広島大学学術情報リポジトリ
Hiroshima University Institutional Repository

Title	Atomic-scale spot structures and gap distributions on apical-fluorine cuprate superconductor Ba2Ca5Cu6O12 (O1-x, Fx)2 observed by STM/STS
Auther(s)	Sugimoto, A.; Shohara, K.; Ekino, T.; Watanabe, Y.; Harada, Y.; Mikusu, S.; Tokiwa, K.; Watanabe, T.
Citation	Physica C: Superconductivity and its Applications , 470 : S160 - S162
Issue Date	2009-12
DOI	10.1016/j.physc.2009.12.004
Self DOI	
URL	http://ir.lib.hiroshima-u.ac.jp/00046730
Right	Copyright (c) 2009. This manuscript version is made available under the CC-BY-NC-ND 4.0 license http://creativecommons.org/licenses/by-nc-nd/4.0/ This is not the published version. Please cite only the published version. この論文は出版社版でありません。引用の際には出版社版をご確認ご利用ください。
Relation	

Hiroshima University Institutional Repository

Atomic-scale spot structures and gap distributions on apical-fluorine cuprate superconductor $Ba_2Ca_5Cu_6O_{12}$ $(O_{1-x},F_x)_2$ observed by STM/STS

A. Sugimoto [a,*], K. Shohara[a], T. Ekino[a], Y. Watanabe[b], Y. Harada[b], S. Mikusu[b], K. Tokiwa[b], T. Watanabe[b]

[a] *Graduate School of Integrated Arts and Sciences, Hiroshima University, Higashi-Hiroshima 739-8521, Japan*

[b] *Department of Applied Electronics, Tokyo University of Science, Chiba 278-8510, Japan*

Abstract

The atomic-scale surface electronic states on the multi-layered apical-fluorine cuprate superconductor $Ba_2Ca_5Cu_6O_{12}$ $(O_{1-x}, F_x)_2$ ($T_C \simeq 70$ K) are investigated by using low temperature scanning tunneling microscopy/spectroscopy (STM/STS). The spatial gap distributions show the patch scale of ~ 0.5 nm, which is quite shorter than the superconducting coherence length $\sim 2-3$ nm of other cuprate superconducters of a few nm. The high-bias (~ 1 V) conductance map contains some characteristic spots with contrasts reverse to those at low bias, which are considered to be due to the charge unbalance of apical atoms such as O^{2-} and F^-.

Key words: Apical fluorine cuprate, F0256, STM/STS.
PACS: 68.37.Ef, 74.25.Jb, 74.72.Hs

1. Introduction

The apical fluorine (F) cuprate superconductors are very attractive materials not only for the high critical temperature (T_C) over 100 K, but also the flexible stacking number of CuO_2 sheets as well as arbitrary carrier-density tuning by doping rate of F [1]. These materials have been investigated by various experimental methods [2, 3, 4, 5, 6]. Among them, the direct observation of local density of states (LDOS) and gap structures with atomic scale are particularly important for the basic understanding of the cuprate superconductivity. However, such LDOS in the apical F cuprates have not been well clarified. In this paper, we present the first observation of the gap and the conductance distribution of $Ba_2Ca_5Cu_6O_{12}$ $(O_{1-x},$ $F_x)_2$ (F0256) with nanometer scale by scanning tunneling microscopy/spectroscopy (STM/STS).

2. Experimental

The F0256 superconducting single crystals ($T_C \sim$ 70 K) were fabricated by a high-pressure synthesis technique [1]. The single crystals were cleaved at 77 K and the exposed surface is considered to be the Ba-F/O layer of c-plane. The STM equipment used in this experiment is commercially based system (Omicron LT-STM) with some modifications [6, 7]. The STM/STS observations were carried out at the temperature of 4.9 K with the ultra-high vacuum condition of $\sim 10^{-8}$ Pa.

