J-2-03

Extended Abstracts of the 2020 International Conference on Solid State Devices and Materials, VIRTUAL conference, 2020, pp661-662

Hydrogenated In–Ga–Zn–O thin-film-transistors with an anodize Al_2O_3 gate insulator for flexible devices

Shuya Kono[1], Marin Mori[1], S G Mehadi Aman[1], Yusaku Magari[1,2], Norbert Fruehauf[3] and Mamoru Furuta[1,2]

[1] Materials and Science and Engineering Course, [2] Center for Nanotechnology
Kochi University of Technology, Tosayamada, Kami city, Kochi 782-8502, Japan
[3] Institute for Large Area Microelectronics, University of Stuttgart, Germany
Tel: +81-887-57-2521 E-mail: 245109v@gs.kochi-tech.ac.jp

Abstract

For the purpose of fabricating TFTs on a flexible substrate, we developed a low-temperature (150 °C) processed thin-film transistor (TFT) with an anodize alumina gate insulator and a hydrogenated In–Ga–Zn–O (IGZO:H) channel. An IGZO:H TFT with a 20 nm-thick alumina gate insulator exhibited good electrical properties with a field effect mobility of 18.9 cm²/Vs, a subthreshold swing of 0.14 V/dec., a hysteresis of 0.02 V, and a threshold voltage of -0.89 V. The anodized alumina gate insulator and IGZO:H channel are promising for achieving high performance flexible devices.

1. Introduction

IGZO is a promising candidate for an active channel of flexible thin-film transistors (TFTs) because it shows superior electrical properties ($\mu_{FE} > 10$ cm^{2}V^{-1}s^{-1}) even when deposited at room temperature[1]. Therefore, IGZO TFT has been studied for flexible device applications. We previously reported that post-annealing temperatures for defect reduction of IGZO TFTs can be reduced from 300 °C to 150 °C by adding hydrogen gas during IGZO sputtering (denoted as hydrogenerated IGZO, IGZO:H), which is lower than the softening temperature of flexible plastic substrates[2,3]. However, low-temperature formation of high quality gate insulator (GI) is still challenging issue for flexible IGZO TFTs because performance and reliability of the TFTs strongly influenced by both GI and IGZO/GI interface qualities. Aluminum oxide (Al_xO_y) has a dielectric constant of ~9 (high-k), and can be grown at room temperature by anodization of Al film.

In this work, high mobility oxide TFT with an IGZO:H channel and an anodized Al_xO_y GI was demonstrated at a maximum processing temperature of 150 °C.

2. Experimental method

A bottom gate and top contact type IGZO TFT was fabricated on a 4-inch nonalkaline glass substrate as schematically illustrated in Fig. 1(a). First, a 150-nm-thick Al:NdTi alloy film was deposited by DC sputtering, and patterned into a gate electrode. Then the Al:NdTi film was anodized in an electrolyte to form an Al_xO_y layer. Since the Al_xO_y thickness can be controlled by an anodization voltage (1.25 nm/V), film thickness of 20 and 60 nm were used for GIs. After anodization, the films were annealed in vacuum at 150 °C for 1 hour followed by O_2 plasma treatment. Next, a 20 nm-thick IGZO:H (In:Ga:Zn=6:2:1 at.%) film was deposited by RF sputtering, and patterned into an active channel. Then, the IGZO:H film was annealed at 150 °C for 1 hour in air. A permanent epoxy-based negative-type photoresist (SU-8) was spin-coated as an organic passivation layer (OPVL) to exclude water and oxygen molecules in ambient air. After opening contact holes, source and drain electrodes were formed by Mo/Al/Mo stacked film. The channel length and width were 20 and 66 μm, respectively. A post-annealing was carried out at 150 °C for 1 hour before electrical characterization. The micrograph of fabricated TFT was shown in Fig. 1(b).

