High-performance high-κ SmTiO₃ gate dielectrics for amorphous InGaZnO thin-film transistor applications

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1. Introduction

The amorphous InGaZnO (α-IGZO) material has attracted much attention as active layer for next generation thin-film transistor (TFT) applications due to the transparent characteristics, high field mobility, and good uniformity [1]. In order to decrease the operation voltage, the high-k materials have been extensively studied as gate dielectrics for α-IGZO TFT applications [2-3]. Recently, samarium oxide (Sm₂O₃) film has been considered as a potential gate dielectric due to its high dielectric constant, wide band gap, and thermodynamically stable [4]. Additionally, it has been reported that the incorporation of Ti into lanthanide oxide exhibited better electrical characteristics [5]. In this paper, we investigated the high performance α-IGZO TFT with a high-κ SmTiO₃ gate dielectric for active-matrix organic light-emitting diode applications.

2. Experiment

Fig. 1 illustrates the schematic cross section of the high-κ SmTiO₃ α-IGZO TFT devices. The 40 nm TaN bottom gate electrodes were deposited on the thermally grown SiO₂/Si substrates by rf sputtering. The 120 nm SmTiO₃ films were deposited as a gate dielectric using co-sputtering. Then, samples were annealed at 400 °C by furnace in O₂ ambient for 10 min. The active layer of α-IGZO film was deposited on the dielectric film by sputtering. The thermal evaporated Al source-drain electrodes were patterned by lift-off process.

3. Result and Discussion

Fig. 2 depicts the XRD patterns that three SmTiO₃ (221), (311), and (132) peaks are found in the annealed film, suggesting that formation of a crystallized SmTiO₃ compound. The C-V curves of the Al/SmTiO₃/TaN capacitors are shown in Fig. 3. The dielectric constant of SmTiO₃ films with and without oxygen annealing is 11 and 9.2, respectively. Fig. 4 shows the Sm 3d₆/₂, Ti 2p₃/₂, and O 1s core level XPS spectra of the SmTiO₃ films. The Sm 3d₆/₂ peak position located at 1084.7 eV of the annealed sample is shifted to a higher binding energy by about 0.4 eV as compared to the Sm₂O₃ reference position, as shown in Fig. 4 (a). The Ti 2p₃/₂ peak of the annealed film is shifted to higher binding energy than the TiO₂ reference position, as shown in Fig. 4 (b). This shift was attributed to Ti in SmTiO₃ compound structure. The O 1s spectra for the SmTiO₃ films with/without oxygen annealing are shown in Fig. 4 (c). The O 1s signal comprised three peaks at 530.4, 531.4, and 532.8 eV, which we assign to SmO₂, Sm₂O₃, and nonlattice, respectively. The O 1s peak intensity corresponding to SmTiO₃ for the annealed film is larger than that of as-deposited film.

Fig. 5 and 6 demonstrate the transfer characteristics and output characteristics for the SmTiO₃ α-IGZO TFT devices with/without oxygen annealing, respectively. After oxygen annealing, the SmTiO₃ α-IGZO TFT exhibited good electrical characteristics, including low threshold voltage (V_th) of 0.27 V, large field-effect mobility of 10.9 cm²/V-s, small subthreshold swing (S.S.) of 184 mV/dec, and high I_on/I_off ratio of 3.2×10⁷. Fig. 7 shows the threshold voltage variations as a function of the stress time for the SmTiO₃ α-IGZO TFT devices. The TFT device with oxygen annealing exhibited lower shift than that without oxygen annealing, suggesting the low number of negative charges in the SmTiO₃ dielectric and/or the interface of SmTiO₃ and IGZO layer. The corresponding schematic band diagram of a SmTiO₃ α-IGZO TFT device is shown in Fig. 8. The measured and extracted key parameters are summarized in Table 1, where the data from α-IGZO TFT devices incorporating HfO₂ [2], Al₂O₃/SiNₓ [3], SiO₂ [6] and SiNₓ [7] gate dielectrics are shown for comparison.

4. Conclusion

We investigated high performance high-κ SmTiO₃ α-IGZO TFT device with oxygen annealing. The high-κ SmO₂ α-IGZO TFT device exhibited a low threshold voltage of 0.27 V, large mobility of 10.9 cm²/V-s, small S.S. of 184 mV/dec and high I_on/I_off current ratio of 3.2×10⁷. The high-κ SmTiO₃ gate dielectric is a suitable material to fabricate high performance α-IGZO TFTs.

Acknowledgements

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References

(a) Sm 3d\textsubscript{5/2}, (b) Ti 2p\textsubscript{3/2}, and (c) O1\textsubscript{s} energy levels in high-k SmTiO\textsubscript{3} films with/without oxygen annealing.

Table I. Comparison of key parameters for α-IGZO TFTs fabricated with a SmTiO\textsubscript{3}, HfO\textsubscript{2}, Al\textsubscript{2}O\textsubscript{3}/SiN, SiO\textsubscript{2}, and SiN\textsubscript{x}.

<table>
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<tr>
<th>Gate oxide</th>
<th>V\textsubscript{on} (V)</th>
<th>V\textsubscript{th} (V)</th>
<th>P\textsubscript{th} (cm\textsuperscript{2}/V\textsuperscript{2})</th>
<th>S.S. (V/dec)</th>
<th>L\textsubscript{f}/L\textsubscript{on}</th>
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<td>SmTiO\textsubscript{3}, 400 °C</td>
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<td>0.27</td>
<td>10.9</td>
<td>0.18</td>
<td>3.2×10\textsuperscript{6}</td>
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<td>SmTiO\textsubscript{3}, as-dep</td>
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<td>0.30</td>
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<tr>
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<td>1.00</td>
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