Thin Solid Films 605 (2016) 129–135

Contents lists available at ScienceDirect

Thin Solid Films

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

Effects of argon flow rate on electrical properties of amorphous indium gallium zinc oxide thin-film transistors

A.K. Sahoo, G.M. Wu *

Institute of Electro-Optical Engineering, Department of Electronic Engineering, Chang Gung University, Taoyuan 333, Taiwan, ROC

ARTICLE INFO

Article history:
Received 16 May 2015
Received in revised form 2 December 2015
Accepted 5 December 2015
Available online 8 December 2015

Keywords:
Argon
Gas flow rate
Electrical properties
Amorphous indium gallium zinc oxide
Thin-film transistor

ABSTRACT

In this report, amorphous indium gallium zinc oxide (*a*-IGZO) thin films were deposited on glass substrates using different argon flow rates (AFRs). The impact on the electrical properties of the *a*-IGZO thin-film transistors with various AFRs during film growth has been carefully investigated. The AFR varied 20–60 sccm while the oxygen flow rate was maintained at 1 sccm. All *a*-IGZO films achieved transmittance higher than 80% in the wavelength range of 350–1000 nm, and it increased slightly with increasing AFR in the higher wavelength region. The rise in partial pressure due to increased AFR could affect the performance, in particular by increasing the current on/off ratio, and changes in electron mobility, sub-threshold swing voltage and threshold voltage. The optimal results were attained at AFR of 50 sccm. The field effect mobility, sub-threshold swing, ratio of on-current to the off-current, interfacial trap density and threshold voltage are 27.7 $cm^2/V \cdot s$, 0.11 V/dec, 2.9×10^8, $1.1 \times 10^{12}\ cm^{-2}\ eV^{-1}$ and 0.84 V, respectively. In addition, good electrical properties were achieved using dielectric SiO_2 prepared by simple, low-cost electron beam evaporator system.

1. Introduction

Thin-film transistor (TFT) has been the prevailing technology as a switching element for flat panel display applications, such as active-matrix liquid crystal displays [1], active-matrix organic light-emitting diode displays [2] and electronic papers [3]. Recently, transparent electronics received much attention due to their excellent promising characteristics for the next generation optoelectronic devices. They can effectively produce high/low conductivity as well as high visual transparency. Among all transparent conducting oxide materials, the amorphous indium gallium zinc oxide (*a*-IGZO) has been considered as one of the promising materials for thin-film transistor applications because of the high optical transmittance characteristics, low cost processing at low temperature, and excellent surface quality which can provide superior electrical properties, including high field-effect mobility, sharp sub-threshold swing, and high on/off current ratio. These are much superior to those based on hydrogenated amorphous silicon (*a*-Si:H) [4], poly-Si [5], ZnO [6,7], and IZO [8] thin-film transistors. The amorphous phase films can be easily grown at low temperature not only on silicon and glass but also on flexible organic substrates. Several physical vapor deposition methods can be used to grow *a*-IGZO, such as pulsed-laser deposition [9], RF magnetron sputtering [10], DC magnetron sputtering [11], and also non-vacuum techniques such as atmospheric-pressure plasma jet [12], sol–gel [13], and ink-jet printing [14]. Recently, remarkable performance of *a*-IGZO based TFT for replacing the Si-based technology [15] has been reported.

Dielectric materials also play an important role in obtaining high performance TFTs. Silicon dioxide exhibits inherent dielectric properties. The thermo-dynamical and electrical stability, high quality interface state density, and better electrical insulating properties render it unique advantages over other gate dielectrics. Several deposition techniques are available for SiO_2 deposition, such as plasma enhanced chemical vapor deposition [16], RF sputtering [17], atomic layer deposition [18], and growth of SiO_2 on Si substrate using high temperature thermal oxidation [19]. In this study, the SiO_2 deposition was carried out by an e-beam evaporator, because of the distinct advantages in process simplicity at room temperature, cost effectiveness and easy thickness monitoring over a wide area.