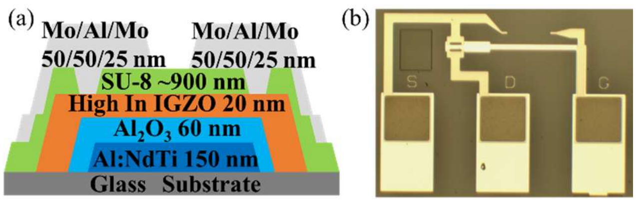

Fig. 1(a) Schematic cross-sectional view and (b) micrograph of the TFT.

3. Results and discussion

Figure 2 shows current density (J) and electric field (E) characteristics of anodize Al_xO_y films which were measured by a metal/insulator/metal (MIM) capacitor. The measurements were taken from different electrode sizes.

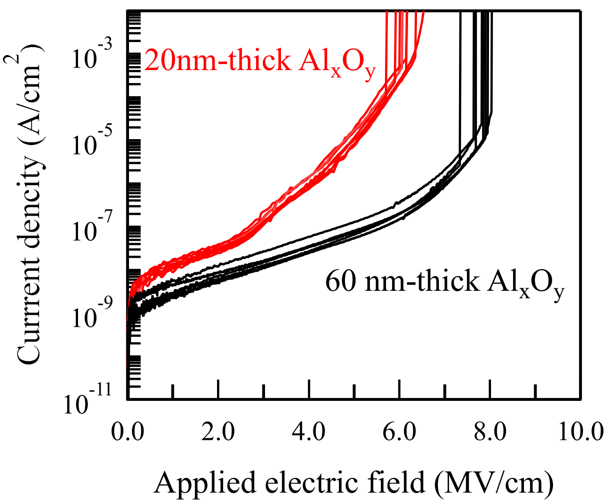

Fig.2 The current density in the 20 and 60-nm-thick Al_xO_y films as a function of applied electric field.

For the 60 nm-thick Al_xO_y film, electric breakdown was observed over 7 MV/cm. When the thickness reduced to 20 nm, breakdown field degraded to 5~6 MV/cm. In addition, current density in the 20 nm-thick Al_xO_y film increased when applied electric field exceeded 3 MV/cm. It was confirmed that Fowler-Nordheim tunneling is a dominant current mechanism in the 20 nm-thick film under the electric field of over 3 MV/cm.

Figure 3 shows transfer characteristics and transconductance of the TFTs with 20 and 60 nm-thick Al_xO_y GIs. Table I summarizes the field effect mobility (μ_{FE}), subthreshold swing (*S.S.*), hysteresis, maximum transconductance (g_{mMax}) at W/L=1, and threshold voltage of TFTs. The g_{mMax} is defined by the Eq (1).

$$g_{mMax} = \frac{L}{W}\frac{dI_D}{dV_G} = \mu_{FE} \cdot C_{ox} \cdot V_d \qquad (1)$$

where C_{ox} is a gate capacitance per unit area.

Low off current of below 1 pA was obtained from both TFTs, indicating that gate leakage current is negligible even for 20 nm-thick Al_xO_y GI. On the other hand, S.S. improved from 0.28 to 0.14 V/dec. when Al_xO_y GI thickness reduced from 60 to 20 nm. Moreover, on current increased by decreasing Al_xO_y GI thickness. The g_{mMax} of the 20 nm-thick Al_xO_y GI was approximately three times higher than that of the 60 nm-thick Al_xO_y GI. μ_{FE} of 18.9 cm^2/Vs, *S.S.* of 0.14 V/dec., and threshold voltage (V_{th}) of -0.89 V were obtained without hysteresis (ΔV_H) from the TFT with a 20 nm-thick Al_xO_y GI.

