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Scanning Tunneling Spectroscopy of $YBa_2Cu_3O_y$ and $M/YBa_2Cu_3O_y$ Thin Films†

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A scanning force microscope and/or a scanning tunneling microscope were used to probe the surface morphology and the tunneling spectroscopy of $YBa_2Cu_3O_y$ (YBCO) and $M/YBa_2Cu_3O_y$ (M/YBCO) thin films, M= Ag, Au, etc.. The tunneling spectroscopy of YBCO and M/YBCO thin films disclosed gap structures and Coulomb staircases in its I-V curves. The results are discussed.

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PACS. 73.40.Gk– Tunneling.

The Scanning Tunneling Microscope (STM) and/or Scanning Force Microscope (SFM) have both been widely used to characterize the surface morphology [1,2], the STM being able to do tunneling spectroscopy [3-4], investigating the charging effects [5-6] and the flux lattices [7] etc.. The tunneling spectroscopy of single crystals [3] or thin films [8] is quite often reported in literatures. However, seldom were experiments done on the tunneling spectrocopy of the proximity bilayer $M/YBa_2Cu_3O_y$ system, M = metals. In this paper we report the surface morphology and tunneling spectroscopy of $YBa_2Cu_3O_y$ and $M/YBa_2Cu_3O_y$ films.

YBCO and bilayer M/YBCO (M = Ag, Au etc.) thin films were prepared in situ by off-axis radio frequency magnetron sputtering or the pulsed laser ablation. YBCO and M targets were mounted face to face in a vacuum chamber, with M = Ag or Au. The chamber was evacuated by mechanical and diffusion pumps. The base pressure of the vacuum system was about 2×10^{-6} Torr. YBCO films were deposited onto the $SrTiO_3(001)$ or $MgO(001)$ substrates at 700 °C in a mixture of Ar and O_2 (3:7) at a pressure of 300 mTorr. After the growth of the YBCO films, one atmosphere of oxygen was introduced into the sputtering chamber and the YBCO films were cooled down to room temperature at a rate of 5 °C per minute and maintained at 600 °C for an hour during the cooling process. YBCO films prepared by these processes showed $T_{c,zero} = 88 \sim 90$ K on $SrTiO_3(001)$ and

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$T_{c,zero} = 86 \sim 88$ K on MgO(001) substrates. For the growth of M/YBCO films, M = Ag or Au film was deposited onto the grown YBCO film in pure argon gas at a pressure of 50 ~ 100 mTorr without breaking the vacuum chamber.

The tunneling spectroscopy and surface morphology were investigated with Scanning Force Microscope (STM) and/or a Scanning Tunneling Microscope (SFM) (Park Scientific Inc.). The tunneling spectroscopy was measured at temperatures below $T_{c,zero}$ of YBCO and M/YBCO films with a low temperature STM cryostat while the surface morphology was performed with contact SFM in contact mode in air at 295 K. Tungsten tip was used in STM measurements.

Figure 1 shows resistance as a function of temperature and surface morphology of a Au/YBCO film (sample a) on MgO(001) probed by SFM. In the resistivity and tunneling measurements, the sample was patterned to a geometry shown in the inset of Fig. la. The Au film was 15 nm thick. A resistive tail was observed and $T_{c,zero}$ of the YBCO film was about 80 K. We attributed the presence of superconductivty of Au/YBCO films to the effect of the proximity effect. A detailed study of the proximity effects of Ag/YBCO films will be reported elsewhere.

Figure 2 shows $I-V$ and dI/dV curves as a function of temperature at T = 10.4 K for sample a taken at a certain position of the sample. The $I-V$ curve shows periodic staircases with a voltage period $\Delta V = 2$j mV. The Au film of 15 nm thick is granular and forms islands on the surface of the YBCO film. The surface of the YBCO film is insulating. hence a capacitance was formed between Au islands and the YBCO film. In addition, the STM tip and Au island formed a capacitance and the capacitance can be varied by changing the distance betneen the tip and the sample. The tunneling can be simulated by a two junctions model. In this model two junctions with capacitance C_1 and C_2 were connected in series. If two-junctions model [8] can be applied to explain behavior of the $I-V$ curve. The effective capacitance C_{eff} of the junction is $C_{eff} = e/\Delta V = 6.4 \times 10^{-18}$ F. We roughly estimated the effective junction capacitance from the equation [9]: $\Delta I \times R = e/C_{eff} = \Delta V$. where ΔI is the average value of the current width, $R = V_t/I_t$ (tunneling voltage devided by tunneling current) and e is the electronic charge, and obtained $C_{eff} \sim 5.3 \times 10^{-18}$ F, a value close to that obtained previously.

