Upper critical field measurements using pulsed magnetic fields in $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_{2+x}O_y$ (x=0.8, 1.2, 1.6)

1989 J. Phys.: Condens. Matter 1 2755

(http://iopscience.iop.org/0953-8984/1/16/015)

J. Phys.: Condens. Matter 1 (1989) 2755–2758. Printed in the UK

LETTER TO THE EDITOR

Upper critical field measurements using pulsed magnetic fields in $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_{2+x}O_y$ ($x = 0.8, 1.2, 1.6$)

Mao Xianglei, Liu Hongbao, Du Quan, Zhang Weijie, Mao Zhiqiang, Zhou Ling, Wang Yu and Zhang Yuheng

Department of Physics, University of Science and Technology of China, Hefei, Anhui 90028, People's Republic of China

Received 6 December 1988, in final form 6 February 1989

Abstract. Upper critical magnetic fields of the $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_{2+x}O_y$ system with $x = 0.8$, 1.2, 1.6 were measured by a magnetoresistance method using a pulsed magnetic field. The $H_{c2}(0)$ are estimated to be 45. 9, 218 and 64.9 T for $x = 0.8$, 1.2, 1.6, respectively. $H_{c1}(T)$ for each composition was determined from magnetisation curves. The superconducting parameters ξ, κ and λ were derived from experimental data. X-ray diffraction patterns show that there is no obvious change in structure. It is suggested that the coordination number of Cu strongly influences the superconductivity.

After the discovery of a new type of superconducting Bi–Sr–Ca–Cu–O system with a transition temperature above 100 K [1, 2], a sample of the Pb-doped Bi–Sr–Ca–Cu–O system with transition temperature 107 K was prepared [3]. We have prepared samples of $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_{2+x}O_y$ with $x = 0.8, 1.2, 1.6$. In this work, we measured the $H_{c1}(T)$ and $H_{c2}(T)$ of the system, and estimated the parameters κ, ξ and λ for three samples. It is found that H_{c2} is very sensitive to variations in the proportion of Cu in the compound.

The samples were prepared by solid state reaction of Bi_2O_3, CuO, $SrCO_3$, $CaCO_3$ and PbO in air [4, 5]. The compositions of the compounds formed were $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_{2+x}O_y$ with $x = 0.8$, 1.2, 1.6. The mixture was heated at 830 °C for 12 h. After being ground and pelleted the samples were sintered at 865 °C for 60 h and then cooled to room temperature in air.

The H_{c2} measurements were performed in a pulsed magnetic field [6, 7]. An AC current with frequency 100 kHz was applied to the sample. The magnetic field and voltage signals were recorded simultaneously. When the applied magnetic field reaches H_{c2}, the resistance reaches a saturation level. The value of H_{c2} corresponds to the field above which the resistance becomes field-independent. The peak in the magnetisation curve was identified as the low critical temperature. Often, $H_{c1}(T)$ is defined as the field where M no longer varies linearly with H, but for our samples the pinning forces are weak, so we consider the two criteria to be the same [8, 9].

The $\chi(T)$ curves for the samples with $x = 0.8$, 1.2, 1.6 are shown in figure 1. The critical temperatures are 107, 107 and 102 for $x = 0.8$, 1.2, 1.6, respectively. The $H_{c2}(T)$ curves for these samples are shown in figure 2. It can be seen from figure 2 that the values of T_c deduced from the $H_{c2}(T)$ curves are 109, 109 and 110.5 K for $x = 0.8$, 1.2 and 1.6, respectively. Because values of H_{c2} were determined by resistance measurements, the

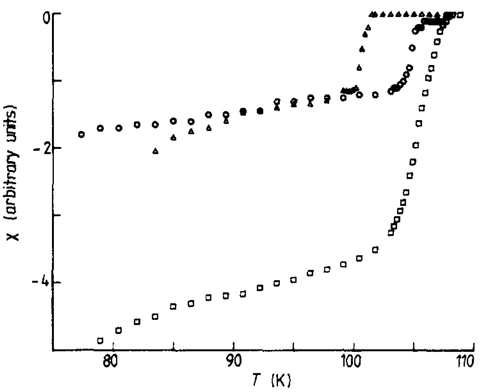

Figure 1. The AC susceptibility as a function of temperature, $\chi(T)$, of $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_{2+x}O_y$: ○, $x = 0.8$; □, $x = 1.2$; △, $x = 1.6$.