The TFT channel of *a*-IGZO has been deposited by RF sputtering, and there still remained challenges to optimize the deposition parameters such as inlet gas ratio, RF power, substrate temperature, post-annealing and passivation effect [20–24]. It has been noted that the effects of argon flow rate (AFR) at fixed O_2 flow on *a*-IGZO films have not been well established in the literatures. The TFT performance can be substantially influenced by the *a*-IGZO film surface physical properties. The changed AFR during deposition alters the inlet gas partial pressure in the chamber, due to the collision rate between plasma ions and varied scattering of Ar ions with neutral Ar atoms. The change in partial pressure due to AFR may influence the characteristics of the films such as optical transmittance, surface roughness, grain size, packing factor and composition of material. However, the TFT electrical performance relies on these physical properties that can be varied and controlled. Based on the

---

* Corresponding author.
E-mail address: wu@mail.cgu.edu.tw (G.M. Wu).

http://dx.doi.org/10.1016/j.tsf.2015.12.016
0040-6090/

reported results, it is important to better understand the impact of different AFRs during the RF magnetron sputtering to obtain the optimum characteristics of *a*-IGZO TFTs.

In this report, the impact of AFR on surface characteristics of *a*-IGZO films as well as the electrical properties of *a*-IGZO TFTs has been studied. The comparative study in performances of TFTs with the reported results was performed using SiO_2 dielectric and good contact of source–drain on channel surface. The influence of AFR on *a*-IGZO surface roughness, optical and binding energy of electronic state of component have been investigated. The mechanisms behind the variation in electrical performance parameters such as mobility, ratio of the on-current to off-current, subthreshold swing voltage, interfacial trap charge density and threshold voltage were thoroughly discussed. In addition, the high performance TFTs and good contact of source–drain on channel surface revealed that importance of simple and low cost e-beam deposited dielectric SiO_2 and the straight-forward device fabrication process.

2. Experimental details

Glass sputter-coated with indium-tin-oxide (ITO, 150 nm thick) has been used as the substrates for *a*-IGZO (Tanaka Kikinzoku) deposition. The sheet resistance was about 15 Ω/sq. The glass substrates were subsequently washed in acetone, alcohol and DI water under ultrasonic agitation, then dried by N_2 gun and 120 °C hotplate. Before the deposition process, 1 mm × 20 mm area from one side was covered using shadow mask for common bottom gate of ITO. The samples were firstly deposited with gate dielectric SiO_2 of 200 nm in thickness by e-beam evaporator system (ULVAC) using SiO_2 source (99.99%). The vacuum chamber base pressure was about 1.1×10^{-3} Pa before the evaporation, and it was increased to 5.3×10^{-3} Pa during the evaporation. The deposition rate was about 0.01–0.1 nm/s. The chamber temperature could be varied at 23–30 °C during the deposition, caused by the heating effect from e-beam sources. No post-deposition annealing was carried out. The distance between the sources and the substrates was fixed at about 36 cm. Additional SiO_2 samples were prepared, also by e-beam evaporator on p^+ Si to evaluate the capacitance per unit area. Then, *a*-IGZO films of 40 nm in thickness were controlled and deposited on bi-layer SiO_2/ITO glass by RF sputtering. The deposited power and pressure were fixed at 70 W and 0.4 Pa. The various Ar/O_2 inlet gas ratios were carried out at 20:1, 30:1, 40:1, 50:1 and 60:1 (sccm:sccm) for the different *a*-IGZO film samples. The other deposition conditions were fixed at all time to avoid any other uncertain effect on films. Finally, metallic Al film of 60 nm in thickness was coated by a thermal evaporator system and patterned to form the source and drain of thin-film transistor, followed by photolithography and lift-off processes. The channel width and length were fixed at 500 μm and 200 μm, respectively. The *a*-IGZO films grown on clean bare glass, with average transmittance of 90%, were used for the investigation of physical characteristics such as optical transmittance, X-ray diffraction analysis (XRD, Bruker D2 Phaser, Cu-K_α 0.154 nm radiation), X-ray photoelectron spectroscopy (XPS, VG scientific Microlab 350, using Al-K_α radiation source with referencing C1s peak at a binding energy of 285 eV), and atomic force microscopy (AFM, Park System, XE-70, using non-contact tapping mode). In addition, field-emission scanning electron microscopy (FE-SEM, Hitachi S-5000) was used to study the cross section of the multilayer samples at an operating voltage of 30 kV. A schematic illustration of the simple device structure is shown in Fig. 1. The TFT devices' electrical properties were evaluated using a semiconductor parameter analyzer (Agilent B1500A).

