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All Solution Processed High Performance In-Ga-Zn-O Thin Film Transistor Fabricated at Low Temperature using Microwave irradiation

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Abstract

We fabricated the all solution proceesed IGZO thin-film transistors (TFTs) using solution deposited Al_2O_3 gate insulator and IGZO active channel layer. For a low thermal budget, the microwave irradiation was conducted to condensate the solution precursors. As a result, we successfully demonstrated highly stable IGZO TFTs with excellent performances (S.S.= 112 mv/dcade, u_{FE} = 35 $cm^2/V\cdot s$) at low temperature below 100 ℃.

1. Introduction

Transparent amorphous oxide thin-film transistors (TAOS TFTs) have been attracting a lot of interest for the applications in mobile electronics, future display, and other consumer electronics owing to high field effect mobility, good uniformity, low cost, low temperature process, visible light transparency, and application on flexible substrates. Although much effort has been expended on improving the performance of TAOS TFTs, further promotion of carrier mobility over 20~50 $cm^2/V\cdot s$ is desirable for application of high performace 3-D displays. Especially, the electrical instability issue places limitations on commerciallization of TAOS TFTs for backplane application of active-matrix organic light-emitting diode (AMOLED) displays. TAOS films can be deposited using low thermal-budget processes and exhibits levels of mobility that can be orders of magnitude higher than that of a-Si. This unique feature makes it the most promising candidate involved in flexible electronics such as RFIDs, flexible displays, wearable electronics, e-textiles, artificial skin/muscles, etc [1]. Recently, as a formation method of TAOS films, vacuum-free process based on solution deposition have been attracting much attention than the conventional vacuum processes (CVD, PVD) because of large area and low cost. However, the drawback of solution process is a lower film quality than vaccum process [2].

In this study, we fabricated the high performance solution-derived IGZO TFTs at a low process temperature below 100 ℃. The Al_2O_3 high-k gate insulator and IGZO channel layer were deposited by solution process and the postdeposition heat treatment was carried out by microwave irradation. Additionally, we fabricated the partial solution-derived IGZO TFTs with thermal SiO_2 or sputtered Al_2O_3 gate insulator for comparison. As a result, all solution-derived IGZO TFTs showed higher performace and better stability than partial solution-derived IGZO TFTs.

2. Experimental

Aluminum chloride (1M) was dissolved in 2-methoxyethanol to mafufacture the precursor solution of Al_2O_3 for gate insulator. Indium nitrate hydrate (2M), gallium nitrate hydrate (1M) and zinc nitrate hydrate (1M) were dissloved in 2-methoxethanol and ethanolamine to prepare the IGZO precursor solution for channel. The mixture solutions were stirred at 50 ℃ in atomosphere for 3 h and aged for 24 h. For fabrication of all solution-derived IGZO TFTs, the Al_2O_3 solution was spun on the p-Si substrate and baked at 180 ℃ for 10 min in the air. Microwave irridation of 1000 W for 25 min was followed in air to condensate the gate insulator film. The process temperature of microwave irridiation monitored by a thermocouple in contact with the sample was 89 ℃. The thickness of Al_2O_3 gate insulator after microwave irradiation was 100 nm. To fabricate active layer, the IGZO solution was spun on 100 nm-thick Al_2O_3 gate insulator and a microwave irradiation was carried out for 15 minute. The thickness of IGZO channel after microwave irradiation was 40 nm. After patterning of actve by phtolithography and wet etching, source/drain (Ti/Au=10/100 m) was formed by e-beam evaporation for back gate type TFTs. For comparison, we fabricated the partial solution-derived IGZO TFTs including sputtered Al_2O_3 or thermally grown SiO_2 gate insulator with a thickness of 100 nm. The electrical characteristics were measured using semiconductor parameter analyzer (HP 4156-B) in dark box. The instability was measured by threshold voltage shift under positive/negative gate bias (PBS/NBS) stress (V_{GS}=± 5 V, V_{DS}=10 V) for 10,000 sec.

3. Results and Discussion

Fig. 1 shows the schematic illustrations of microwave irridiation for condensation of solution precursors as gate insulator and channel formation process. Microwave irridiation is effective process (low thermal budget, low process cost) compared to the conventional annealing, because microwave can heat the inside of sample via molecular rotaions. The process temperature monitored by a thermocouple in contact with the sample was less than 100 ℃ under 1000 W.

Fig. 2 shows the O1s peak of as-spun (a), microwave irradated (b) and thermally annealed (c) IGZO films measured by X-ray photoelectron spectra (XPS). It is noteworthy that the oxygen binding states of microwave irradiated film and thermally annealed film are comparable. Meanwhile, it has been reperted that the microwave irradition improves the property of solution proceesd high-k film; the density and roughness of microwave irradiation are better than those of conventional thermal annealing (CTA) [3].

Fig. 3 (a)-(c) show the transfer (I_D-V_G) characteristics of IGZO TFTs of (d)-(f), respectively.

Fig. 4 shows the output (I_D-V_D) characteristics. It is found that the drain current linearly increases with the drain voltage and then saturated at pinch off. The saturation current is larger in high-k dielectrics than thermal SiO_2. Especially, all solution-derivated IGZO TFTs (c) have higher drivability than partial solution-derived IGZO TFTs (a) and (b).

