Ion-Beam Assisted Deposition of Oxide Semiconductor Thin Films for Optical Devices

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***Abstract* —This study investigated the use of a tin-based oxide (SnOx) semiconductor layer as the active layer for a light-addressable potentiometric sensor (LAPS) on a commercial indium tin oxide (ITO)/glass substrate. We characterized the optical absorption properties of the SnOx layer, as well as changes in Hall mobility and Raman spectroscopy, using ion beam assisted discharge (IBAD) and varying argon/oxygen flow ratios. The experimental results demonstrate the potential of SnOx as an active layer for LAPS, but the stability and lifetime performance of SnOx LAPS require further process optimization.**

***Index Terms* —IBAD Evaporation, P-type SnO, light-addressable potentiometric sensor (LAPS)**

I. Introduction

LAPS (light-addressable potentiometric sensor) is a device based on a modified EIS (electrolyte-insulator-semiconductor) structure. The LAPS structure retains the advantages of EIS, combining its simple structure with a fixed sensing point's light-spot control system. By moving the light source, the LAPS structure enables two-dimensional sensing in a single device.

In recent years, tin monoxide (SnO) has emerged as a promising oxide semiconductor for thin-film transistors (TFTs) owing to its high hole mobility, which originates from the strong hybridization between Sn $5s^2$ and O 2p orbitals. However, SnO is a metastable phase that readily oxidizes into SnO_2 or other intermediate oxide states. In this study, ion beam – assisted deposition (IBAD) was employed to fabricate a p-type SnO semiconductor layer within the LAPS structure, resulting in an optimized optical bandgap and enhanced hole mobility.[2]

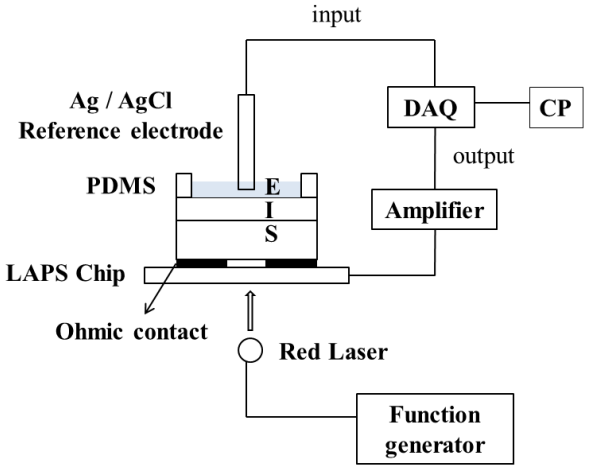

Fig. 1 Schematic of the LAPS sample

II. Material Analysis

A. 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 500 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.

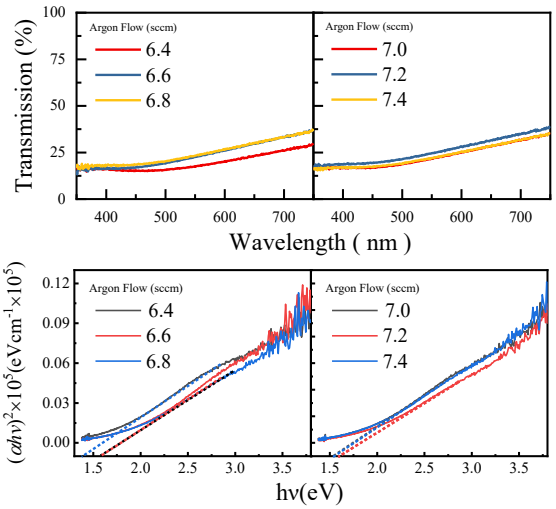

Fig. 2 UV-Vis spectra of samples deposited under different argon flow rates.

B. 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 [4]. 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 3, 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.

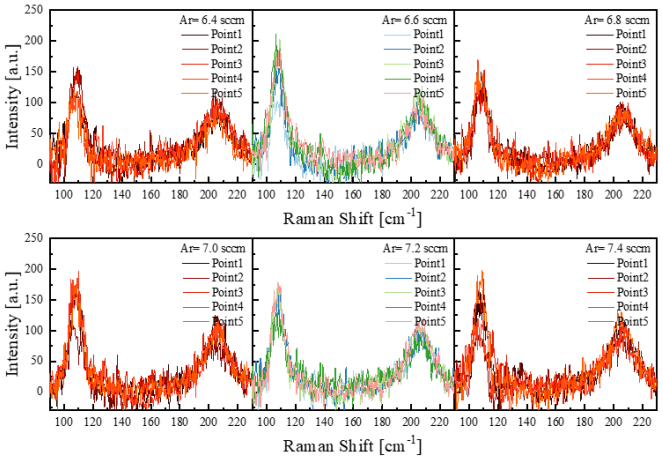

Fig. 3 Raman spectra of samples deposited under different argon flow rates.(Each sample was measured 5 points)