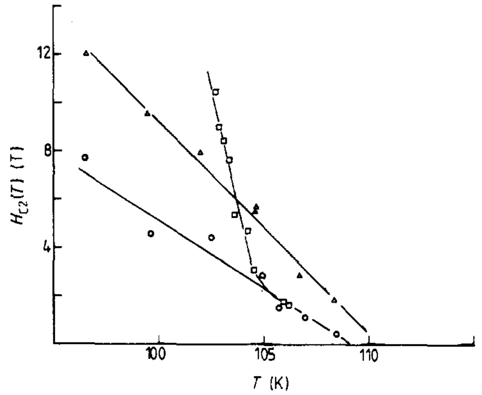

Figure 2. $H_{c2}(T)$ of $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_{2+x}O_y$. The symbols are as given for figure 1. The full curves are given as a guide to the eye.

T_c deduced from $H_{c2}(T)$ were sensitive to the small volume of the high-temperature superconducting phase. If a sample with $x = 1.6$ has a small amount of a phase with T_c = 110 K, it is detectable by H_{c2} measurements, but not by AC susceptibility measurements. Thus the value of T_c determined from $H_{c2}(T)$ is slightly higher than T_c determined from $\chi(T)$.

We also note that the behaviour of $H_{c2}(T)$ for $x = 1.2$ (figure 2, □) seems to show a drastic change of slope near T_c. It may be related to the two phases which occur simultaneously for this composition. However, a definite upward curvature in $H_{c2}(T)$ has been found in $YBa_2Cu_3O_{7-x}$ and $La_{2-x}Sr_xCuO_4$ single crystals [10]. Thus it is an intrinsic feature of oxide superconducting materials. Therefore it also may be an intrinsic feature of the system Bi–Pb–Sr–Ca–Cu–O. It can be obtained from figure 2 that $(dH_{c2}/dT)|_{T_c} = -0.6$, -3.0 and -0.86 for $x = 0.8$, 1.2, 1.6, respectively. The $H_{c2}(0)$ can be estimated according to the WHH theory [11] (see table 1).

The $H_{c1}(T)$ curves are shown in figure 3. From our previous work [9] we know that for some multiphase samples the $H_{c1}(T)$ curves can be divided into two distinct regions. It was concluded in [9] that there are at least two different superconducting phases present in these samples. The relation

Table 1. The superconducting parameters of $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_{2+x}O_y$ for the three compositions $x = 0.8, 1.2, 1.6$.

Sample	x	T_c (K)	$H_{c1}(0)$ (G)	$H_{c2}(0)$ (T)	κ	$\xi(0)$ (Å)	$\lambda(0)$ (Å)	ρ_n (150 K) (mΩ cm)
1	0.8	107	130	44.5	43	27	1161	2.25
2	1.2	107	195	221	86	12	1032	4.20
3	1.6	102	220	61.4	39	23	897	2.48

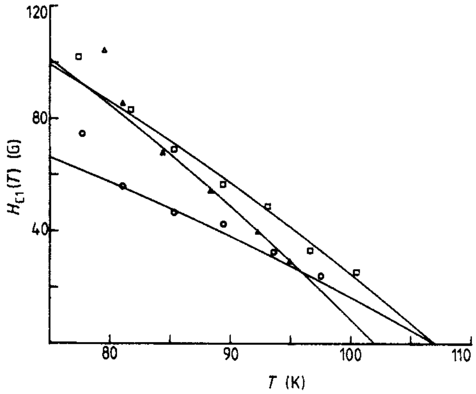

Figure 3. $H_{c1}(T)$ of $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_{2+x}O_y$. The symbols are as given for figure 1. The full curves are fittings of the relation $H_{c1}(T) = H_{c1}(0)(1 - T^2/T_c^2)$ to the data. ($H_{c1}(0)$ values deduced from this relation are given in table 1.)