3. Results and discussion

The amorphous structure of all types of *a*-IGZO films were confirmed by XRD analysis for the as-deposited films. The amorphous properties have been achieved by maintaining room temperature during film deposition, as shown in Fig. 2. The prominent broadened peaks occur at the range of angle 22°–24°, because of the SiO_2 component in glass substrate. Individual sharp diffraction peak, mainly from crystalline structure of film, does not exist. It is difficult to seek for atomic orientation and to obtain grain size information due to the amorphous nature. Although, the variation in grain size with different AFRs could be observed for crystalline based films, such as titanium nitrite (TiN) and aluminum zinc oxide (AZO) using XRD analysis [25,26].

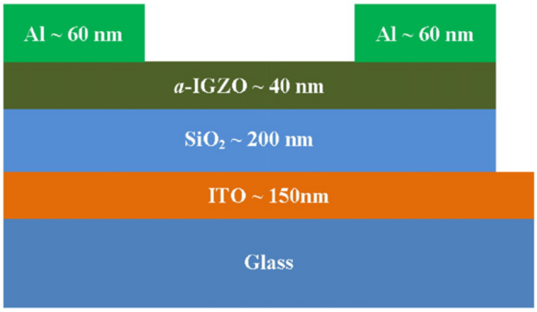

Fig. 1. Schematic illustration of the sample structure of *a*-IGZO based TFTs.

The optical transmittance spectra have been investigated by UV spectrometer (Jasco, ISN-723) for the five different types of as-deposited *a*-IGZO films on clean bare glass, as shown in Fig. 3. They all exhibited transmittance higher than 80% in the visible and near-infrared range (VNIR, wavelength 400–1000 nm). In general, the transmittance is slightly increased with increasing AFR from 30 sccm to 60 sccm in the higher wavelength region. The optical coefficients could vary with changes in wavelength and thickness of films deposited on transparent substrates [27]. Peng et al. modified the envelope analysis theory that the optical transmittance only depends on the thickness of film at fixed other optical parameters [28]. The slight increase in the transmittance was not likely caused by the change in thickness due to little increase of deposition rate with increased AFR for short time deposition [25]. Thus, the enhancement of transmittance could be attributed to refractive index and improved film quality with respect to optical properties of film. The reason behind the increased transmittance could be verified with the cadmium sulfide thin films [29]. The improvement of transmittance due to AFR was also reported for other films such as crystalline cuprous oxide (Cu_2O) films [30,31]. On the other hand, the noticeable high transmittance observed in the visible range (390–790 nm) for the AFR at 20 sccm was likely caused by the low density of plasma inside the chamber that could not influence the transmittance of the bare glass at low wavelength region. The similar kind of phenomena at lower Ar flow had been observed for gallium doped zinc oxide (GZO) films during deposition [32]. In addition, the sharp absorption

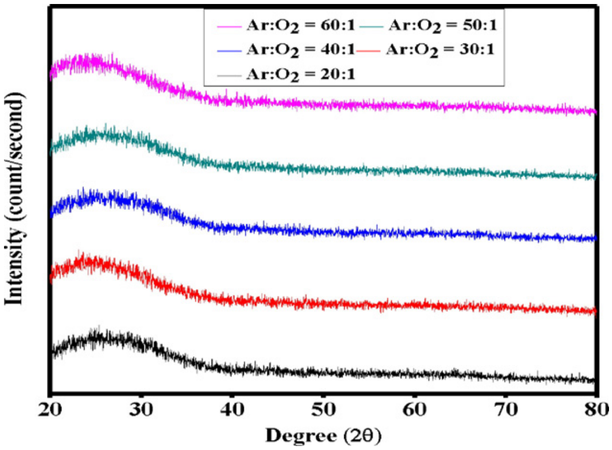

Fig. 2. Amorphous phase of the as-deposited IGZO films under different AFRs has been confirmed by XRD analysis.