8}Ca_{1.2}Cu₂O_y composites (from bottom to top) with $p_{\text{Au}}=0.00, 0.25, 0.50, 0.60,$ and 0.75 , respectively.

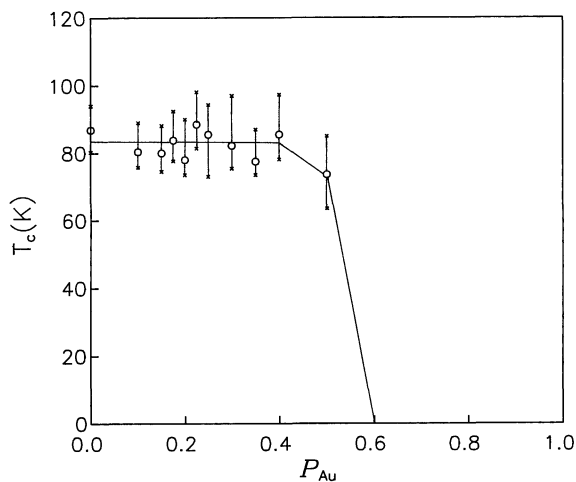


Fig. 3. The 10-90% superconducting transition temperature T_c as a function of Au volume fraction p_{Au} for Au-Bi₂Sr_{1.8}Ca_{1.2}Cu₂O_y composites. The circles represent the 50% transition temperatures. The solid line is a guide for the eye.

tion of (almost) single-phased Bi₂:2:1:2. What is more noteworthy in Fig. 2 is that all the samples with $p_{\text{Au}} < 0.6$ reveal a very similar resistive superconducting transition, i.e., there is only minor degradation of the bulk superconductivity even in the presence of a sizeable amount of Au. On the other hand, the samples with $p_{\text{Au}} \geq 0.6$ do not exhibit superconductivity down to the 25 K measured.*

Figure 3 shows the 10-90% superconducting transition temperature, T_c , as a function of p_{Au} determined resistively. (The circles represent the 50% transition temperatures.) This figure clearly reveals that T_c is essentially the same for the samples with $p_{\text{Au}} \leq 0.4$; while for the sample with $p_{\text{Au}}=0.50$, T_c is slightly reduced. At $p_{\text{Au}} \approx 0.6$, the superconducting state in the composites suddenly disappears. In other words, the critical volume fraction (below which no superconducting path exists throughout the sample) for the Bi₂:2:1:2 matrix is at $1-p_{\text{Au}} \approx 0.4$. This value is the same as that observed in the Ag-Bi₂:2:1:2 composite system.¹¹⁾ Note that the present observation of an essentially constant T_c for $p_{\text{Au}} \leq 0.4$ is different from that observed in the Ag-Bi₂:2:1:2 composites.¹¹⁾ In the latter system, a slightly decreasing T_c with increasing p_{Ag} is reported, even for $p_{\text{Ag}} \leq 0.4$, due to the uptake of extra oxygen by the Bi₂:2:1:2 phase during high-temperature composite processing. (In our previous fabrication of Ag-Bi₂:2:1:2 composites,¹¹⁾ powders of Ag₂O were used to mix with Bi₂:2:1:2, which decomposed to metallic Ag releasing oxygen at around 300-500°C (refs. 12 and 13). This work therefore suggests that metallic Ag, rather than Ag₂O or AgO, might be a better starting material for the fabrication of Ag-Bi₂:2:1:2 composites.**

Figure 4 plots the room-temperature resistivity $\rho(300\text{ K})$ as a function of p_{Au} . Starting from $\approx 1900\ \mu\Omega \cdot \text{cm}$ for the gold-free Bi₂:2:1:2, $\rho(300\text{ K})$ decreases monotonically with increasing p_{Au} to a value of $4.9\ \mu\Omega \cdot \text{cm}$ for the Au

