Ion-Beam Assisted Deposition of p-type Oxide Semiconductor Thin Films in room temperature

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***Abstract* —**
Transparent semiconductor oxides are an important class of materials in materials science, including SnO_2, In_2O_3, ZnO, and dozens of doped transparent semiconductor oxides. These materials have been widely used in various electronic and optoelectronic devices. Tin monoxide (SnO), due to the overlap between its 5s orbital and the oxygen 2p orbital, exhibits unique characteristics that enable hole transport. This makes it one of the most promising candidates for p-type oxide semiconductors. In this study, our p-type SnO thin film achieved a mobility of 4.52 $cm^2 V^{-1} s^{-1}$.

Index Terms* —*Ion Beam Assisted Deposition Evaporation, P-type SnO, room temperature process for tin oxide

I. Introduction

Oxide semiconductors have received extensive research and application in recent years, such as in organic/inorganic solar cells, gas sensors, and thin-film transistors. However, most oxide semiconductors exhibit n-type conductivity, and the hole mobility in p-type conductivity is generally low. SnO, due to the characteristic of its Sn $5s^2$ and O 2p orbitals easily bonding, is considered a promising p-type oxide semiconductor. However, SnO is a metastable phase and can easily further oxidize into crystalline or amorphous forms such as SnO_2 or an intermediate phase.To date, the feasibility of p-type conductivity in SnO has been experimentally demonstrated using several techniques, including reactive magnetron sputtering,[1] atomic layer deposition,[2] pulsed laser deposition,[3] e-beam evaporation[4] and solution process[5]. However, the performance of the prepared SnO still varies greatly depending on the type of sample and the resulting crystal structure. This study demonstrates the process of fabricating p-type SnOx thin films at room temperature using ion beam-assisted deposition (IBAD) technology. Since the technique independently controls ion density through the anode current of the ion gun and the oxygen flow rate, while the anode voltage of the ion gun controls the ion energy, the optical bandgap and hole mobility of SnO films can be optimized [6].

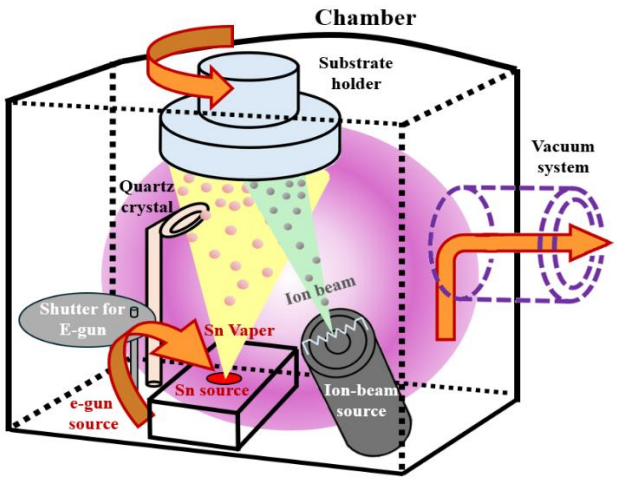


Fig. 1 Schematic components of the IBAD system

II. Material Analysis

A. *Hall Effect Measurement*

In the electrical properties measurement, we discover that the data showed volcano-shaped evolution in Hall mobility inversely in the Ar flow rate, as illustrated in Fig. 2. This result is close to that reported in the literature. [7]Although the SnO film exhibits some degradation over time due to oxidation, this study still demonstrates impressive mobility without annealing.

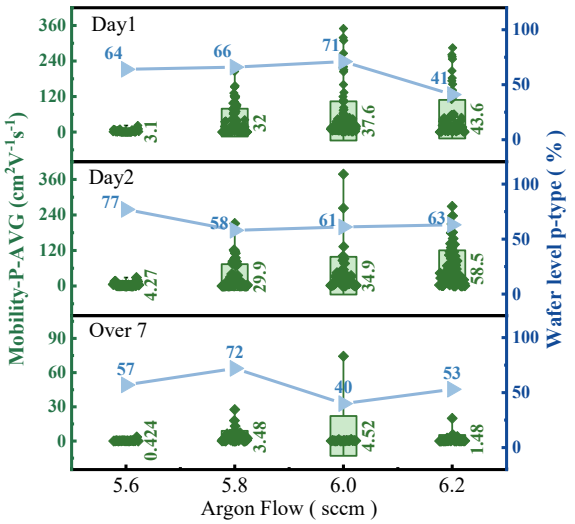
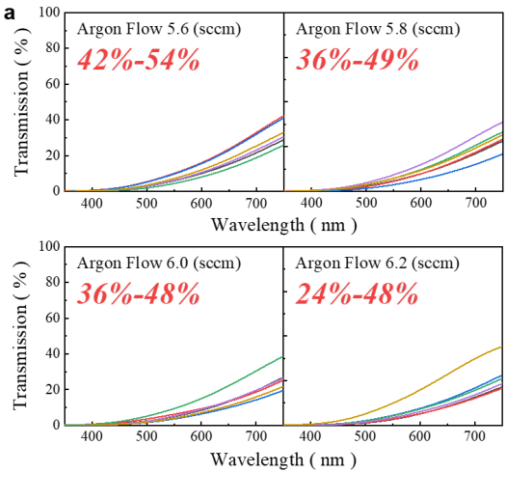


