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The Optimization of Ar/O_2 Mixed-plasma Treatment for Improving the Microwave-assisted In-Ga-Zn-O Nanofiber Thin Film Transistors

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Abstract

In this study, we fabricated high performance In-Ga-Zn-O (IGZO) nanofiber thin-film-transistors (TFTs) by low thermal budget process using microwave annealing (MWA) and Ar/O_2 plasma treatment. We compared the electrical properties and reliability, in order to confirm the effect of various Ar/O_2 mixed-plasma treatment on the nanofiber IGZO TFTs. As a result, the electrical properties gradually improved as the O_2 gas ratio increased in Ar/O_2 gas flow. In particular, the Ar/O_2 mixed-plasma treatreated device with a gas flow rate of 0:50 sccm exhibited the most excellent electrical properties. Moreover, the reliability of the IGZO nanofiber TFTs was evaluated by gate bias temperature stress test at room temperature and high temperature. Likewise, the reliability was mor stable as the O_2 gas ratio increased in Ar/O_2 gas flow, and the Ar/O_2 mixed-plasma treated device with a gas flow rate of 0/50 sccm was the most stable. Therefore, MWA and Ar/O_2 mixed-plasma treatment technologies are expected to be applied to the fabrication of high-performance IGZO nanofiber TFTs with low thermal budget.

1. Introduction

Recently, IGZO, which is advantageous for high mobility and large area, is being studied for forming a nanofiber instead of films in order to apply it to a flexible and stretchable next-generation device. Electrospinning is one of the most commonly used methods of forming nanofibers due to the low manufacturing cost and simplicity of the process because it does not use vacuum equipment.[1] In particular, electrospun IGZO nanofibers have flexibility and very large specific surface area in 1-dimensional (1D). Electrospun IGZO nanofibers require high temperature calcination annealing and post deposition annealing (PDA) processes to vaporize the polymer matrix and remove defects in the metal oxide to improve electrical properties. However, a high temperature and long time annealing process has a large thermal budget to be transferred to the device. This is a major limiting factor for flexible device applications. In order to solve these problems, low temperature MWA using electromagnetic wave and low temperature surface treatment using plasma have been studied. MWA is a high efficiency heat treatment method that can transfer uniform heat energy and selectively heat treatment inside the device.[2] On the other hand, many researches about the optimized plasma treatment conditions for the IGZO film was reported. Plasma treatment using Ar or O_2 gas is an effective post treatment method to improve electrical properties such as conductivity, channel resistance and stability of IGZO devices.[3-4] However, there is no notable study of optimized plasma treatment conditions for IGZO nanofiber. It is essential to optimize plasma treatment conditions to improve the device characteristics.

Therefore, in this study, we fabricated IGZO nanofiber TFTs by applying MWA technology of low thermal budget to electrospun IGZO nanofibers, and plasma treatment was performed in various Ar/O_2 mixed-gas flow to improve device characteristics. We also investigated the effect of various Ar/O_2 mixed-plasma treatment on electrical properties and reliability of IGZO nanofiber TFTs. As a result, electrical properties and reliability of IGZO nanofiber TFTs were different according to Ar/O_2 mixed-gas flow, and it was confirmed that electrical properties and reliability were improved as O_2 gas ratio increased in Ar/O_2 gas flow.

2. General Instructions

On the p-type Si wafer, a 100-nm-thick of SiO_2 was thermally grown and standard radio corporation of America (RCA) cleaning was performed. IGZO nanofiber was formed by electrospinning method using IGZO precursor solution. To remove the polymer matrix and improve the electrical properties, the calcination annealing was conducted by MWA at the power of 1000 W in air, for 2 min. Then, the active channel region of the IGZO nanofiber TFTs was defined by photolithography and wet-etching using a 30:1 buffer oxide etchant (BOE). After that, the IGZO nanofibers were exposed to a plasma in a reactive-ion etching system for various Ar/O_2 mixed-gas flows (50/0, 40/10, 25/25, 10/40, 0/50 sccm). The power of the plasma treatment, the forward pressure, and the exposure time were 200 W, 300 mTorr, and 20 sec, respectively. For the PDA process, conventional thermal annealing (CTA) was performed in a furnace at 600 °C in O_2 ambient, for 30 min. Finally, TFTs were fabricated by depositing a 150 nm-thick Ti using E-beam evaporator and forming source and drain electrode of TFTs through the lift-off process.

The structure of IGZO nanofibers was analyzed by scanning electron microscope (SEM) images (×15000) shown in Fig. 1, and the average diameter of fibers was about 200 nm.

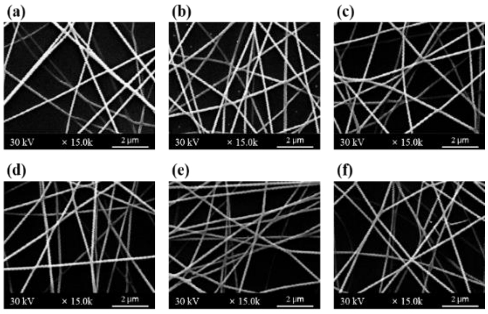

Fig. 1 SEM image of IGZO nanofiber TFTs (a) without plasma treatment, and under various Ar/O_2 mixed-plasma gas of (b) 50/0 sccm, (c) 40/10 sccm, (d) 25/25 sccm, (e) 10/40 sccm, (f) 0/50 sccm

Fig. 2 (a) and (b) show transfer curves (I_D-V_G) and output curves (I_D-V_D) of various Ar/O_2 mixed-plasma treated IGZO nanofiber TFTs, respectively. As a result, the drain current increased as O_2 gas ratio increased in Ar/O_2 gas flow. In particular, the Ar/O_2 mixed-plasma treated device with a gas flow rate of 0/50 sccm show the highest current level.

