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Effect of a SrF_2 Interlayer on Epitaxial Growth of InAs on $EuBa_2Cu_3O_{7-y}$ Superconducting Films

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A SrF_2 interlayer, to prevent reaction at the interface between superconducting $EuBa_2Cu_3O_{7-y}$ (EBCO) and narrow band-gap InAs overlayers, has been proposed. Photoemission spectroscopy studies show the effectiveness of the SrF_2 interlayer in preventing both removal of oxygen from the EBCO surface and oxidation of the InAs overlayer. The InAs shows highly (111) oriented and its X-ray diffraction linewidth is about 950 arcsec with a thickness of 1 μm.

§ 1. Introduction

Growth of semiconductor films on high-temperature superconductors (HTS) has the attractive feature of combining conventional semiconducting devices with superconducting devices.[1] However, growth of semiconductor films on HTS oxidizes the semiconductor films and reduces the superconductivity of the underlying HTS at the interface because of oxygen instability near the HTS surface region.[2]

This study proposes a SrF_2 interlayer to prevent reaction at the interface between superconducting $EuBa_2Cu_3O_{7-y}$ (EBCO) and narrow band-gap InAs overlayers. SrF_2 is an interesting material as an insulating layer for semiconductor-on-insulator (SOI) systems, and seems to be a promising candidate as an interlayer between InAs and EBCO because SrF_2 is a close structural match for both InAs and EBCO. The superconducting EBCO films used here is smooth and fully c-axis oriented with T_c endpoints of $\sim$90 K.[3] InAs was selected because n-type InAs has a high electron mobility, light electron effective mass and a negative Schottky barrier.[4] Experimental results on the effectiveness of the interlayer, as studied by synchrotron-radiation photoemission spectroscopy (SRPES) and x-ray photoemission spectroscopy (XPS) are presented.

§ 2. Experimental

The EBCO thin films were deposited on MgO(001) using planar-type magnetron sputtering with a typical film thickness of about 300 nm.[3] SrF_2 deposition, InAs growth, and in situ surface analysis were performed at the National Laboratory for High Energy Physics, Photon Factory on beam line BL-1A. The SrF_2 was deposited from resistively heated tungsten baskets in a sample preparation chamber while InAs was grown by molecular beam epitaxy (MBE) in an MBE chamber. Photoelectrons were measured with a hemispherical angle-integrated type analyzer with an electrostatic lens in the analysis chamber. SRPES and XPS spectra were taken with a monochromatized synchrotron radiation source ($h\nu$ = 76 eV) and an Al Kα x-ray source ($h\nu$ = 1486.6 eV). The total energy resolution for the SRPES and XPS measurements were 0.3 eV and 1.1 eV respectively.

The fabrication sequence of InAs layers on EBCO films with SrF_2 interlayers was as follows. EBCO surfaces were first cleaned by heating the EBCO substrate up to 300°C in vacuum.[2] Then, 1 to 30 monolayers (ML) of SrF_2 were deposited on the clean surface at room temperature followed by electron beam (EB) or As_2 flux exposure (as described later in the text) onto the SrF_2 surface to improve wettability between InAs and SrF_2. Next, InAs was grown at various temperatures up to 200°C with various thicknesses from the order of monolayers to 1 μm. In MBE growth, conventional effusion cells containing solid arsenic (As_4) and indium were used as sources. The InAs deposition rate was set at 0.5 ML/sec with a As_4/In flux ratio on the order of 10. The MBE growth chamber was surrounded by liquid nitrogen shrouds. The background pressure was 5×10^{-10} Torr and the base pressure during growth was typically about $3\times10^{-}$

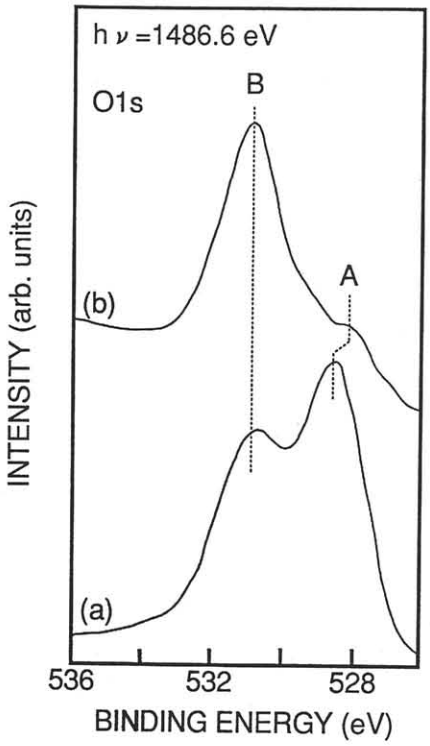

Fig. 1 The O1s XPS spectra for a 2-ML InAs sample grown at room temperature without a SrF_2 interlayer: (a) clean surface by heating the EBCO substrate up to 300°C and (b) 2-ML InAs-grown surface.