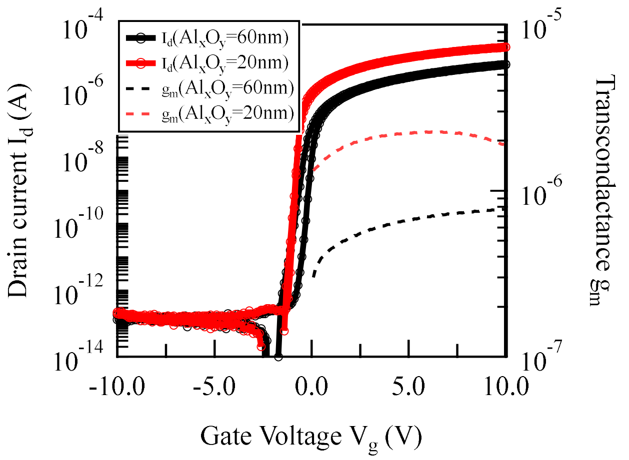

Fig.3 Transfer characteristics of the TFTs with 20 and 60-nm-thick Al_xO_y GI. (V_{DS} = 0.1 V)

Table1 Summary of the electrical properties

GI-Al_xO_y (nm)	μ_{FE} (cm^2/Vs)	*S.S.* (V/dec.)	ΔV_H (V)	g_{mMAX} (S)	V_{th} (V)
20	18.9	0.14	0.02	2.3×10^{-6}	-0.89
60	22.8	0.28	0.47	8.1×10^{-7}	-0.64

Figure 4 shows a hysteresis of the TFT with 20 nm-thick Al_xO_y GI as a function of applied positive gate electric field during transfer curve measurements. Hysteresis was negligible until applied electric field of below 5 MV/cm (maximum V_G of 10 V); however, it increased with increasing applied electric field. Since clockwise hysteresis is mainly due to an electron trapping at an IGZO:H/Al_xO_y interface or in an Al_xO_y GI, applied gate electric field should be kept below 5 MV/cm for 20 nm-thick Al_xO_y GI.

Reliability of the TFTs will be discussed at the conference.

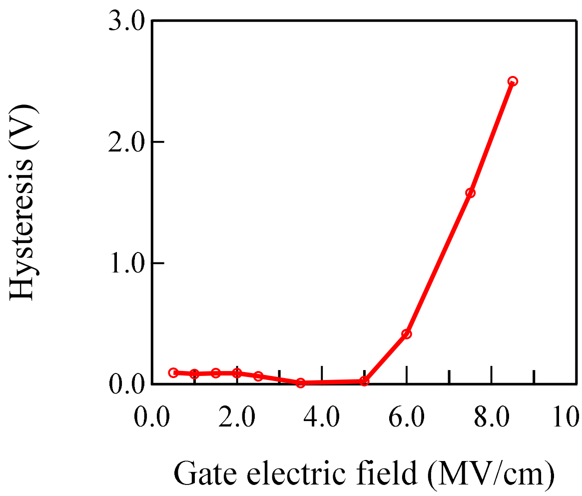

Fig.4 Hysteresis of the TFT with a 20 nm-thick Al_xO_y GI as a function of applied gate electric field during transfer characteristics measurements.

4. Conclusions

In this work, for the purpose of fabricating TFTs on flexible substrates, we proposed to fabricate high performance IGZO:H TFTs with an anodized Al_xO_y GI at a maximum processing temperature of 150 °C. A 20 nm-thick anodized Al_xO_y exhibited a dielectric constant of 8.8 and a breakdown electric field of over 5 MV/cm. An IGZO:H TFT with a 20 nm-thick Al_xO_y GI exhibited good electrical properties with a μ_{FE} of 18.9 cm^2/Vs, a *S.S.* of 0.14 V/dec., and a V_{th} of -0.89 V without hysteresis. An anodized Al_2O_3 is one of promising material for GI in the low-temperature-processed IGZO TFTs for low power consumption flexible electronics.

References

[1] K. Nomura *et al.*, *Nature* **432** (2004) 488.
[2] S G M. Aman *et al.*, *Appl. Phys. Express* **11** (2018) 081101.
[3] D. Koretomo *et al.*, *Appl. Phys. Express* **13** (2020) 076501.