3. Results and discussion

Figure 1 (a) shows a gap distribution (Δ map) and an STM topography (inset) on the cleaved F0256 surface. The STM topography, which is related to

LDOS, shows randomly-distributed bright spot structures with a size of ~ 0.5 nm [6]. The Δ map also shows a similar spot structure. Its characteristic size ($2\xi_\Delta$), defined as the full width of half maximum of autocorrelation analysis, is quite shorter than those of other Bi-based cuprates: $2\xi_\Delta \simeq 0.45$ nm for F0256 and ~ 3 nm for Bi2212[8]. Therefore, the length of $2\xi_\Delta$ for F0256 is also considerably shorter than the superconducting coherence length of the other cuprate superconductors, $\xi_0 \sim 2-3$ nm. We consider that the inhomogeneous LDOS is probably related to the distribution of such apical oxygens and/or fluorines. Then, these apical atom disorders should induce the pseudogap state. The disordered apical atoms are believed to affect the carrier density of the nearest CuO_2 layer and stabilize the pseudogap [8, 9].

To clarify the properties of these spots, the measurements of the high-bias conductance spectra (-1.0 V to $+1.0$V) were carried out. Fig. 1(b) and (c) show the conductance map at $V = 0.65$V and $V = 1.00$V, respectively. The small black (partly white) dots indicate the spot positions identified by the STM topography. The conductance map at $V = 0.65$ V show random spot structures which are almost same as those of the STM topography. On the other hand, at $V = 1.00$ V, some spots show the reversed contrast (indicated by the white dots in Fig. 1(c)).

Figure 2 show the typical examples of the high-bias dI/dV curves taken on the different kinds of spots. The curves A and C represent the averaged dI/dV curves at the bright area ($G > 0.6$ nS) and at the dark (reversed contrast) spot area ($G < 0.25$ nS) on Fig. 1(c), respectively. The curve B shows the medium conductance area ($G = 0.4$ nS ~ 0.5 nS) on Fig. 1(c) for reference. Obviously, the curve C shows a large peak structure at $V \sim 0.7$ V, while the curve A is monotonically increasing as the bias voltage increases. This dI/dV peak is considered to be due to the charge unbalance of anions such between F^- and O^{2-} in apical sites. Namely, such dark spots may correspond to the positions of the replaced F and/or the irregular configuration of these anions. However, at present, no clear correlation is found between the Δ map and such dark positions, indicating that these irregular configurations do not simply affect the inhomogeneity of the gap.

4. summary

The STM/STS observations of the $Ba_2Ca_5Cu_6O_{12}$ $(O_{1-x}, F_x)_2$ superconductor were carried out. The gap distribution shows the characteristic length scale of ~ 0.5 nm, which is much shorter than that of Bi-based cuprate and the superconducting coherence length of the other cuprate superconductors.

The conductance map at 1.00 V shows some spots with reversed contrast structures, which are considered to be due to the charge unbalance of apical sites.

References

[1] A. Iyo, M. Hirai, K. Tokiwa, T. Watanabe, Y. Tanaka, Physica C 392-396 (2003) 140.

[2] Y. Chen, A. Iyo, W. Yang, X. Zhou, D. Lu, H. Eisaki, T. P. Devereaux, Z. Hussain, Z.-X. Shen, Phys. Rev. Lett. 97 (2006) 236401.

[3] N. Miyakawa, H. Haya, A. Iyo, Y. Tanaka, K. Tokiwa, T. Watanabe, T. Kaneko, Int. J. Mod. Phys. B 21 (2007) 3233.

[4] P. M. Shirage, D. D. Shivagan, Y. Tanaka, Y. Kodama, H. Kito, A. Iyo, Appl. Phys. Lett. 92 (2008) 222501.

[5] S. Shimizu, T. Sakaguchi, H. Mukuda, Y. Kitaoka, P.M. Shirage, Y. Kodama, and A. Iyo, Phys. Rev. B 79 (2009) 064505.