Fig. 2 Each sample was measured 20 times to obtain (a) p-type mobility along with its percentage distribution, and (b) resistivity and carrier concentration values.

B. *UV-vis Measurement*

Optical characterization reveals that, while variations in argon flow rate lead to shifts in the absorption edge, all specimens exhibit the onset of absorption at wavelengths beyond approximately 450 nm. In addition, the direct bandgap energies, determined using the Tauc plot equation, exhibit slight variations as a function of argon flow rate, yet consistently remain below 3.0 eV.



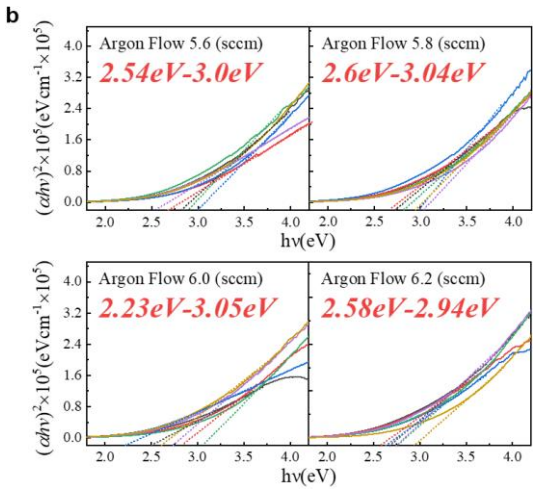


Fig. 3 UV-Vis spectra of samples deposited under different argon flow rates. (a) optic transmission (b) direct bandgap

C. Raman Measurement

According to the literature, SnO thin films exhibit two characteristic Raman peaks at approximately 110 and 210 cm^{-1}. These peaks have been reported to intensify under oxygen-rich and tin-rich conditions, respectively [8]. Specifically, the peak at 110 cm^{-1} is associated with the Sn–Sn vibrational mode within the SnO lattice. An increase in its intensity typically indicates a higher degree of tin atom aggregation, which may be attributed to an increased tin supply during the film deposition process. This observation underscores the significant influence of deposition conditions on both film quality and electrical performance. As shown in Figure 4, the Raman spectra of our samples reveal a pronounced peak at 110 cm^{-1}, suggesting a tin-rich composition relative to oxygen within the film structure. This confirms that the enhanced mobility observed in our p-type SnO thin films can be attributed to the tin-rich deposition conditions employed during fabrication.

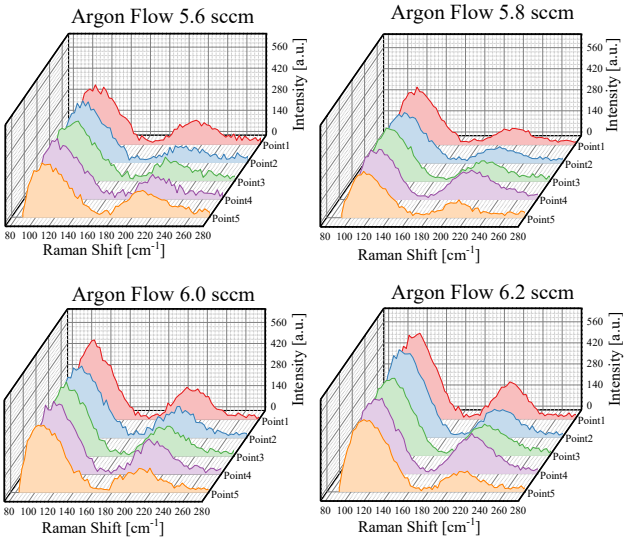


Fig. 4 Raman spectra of samples deposited under different argon flow rates.(Each sample was measured 5 points)

IV. Conclusion

The optimized p-type SnO thin film exhibited a highest mobility and optical transmittance (bandgap) of 4.52 $cm^2 \cdot V^{-1} \cdot s^{-1}$ and 50.5% (2.70 eV), respectively.

By integrating the structural characteristics of SnO with the design of the.

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