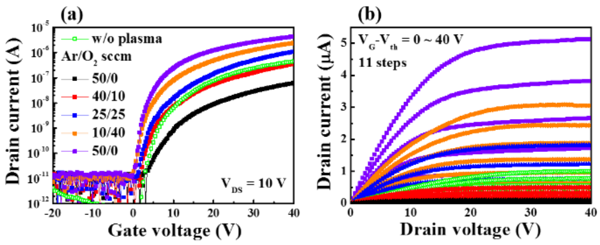

Fig. 2 (a) Transfer curves and (b) output curves of the various Ar/O_2 mixed-plasma treated IGZO nanofiber TFTs

Fig. 3 (a) shows the voltage transfer curves (V_{OUT}-V_{IN}) of the resistor-loaded inverter based on IGZO nanofiber TFTs and inset of (a) shows the corresponding gain. As the input voltage is swept from "0" (-20 V) state to "1" (40 V) state, the output voltage varies from "1" (100 V) state to "0" (0 V) state. The output level was approximately equal to the input V_{DD} value, and the low output level was closer to 0 V as the O_2 gas ratio increased in Ar/O_2 gas flow. Fig 3. (b) shows the dynamic response of resistor-loaded inverter when V_{IN} was pulsed 1 Hz. Likewise, the low output level was closer to 0 V as O_2 gas ratio increased in Ar/O_2 gas flow

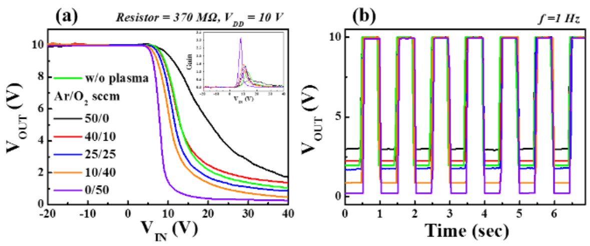

Fig. 3 (a) Voltage transfer curves and (b) dynamic responses of resistor-loaded inverter based on IGZO nanofiber TFTs

Table I. shows the threshold voltage shifts (ΔV_{TH}) in the positive gate bias temperature stress (PBTS, V_{GS} = + 20V) test and the negative gate bias temperature stress (NBTS, V_{GS} = - 20V) test measured at 25, 55, and 85 °C of various Ar/O_2 mixed-plasma treated IGZO nanofiber TFTs. The activation energy was extracted by gate bias temperature test. As a result, the plasma treatment improved the reliability and reduced the activation energy of the IGZO nanofiber TFTs. Especially, as O_2 gas ratio increased in Ar/O_2 gas flow, the reliability of the device gradually improved. And the Ar/O_2 mixed-plasma treated device with a gas flow rate of 0/50 sccm shows the best reliability and lowest activation energy.

Table I. Time dependence of ΔV_{TH} and activation energy under PGBS and NGBS tests for various Ar/O_2 mixed-plasma treated IGZO nanofiber TFTs

Ar/O_2 sccm		50/0	40/10	25/25	10/40	0/50	w/o plasma
PBTS (ΔV_{TH}@1000 s)	25 ˚C	7.46	7.00	6.38	5.30	4.69	8.01
	55 ˚C	10.23	9.52	8.93	8.23	7.61	12.57
	85 ˚C	14.11	13.50	13.21	12.51	9.50	15.62
NBTS (ΔV_{TH}@1000 s)	25 ˚C	-2.31	-1.78	-1.52	-1.05	-0.67	-3.54
	55 ˚C	-6.25	-4.53	-4.29	-4.06	-2.64	-6.61
	85 ˚C	-9.34	-7.20	-6.33	-5.06	-3.57	-9.38
Activation energy (eV)	PBTS	0.3379	0.3213	0.3069	0.2931	0.2903	0.404
	NBTS	0.5539	0.5437	0.5413	0.5359	0.5020	0.579

3. Conclusions

In this study, we fabricated high performance IGZO nanofiber TFTs with low thermal budget process using MWA and Ar/O_2 mixed-plasma treatment. We compared the electrical properties to confirm the effect of Ar/O_2 mixed-plasma treatment on microwave-assisted IGZO nanofiber TFTs. As a result, the electrical properties were improved as O_2 gas ratio increased in Ar/O_2 gas flow. Likewise, the reliability evaluation results of the device through the gate bias temperature stress test was improved as the O_2 gas increased in Ar/O_2 gas flow, and the activation energy also decreased. Therefore, it is expected that MWA and Ar/O_2 plasma treatment will be a promising technology for achieving low thermal budget process for next generation display using IGZO nanofiber TFTs.

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