CHARACTERISTICS OF OXIDE TFT USING ATOMIC-LAYER DEPOSITED InO_x- BASED METAL OXIDE CHANNEL

Toshihide Nabatame, National Institute for Materials Science
NABATAME.Toshihide@nims.go.jp
Riku Kobayashi, National Institute for Materials Science
Kazuhito Tsukagoshi, National Institute for Materials Science

Key Words: Carbon-doped InOx, TFT, Atomic layer deposition, Oxygen vacancy, Reliability

InOx-based metal oxide semiconductors (InOx-OSs) including In-Ga-Zn-O (IGZO) [1,2] have been investigated as active channel materials in oxide thin film transistors (TFTs) for flat-panel display applications. These InOx-OSs have recently attracted attention for n-channel field effect transistor (n-FET) in back-end of line [3-5] and ferroelectric FET with HfO2-based ferroelectric gate insulator [6] First, InOx-OS films were deposited vis sputtering method. Considering to the growth of ultra-thin films, atomic layer deposition (ALD) technique is of great interest in the angstrom-scale thickness controllability, atomically smooth surface and composition control of multicomponent films as well as excellent step coverage on three-dimensional structure. The superior transistor performance of TFTs with ALD-In2O3 and IGZO channels and n-FET with ALD-In2O3 channel have been demonstrated [3,4,7]. Here, In2O3 films have been deposited via ALD with a combination of various precursors and oxidant gases such as trimethyl indium-O2, O3, H2O, or H2O2, and ethylcycropentadienyl indium (InEtCp)-H2O/O3 [8-10].

To improve metal-like properties due to excess oxygen vacancies (Vo) in pure In2O3 channel, several elements such as Ti, W, Si and C have been doped into In2O3 according to the bond dissociation energy (BDE) between element and O (Ti-O: 666kJmol-1; W-O: 720kJmol-1; Si-O: 779kJmol-1; C-O: 1076kJmol-1) [11]. Carbon-doped InOx-OS channel is of great interest due to the highest BDE value, and we also reported characteristics of TFT with C-doped In-Si-O channel [12]. Furthermore, another viewpoint of a simple material and process, H-incorporated In2O3 TFT exhibited superior transistor performance of high μ of around 140cm2V-1s-1 and small SS of 0.19 [13].

In this paper, we report characteristics of TFTs with amorphous In2O3 and carbon-doped In2O3 channels, and we also discuss about reliability of the carbon-doped In2O3 TFT under NBS and PBS.

Back-gate type TFTs were fabricated using the following processes [9,10]. Channel layers of 5nm-thick In2O3 (InO1.2) and carbon-doped In2O3 (In1.16O0.04) were deposited on p++-Si/SiO2 (250nm)/Al2O3 (5nm) via ALD at 200 and 150 °C, respectively, using InEtCp precursor and a sequential supply of H2O/O3 oxidant gas. We found that growth rate of In2O3 film deposited by ALD using H2O/O3 gases was three times larger than those of ALD using H2O or O3 gas because of precursor adsorption and oxidation mechanism. Next, the active channels were patterned using photolithography and dry etching processes and Ti/Au as source-drain electrodes were formed using lift-off process. Post-metallization annealing was carried out in O3.

The In1.16O0.04 TFT exhibited superior transistor properties such as μ of 20.4 cm2V-1s-1, SS of 0.37Vdec-1, Vth of 3.2V and Von of 1.1V, which allow normally-off operation, and stability of no Vth shift in N2 ambient under zero bias. On the other hand, the InO1.2 TFT showed poor electrical properties such as no Id saturation (no Vg control), a relatively high SS of 0.50 and a large negative Von of -22.3V, and instability due to negative Vth shift in N2 ambient under zero bias. This is strongly related to the Vo formation into the channel. Based on these experimental data, it is clear that a carbon doping into In2O3 plays a useful role to obtain stable transistor properties because Vo formation is suppressed due to the high BDE between C and O element.

The In1.16O0.04 TFT showed a large negative Vth shift of -3.6V after stress time of 10800s under NBS at Vg-Vth = -20V while a small positive Vth shift of 0.7V after same 10800s under PBS at Vg-Vth = 20V, suggesting that the TFT contained small and large numbers of trapped electrons and holes, respectively. However, a large positive Vth shift of around 3.5V was observed when ambient gas changed to N2 to 0.001% O2 under PBS. This is attributed to PBS enhancing O2 absorption at the back side of the In1.16O0.04 channel.

This work was supported in part of JSPS KAKENHI Grant No.JP20H02189.

[1] K. Nomura et al., Nature, 432, 488 (2004). [2] M. N. Fujii et al., ECS J. Solid State Sci. Technol., 3, Q3050 (2014). [3] W. Tang et al., IEDM Tech. Dig., 2022, p.483. [4] M. Si et al., Nano Lett., 21, 500 (2021). [5] H. Kim et al., IEEE Electron Device Lett., 40, 411 (2019). [6] F. Mo et al., IEEE J. Electron Devices Soc., 8, 717 (2020). [7] W.-H. Choi et al., IEEE Trans. Electron Devices, 68, 6147 (2021). [8] D. J. Lee et al., J. Phys. Chem. C, 115, 15384 (2011). [9] R. Kobayashi et al., Jpn. J. Appl. Phys., 60, 030903 (2021). [10] R. Kobayashi et al., Jpn. J. Appl. Phys., 60, SCCM01 (2021). [11] S. Aikawa et al., Appl. Phys. Lett., 103, 172105 (2013). [12] K. Kurishima et al., J. Vac. Sci. Technol. B, 36, 2166 (2018). [13] T. Kataoka et al., Materials, 15, 187 (2022)