C. Hall Effect Measurement

As revealed by the electrical measurements, the carrier mobility showed a clear increasing trend with the rise of argon flow rate. The most pronounced change occurred when the flow rate reached 7.0 sccm. Although this condition did not yield the highest absolute mobility among all samples, it maintained high mobility and a dominant p-type ratio even after long-term storage. However, when the argon flow rate was further increased to 7.4 sccm, both the mobility and the proportion of p-type measurements decreased, which is likely attributed to the excessive metallic Sn content in the film. This observation is consistent with the findings reported in previous literature.[5]

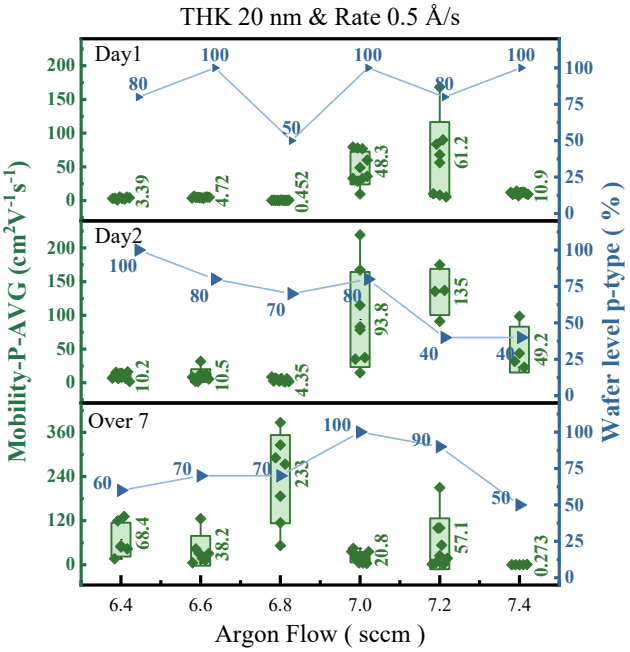

Fig. 4 p-type mobility along with its percentage distribution

III. LAPS MEASUREMENT

For the electrical and sensing characterization of SnOx LAPS, a function generator was used to provide a sine wave to a multi-wavelength LED system for providing an illumination source for the LAPS.The wavelength of the pE-4000 system was selected to be 365 nm to fit the possible absorption of the SnOx layer, as determined by its energy gap and UV–Vis spectra. In the basic pH sensing measurement for the LAPS, a commercial Ag/AgCl reference electrode and standard pH buffer solutions were put all together into a PDMS container to provide the gate bias voltage for the LAPS. The bottom ITO layer was connected as ground. A DC bias from 1 to −2 V with a decrement step of 50 mV was provided by a data acquisition (DAQ) card.[6]

IV. CONCLUSION

By integrating the structural characteristics of SnO with the design of the LAPS measurement system, the material's strong ultraviolet absorption and high mobility can be effectively utilized for highly sensitive pH detection, demonstrating its potential in chemical sensing applications.

REFERENCES

[1] Y. Ogo, H. Hiramatsu, K. Nomura, H. Yanagi, T. Kamiya, M. Hirano, H. Hosono, pchannel thin-film transistor using p-type oxide semiconductor SnO, Appl. Phys. Lett.93 (2018) 032113.

[2] Mochamad Januar, Suhendro Purbo Prakoso, et.al," Room-Temperature Fabrication of p-Type SnO Semiconductors Using Ion-Beam-Assisted Deposition " *ACS Appl. Mater. Interfaces* (2022) 14, 46726−46737

[3] Mochamad Januar, Tsung-Yu Huang, Chia-Ming Yang, Kou-Chen Liu, et.al," Unveiling the nature of room-temperature fabricated p-type SnO thin films: the critical role of intermediate phases, lattice disorder, and oxygen interstitials" *Materials Advances*, 2024, 5 , 4679.

[4] Quan Liu,ab , Lingyan Liang et al. " Tunable crystallographic grain orientation and Raman fingerprints of polycrystalline SnO thin films" *Materials Chemistry C* 2015, 3, 1077–1081

[5] Caraveo-Frescas, J. A.; Nayak, P. K.; Al-Jawhari, H. A.; Granato,D. B.; Schwingenschlogl, U.; Alshareef, H. N. Record Mobility in Transparent p-Type Tin Monoxide Films and Devices by Phase Engineering. *ACS Nano* 2013, *7*, 5160−5167.

[6] Chia-Ming Yang, Yu-Cheng Yang, Chun-Hui Chenb," Thin-film light-addressable potentiometric sensor with SnOx as a photosensitive semiconductor" *Vacuum 168* (2019) 108809