Figure 3 show the $I-$ V and dI/dV curves of a Ag/YBCO film at 11.7 K. The Ag layer was 200-250 Å thick. dI/dV curves show features similar to that observed in Fig. 2. The modulation voltage AV was about 6 mV, a value is smaller than that shown in Fig. 2. A smaller AV value was observed because a larger junction capacitance was formed between Ag island and the YBCO film.

Figure 4 shows dI/dV curves of a YBCO film (sample b) on $SrTiO_3$(001) at various temperatures. The dI/dV curve disclosed a gap structure with multiple peak structures for energy above the energy gap. The peak features above the energy gap was probably due to the charging effects mainsioned previously. Taking the finite lifetime of quasiparticle recombination into account and using the Dyne equation [10]:

$$dI/dV = N_s(E)/N_N(E) = Re[(E - i\Gamma)/((E - i\Gamma)^2 - \Delta^2))^{1/2}], \quad (1)$$

where $\Gamma = h/\tau$ is the broading parameter, τ is the life time of quasi-particle, to fit the tunneling conductance, we obtained the gap value as shown in Fig. 5 with $2\Gamma_{Dyne}/k_B T_c =$

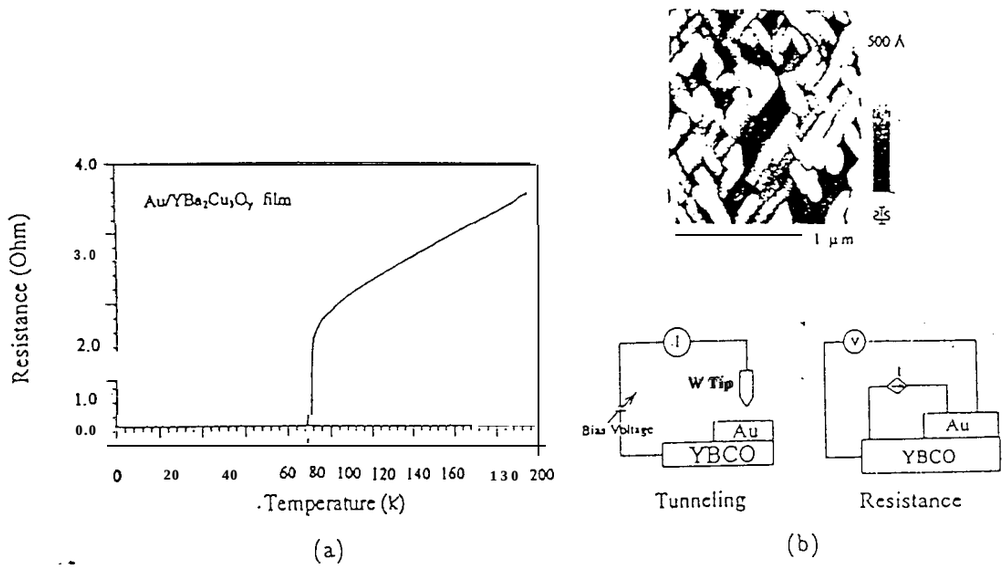

FIG. 1. (a) Resistance as a function of temperature and (b) surface morphology probed by SFM for a Au/YBCO film (sample a). The scanning area of SFM was 1.2 x $1.2\mu m^2$. The inset of Fig. lb shows the geometry of a Au/YBCO film in the measurements of the tunneling spectroscopy and resistivity.

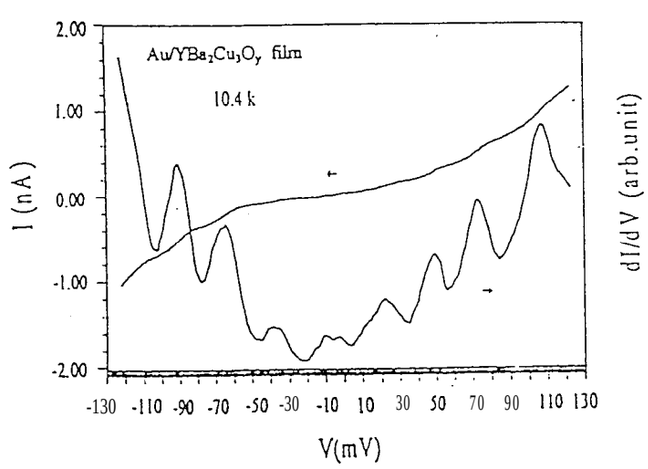

FIG. 2. Shows I − V and dI/dV curves as a function of temperature at T = 10.4 K for sample a taken at a certain position of the sample.

