J-2-02

Extended Abstracts of the 2020 International Conference on Solid State Devices and Materials, VIRTUAL conference, 2020, pp659-660

Thermal Damage-free Microwave Annealing for Fabricating High-performance a-IGZO Thin Film Transistors on Flexible Substrates

Ki-Woong Park and Won-Ju Cho*

Department of Electronic Materials Engineering, Kwangwoon University, Seoul 139-701, Republic of Korea
Phone: +82-2-940-5163 *E-mail: chowj@kw.ac.kr

Abstract

In this study, we studied thermal damage-free microwave annealing to fabricate an amorphous In-Ga-Zn-O (a-IGZO) thin film transistor (TFT) on a flexible and transparent polyimide (PI) substrate. In order to confirm the process durability of the PI substrate for the microwave, microwave annealing (MWA) was performed with various electric powers. In addition, the thermal damage of the PI substrate due to microwave furnace and conventional thermal processing furnace was compared. As a result, in the conventional thermal annealing (CTA), the PI substrate was severely damaged at high temperature, but in the MWA, little damage occurred even when the microwave power was increased. The electrical properties of the flexible TFTs prepared by CTA at 300 °C for 30 min, which is the upper limit without thermal damage, and the flexible TFTs fabricated by MWA of 1800 W for 2 min, were compared. Despite the short processing time, MWA effectively eliminated the defects and traps of the a-IGZO TFTs through direct energy transfer, resulting in higher mobility, higher on-off current ratio, lower subthreshold swing and interface trap density, and better stability for gate bias temperature stress than CTA-treated TFTs. Therefore, thermal damage-free MWA with low-thermal budget is promising for transparent and flexible electronics.

1. Introduction

The predominantly used hydrogenated-amorphous silicon (a-Si:H) in large area flat-panel display has limitations due to low mobility and instability. In contrast, amorphous oxide semiconductors (AOSs) consist of ionic bonds of heavy metal cations have highly applicable potential. Overlapped spherical s-orbital induce excellent electrical uniformity and high electron mobility even at large or flexible substrate. [1,2] Flexible displays have been attracted interest in the future display industry. Accordingly, AOSs-based thin-film transistors (TFTs) fabrication on a flexible and transparent substrate such as ultra-thin glass (UTG) or polymer is necessary. Among flexible substrate, polyimide (PI) is expected to be promising for flexible TFT by low-cost, high flexibility, and high transparency.

In this study, we fabricated amorphous In-Ga-Zn-O (a-IGZO) TFTs on highly flexible and transparent PI substrate. For further electrical improvement of the a-IGZO channel layer and gate oxide/channel interface, the post-deposition-annealing (PDA) process is required. Conventional thermal annealing (CTA) has been extensively investigated as an annealing method to improve electrical properties. However, it relatively involves a long process time and high thermal budget. In particular, in the case of flexible devices, a high thermal budget is more critical issue due to inherent thermal limitation. [3] On the other hand, microwave annealing (MWA) has been received much attention as PDA process. The electromagnetic waves directly transfer to heat energy into devices, which result in a low-thermal budget, short process time, and effectively removing the defects in the devices. [4] For this reason, unlike CTA process, MWA is thermal damage-free annealing process by a low-thermal budget. Therefore, we evaluated highly improved electrical performance, resistor-loaded inverting operations, and gate bias temperature stress tests of MWA-treated a-IGZO TFTs on a flexible PI substrate with CTA-treated devices.

2. General Instructions

To avoid thermal expansion and shrinkage problems during the fabrication of flexible TFTs, the PI substrate was attached to a rigid glass substrate. In addition, to suppress chemical, mechanical, and thermal damage to PI, the silicon nitride layer was deposited above PI substrate. The prepared flexible substrate was cleaned by standard Radio Corporation of America (RCA) cleaning process to remove surface contamination. In order to fabricate bottom-gate structure TFTs, the 150-nm-thick Al gate electrode was deposited by the e-beam evaporator and patterned by photolithography/wet etching using H_3PO_4 solution. After the 130-nm-thick SiO_2 layer was deposited for the gate oxide by using RF magnetron sputtering system. As for channel layer, 50-nm-thick a-IGZO was deposited by RF sputter. Finally, the 150-nm-thick Al source/drain electrode was deposited by E-beam evaporator and patterned by the lift-off method. At last, 500 W power MWA in air ambient was performed for PDA. For comparison, the CTA process was conducted at 300 °C for 30 min in air ambient. The CTA temperature is equivalent to the heat generated by microwave irradiation at 500 W power which measured by infrared (IR) thermometer.

