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# Effects of Composition on Electrical Properties of Amorphous In – Ga – Zn – O Thin-Film Transistors Deposited Using Atmospheric Pressure Plasma Jet

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## 1. Introduction

Amorphous indium-gallium-zinc-oxide thin-film transistors (a-IGZO TFTs) are of considerable interest for backplanes of the next-generation flat-panel displays, such as active matrix liquid crystal displays (AMLCDs) and active matrix organic light emitting diode displays (AMOLEDs), due to their better field-effect mobility (> 10 $cm^2$/V-s), larger $I_{on}/I_{off}$ ratio (> $10^6$), smaller subthreshold swing and better stability against electrical stress in comparison with traditional amorphous silicon-based TFTs.

Compared to the conventional vacuum techniques, such as radio-frequency/direct-current magnetron sputtering, pulsed laser deposition and solution process, IGZO films deposited by atmospheric pressure plasma jet (APPJ) has many advantages such as low cost and good suitability for large scale applications. Since it does not need a vacuum chamber and associated pumping system. We have reported that IGZO prepared by APPJ with a gate dielectric of $Al_2O_3$ exhibited good electrical performance on mobility, $I_{on}/I_{off}$ ratio, subthreshold swing and threshold voltage [1, 2].

In this study, we prepared the IGZO films with three kinds of In:Ga:Zn composition ratio by APPJ to further investigate the compositional effects of this technique [3]. In addition, $HfO_2/ZrO_2$ high-κ stack as the gate dielectric annealed at various temperature conditions is also investigated to improve the electrical performance of the TFT device.

## 2. Experimental

Staggered bottom-gate a-IGZO TFTs were fabricated on heavily doped n-type silicon substrates. High-κ gate dielectrics of $HfO_2$ and $ZrO_2$ were deposited by e-beam evaporation with the same thickness of 25nm on the substrate. Annealing of gate insulators were then carried out at various temperatures ranging from 300°C to 600°C in $N_2$ for 30min. Subsequently, a 50-nm-thick a-IGZO layer was deposited by APPJ at substrate temperature of 200°C. The schematic diagram of the experimental apparatus for APPJ is shown in Fig. 1. The post annealing temperatures of the a-IGZO layers ware ranging from 200°C to 500°C in $N_2$ for 30min. The a-IGZO layer was then patterned by photolithography and etching. Finally, the source/drain contacts were formed by lift-off of thermally deposited Al which has a thickness of 300 nm. The channel width (W) and length (L) were 500 μm and 50 μm, respectively. The cross-sectional view of the fabricated device is as illustrated in Fig. 2.

## 3. Results and Discussions

The optical transmittance spectra of the a-IGZO film deposited on a glass substrate is shown in Fig. 3. The average transmittance is higher than 80% in the visible region. Fig. 4. is the SIMS profile of the fabricated IGZO film with In:Ga:Zn = 1:1:2. The J-V characteristics of the $Al/HfO_2/ZrO_2/Al$ capacitors are shown in Fig. 5. As the post annealing temperature of the high-κ insulator rises up to 500° C, the leakage current begins to be reduced. The leakage level could be further improved at a 600° C annealing condition. The output curve and the transfer curve are shown in Fig. 6 and Fig. 7, respectively. Three kinds of composition ratio of In:Ga:Zn = 1:1:1, 1:1:2, and 3:1:2 were investigated. It can be seen that the 1:1:2 device exhibits the best performance of $I_{on}/I_{off}$ ratio > $10^6$, which is an order higher than the other two devices. The device $V_{th}$ of composition ratio of In:Ga:Zn = 1:1:1, 1:1:2, and 3:1:2 are 0.26, 0.63, and -0.08 V, respectively. All the $V_{th}$ values are smaller than 1V, which is an advantage of the APPJ technique and is suitable for low voltage drive application. The extracted field-effect mobility and subthreshold swing of the 1:1:2 device are 34 $cm^2$/V-s and 0.37 V/dec, respectively. Table 1 summarizes the characteristics of a-IGZO TFTs fabricated with variant process conditions.

## 4. Conclusions

TFTs with a-IGZO as channel layer prepared by APPJ and $HfO_2/ZrO_2$ high-κ stack as gate dielectric were fabricated. The high-κ leakage current reduces as the post annealing temperature rises. The best composition ratio of IGZO was In:Ga:Zn = 1:1:2, which exhibited a mobility of 34 $cm^2$/V-s, $I_{on}/I_{off}$ ratio of $7\times10^8$, $V_{th}$ of 0.63V, and subthreshold swing of 0.37 V/dec.

## Acknowledgements

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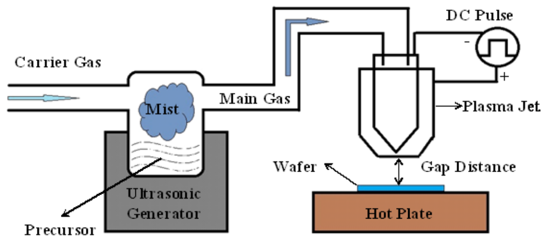

Fig.1 Schematic diagram of the experimental apparatus APPJ system.

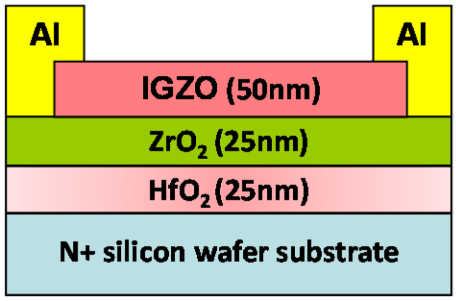

Fig.2 Schematic cross-sectional view of the staggered bottom-gate a-IGZO TFT with $HfO_2/ZrO_2$ gate insulators.