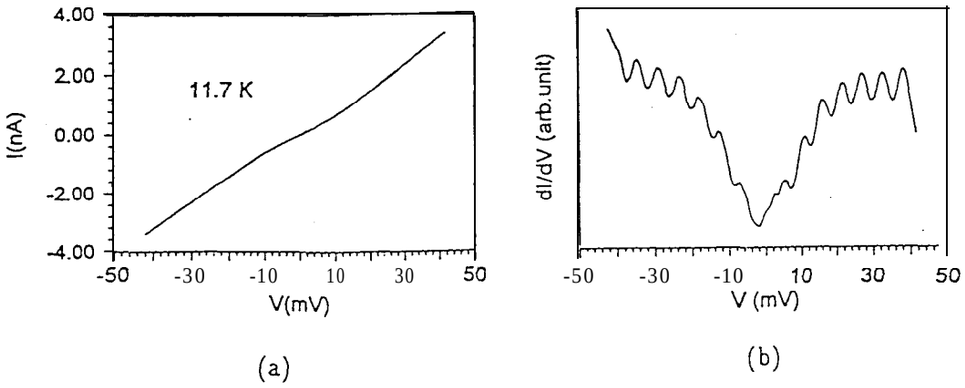

FIG. 3. (a) $I-V$ and (b) dI/dV *curves* of a Ag/YBCO film at 11.7 K.

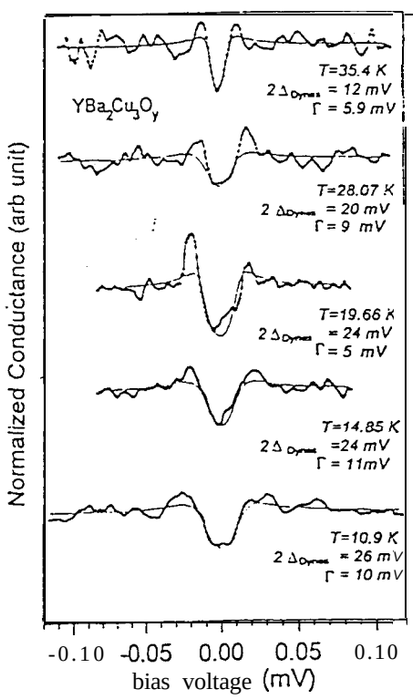

FIG. 4. dI/dV curves of sample b at 10.9, 14.85, 19.66, 28.07 and 35.4 K. The results of the fitting of quation (1) to the data are plotted in solid line.

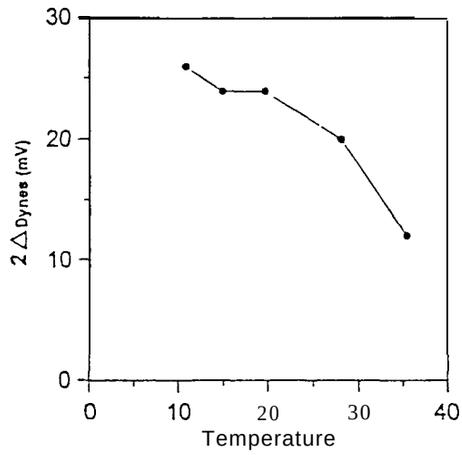

FIG. 5. Temperature dependence of Δ_{Dyne} for sample b

3.39 at T = 10.9 K. The Dyne equation implies the phonon-induced quasiparticle recombination causes the essential smearing of the conductance *curves.*

The tunneling spectroscopy of YBCO and M/YBCO thin films disclosed gap structures and Coulomb staircases in I − V curves. The gap value is $2\Delta_{Dyne}$ = 26 meV and $2A_{Dyne}/K_BT_c$ = 3.39 at 10.9 K for a YBCO film on $SrTiO_3(001)$ with T_c = 89 K.

References

[1] C. K. Shih, R. M. Feenstra, and G. V. Chandrashekhar, Phys. Rev. B43, 7913 (1991).
[2] Sufen Chen, L. M. Wang, W. B. Jian, S. Y. Wang, and H. C. Yang, J. Appl. Phys. 76, 2.535 (1994).
[3] Jeffrey, Qun Chen, K.-W. Ng, and H.-J. Tao, Phys. Rev. Lett. 72, 128 (1994).
[4] H. L. Edwards, J. T. Markert, and A. L. de Lozanne, Phys. Rev. Lett, 69, 2967 (1992).
[5] S. T. Ruggiero, and S. B. Barner, Phys. Rev, B36, 8870 (1987),
[6] P. J. M. van Bentum, R. T. M. Smokers, and H. van, Kempen, Phys. Rev. Lett. 60, 2543 (1988).
[7] H. F. Hess, C. A. Murray, and 3. V. Waszezak, Phys. Rev. Lett. 69. 2138 ' (1992).
[8] M. Arnman, S. B. Field, and R. C. Jaklevic, Phys. Rev. B48, 12104 (1993).
[9] M. D. Kirk, Ph. D. thesis, *Low Temperature* Scanning Tunneling *Spectroscopy*, Edward L. Ginzton Laboratory, W. W. Hansen Laboratories of Physics, (Stanford University 1989).
[10] R. C. Dynes *et* al. Phys. Rev. Lett. 41, 1509 (1978).