Structure and Electron Transport of Undoped *n*-SnO Films

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Tin monoxide (SnO) is an attractive *p*-type semiconductor for its relatively high hole mobility. As well as recent intensive studies on thin film transistors using SnO as *p*-channel layers [1-3], there have been several efforts toward its carrier polarity conversion into *n*-type [4-6]. The reports on Y- or Sb-doped SnO films grown by electron beam deposition using SnO_2 targets indicated that the films remained to show *p*-type conductivity [4,5]. On the other hand, Ogo *et al*. reported the fabrication of Sb-doped *n*-SnO films by pulsed laser deposition (PLD) using SnO targets and their electron mobility of approximately 1 cm^2/Vs [6]. Since the doped Sb atoms may deteriorate the electron transportation, undoped *n*-SnO films are attractive. In this study, we report the fabrication of epitaxial undoped SnO films with *n*-type conductivity and their crystal and surface structures, and electric transport properties.

SnO thin films were prepared by PLD using a KrF* excimer laser source on yttria stabilized zirconia (YSZ) (001) single crystal substrates. A compact of high-purity Sn was used as the PLD target. A laser energy of 160 mJ at the target surface with an irradiation spot size of 9.0 mm^2 and a laser frequency of 2 Hz were used. The distance between the target and the substrate was set at 45 mm. The substrate temperature was kept at 473 K and oxygen gas was introduced in order to control the oxygen pressure to be 0.4 or 0.9 Pa during the deposition. After the deposition, the oxygen gas flow was stopped and the films were cooled to room temperature in the chamber pumped down to less than 2×10^{-4} Pa. The crystal structures and crystallinity of the films were investigated using high-resolution five-axes X-ray diffraction (XRD) with Cu-$K\alpha$ radiation. An asymmetric two-crystal Ge monochromator was used against the incident beam. The surface roughness and morphology were observed by atomic force microscopy (AFM). Hall effect measurements were carried out using the van der Pauw method in a temperature range from 200 to 300 K to obtain carrier mobilities and concentrations. Seebeck coefficients were estimated from thermoelectric power measurements. The carrier types of the films were determined with both Hall and Seebeck coefficients. The optical band gaps of the films were estimated from optical transmission spectra measured using a dual beam UV-VIS-IR spectrophotometer.

Both Seebeck and Hall coefficients compatibly indicate that the film grown at the oxygen partial pressure of 0.4 Pa shows *n*-type conductivity while the film prepared at 0.9 Pa is *p*-type. The carrier mobilities at room temperature are 11 cm^2/Vs for the *n*-type film and 2.3 cm^2/Vs for the *p*-type film.

Figure 1(a) shows the XRD 2θ-θ profiles of the films deposited at 0.4 and 0.9 Pa, respectively. Both films show a single phase and *c*-axis oriented growth on the

YSZ substrates. The full widths at half maximum of out-of-plane rocking curves of the 002 diffractions are 1.0° for the 0.4 Pa film and 0.5° for the 0.9 Pa film. The XRD in-plane ϕ scans show that the 200 diffractions of SnO for the 0.4 Pa film exhibits a fourfold rotational symmetry and their peak positions match those of the 220 diffraction peaks of the substrate as shown in Fig. 1(b). This orientation relationship is the same as the results for the 0.9 Pa film and the reported relationship for a *p*-SnO film on a YSZ substrate [1]. AFM observations suggest island growth of SnO. Optical band gap is estimated at 2.8 eV for both films, which is also comparable with the reported value [1].

This work was supported by Grants-in-Aid for JSPS fellows (Grants No. 242558) and Scientific Research on Innovative Areas "Nano Informatics" (grant number 25106005) from JSPS. R.H. was supported in part by the National Key Project for Basic Research of China (Grants No. 2013CB922301 and 2014CB921104).

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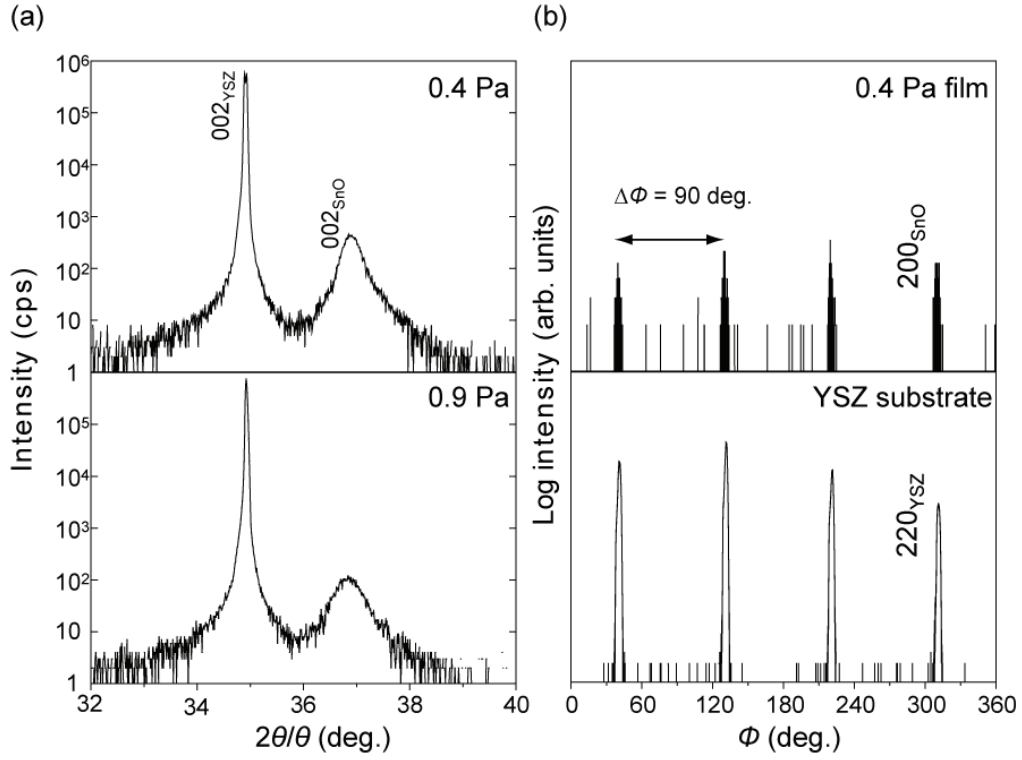

FIG. 1. (a) XRD 2θ-θ profiles of the films grown at the oxygen partial pressure of 0.4 and 0.9 Pa. (b) XRD in-plane ϕ scan of 200 diffractions from the 0.4 Pa film and 220 diffractions from the YSZ substrate.