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# Electrical Properites of Superconducting Cross - (nano) Whiskers Junction

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**Abstract**

Bi-2212 superconducting single crystal (nano) whiskers have been fabricated by annealing a melt-quenched (glass) $Bi_3Sr_2Ca_2Cu_3O_x$ precursor. A couple of (nano) Whiskers obtained were placed cross-wise on a YSZ single crystal substrate and then heat treated at 830 C for 25 minute to form nano-scale junction. The $T_c$ of each nano-whisker was found to be 85 K and the critical current density, $J_c$, of the whiskers was calculated to be 1177 $Acm^{-2}$ at zero field. The $I-V$ characteristics of the nano-junction at 30 K were found to show a multiple-branch structure, which is the main behavior of the Josephson junction.

**Key Words:** BSCCO superconductors, H$T_c$ superconductors, whiskers.

## 1. Introduction

Since the discovery of Bi-based H$T_c$ superconductors [1] several groups have reported $Bi_2Sr_2CaCu_2O_x$ ($Bi-2212$) single crystal whiskers [2, 3]. Subsequently their physical, electrical and magnetic properties have been characterized. The results obtained from the previous works showed that they were grown as single crystals with various dimensions. Thus, investigation of these materials have not only technological meaning but also significant theoretical interest. It was also shown that these fibrous single crystals highly flexible can be bent elastically to form a circle with various radius, exhibit high mechanical strength and large critical current density. Bi-2212 whiskers can be grown by three different methods. The first and most used method is glass-ceramic method [4]. After obtaining glass pieces from the melt quenching process a simple heat treatment schedule can be applied and whiskers grow on the surface of the glasses. The second method is the sintering of pressed pellets of the BSCCO based materials [5]. Generally Bi-rich compositions and controlled heat treatment cycles required for this method. The third method is the flux method [6]. Particularly high temperature heating and flux agents such as, CuO and $Bi_2O_3$ required for this method. However, size of the whiskers are small comparing with the other two methods. Recently, theoretical prediction was proposed that the Josephson devices could generate terahertz frequency electromagnetic radiation [7] which is very important for technological applications. Therefore, the Josephson effect and Josephson devices have received much attention. Today it is possible to produce Josephson device using superconducting whiskers in nano-scale without using advanced fabrication techniques, such as, ion beam technology or complicated high resolution lithography techniques. In this work we have attempted to produce whiskers by glass-ceramic method. Then we have produced cross junction using two separate nano whiskers and investigated its physical and electrical properties.

## 2. Experimental

We used glass-ceramic method for preparation of the whiskers. At the first stage appropriate amounts of reagent grade $Bi_2O_3, SrCO_3, CaCO_3$ and CuO were mixed to give a nominal composition of $Bi_3Sr_2Ca_3Cu_3$ $O_{10+x}$. The mixture was melted in an alumina crucible at $1100^0C$ for 2 h. The melt was then rapidly quenched between two cold copper plates. Approximately 1.5 mm thick glass sheets were obtained with various sizes. In the second stage, glass sheets were placed into the tube furnace and heat treated at $805^0C$ for 60 h. with $10^0C/min.$ heating and $1^0C/min.$ cooling ramps. After the heat treatment cycle a large number of whiskers were found to grow on the surface of the glass sheets with different size such as, $1-10mm$ long and cross-sectional dimensions ranging $275nm - 150\mu$m by $900nm - 100\mu$m. Then a couple of whiskers were placed crosswise on a Yittria stabilized Zirconia substrate and heat treated at $830^0C$ for 25 min. to form nano-scale junction. Samples were first examined by an x-ray powder diffractometer (XRD). Microstructural and compositional characterizations were carried out using a scanning electron microscope (SEM) with an energy dispersive x-ray analyzer (EDX). The electrical resistivity measurements were carried out with Cryogenic Q 3398 vibrating sample magnetometer (VSM). $I-V$ characteristics of the samples were measured with Leybold LT-10 closed cycle cryostat system. Contacts to the whiskers were made using four probe method and conductive silver paint.

