Applied Surface Science 357 (2015) 1915–1919

Contents lists available at ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc

Performance enhancement of amorphous indium-zinc-oxide thin film transistors by microwave annealing

Rui Xu[a,b,1], Jian He[b,c,1], Wei Li[a,*], David C. Paine[b,*]

[a] State Key Laboratory of Electronic Thin Films and Integrated Devices, University of Electronic Science and Technology of China (UESTC), Chengdu 610054, People's Republic of China
[b] School of Engineering, Brown University, Providence, RI 02912, United States
[c] Key Laboratory of Instrumentation Science and Dynamic Measurement, North University of China, Taiyuan 030051, People's Republic of China

ARTICLE INFO

Article history:
Received 10 February 2015
Received in revised form 25 April 2015
Accepted 14 September 2015
Available online 16 September 2015

Keywords:
Indium zinc oxide
Thin film transistors
Threshold voltage
Microwave annealing

ABSTRACT

The effect of microwave annealing on the field effect mobility and threshold voltage of amorphous indium zinc oxide (a-IZO) thin film transistors (TFTs) is reported. A control device with traditional hotplate annealing at 200 °C for 1 h was applied for comparison. The results show that both microwave annealing and low-temperature hotplate annealing increase the field effect mobility from 12.3 cm^2/V s in as-deposited state to ~19 cm^2/V s in annealed state. However, the negative shift in threshold voltage with microwave annealing (from 0.23 V to −2.86 V) is smaller than that with low-temperature hotplate annealing (to −9 V). A mechanism related with the electrical properties of a-IZO material is proposed. This rapid low-temperature annealing technology makes a-IZO TFTs promising for use in flexible, transparent electronics.

1. Introduction

Amorphous oxide semiconductors (AOS) thin film transistors have recently attracted considerable attention in the applications of transparent and flexible electronics for next generation displays because of its high field effect mobility and compatibility with present solid-state semiconductor technologies. Among the AOS materials, amorphous In_2O_3–10 wt.%ZnO (a-IZO) is a particularly attractive candidate material due to its high carrier mobility (~15–50 cm^2/V s) [1–5], room temperature processing, amorphous phase stability (crystallized at above 500 °C) [6,7], smooth surface (RMS roughness ~0.2 nm) [8] and isotropic etch characteristics. In addition, the electrical conductivity of a-IZO can be tuned by control of the oxygen content in the sputter gas during deposition.

Unfortunately, defects are easily formed by the ion bombardment during plasma glow discharge. These incorporation ions such as Ar^+ and H^+ work as carrier scattering centers and degrade the electrical performance [9]. Therefore, posting conventional thermal annealing above 200 °C for 1 h or longer is required to improve the electrical performance of a-IZO TFTs device [10,11]. However, this conventional thermal annealing technology causes the threshold voltage shift to large negative, resulting in the stability and reliability issues for practical applications. The other disadvantage of thermal annealing is that the temperature of 200 °C is too high for flexible substrate, limiting the application in heat-sensitive polymeric substrates that are inexpensive, flexible, and lightweight.

Unlike the kinetic and mechanism of energy transfer in conventional thermal processing such as hotplates or a thermal oven, microwave energy is selectively and directly delivered to the material through molecular interaction within the electromagnetic field and converts the electromagnetic energy into thermal energy [12]. Therefore, it offers advantages such as rapid and effective heating process, low temperature process, cost saving, and non-destructive to the adjacent material. Recently, it is reported that microwave annealing is efficient to improve the electrical performance of sputtering IGZO TFTs [13,14] and solution-processed IZOTFTs [15,16]. However, the effect of microwave annealing is seldom reported on IZO TFTs deposited by sputtering method, which is widely adopted for the large-size amorphous IZO TFTs display backplane manufacturing.

In this work, we investigate the effect of microwave annealing on the structural, mobility and stability properties of a-IZO TFTs. Since the absorption of wave energy is in the frequency range of 2–18 GHz for ZnO based materials [17,18]. Therefore, the electrical properties improvement of TFTs with a-IZO active layer is expected by absorbing the microwave energy with frequency of 2.45 GHz.

* Corresponding author.
E-mail addresses: wli@uestc.edu.cn (W. Li), david_paine@brown.edu (D.C. Paine).
[1] These authors contributed equally to this work.

http://dx.doi.org/10.1016/j.apsusc.2015.09.135
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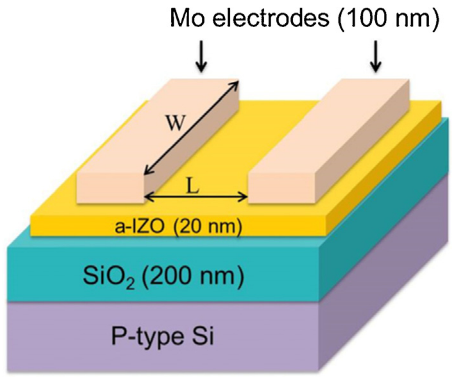

Fig. 1. Schematic view of the a-IZO TFTs device (W/L = 1000 μm/100 μm).