[6] A. Sugimoto, K. Shohara, T. Ekino, Y. Watanabe, Y. Harada, S. Mikusu, K. Tokiwa, T. Watanabe, Physica C 469 (2009) 1020.

[7] T. Ekino, T. Takasaki, R. A. Ribeiro, T. Muranaka, J. Akimitsu, J. Phys.;Conf. Ser. 61 (2007) 278.

[8] A. Sugimoto, S. Kashiwaya, H. Eisaki, H. Kashi-
waya, H. Tsuchiura, Y. Tanaka, K. Fujita, S.
Uchida, Phys. Rev. B 74 (2006) 094503.

[9] K. Fujita, T. Noda, K.M. Kojima, H. Eisaki, and
S. Uchida, Phys. Rev. Lett. 95 (2005) 097006.

Figure Caption

Figure 1 (a) Gap (Δ) map and STM topography
($I_t = 0.25$ nA , $V_{sample} = 0.8$V) on F0256. The Δ is
defined as the lowest peak voltage at the positive bias
side. The conductance map areas are identical with
the Δ map. (b), (c) Conductance map at $V_{sample} =$
0.65 V (b) and 1.00 V (c).

Figure 2 Averaged dI/dV spectra at bright spot
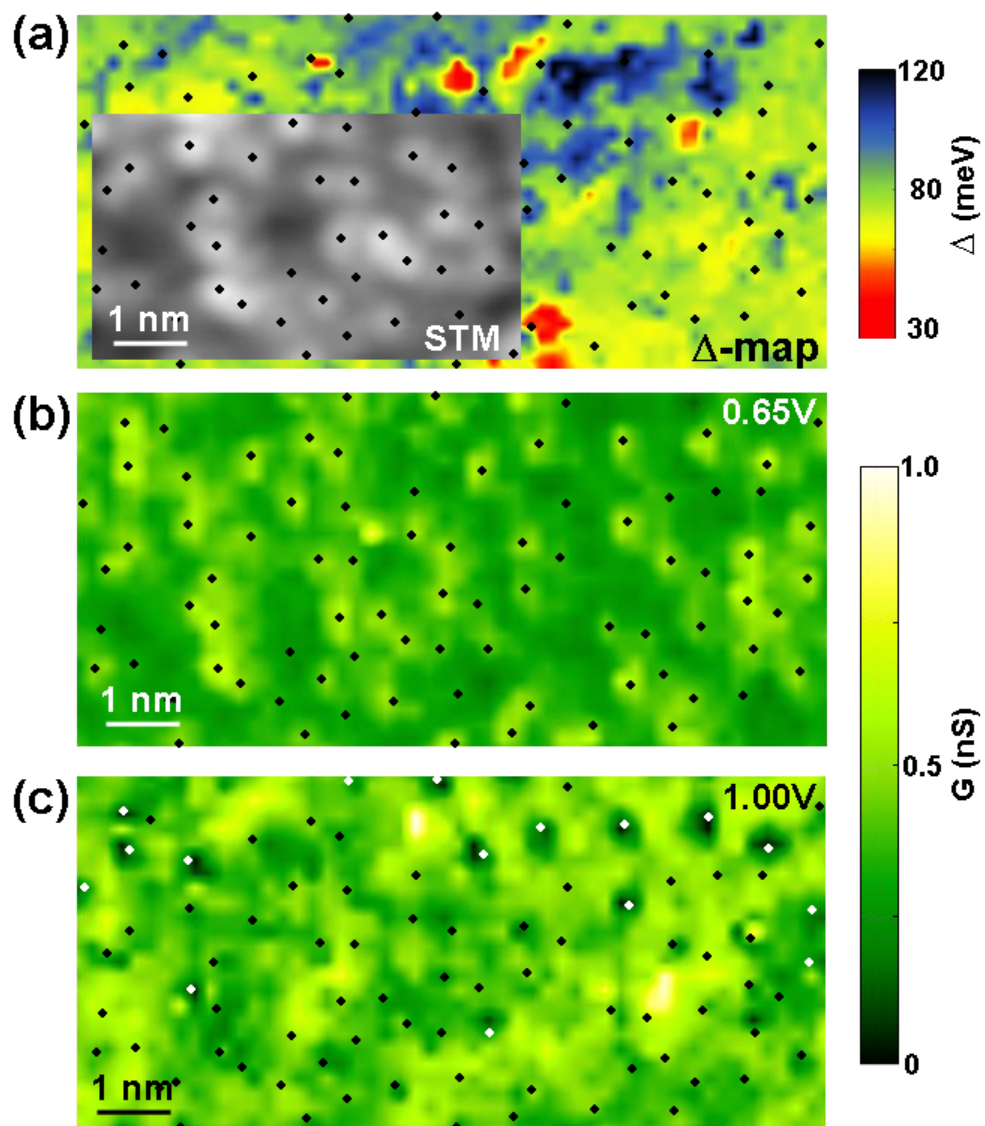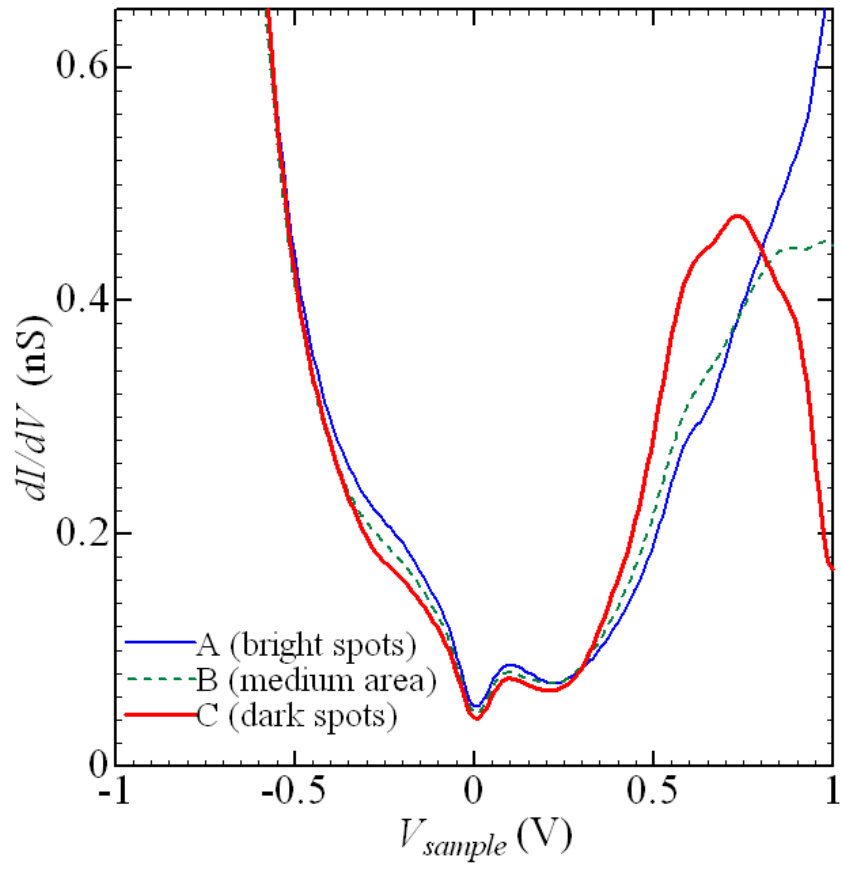areas (A), medium areas (B), revarsal spot areas(C)
.

(a)

1 nm

STM

Δ-map

120

Δ (meV)

80

30

(b)

0.65V

1 nm

1.0

G (nS)

0.5

0

(c)

1.00V

1 nm

Fig. 1

Fig. 2