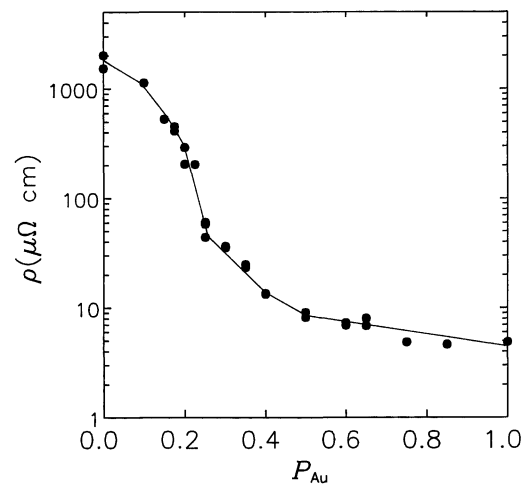


Fig. 4. Variation of the room-temperature resistivity $\rho(300\text{ K})$ with Au volume fraction p_{Au} for Au-Bi₂Sr_{1.8}Ca_{1.2}Cu₂O_y composites. The solid line is a guide for the eye.

*The samples with $p_{\text{Ag}} \geq 0.6$ are believed to be nonsuperconducting down to absolute zero.

**Our recent results of an Ag-Bi₂:2:1:2 composite system fabricated from metallic Ag have shown improved bulk superconductivity, compared with that in the same composite system fabricated using Ag₂O (Ren-Fen Tusei, Wen-Yuan Lin and J. J. Lin, (unpublished)).

reference sample ($p_{\text{Au}}=1.00$) fabricated under the same firing conditions as described in §2. The decrease of $\rho(300\text{ K})$ results presumably from the Au particles filling the pores between the Bi₂:2:1:2 grains. In addition, Fig. 4 indicates a percolation threshold, p_c , for the Au matrix occurring at ≈ 0.20 . (The precise value of p_c determined by least-squares fits is given below.) This threshold value is what would be expected for three-dimensional random composites^{14,15} and is close to that (≈ 0.17) observed in the Ag-Bi₂:2:1:2 composites.¹¹ Once Au channels percolate, $\rho(300\text{ K})$ varies only slightly with p_{Au} ; *e.g.*, the magnitude of $\rho(300\text{ K})$ only decreases by a factor of 2–3 when $\rho(300\text{ K})$ is increased from 0.4 to 1.0, while it varies by a factor of ≈ 20 when p_{Au} is increased from 0.0 to 0.2. The variation of $\rho(300\text{ K})$ with p_{Au} for the samples with $p_{\text{Au}} \geq 0.2$ can be analyzed in terms of the percolation theory. In three dimensions, the percolation theory predicts that the sample resistivity of a two-component random composite can be written as^{14,15}

$$\rho = \rho_0 (p_{\text{Au}} - p_c)^{-t}, \quad p_{\text{Au}} > p_c, \quad (1)$$

where ρ_0 is a constant, and t is a critical exponent. Comparing our data with eq. (1), we obtain $p_c = 0.183 \pm 0.003$, $t = 1.04 \pm 0.08$, and $\rho_0 \approx 3.4 \mu\Omega \cdot \text{cm}$. With these least-squares-fitted values, our data (the symbols) fall on a straight line in a log-log plot of $\rho(300\text{ K})$ versus $p_{\text{Au}} - p_c$ (Fig. 5). Figure 5 shows that eq. (1) can describe the resistivity of our Au-Bi₂:2:1:2 composite system in the

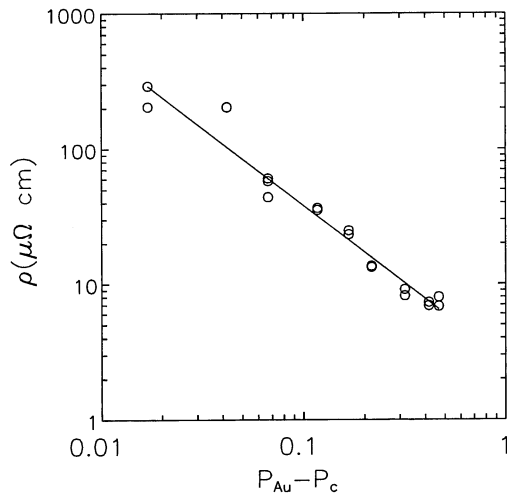


Fig. 5. The log-log plot of the room-temperature resistivity $\rho(300\text{ K})$ vs $p_{\text{Au}} - p_c$ for Au-Bi₂Sr_{1.8}Ca_{1.2}Cu₂O_y composites. The straight line is a least-squares fit to the data according to eq. (1) (with $p_c = 0.183$ and $t = 1.05$).

