Development of Thin Film Transistor Using an Amorphous Mixed-anion Semiconductor a-ZnOS

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Introduction: Amorphous oxide semiconductors (AOSs) have been under intensive study during recent years. Because of their high electron mobility even under amorphous state, they have been widely used as key materials for flat panel displays and flexible electronics devices, especially as channel layers of thin film transistors (TFTs). Recently, it has been reported that an amorphous mixed-anion semiconductor consisting of only earth-abundant elements, zinc oxynitride (a-ZnON), shows high electron mobility and capability to TFT application [1]. However, a-ZnON is unstable in air. To overcome this drawback, we synthesized another earth-abundant amorphous mixed-anion semiconductor, amorphous zinc oxysulfide (a-ZnOS), in thin film form and found that their electron mobility is comparable to those of conventional AOSs (~15 $cm^2V^{-1}s^{-1}$), in addition to good chemical stability under ambient conditions [2]. In this study, we fabricated a-ZnOS based TFTs and evaluated their performance.

Experiment: a-ZnOS based TFTs with bottom-gate and top-contact configuration were prepared on heavily doped n-type Si substrates with a 100 nm-thick thermally grown SiO_2 layer. An a-ZnOS channel layer (thickness of 30~40 nm) was grown on the substrate by pulsed laser deposition [2]. Subsequently, Au/Ti films were deposited as the source and the drain electrodes. The channel layer and the source and drain electrodes were patterned by using shadow masks (W = 1000 μm, L = 100 μm or 200 μm). Characteristic properties of TFTs were evaluated at room temperature under ambient condition by using a two-channel source measure unit. Anion composition of the films [S/(S+O)] were evaluated by SEM-EDS measurement.

Results: a-ZnOS thin films with S/(S+O) = ~0.30 shows obvious TFT performance in the pristine states, although their field effect mobility (μ_{FE}) was moderate (μ_{FE} <1 $cm^2V^{-1}s^{-1}$). μ_{FE} increased with the decrease of S/(S+O). However, at the same time, off current became larger and threshold voltage (V_{th}) shifted negatively, indicating that the carrier density became too large for TFT operation. By annealing these films in vacuum at 150 °C for 10 min, their TFT performance was significantly improved (Fig. 1), *i.e.*, μ_{FE} increased and off current decreased. On the other hand, annealing at higher temperature or for longer time degraded the performance, possibly due to oxidation of the a-ZnOS layer. After the annealing under an optimal condition, a-ZnOS based TFT with S/(S+O) = ~0.17 exhibited an on/off ration over 10^4, μ_{FE} of 11.3 $cm^2V^{-1}s^{-1}$, V_{th} of 4.4 V and a subthreshold swing of 2.0 $Vdec^{-1}$ (Fig. 2).

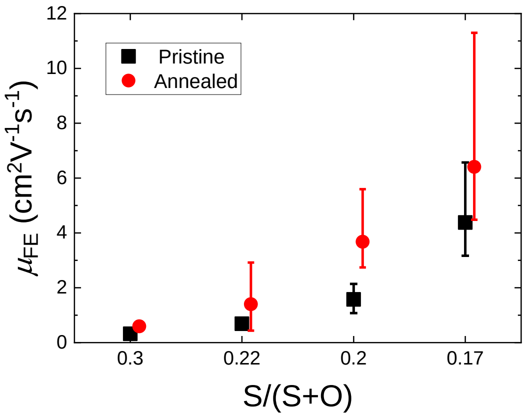

Fig. 1. Average of μ_{FE} of a-ZnOS with various anion compositions. The error bars indicate the maximum and minimum value among the devices. The number of devices is 6, 5, 8 and 8 for S/(S+O) = 0.3, 0.22, 0.2 and 0.17, respectively

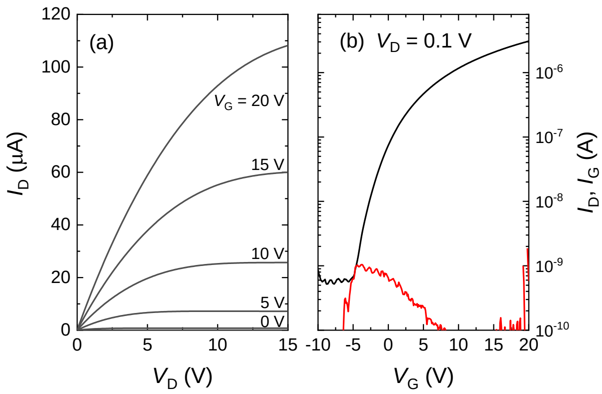

Fig. 2. (a) Output curves and (b) transfer curve (V_D = 0.1 V) of an a-ZnOS based TFT with S/(S+O) = 0.17, black line and red line indicate I_D and leakage current, respectively

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[1] Kim *et al.*, Sci. Rep. **3**, 1459 (2013).
[2] Y. Zhu, T. Yamazaki, Z. Chen *et al.*, Adv. Electron. Mater. **6**, 1900602 (2019).