## 3. Results and Discussion

Bi-2212 superconducting nano whiskers have been fabricated using a Bi-3223 starting material. The overall degree of regularity in the atomic arrangement were found to be formed in three dimensional and well designed crystalline networks and the type of microstructure encountered as single crystal. A typical XRD pattern of the whiskers are shown in Figure 1.

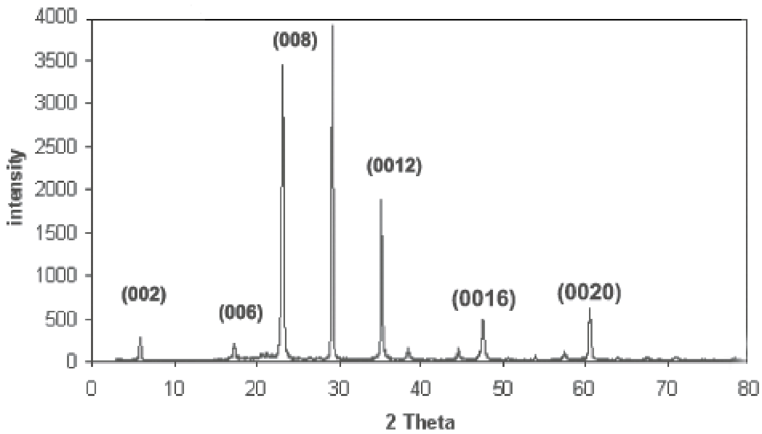


**Figure 1**. XRD pattern of the whiskers produced.

It is clearly seen that whiskers were grown c-axis oriented Bi-2212 phase of BSCCO system. The calculated value of the unit-cell parameters showed that structural symmetry in the tetragonal form with $a = b = 5.4049\AA$ and $c = 30.6017\AA$ matched values previously obtained for single crystal Bi-2212 materials by other groups [8]. The joining process occurred at the cross area of the whiskers by surface diffusion. After joining process (by heating them in the furnace) cross whiskers and also cross area were showed similar properties. A microanalysis and morphology (by EDX- dot mapping) are shown in Figure 2.

According to microqualitative analysis whiskers consists mainly of the single phase of $Bi_{1.99}Sr_{1.98}Ca_{1.01}$ $Cu_{2.05}O_x$. However, dot type grains which formed on the cross whiskers after the heat treatment were also found to be single phase of the same material. The electrical property of the whiskers and also cross-junction were examined by resistivity measurements. For the resistivity measurements well defined metallic behavior and single phase superconducting transition at 85 K are clearly obtained, Figure 3. There exist no residual or extra resistance were obtained on the junction area. That indicate diffusion process which occurs on the junction area, sufficient to make good quality and strong bonding behavior between the cross whiskers.

Figure 4 shows $I - V$ curves of cross-whiskers taken at 3 different temperatures. The $I$-V measurements showed zero voltage for current values below the critical current values. Obviously this is an ideal characteristic in superconducting state. In the superconducting state (at 30 K) the voltage jump is obtained at $12.76mA$ and for the cross whiskers the magnitude of the voltage jump is found to be $13.22mV$. That shows good agreement with a jump typical of micro-fabricated intrinsic Josephson junction structures [7].

The critical current density, $J_c$, at 30 K, using junction area $574\mu m^2$ and $6.76mA$, was calculated to be 1177 $Acm^{-2}$. This value is well over the typical $J_c$ value observed in Bi-2212 intrinsic Josephson junction previously by R. Kleiner et.al. [9].