$$H_{c1}(T) = H_{c1}(0)(1 - T^2/T_c^2) \qquad (1)$$

was used to fit experimental data in a higher-temperature range, as shown in figure 3. It is found that the data near 80 K for all three samples diverge from equation (1). As mentioned in [9], this is caused by the existence of multiple phases. The $H_{c1}(0)$ and T_c for the three samples studied in this work are listed in table 1. These are in agreement with the $\chi(T)$ results. These parameters correspond to the high-temperature superconducting phase.

According to GL theory, the $H_c(0)$, κ, ξ and λ can be determined from the above experimental data. These parameters are listed in table 1 for the three samples.

X-ray diffraction data show that each of these three samples contains two phases with lattice constants of 37.3 Å and 30.8 Å. These three samples produce the same x-ray diffraction patterns. This indicates that there is little change in structure with varying composition x. Table 1 shows that the proportion of Cu strongly influences $H_{c2}(0)$ because $H_{c2}(0)$ is proportional to the residual resistivity of the sample. The resistivities at 150 K of the three samples are listed in table 1. The variation of normal resistivity with x coincides with that of H_{c2}. Since the preparation conditions of these three samples were almost the same, the proportion of Cu alone being varied, and the superconducting behaviour has not changed, the change in the coordination number of Cu may influence normal resistivity and cause changes in H_{c2}.

In summary, we measured the H_{c1} and H_{c2} of $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_{2+x}O_y$ with $x = 0.8$, 1.2, 1.6. The superconducting parameters were estimated. It has been found that $H_{c2}(0)$ varies strongly with the Cu composition x.

References

[1] Maeda H, Tanaka Y, Fukutomi M and Asano T 1988 *Japan J. Appl. Phys.* **27** 2

[2] Chu C W, Bechtold J, Gao L, Hor P H, Huang Z J, Meng R L, Sun Y Y, Wang Y Q and Xue Y Y 1988 *Phys. Rev. Lett.* **60** 941

[3] Green S M, Jiang C, Mei Yu, Luo H L and Politis C 1988 *Preprint*

[4] Liu Hongbao, Cao Liezhao, Zhou Ling, Mao Zhiqiang, Zhang Weijie, Li Xiaoxian, Yu Zhidong, Xue Bai, Mao Xianglei, Zhou Guien, Ruan Yaozhong, Chen Zhaojia and Zhang Yuheng 1988 *Solid State Commun.* submitted for publication

[5] Liu Hongbao, Zhang Weijie, Mao Zhiqiang, Zhou Ling, Mao Xianglei, Li Xiaoxian, Yu Zhidong, Xue Bai, Li Biyou, Cao Liezhao, Ruan Yaozhong, Chen Zhaojia and Zhang Yuheng 1988 *J. Phys.: Condens. Matter.* submitted for publication

[6] Wang Ju, Mao Xianglei, Chen Lin, Wu Baimei, Chen Zhaojia, Chen Jinsong, Le Defeng, Zhang Yuheng, Cao Xiaowen, Wen Haihu, Zhang Tingyu and Chi 1988 *J. Low Temp. Phys.* **10** 12

[7] Mao Xianglei, Zhang Yuheng and Chi 1986 *J. Low Temp. Phys.* **8** 147

[8] Strobel J P, Thoma A, Hensel B, Adrian H and Saemann-Ischenko G 1988 *Physica* C **153–5** 1537

[9] Liu Hongbao, Mao Xianglei, Zhang Weijie, Mao Zhiqiang, Chen Zhaojia and Zhang Yuheng 1989 *J. Phys.: Condens. Matter* at press

[10] Crabtree G W, Kwok W K, Welp U, Burriel R, Claus H, Vandervoort K G and Liu J Z 1989 *J. Magn. Magn. Mater.* at press

[11] Werthamer N R, Helfand E and Hohenerg P C 1966 *Phys. Rev.* **147** 362