7 Torr. The substrate temperature was measured with an optical pyrometer.

§ 3. RESULTS AND DISCUSSION

Figure 1 shows a typical result of the O1s XPS spectra for a 2-ML InAs sample grown at room temperature without a SrF_2 interlayer. Figure 1(a) is the O1s from the clean surface and figure 1(b) is from the 2-ML InAs-grown surface. By InAs deposition, the additional As-induced O1s peak (peak B) at a binding energy of around 530.5 eV grows, whereas the O1s bulk emission peak (peak A) becomes attenuated, indicating that the EBCO surface region was degraded due to the removal of oxygen from the EBCO surface and the formation of As-O and/or In-O bonds even at room temperature.

Then, we tried to insert the SrF_2 interlayer between EBCO and InAs. However, it is found that InAs cannot be grown on as-deposited SrF_2 surfaces because As_4 is hardly adsorbed onto the fluorine atoms which are lying at the SrF_2 top layer. Therefore, electron beam exposure on the SrF_2 surface was tried and was successful in improving the wettability between InAs and SrF_2.[5] Table I shows the As3d/In4d photoemission intensity ratio with EB exposure onto the SrF_2 surface. The calculated [As3d]/[In4d] ratio is also included based on photoionization cross sec-

Table I The As3d/In4d photoemission intensity ratio

	[As3d]/[In4d] ratio
Calculated	0.657
Experimental	0.61

tions. As shown in Table I, the InAs layer grown on the EB irradiated SrF_2 surface, even at room temperature is stoichiometric. However, it is difficult to obtain macroscopically uniform surfaces because a scanning electron-beam scanning technique was used. To solve this, a novel SrF_2 surface treatment method was tried. This consisted of exposing the SrF_2/EBCO to As_2 flux prior to InAs growth. As_2 vapor flux was evaporated from a conventional effusion cell containing GaAs blocks. Figure 2 shows the As3d SRPES spectra at two stages: (a) after As_2 flux exposure and (b) after InAs growth. The As3d peak in the elemental As state at around 41 eV binding energy appears after As_2 exposure at room temperature. Moreover, the As-oxide peak at about 45 eV binding energy is not observed after InAs growth on the SrF_2 surface at room temperature.[2] Figure 3 shows the O1s XPS spectra during the same growth process as shown in Fig. 2. The spectral features are not significantly affected by both SrF_2 deposition and InAs growth, which demonstrates the effectiveness of the SrF_2 interlayer in preventing removal of oxygen

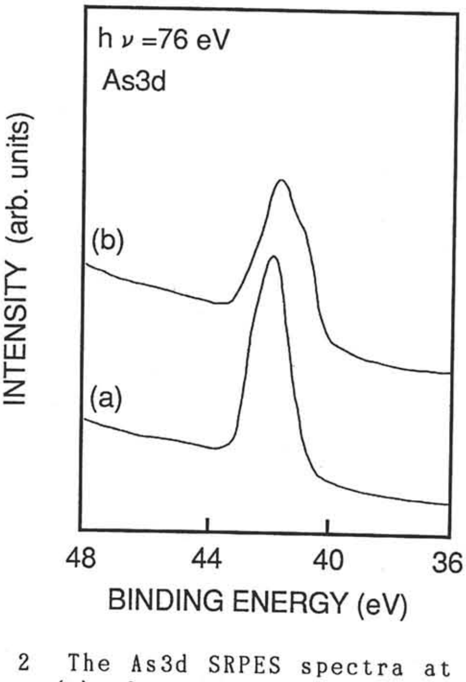

Fig. 2 The As3d SRPES spectra at the two stages: (a) after As_2 flux exposure and (b) after InAs growth at room temperature.

