Facile processing of p-type oxides and oxide-based p-n heterojunction applications

Dong Hun Lee1, Han Wook Song2, and Sunghwan Lee1* (sunghlee@purdue.edu)

1 School of Engineering Technology, Purdue University, West Lafayette, IN 47907, USA

2 Center for Mass and Related Quantities, Korea Research Institute of Standard and Science, Daejeon 34113, Republic of Korea

Oxide electronics have gained prominence in recent years and have been established as one of the most promising new technologies for various electronic and optoelectronic applications including next generation displays, solar cells, and photodetectors. The high potential use seen in oxide electronics is due primarily to their high carrier mobilities and their ability to be fabricated at low temperatures.

However, the vast majority of oxide semiconductors are n-type oxides, which limits the current applications to unipolar devices and ultimately stunts the development of oxide-based bipolar device applications such as p-n diodes and complementary metal–oxide–semiconductors.

The goal of this research is to resolve the scientific questions which prevent the realization of low-temperature processed p-type oxides and oxide-based p-n heterojunctions showcasing high rectification behavior, low saturation current, and a small turn-on voltage.

The current study is unique in that:

(1) 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 consists of sputter-synthesized p-SnOx and n-IGZO of which the manufacturing routes are in-line with current manufacturing requirements.

(2) 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 cm^2/Vs).

(3) 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.

(4) The resulting oxide-based p-n heterojunction exhibits a high rectification ratio greater than 10^3 at ±3 V (highest among the sputter-processed oxide junctions), a low saturation current of ~2×10^{-10} A, and a small turn-on voltage of ~0.5 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.

REFERENCES

1. 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.
2. Kawazoe, H.; Yasukawa, M.; Hyodo, H.; Kurita, M.; Yanagi, H.; Hosono, H., P-type electrical conduction in transparent thin films of CuAlO2. Nature 1997, 389 (6654), 939-942.
3. 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.
4. 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.
5. 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.

ACKNOWLEDGMENT

This work was supported by the U.S. National Science Foundation (NSF) Award No. ECCS-1931088. S.L. and H.W.S. acknowledge the support from the Improvement of Measurement Standards and Technology for Mechanical Metrology (Grant No. 20011028) by KRISS.