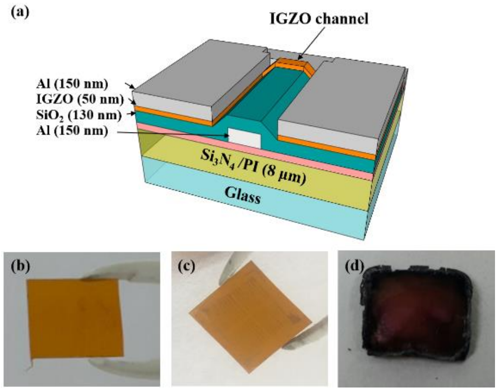

Fig. 1 (a) Schematic illustration of bottom gate type IGZO TFT on PI substrate. (b) Pristine, (c) MWA-treated (1800 W, 2 min), and (d) CTA-treated (600 °C, 30 min) PI substrate photo image.

Fig. 1 (a) illustrates the schematic device structure of the fabricated bottom gate type a-IGZO TFT on the PI substrate. Fig. 1 (b), (c), and (d) show the photo image of pristine, MWA-treated, and CTA-treated PI substrate, respectively. It can be seen that the CTA-treated PI substrate suffered severe thermal damage due to the high-temperature process, but the MWA-treated PI substrate was hardly damaged. Therefore, MWA is a suitable process for annealing flexible substrates that are susceptible to heat.

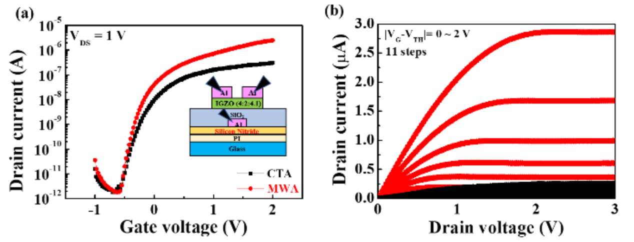

Fig. 2 (a) Transfer and (b) output characteristic curves of the bottom-gate type IGZO TFTs on PI after MWA and CTA.

Fig. 2 shows the transfer curves (I_D-V_G) and output curves (I_D-V_D) of MWA-, and CTA-treated IGZO TFTs on the PI substrate, respectively. As a result, in the transfer curve, the MWA-treated TFT achieved one order higher drain current than CTA-treated TFT. The MWA-treated IGZO TFTs had the mobility of 15.65 $cm^2/V{\cdot}s$, subthreshold swing (SS) of 95.99 mV/dec, the threshold voltage (V_{th}) of -0.45 V, and I_{on}/I_{off} of 1.37 × 10^6. In the output curve, MWA-treated TFTs exhibited much higher driving current than CTA-treated devices.

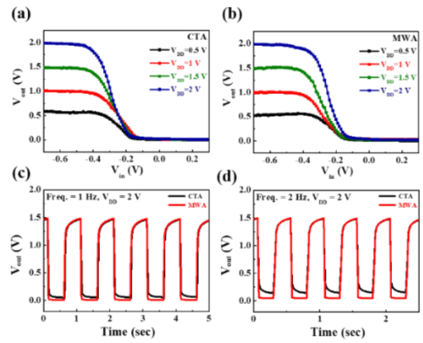

Fig. 3 Resistor-loaded inverter characteristics of MWA- and CTA-treated IGZO TFTs on PI. (a,b) the VTC curve and (c,d) dynamic inverting response at 1, 2 Hz frequency.

