INVITED

IN IIB-1

# Growth and Application of High-$T_c$ Whiskers

T. Hatano*, S. Kawakami, M. Ohmori, A. Fukuyo, M. Nagao, K. Inomata, S. Ikeda, K. Yun, Y. Takano, S-J. Kim, A. Ishii, S. Arisawa, T. Yamashita and M. Tachiki

*National Institute for Materials Science, Tsukuba, Japan.*

We have succeeded in growth of high quality superconducting whiskers of Bi-2212 [1]. Further, Nagao developed Te-doped route which made it possible to grow Bi-22(n-1)n and RE-123 whiskers [2-4]. The dimensions of the whiskers, ~ 10 μm in width, ~ 1 μm in thickness and 1-15 mm in the length, are favorable to apply these single crystals to the various electrical and magnetic experiments, such as "intrinsic Josephson junctions (IJJ) by S-J. Kim [5]" and "cross whiskers junctions by Takano (c-plane twist junction) [6]". Among them, one of the most exciting target is a development of THz band oscillators. The intrinsic Josephson junctions were fabricated in these high-$T_c$ whiskers by a 3-D focused ion beam etching method developed by S-J. Kim [5]. AC Josephson effect and resonance of square lattice Josephson flux-flow to the Josephson plasma predicted by Tachiki [7] was examined by current-voltage characteristics of these IJJs. On the former, we have applied for Bi-2212 and Y-123 inline IJJs and La-214 planer IJJ. On the latter, we have applied Bi-2212 inline IJJ. Besides, the oscillation in R-H curve corresponding to the width of the IJJ and triangular vortex lattice as reported by Ooi [8], we have observed oscillations in $J_c$-H curves corresponding to the square lattice at around 0.8 T. This result is a possible candidate for the realization of the prediction mentioned above. Multi branch spectrum showed a good agreement with the numerical experiments by Machida [9] in which four resonance stages were observed. At the magnetic field where $J_c(H)$ takes minimum in its oscillation (H=0.81 T), multi-branch spectrum corresponding to the resonance of Josephson flux-flow to the Josephson plasma was observed. The voltage jump might be explained that the collective flux-flow of square lattice reached to the phase velocity of the Josephson plasma in Bi-2212 at much lower magnetic field than that reported by H-J. Lee [10].

[1] T. Hatano, Y. Takano, A. Ishii, A. Fukuyo, S. Arisawa and K. Togano: Growth of $Bi_2Sr_2CaCu_2O_{8+\delta}$ whiskers without oxygen stream, Physica C 362 (2001) 296-300.

[2] M. Nagao, M. Sato, H. Maeda, S-J. Kim and T. Yamashita: Growth and superconducting properties of $Bi_2Sr_2CaCu_2O_{8+\delta}$single-crystal whiskers using tellurium-doped precursors: Appl. Phys. Lett. 79(2001)2612.

[3] M. Nagao, M. Sato, H. Maeda, S-J. Kim and T. Yamashita: Growth and superconductivity of $(BiPb)_2Sr_2Ca_2Cu_3O_{10+\delta}$ single-crystal whiskers: Jpn. J. Appl. Phys. 41 (2002) L43.

[4] M. Nagao, M. Sato, H. Maeda, KS Yun, Y. Takano, T. Hatano and S-J. Kim: Superconducting properties of single crystal whiskers of $(Y_{0.86}Ca_{0.14})Ba_2Cu_3O_x$ grown from precursors containing calcium and tellurium: Appl. Phys. Lett. 82 (2003) 1899.

[5] S.-J. Kim, Yu. I. Latyshev and T. Yamashita: Appl. Phys. Lett. 74 (1999) 1156-1158.
[6] Y. Takano, T. Hatano, A. Fukuyo, A. Ishii, M. Ohmori, S. Arisawa, K. Togano and M.Tachiki: d-like symmetry of the order parameter and intrinsic Josephson effects in $Bi_2Sr_2CaCu_2O_{8+\delta}$ cross-whisker junctions, Phys. Rev. B 65,140513(R) (2002).
[7] Tachiki M, Koyama T, Takahashi S, Electromagnetic phenomena related to a low-frequency plasma in cuprate superconductors, Phys. Rev. B. 50: 7065-7084 (1994).
[8] Ooi S, Mochiku T, Hirata K, Periodic oscillations of Josephson-vortex flow resistance in $Bi_2Sr_2CaCu_2O_{8+y}$, Phys. Rev. Lett. 89: 247002 (2002).
[9] M. Machida, T. Koyama and M. Tachiki, Direct numerical experiments for electromagnetic wave emissions with collective Josephson vortex dynamics, Physica C 362 (2001) 16-22.
[10] Dong-In Chang, Myung-Ho Bae, Hyun-Sik Chang, Hu-Jong Lee, Jinhee Kim, Byung-Chill Woo and M. Oda, Collective dynamics of Josephson fluxons in $Bi_2Sr_2CaCu_2O_{8+}$ intrinsic junctions, Phycica C 284 (2003) 297-306.

Corresponding Author:
Takeshi Hatano
Nano Quantum Electronics Group, Associate Director
Nano-materials Laboratory
National Institute for Materials Science
Sengen 1-2-1, Tsukuba, Ibaraki, 305-0047 Japan
HATANO.Takeshi@nims.go.jp
phone: +81(298) 59-2844
FAX: +81(298) 59-2801