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High Performance Solution-deposited InGaZnO Thin Film Transistors using Microwave Annealing and Ar/O_2 Plasma Treatment at Low Process Temperature

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Abstract

Extremely low-temperature process for solution-deposited indium gallium zinc oxide (IGZO) TFT was developed. Microwave irradiation is shown to be an attractive process for reduction of temperature. Solution processed a-IGZO pseudo MOSFETs prepared at 67 ˚C by microwave annealing and plasma treatment have shown enhanced electrical characteristics of 1.37 cm^2/V·s mobility and 5.61x10^6 on/off ratio, a threshold voltage of -0.23 V, and a subthreshold slope of 234 mV/decade. We confirmed that the device performance of microwave annealing at low temperature is superior to conventional annealing at high temperature (600 ˚C).

1. Introduction

Amorphous InGaZnO (a-IGZO) film is promising for channel materials of thin-film transistor (TFT) due to its relatively higher mobility than amorphous Si, transparency and flexibility. The a-IGZO film deposition has been generally used by sputtering, pulsed laser deposition (PLD), chemical vapor deposition (CVD) and solution-processed coating methods. Especially, this solution-derived coating in the normal pressure system instead of high-vacuum system has many advantages such as a low cost production and cover large area. However, the solution processing of them typically requires a high annealing temperature above 450 ˚C to convert the precursor into an metal oxide networks. Also recent efforts to lower the annealing temperature, device quality of oxide semiconductors exhibiting a high performance and device stability that are not easily achievable in organic semiconductor-based electronics have been successfully grown on plastic substrates [1].

In this paper, especially, the influence of Ar/O_2 mixed gas plasma treatment followed by microwave annealing on the electrical and instability properties of channel layer was investigated to reduce the annealing temperature.

2. Device structure and Experiments

A 0.1 M precursor solution of IGZO was prepared by solution method, dissolving mixture of indium nitrate hydrate [$In(NO_3)_3 \cdot xH_2O$], gallium nitrate hydrate [$Ga(NO_3)_3 \cdot xH_2O$] and zinc acetate dehydrate [$Zn(CH_3COO)_2 \cdot 2H_2O$] in 2-methoxyethanol [$C_3H_8O_2$]. Then, monoethanolamine [C_2H_7NO] was used as a solution stabilizer, and stirred at 60 ˚C for 1 h to form the IGZO solution precursor. The molar ratio of IGZO was fixed at 2:1:1 and the active layers were performed by spin-coating at 6000 rpm onto SiO_2 (100 nm)/p-type Si wafer. Fig. 1 and 2 show the schematic diagram of the spin coating method and fabricated pseudo MOSFET device **[2]**, respectively. It should be noted that the highest process temperature for device fabrication is less than 70 ˚C using microwave annealing. Microwave annealing process can transfer of electromagnetic energy directly to the IGZO layers by absorption of microwave energy. The microwave power used in this work is 1000 W during 25 min and applying frequency of 2.45 GHz. Also, the Ar/O_2 (25/25 sccm) plasma treatment was conducted to improve the instability. The measurement of negative bias stress (NBS) and positive bias stress (PBS) for the fabricated IGZO pseudo MOSFET was carried out under the following bias condition of ± 20 V for 1 h. Electrical characteristics were measured in the dark box at room temperature with the Agilent 4156B high-precision semiconductor parameter analyzer.

3. Results and discussions

Fig. 3 shows the transfer characteristics of solution-deposited IGZO pseudo MOSFET annealed by two different methods; microwave annealing after Ar/O_2 plasma and conventional furnace 600 ˚C annealing. Table 1 summarizes important characteristics such as threshold voltage (V_{th}), subthreshold swing (SS), on/off ratio and field-effect mobility (μ_{FE}). Obviously, the device performance of microwave annealing at low temperature is superior to conventional annealing at high temperature (600 ˚C).

Fig. 4 shows the transfer characteristics of solution-deposited IGZO pseudo MOSFET for double sweep of drain voltage 10 V. We conferred threshold voltage variation of reference drain current 1 nA. For furnace annealed device, a large parallel V_{th} shift of 7.32 V to high gate voltage was revealed. On the other hand, the microwave annealed device after Ar/O_2 plasma showed a few parallel V_{th} shift of 0.59 V.

Fig. 5 shows the development of the threshold voltage as a function of the applied PBS and NBS under the stress condition of V_G = ±20 V during 1 h at room temperature. Clearly, the V_{th} stability under the PBS was greatly improved by applying the microwave annealing after plasma treatment. The positive shift of transfer curve is originated from the negative charge being trapped at the chan-

nel/dielectric interface [3].

4. Conclusions

We developed an extremely low-temperature process for solution-deposited indium gallium zinc oxide (IGZO) TFT. The Ar/O_2 plasma treatment and microwave irradiation drastically decreased the annealing process temperature. An excellent improvement in the device performance and stability was obtained from the solution-deposited IGZO devices at a low temperature of 67 ˚C using Ar/O_2 plasma and microwave annealing. The device performance of microwave annealing at low temperature is superior to conventional annealing at high temperature (600 ˚C). Results of this study significantly contribute to application in emerging flat-panel display of transparent oxide TFTs.