Table 1 is electrical parameters extracted from trasfer curves. Excellent on/off ratio, shbthreshold slope are obtained from all solution-derived IGZO TFTs. In particular, a high mobility of $35cm^2/Vs$ is achieved.

Fig 5 shows the threshold voltage shift as a function of NBS/PBS time. V_{TH} shift under PBS is larger than NBS and all solution-derived IGZO TFT has the smallest V_{TH} shift. Accordingly, the microwave irradiation effectively condensates the solution deposited layers and removes the defects in IGZO channel and improves the gate insulator/active interfaces even at low process temperature.

4. Conclusions

We developed all solution-derived IGZO TFTs with Al_2O_3 high-k gate insulator using microwave irradiation at a low temperature below 100 ℃. In addition, we confirmed that all solution-derived IGZO TFT has excellnt electrical peroformances of high mobility and good stability. The microwave irradiation is expected to be a suitable process in solution-derived TAOS TFTs for flexible electronics.

Acknowledgements

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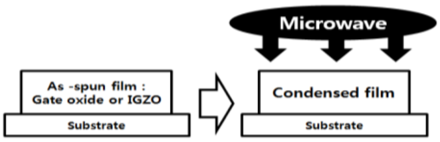

Fig. 1. Schematic illustrations of microwave irridiation for condensation of solution processed metal oxide precursors as gate insulator and channel formation process.

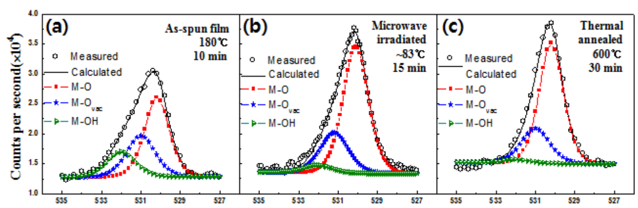

Fig. 2. X-ray photoelectron spectra (XPS) O1speak of as-spun (a), microwave irradiated (b) and thermally annealed (c) IGZO films. The combination of the spectra shows the distributions of peaks at 532.0 eV (triangle), 531 eV (star), 530 eV (square) from respectively oxygen atoms in M-OH compounds, oxygen atoms near M-O_{VAC} bonds and oxygen atoms in M-O lattice.

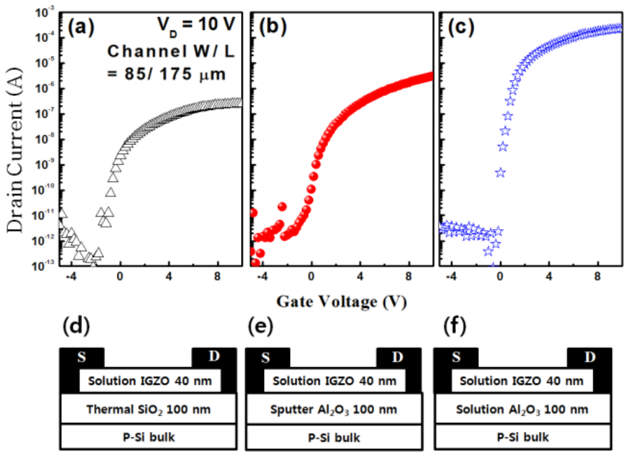

Fig. 3. Transfer characteristics (a), (b) and (c) correspond to the IGZO TFTs with (d) thermal SiO_2, (e) sputter Al_2O_3, and (e) solution deposited Al_2O_3 gate insulators, respectively.

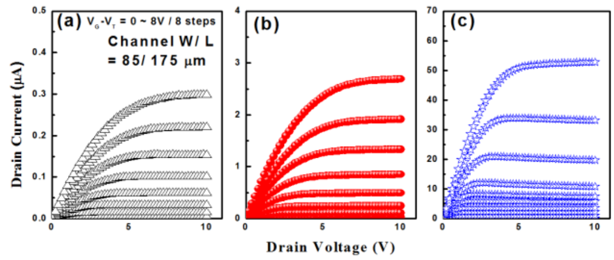

Fig.4. Output chracteristics of IGZO TFTs with (a) thermal SiO_2, (b) sputter Al_2O_3, and (c) solution deposited Al_2O_3 gate insulators.

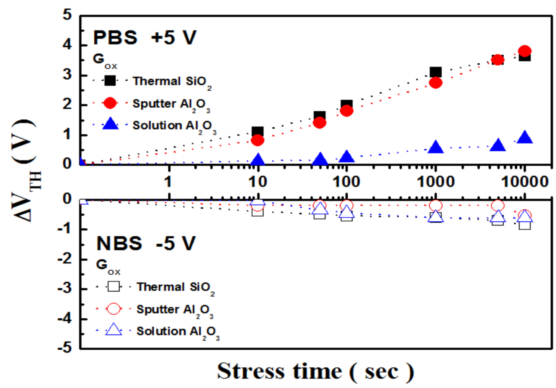

Fig. 5. Threshold voltage shift as a function of PBS/NBS time.

Gate oxide	Active layer	On/off ratio	SS [mV/decade]	μ_{FE} [$cm^2/V \cdot s$]
Thermal SiO_2	IGZO	1.23×10^6	258	0.18
Sputter Al_2O_3	IGZO	1.54×10^7	277	1.5
Solution Al_2O_3	IGZO	9.4×10^8	112	35

Table 1. Electrical parameters of solution-derived IGZO TFTs with different gate inulators.