

Dong Hun Lee, Han Wook Song, Molly Rothschild, Junsoo Choi, and Sunghwan Lee*
(*correspondence: sunghlee@purdue.edu)

Purdue University
West Lafayette, United States

Title: Facile Processing and Properties of P-Type SnOx and Oxide-based p-n Heterojunction Application with n-InGaZnO

Abstract Text:

In recent years, oxide electronics has emerged as one of the most promising new technologies for a variety of electrical and optoelectronic applications, including next-generation displays, solar cells, batteries, and photodetectors. Oxide electronics have a lot of potential because of their high carrier mobilities and ability to be manufactured at low temperatures. However, the preponderance of oxide semiconductors is n-type oxides, limiting present applications to unipolar devices and stifling the development of oxide-based bipolar devices like p-n diodes and complementary metal-oxide-semiconductors.

We have contributed to oxide electronics, particularly on transition metal oxide semiconductors of which the cations include In, Zn, Sn and Ga. We have integrated these oxide semiconductors into thin film transistors (TFTs) as active channel layer in light of the unique combination of electronic and optical properties such as high carrier mobility ($5\text{-}10\text{ cm}^2/\text{Vs}$), optical transparency in the visible regime ($>\sim 90\%$) and mild thermal budget processing ($200\text{-}400^\circ\text{C}$).

In this study, we achieved four different results. The first result is that unlike several previous reports on oxide p-n junctions fabricated exploiting a thin film epitaxial growth technique (known as molecular beam epitaxy, MBE) or a high-powered laser beam process (known as pulsed laser deposition, PLD) that requires ultra-high vacuum conditions, a large amount of power, and is limited for large-area processing, we demonstrate oxide-based heterojunction p-n diodes that consist of sputter-synthesized p-SnOx and n-IGZO of which the manufacturing routes are in-line with current manufacturing requirements. The second result is that the synthesized p-SnOx films are devoid of metallic Sn phases (i.e., Sn^0 state) with carrier density tuneability and high carrier mobility ($> 2\text{ cm}^2/\text{Vs}$). The third result is that the charge blocking performance of the metallurgical junction is significantly enhanced by the engineering of trap/defect density of n-IGZO, which is identified using photoelectron microscopy and valence band measurements. The last result is that the resulting oxide-based p-n heterojunction exhibits a high rectification ratio greater than 10^3 at $\pm 3\text{ V}$ (highest among the sputter-processed oxide junctions), a low saturation current of $\sim 2 \times 10^{-10}\text{ A}$, and a small turn-on voltage of $\sim 0.5\text{ V}$.

The outcomes of the current study are expected to contribute to the development of p-type oxides and their industrial device applications such as p-n diodes of which the manufacturing routes are in-line with the current processing requirements.

Reference:

1. Lee, S.; Paine, D. C., Metallization selection and the performance of amorphous In-Zn-O thin film transistors. *Applied Physics Letters* 2014, 104 (25), 252103.
2. Liu, M.; Kim, H.; Wang, X.; Song, H. W.; No, K.; Lee, S., Carrier Density-Tunable Work Function Buffer at the Channel/Metallization Interface for Amorphous Oxide Thin-Film Transistors. *ACS Applied Electronic Materials* 2021, 3 (6), 2703-2711.
3. Chu, X., Zhuang, S., Chi, C., Xu, H., Du, G., Dong, X., & Yin, J. (2017). Study on the electroluminescence properties of the P-nimgo:Li/mgo/n-zno nanowires/ito heterojunction. *Journal of Luminescence*, 187, 486–491.
4. Kawazoe, H.; Yanagi, H.; Ueda, K.; Hosono, H., Transparent p-Type Conducting Oxides: Design and Fabrication of p-n Heterojunctions. *MRS Bull.* 2000, 25 (08), 28-36.
5. Mo, X., Fang, G., Long, H., Li, S., Wang, H., Chen, Z., Huang, H., Zeng, W., Zhang, Y., & Pan, C. (2014). Unusual electroluminescence from n-ZnO@i-MgO core-shell nanowire color-tunable light-emitting diode at reverse bias. *Phys. Chem. Chem. Phys.*, 16(20), 9302–9308.
6. Nomura, K.; Ohta, H.; Takagi, A.; Kamiya, T.; Hirano, M.; Hosono, H., Room-temperature fabrication of transparent flexible thin-film transistors using amorphous oxide semiconductors. *Nature* 2004, 432 (7016), 488-492.