References

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Table 1. Electrical characteristic and instability of the solution IGZO pseudo MOSFETs compared annealing method.

	V_{th} (V)	S.S (mV/dec)	ON/OFF ratio	μ_{FE} ($cm^2/V{\cdot}s$)
Furnace 600 ˚C	-0.59	283	1.69×10^6	0.31
Plasma + microwave	-0.23	234	5.61×10^6	1.37

	Hysteresis voltage (V)	NBS(ΔV_{th})	PBS(ΔV_{th})
Furnace 600 ˚C	7.32	-1.07	12.3
Plasma + microwave	0.59	-1.45	-1.62

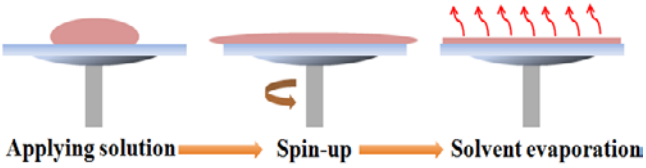

Fig. 1 Schematic diagram of spin coating process.

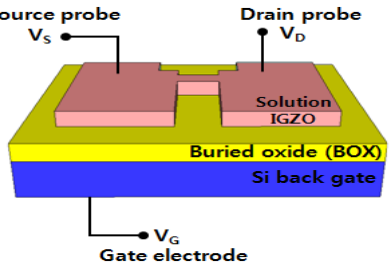

Fig. 2 Schematic structure of solution IGZO pseudo MOSFETs.

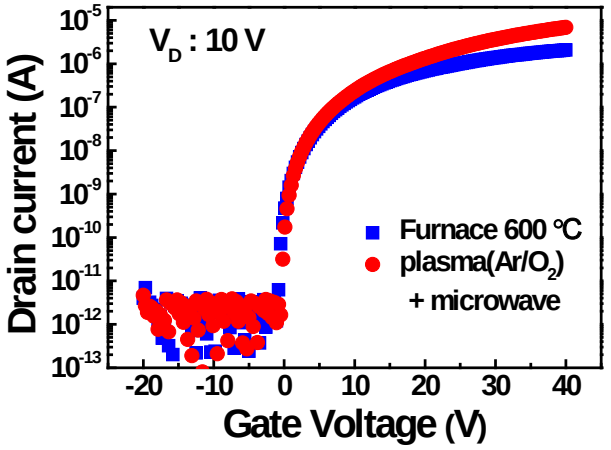

Fig. 3 Transfer characteristic of the solution-deposited IGZO pseudo MOSFET annealed at conventional furnace 600 ˚C and at plasma treated microwave annealing.

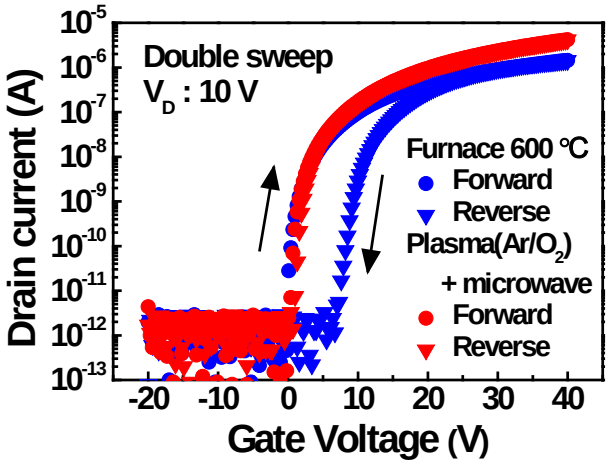

Fig. 4 Transfer characteristics of solution-deposited IGZO pseudo MOSFET measured in double sweep, annealed furnace 600 ˚C and plasma treated microwave annealing. The arrows indicate the bias double sweep direction to measure a hysteresis.

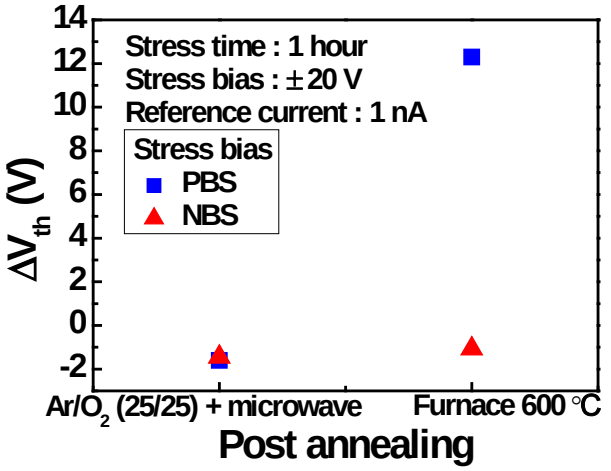

Fig. 5 Dependence of the positive bias stress (V_G=20 V) and negative bias stress (Vg=–20 V) induced threshold voltage shift on stress time (1 h).