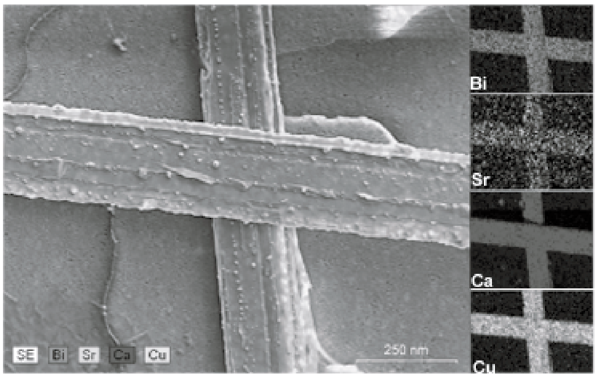


**Figure 2.** SEM micrograph of cross-junction insert shows x-ray dot mapping.

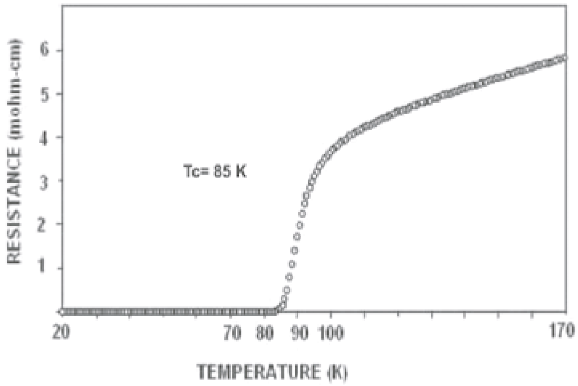


**Figure 3.** Resistance versus temperature plot of whisker.

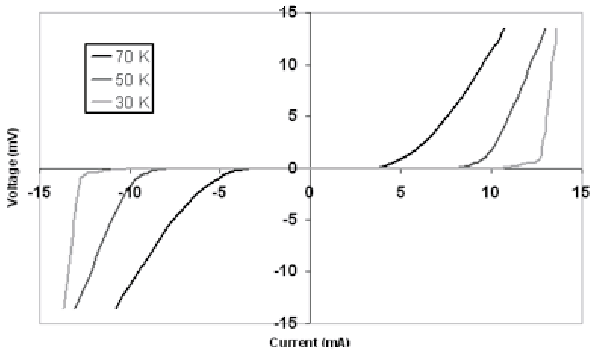


**Figure 4.** I-V characteristics of the cross junction at different temperatures.

## 4. Conclusion

Single crystal superconducting Bi-2212 whiskers in nano size and cross whiskers junction have been fabricated successfully using a simple method. The superconducting properties showed a single phase transition and significantly high critical current density. The *I*-V results of junction suggested intrinsic Josephson effect which opens a new research area for low temperature electronics.

## References

[1] M. H. Maeda, Y. Tanaka, M. Fukutumi and T. Asano, *Jpn. J. of Appl. Phys.*, **27**, (1998), L209

[2] F. Hamed, S. Gygax and A. E. Curzon, *Supercond Sci. Technol.*, **10**, (1997), 857.

[3] Y. Takano, T. Hatano, A. Fukuyo, *Supercond Sci. Technol.*, **14**, (2001), 765.

[4] Y. Q. Zhou, Z. J. Chen, H. Jin P. Zheng, W. H. Wang, *Supercond. J. Crystal Growth.*, **204**, (1999), 289.

[5] S. Ramanathan, Z. Li and K. R. Chandar, *Physica C.*, **289**, (1997), 192.

[6] F. Hamed, S. Gygax, A. E. Curzon and M. Denhoff, *J. Crystal Growth.*, **152**, (1995), 280.

[7] H. Jin, S. Skwirblies and J. Kotzler, *J. Crystal Growth.*, **207**, (1999), 154.

[8] J. M. Tarascon, W. R. McKinnon, P. Barboux, D. M. Hwang, B. G. Bagley, L. H. Greene, and G. W. Hull, *Phys. Rev. Lett.*, **38**, (1988), 8885.

[9] R. Klainer, F. Steinmeyer and P. Muller, *Phys. Rev. Lett.*, **68**, (1992), 2394,