2. Experimental details

The complete bottom-gated a-IZO TFTs device with W/L = 1000 μm/100 μm is shown schematically in Fig. 1. Highly doped *p*-type single crystalline ⟨1 0 0⟩ Si (0.001–0.005 Ω cm) was used as substrate as well as backgate electrode. Thermally grown 200 nm thick SiO_2 was formed as gate dielectric which presents a smooth and uniform surface for the deposition of channel materials. Both a-IZO channel material and Mo electrodes in this experiment were deposited by DC magnetron sputter deposition with shadow mask at room temperature. Before the deposition, the chamber was pumped down to a base pressure less than 5×10^{-6} Torr and the target was pre-sputtered for 600 s to remove surface contamination. The channel a-IZO material with thickness of 20 nm was deposited using a commercially available 90 wt.% In_2O_3–10 wt.% ZnO target (Idemitsu Corp.) at a dc power density of 0.22 W/cm^2, a voltage of 280 V, a vacuum of 2 mTorr and an Ar/O_2 gas volume fraction of 86/14. While the source/drain electrodes of 100 nm Mo were deposited at a dc power density of 0.88 W/cm^2 at 400 V with pure Ar. The devices were subsequently irradiated by microwave in air atmosphere without any auxiliary materials. The microwave frequency in this work is 2.45 GHz, the output power is 700 W and 1000 W, and the irradiation lasted from 60 s to 300 s. In addition, a control device with conventional low-temperature hot plate annealing process in air ambient at 200 °C for 1 h was applied for comparison with microwave annealed a-IZO TFTs.

The output and transfer characteristics were measured in a light-tight probe station using an Agilent 4155C semiconductor parameter analyzer. The amorphous/crystalline structure of the IZO film was evaluated using X-ray diffraction (XRD, Bruker D8 Discover) with Cu *kα* radiation from an X-ray tube source operated at 40 kV and 40 mA. Atomic force microscopy (AFM, Agilent 5500) using Acoustic AC mode probe with Si tip was used to observe the surface morphology and roughness of the IZO films. Hall measurement (100 nm IZO on cover slip glass substrate) using Van der Pauw configuration with magnetic field of 5200 Gauss was applied to measure the carrier density and mobility of IZO films.

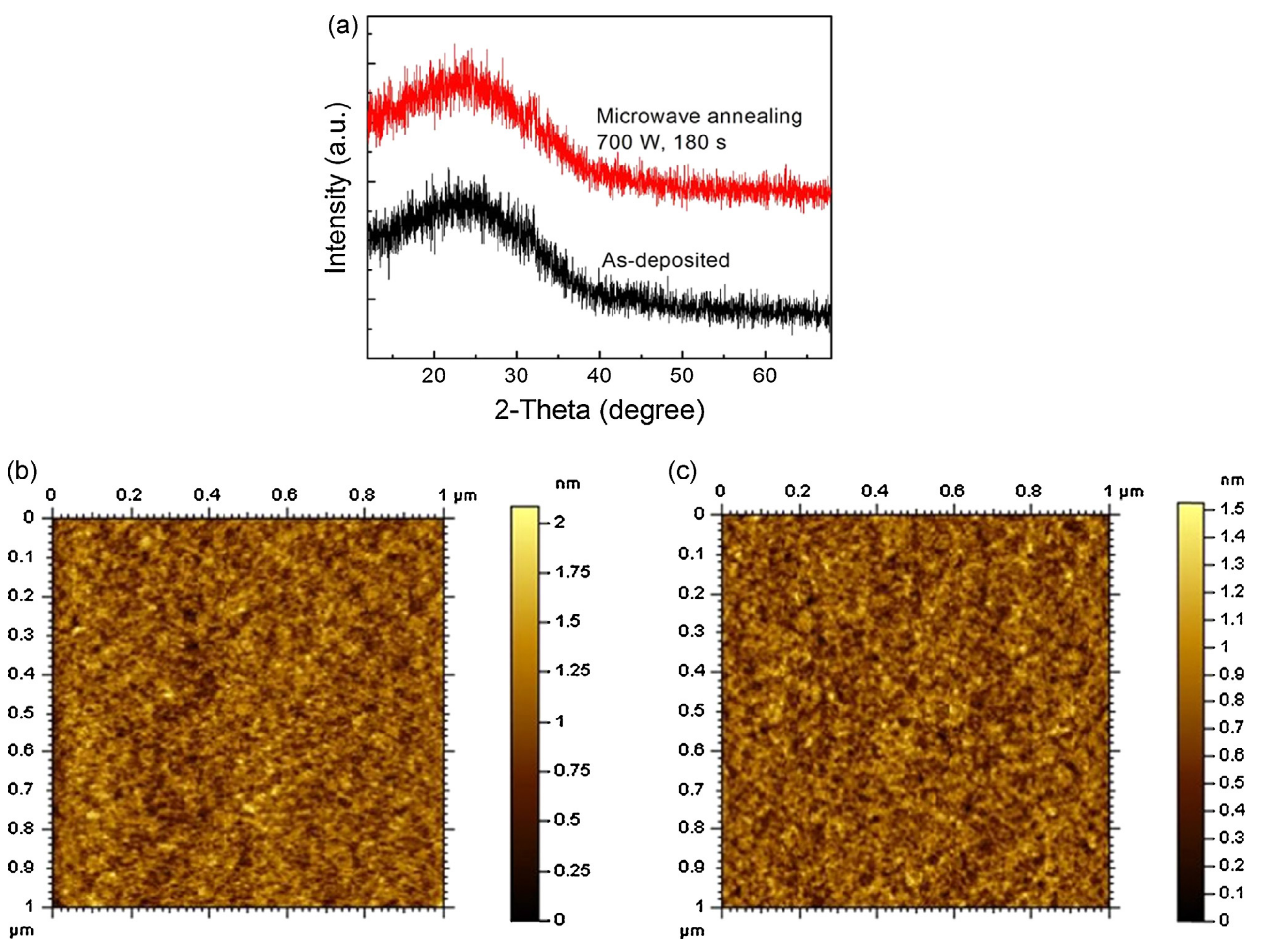

Fig. 2. (a) XRD spectra of 100 nm IZO films on glass substrates. AFM images of 20 nm IZO films in the scan area of 1 μm × 1 μm for (b) as-deposited, and (c) microwave annealed (700 W, 180 s) samples.