Fig. 3 shows resistor (400 MΩ)-loaded inverter characteristics of MWA- and CTA-treated IGZO TFTs on the PI substrate. In Fig. 3 (a,b), the voltage transfer characteristics (VTC) were measured by V_{in} sweep from -0.7 to 0.3 V while changing the V_D from 0.5 to 2 V (0.5 V step). In Fig. 3 (c,d), the dynamic inverting responses were evaluated in V_{in} pulse of 1, 2 Hz at constant V_{DD}=2 V. Consequently, MWA-treated TFTs indicated more accurate ("0", "1") inverting operation and faster switching speed than CTA-treated devices.

Fig. 4 shows the time dependence V_{th} shift under positive-gate bias temperature stress (PBTS, V_G=+2 V) and negative gate bias temperature stress (NBTS, V_G=-2 V) test at 25, 55, and 85 °C, respectively. The MWA-treated IGZO TFTs exhibited smaller ΔV_{th} values than CTA-treated devices for PBTS and NBTS tests. In addition, Table. 1 shows the various parameter, such as ΔV_{th}, charge trapping time (τ), and effective energy barrier (E_τ), which extracted from Fig. 4. As a result, MWA-treated TFTs showed improved reliability than CTA-treated TFTs in terms of charge trapping time and effective energy barrier.

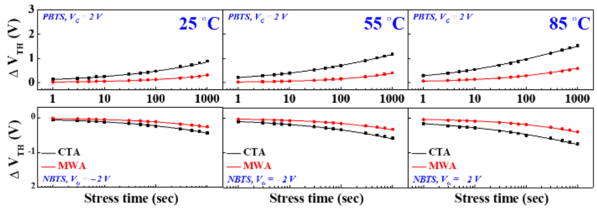

Fig. 4 Time dependence of the V_{th} shift under PBTS (V_G= +2 V) and NBTS (V_G= -2 V) tests at 25, 55, and 85 °C.

Table I. The value of ΔV_{th} after 1000 sec, charge trapping time (τ) and effective energy barrier.

Instability comparison		ΔV_{th} after 1000 sec [V]			Charge trapping time, τ (sec)			Effective energy barrier [eV]
		25 °C	55 °C	85 °C	25 °C	55 °C	85 °C	
CTA	PBTS	0.876	1.171	1.517	7.1×10^3	1.6×10^3	3.7×10^2	0.449
	NBTS	-0.432	-0.581	-0.770	8.7×10^4	3.8×10^4	1.8×10^4	0.238
MWA	PBTS	0.305	0.393	0.577	7.3×10^4	3.4×10^4	1.5×10^4	0.240
	NBTS	-0.255	-0.322	-0.393	1.6×10^5	9.3×10^4	4.9×10^4	0.176

3. Conclusions

In this study, high-performance a-IGZO TFT was fabricated on a flexible and transparent PI substrate employing a thermal damage-free MWA process which has a low-thermal budget and highly efficient energy transference. In addiction. PI substrate was not significantly affected by thermal damage even at high microwave power. On the other hand, severe damage to the PI substrate was observed in the CTA process. Furthermore, when MWA-technology was applied, the electrical and stability performance was successfully improved. The MWA-treated TFTs had higher mobility, lower subthreshold swing, and higher on/off ratio than CTA-treated TFTs. Moreover, in terms of gate bias and temperature stress, the MWA-treated TFTs exhibited a superior immunity to both PBTS and NBTS tests. As a result, a low-thermal budget and thermal damage-free MWA treatment is a promising technology for flexible electronics based TFT applications.

Acknowledgements

The present Research has been conducted by the Research Grant of Kwangwoon University in 2020. And this work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2020R1A2C1007586).

References

[1] Kamiya, T. and Hosono, H. *NPG Asia Mater. 2*(1), (2010) pp.15-22.

[2] Kamiya, T., Nomura, K. and Hosono, H., *Sci. Technol. Adv. Mater*. (2010)

[3] Park, J.H., Lee, H.E., Jeong, C.K., Hong, S.K., Park, K.I. and Lee, K.J., 2019 *Nano Energy*, *56*, pp.531-546.

[4] Shin, J.W. and Cho, W.J., 2018. *Phys. status solidi A*, *215*(20), p.1700975.