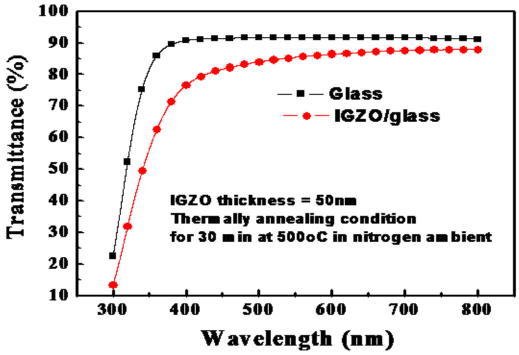

Fig.3 Optical transmission spectra of IGZO films deposition on glass.

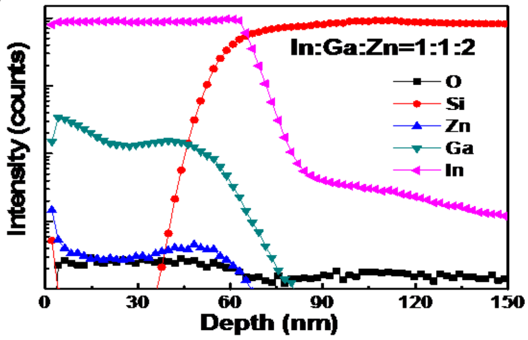

Fig.4 SIMS profile of the fabricated IGZO film with In:Ga:Zn = 1:1:2.

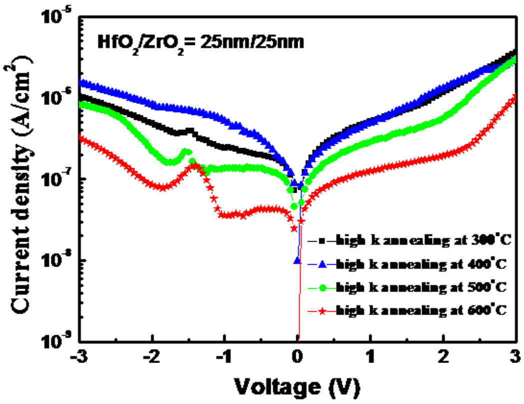

Fig.5 J-V characteristics of the $Al/HfO_2/ZrO_2$ capacitors.

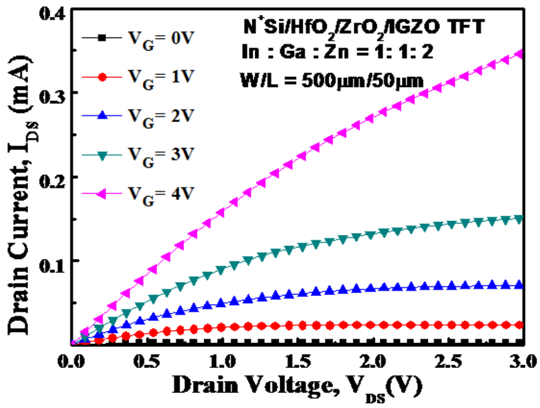

Fig.6 The $I_D$-$V_D$ output characteristics of the IGZO TFT (1:1:2) with $HfO_2/ZrO_2$ gate dielectric.

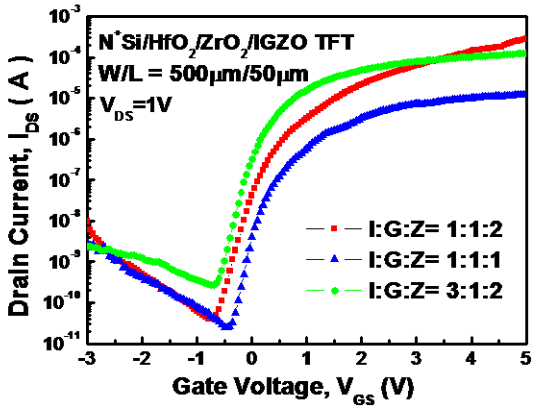

Fig.7 The $I_D$-$V_G$ transfer characteristics of the IGZO TFT with In:Ga:Zn = 1:1:2, 1:1:1, and 3:1:2, respectively.

Table.1. Characteristics comparison of a-IGZO TFTs with variant process conditions.

| Fabrication method | Post treatment | $V_{th}$ (V) | Mobility ($cm^2$/V-s) | S.S. (V/dec.) | $I_{on}/I_{off}$ ratio |
|---|---|---|---|---|---|
| APPJ This Work | 500 ˚C for 30 min in $N_2$ | 0.63 | 34 | 0.37 | $7\times10^8$ |
| APPJ Ref[1] | 500 ˚C for 30 min in $N_2$ | 0.71 | 8.39 | 0.28 | $10^8$ |
| Solution-based Ref[2] | 350 ˚C for 1 hr in forming gas | 3.6 | 4.2 | 0.55 | $10^8$ |
| DC sputter Ref[3] | 150 ˚C for 2 hr in a vacuum | 1.93 | 7.83 | 0.24 | $10^8$ |
| Solution-based Ref[4] | 500 ˚C for 1 hr | -5 | 1.13 | 2.5 | $>10^6$ |