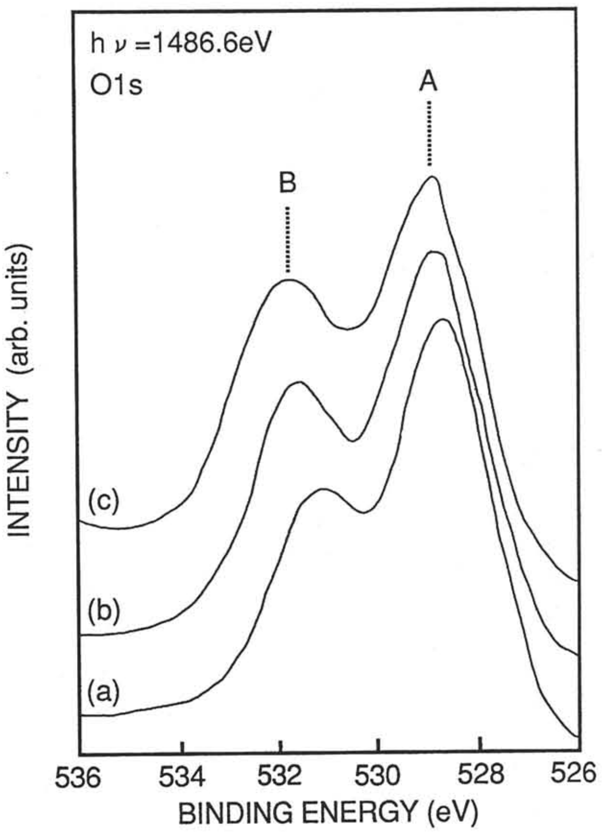

Fig. 3 The O1s XPS spectra during the same growth process as Fig. 2. (a) after cleaning at 300 C, (b) after 3-ML SrF_2 deposited at room temperature, and (c) after InAs growth at room temperature.

from the EBCO surface. Furthermore, it is found that the interlayer effectively prevents oxidation of the InAs overlayer, as verified by the fact that the As3d peak in the As-oxide state does not appear.

Using a SrF_2 interlayer followed by As_2 exposure, 1-μm-thick InAs layers were sucessfully grown on SrF_2-coated EBCO thin film substrates using a two-step growth procedure. An initial InAs layer was grown at room temperature and then the substrate temperature was raised to 200°C. Following this, a top InAs layer was grown with a total InAs layer being 1 μm thick. Figure 4 shows the surface morphologies of (a) the EBCO thin film and (b) the 1-μm-thick InAs overgrown layer. The EBCO surface is very smooth and the grain boundaries are only slightly visible. The surface appears to be roughened after InAs deposition. However, the InAs grain size is about 300 nm, which is similar to the grain size of the underlying EBCO films. Figure 5 shows the X-ray diffraction pattern of the InAs grown sample. The (111) InAs reflection peak at $2\theta = 25.4^{\circ}$ with a full width at half-maximum of 950 arcsec comfirms that highly (111) oriented InAs layers are obtained.

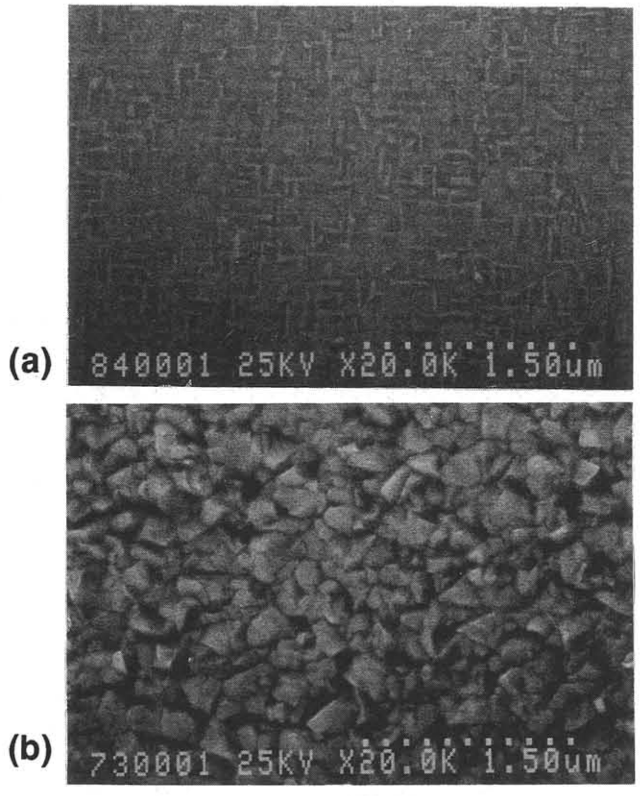

Fig. 4 Surface morphologies: (a) the EBCO thin film and (b) the 1-μm-thick InAs overgrown layer.

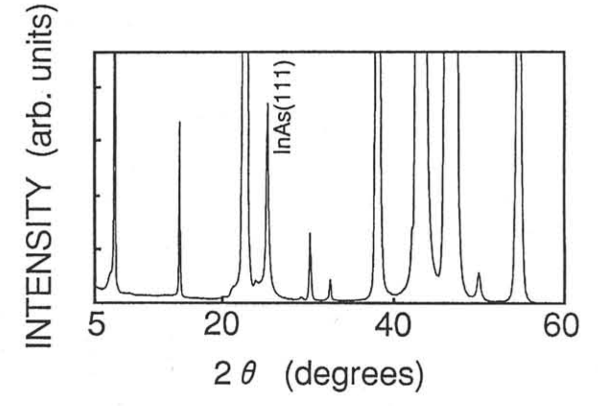

Fig. 5 The X-ray diffraction pattern of the 1-μm-thick InAs grown sample.

In conclusion, a novel technique to grow a narrow band-gap semiconductor InAs on EBCO films has been developed, and verified by synchrotron radiation photoelectron spectroscopy.

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