$p_{\text{Au}} - p_c$ range of ≈ 0.02 – 0.45 . The value of t is similar to that (1.1 ± 0.1) observed in the Ag-Bi₂:2:1:2 composites.¹¹

§4. Conclusions

We have performed resistivity measurements in the Au-Bi₂Sr_{1.8}Ca_{1.2}Cu₂O_y composites with the Au volume fraction p_{Au} ranging from 0.00 to 1.00. A three-dimensional percolation threshold is observed for the Au matrix occurring at $p_{\text{Au}} \approx 0.18$, and for the superconducting matrix occurring at $1 - p_{\text{Au}} \approx 0.4$. The superconducting transition temperature is essentially undisturbed for $p_{\text{Au}} < 0.5$.

Acknowledgments

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References

- 1) Y. Kubo, K. Michishita, N. Shimizu, Y. Higashida, H. Yokoyama, Y. Hayami, E. Inukai, A. Saji, N. Kuroda and H. Yoshida: Jpn. J. Appl. Phys. **28** (1989) L1936.
- 2) N. Imanaka, H. Imai, G. Adachi, K. Inada, M. Yoshikawa and K. Okuda: Z. Phys. B **83** (1991) 327.
- 3) S. X. Dou, K. H. Song, H. K. Liu, C. C. Sorrell, M. H. Apperley, A. J. Gouch, N. Savvides and D. W. Hensley: Physica C **160** (1989) 533.
- 4) N. Imanaka, F. Saito, H. Imai and G. Adachi: Jpn. J. Appl. Phys. **28** (1989) L580.
- 5) Y. Hikichi, M. Kato, S. Suzuki, T. Nomura and M. Miyamoto: Jpn. J. Appl. Phys. **29** (1990) L1615.
- 6) B. Ropers, R. Canet, F. Carmona and S. Flandrois: Solid State Commun. **75** (1990) 791.
- 7) J. J. Lin and T.-M. Chen: Z. Phys. B **81** (1990) 13.
- 8) M. Z. Cieplak, G. Xiao, C. L. Chien, A. Bakhshai, D. Artymowicz, W. Bryden, J. K. Stalick and J. J. Rhyne: Phys. Rev. B **42** (1990) 6200.
- 9) A. Maeda, T. Yabe, H. Ikuta, Y. Nakayama, T. Wada, S. Okuda, T. Itoh, M. Izumi, K. Uchinokura, S. Uchida and S. Tanaka: Jpn. J. Appl. Phys. **27** (1988) L661.
- 10) A. Maeda, T. Yabe, S. Takebayashi, M. Hase and K. Uchinokura: Phys. Rev. B **41** (1990) 4112.
- 11) J. J. Lin and T.-M. Chen: Jpn. J. Appl. Phys. **30** (1991) L1256.
- 12) T. H. Tiefel, S. Jin, R. C. Sherwood, M. E. Davis, G. W. Kammlott, P. K. Gallagher, D. W. Johnson, Jr., R. A. Fastnacht and W. W. Rhodes: Mater. Lett. **7** (1988) 363.
- 13) J. J. Lin, T. M. Chen, Y. D. Yao, J. W. Chen and Y. S. Gou: Jpn. J. Appl. Phys. **29** (1990) 497.
- 14) G. Deutscher, A. Kapitulnik and M. Rappaport: *Percolation Structures and Processes*, eds. G. Deutscher, R. Zallen and J. Adler (Hilger, Bristol, 1983) p. 207.
- 15) G. Deutscher: *Percolation, Localization, and Superconductivity*, eds. A. M. Goldman and S. A. Wolf (Plenum, New York, 1984) p. 95.