

Superconductivity and Electric Field Effects in Ultrathin $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ Films

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Effect of adjacent insulating cap oxide layers on superconductivity of one unit cell thick (1-UCT) $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (YBCO) layers in $\text{PrBa}_2\text{Cu}_3\text{O}_{7-\delta}$ /YBCO/insulating oxide trilayers has been studied. It is found that the small lattice mismatch between YBCO and the cap oxides, in addition to divalent A ions in atomic AO layers subsequent to the $\text{CuO}_{1-\delta}$ terminated surface, is a requirement for superconductivity in 1-UCT YBCO layers. The change in the normal state resistance is well explained by the field-induced change of carrier density.

Keywords: High- T_c superconductivity / $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ / Ultrathin film / One-unit-cell / Charge reservoir block / Electric field effect

Ultrathin films and superlattices of high- T_c superconductors have been extensively studied to elucidate the minimum unit for the occurrence of high- T_c superconductivity and interlayer coupling of the CuO_2 layers. High- T_c superconductors are characterized by two dimensional CuO_2 layers, which are separated by the charge reservoir blocks. A stringent test of the intrinsic nature of the high- T_c superconductors characterized by layered structures can be obtained from transport measurements on one unit cell thick (1-UCT) layer of the superconductor. The smaller carrier density of high- T_c superconductor than that in metal superconductor enables the change of carrier density by applying electric fields. The ultrathin films are expected to exhibit remarkable field effects in T_c and other properties.

In the preparation of such ultrathin layers, we

need the deposition technique which enables us to prepare epitaxial films with excellent superconducting properties, precise layer thicknesses and smooth surfaces. We have used a molecular beam epitaxy (MBE) system equipped with reflection high energy electron diffraction (RHEED), which enables real-time, *in situ* layer thickness monitoring by specular beam intensity oscillations [1].

We have found that superconductivity can occur at finite temperatures in the single layer of 1-UCT $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (YBCO) sandwiched between nonsuperconducting $\text{PrBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (PrBCO) layers [2] and the minimum unit needed for the occurrence of superconductivity is the CuO_2 bilayer sandwiched between the charge reservoir blocks, as shown in Fig. 1(a) [3]. It has been reported that the terminating surface of

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Scope of research

Syntheses of oxide thin films by reactive evaporation and ceramics by solid state reaction and their characterizations are studied. The main subjects are: preparation and characterization of ultrathin films of high- T_c superconductors: investigation of growth mechanism of thin films by *in situ* reflection high-energy electron diffraction: phase diagram of Bi_2O_3 - SrO - CaO - CuO system: growth and characterization of single crystals of Bi - Sr - Cu - O system: preparation and observation of dielectric properties of ferroelectric thin films: preparation and characterization of metallic and ferromagnetic SrRuO_3 thin films: scanning tunneling microscope observation of surface structures and electronic states of metallic oxide thin films



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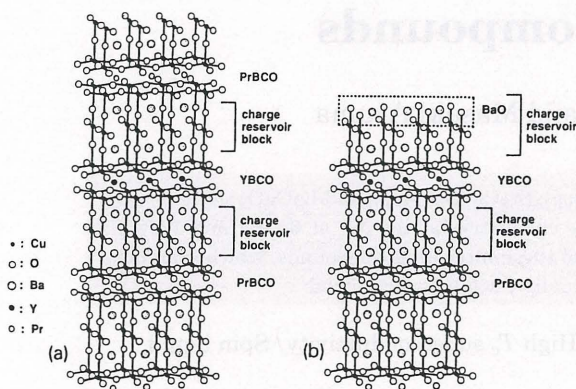


Figure 1. Structures of trilayers of (a) PrBCO/1-UCT YBCO/1-UCT PrBCO and (b) PrBCO/1-UCT YBCO/BaO. Note that the CuO_2 bilayer interposing an Y layer is sandwiched between the charge reservoir blocks and the terminating layers of growing YBCO and PrBCO are the $\text{CuO}_{1-\delta}$ layer.

the YBCO layer grown by MBE is the $\text{CuO}_{1-\delta}$ layer. As a result, the 1-UCT YBCO layer on the buffer PrBCO layer needs an addition of the BaO layer for the completion of the charge reservoir block, as shown in Fig. 1(b). It is found that the capping of the 1-UCT YBCO layer with BaO makes the 1-UCT layer superconducting.

In place of BaO layers, the effects of other alkaline-earth metal oxide "AO" caps on the superconductivity of the samples have been examined. The experimental results are summarized as a function of lattice mismatch value in Fig. 2. We can conclude that divalent metal ions in AO layer adjacent to the $\text{CuO}_{1-\delta}$ layer, in systems with mismatch values ($<6\%$) exhibit superconductivity in PrBCO/1-UCT YBCO/cap oxide trilayers.

We have studied electric field effects in ultra-thin YBCO films using heterostructures of $\text{Ag}/\text{BaTiO}_3(200\text{nm})/\text{SrTiO}_3(1.5\text{nm})/\text{YBCO}/\text{SrTiO}_3(\text{substrate})$ [4]. Gate voltage, V_{gate} , dependence for 2-UCT YBCO at 72.8K is shown in Fig.3. The application of negative voltage to the Ag electrode, i.e. the YBCO layer is positively charged, lowers the resistance of YBCO layer linearly in V_{gate} , while a positive V_{gate} having the opposite effect. The field induced change of the resistance $\Delta R/R$ is 0.5% for the applied field of 0.5V.

Observed $\Delta R/R$ in the normal state can be explained by the field induced carriers (ΔN). In the present experiment, field induced charge ΔN in the areal density is evaluated as follows.

$$\Delta N = \Delta Q/e, \Delta Q = CV_{\text{gate}}/S, N = nd,$$

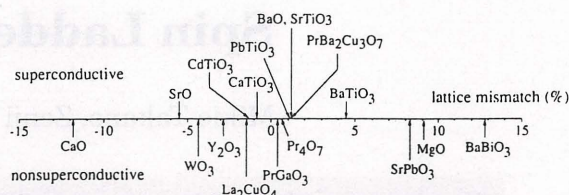


Figure 2. Effect of cap oxides on superconductivity in 1-UCT YBCO as a function of value of lattice mismatch to YBCO.

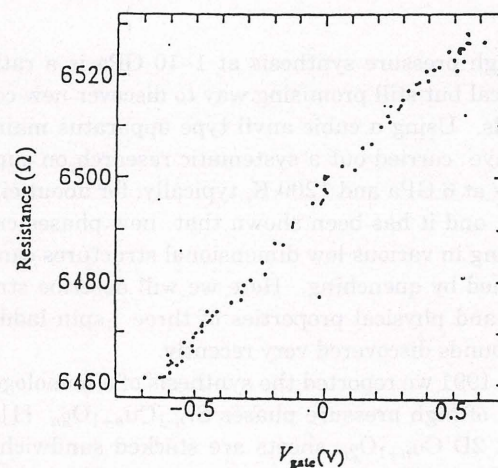


Figure 3. Gate voltage, V_{gate} , dependence of resistance for 2-UCT YBCO at 72.8K.

where S is area of electrode, N is total carrier of YBCO layer, d is the thickness of YBCO layer and n is carrier density of bulk YBCO. $\Delta N/N$ is evaluated to be 0.55% by using the values of $n=5 \times 10^{21}(\text{cm}^{-3})$, $C=500(\text{nF})$ and $S=2.2 \times 10^{-1}(\text{cm}^2)$. The observed $\Delta R/R$ is in good agreement with the change of the carrier density, $\Delta N/N$.

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