Doping Mechanisms and Defect Passivation of p-type SnOx for TFTs and Bipolar Devices

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Despite the outstanding achievements in multiple areas such as displays and energy, oxide electronics has been limited to single-polar (n-type) applications due to the facile generation of oxygen vacancies as native donors. On the contrary, the processing of p-type oxides is restrained due to the high formation energy of native acceptors. Furthermore, the oxygen 2p orbitals of the majority of oxide semiconductors are anisotropic and localized to the valence band maximum (VBM), resulting in a large effective mass of holes and hence low carrier mobility.

Hybrid orbital electronic configurations with cation d10 (closed shell structure) and cation s2 (pseudo-closed structure) have been suggested initially in complex oxides (e.g., CuMO2 where M= Al, Ga, and In; and SrCu2O2) to delocalize the oxygen 2p orbitals from the VBM. However, these complex oxides require high temperatures to process and are difficult to engineer the electrical properties of carrier density and carrier mobility due to the correlated nature of multi-cation species. Several single-cation p-type oxides such as PbO, Bi2O3, and SnO have emerged as well, where the energy level of a unique s-orbital of cations is similar to oxygen 2p orbitals, forming strong hybrid structures. In addition, a simpler single-cation structure leads to easier control of electrical properties required in practical device applications such as thin film transistors (TFT) and complementary logic inverters.

We previously reported scalable processing of p-type SnOx through thermodynamic-based interfacial reactions as well as reactive sputtering.[1] More recently, we also suggested multi-modal encapsulation to enhance TFT on- and off-state behaviors and identified a defect complex as an effective p-type doping agent.[2] However, challenges remain since the TFT off-state current is large, and the defect/trap state density is high.

In this presentation, we share our approaches to engineer the off-state current and passivate the defect/trap states. In addition to channel thickness optimization, intrinsic (Sn vacancy or oxygen interstitial) and extrinsic (H-related species) doping strategies to adjust channel carrier density will be compared. The performance of several surface treatments (oxygen plasma and UV) and TFT back channel encapsulations (SiO2 and Al2O3) will be systematically compared. Then, the device performance of optimized p-type SnO TFTs and complementary inverters with n-type InZnO TFTs will be discussed.

References

1. Lee et al., ACS Applied Materials & Interfaces, 13 (46), 55676–55686 (2021)
2. Lee et al., ACS Applied Materials & Interfaces, 14 (48), 53999–54011 (2022)

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