Materials Science in Semiconductor Processing 71 (2017) 204–208

Contents lists available at ScienceDirect

Materials Science in Semiconductor Processing

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

Magnetron-sputtered high performance Y-doped ZnO thin film transistors fabricated at room temperature

Manoj Kumar[a], Hakyung Jeong[a], Amit Kumar[b], Beer Pal Singh[c], Dongjin Lee[a,*]

[a] Department of Mechanical Engineering, Konkuk University, 120 Neungdong-ro, Gwangjin-gu, Seoul 05029, South Korea
[b] Institute of Engineering & Technology, North Extn., M.I.A., Alwar 301030, Rajasthan, India
[c] Department of Physics, Ch. Charan Singh University, Meerut 250004, India

ARTICLE INFO

Keywords:
ZnO
Y doping
Thin film transistor
Sputter
Mobility

ABSTRACT

In this report, sputtered-grown undoped ZnO and Y-doped ZnO (ZnO:Y) thin film transistors (TFTs) are presented. Both undoped ZnO and ZnO:Y thin films exhibited highly preferred *c*-axis oriented (002) diffraction peaks. The ZnO:Y thin film crystallinity was improved with an increase of (002) peak intensity and grain size. The electrical properties of ZnO:Y TFTs were significantly enhanced relative to undoped ZnO TFTs. ZnO:Y TFTs exhibited excellent performance with high mobility of 38.79 $cm^2 V^{-1} s^{-1}$, small subthreshold swing of 0.15 V/decade, and high I_{on}/I_{off} current ratio of the order of 8.17×10^7. The O_{1s} X-ray photoelectron spectra (XPS) showed oxygen vacancy-related defects present in the ZnO:Y TFTs, which contributed to enhancing the mobility of the TFTs.

1. Introduction

Oxide semiconductor-based TFTs have emerged as a promising technology for application in large area future display electronics. There is a continuous effort to develop reliable channel layers based on oxide semiconductors [1,2]. High resolution and fast speed display electronics are essential parameters for rapid developments in display technology. It is vital to enhance the mobility of oxide-based semiconductor TFTs to meet the criteria of display electronics. ZnO-based semiconductors have attracted immense attention because of its high mobility, high transparency, and high radiation hardness in the visible region [3,4]. ZnO is a II-VI n-type compound semiconductor (without any intentional doping) with a wide bandgap of 3.37 eV at room temperature and large exciton binding energy of 60 meV. Owing to its natural n-type conduction, ZnO has a large number of native defects such as oxygen vacancies. ZnO can be doped with group III elements to increase its electron mobility, which can reach values of 200 $cm^2 V^{-1} s^{-1}$ at low doping levels [5–7]. A considerable amount of research is focused on indium gallium zinc oxide (InGaZnO), which produced high quality results that are good enough for use in active matrix flat panel displays [8,9]. However, both In and Ga are expensive and rare elements on the earth, making it difficult to sustain large-scale production. Therefore, new materials need to be explored to substitute these elements. Yttrium is an environmentally friendly and abundant rare earth element, and yttrium oxide (Y_2O_3) has several important parameters such as large band gap (~ 5.5 eV), high dielectric constant, and low electron negativity (1.22). One can easily control and modulate the carrier concentration of an active ZnO thin film layer by doping Y in the ZnO thin film. The main fabrication methods of Y-doped ZnO thin films are sol-gel and RF magnetron sputtering. RF magnetron sputtering is a simple deposition device that has a high deposition rate. Moreover, it is widely used for commercial production and even low temperature deposited films have high quality along with being stable, dense, and uniform. In the present study, Y is selected to dope ZnO to address this issue because Y has a lower electronegativity than Zn and is expected to form stable ionic bonds between Y and O in the ZnO matrix. Electrical, structural, and optical properties of ZnO:Y have already been studied in detail by several research groups who observed excellent properties. Therefore, it could be considered a favorable semiconductor channel for TFTs. We demonstrate the fabrication and characterization of high performance TFTs using magnetron-sputtered undoped ZnO and ZnO:Y as active channel layers.

2. Experimental details

The SiO_2 grown by metal organic CVD on a Si wafer used in this study was commercially available. Undoped ZnO and ZnO:Y (2 at% Y) thin films were deposited by RF magnetron sputtering on the SiO_2/Si substrate. ZnO (purity 99.99%) and that doped with 2 at% Y_2O_3 (purity 99.99%) were used as targets. The deposition was carried out in a

* Corresponding author.
E-mail address: djlee@konkuk.ac.kr (D. Lee).

http://dx.doi.org/10.1016/j.mssp.2017.07.029
Received 26 May 2017; Received in revised form 13 July 2017; Accepted 29 July 2017

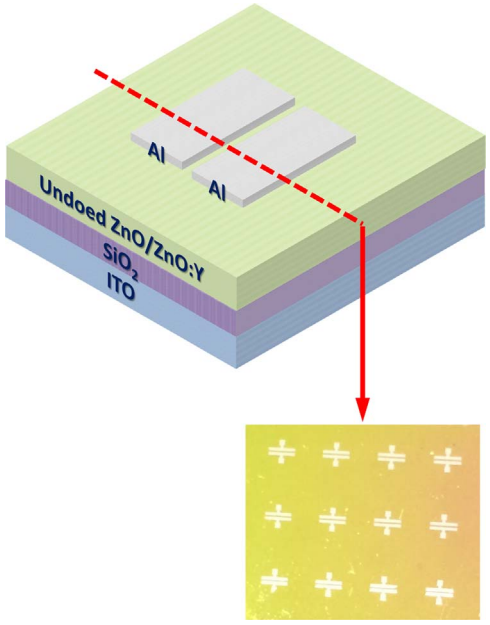

Fig. 1. Schematic diagram of magnetron sputtered undoped ZnO and ZnO:Y TFTs.

vacuum chamber evacuated to a base pressure of 5×10^{-6} Torr. High purity Ar and O_2 gases were used during deposition. During the deposition time of 4 min, the power of 50 W, gas flow rate of 50 sccm, and working pressure of 10 mTorr were kept constant. Both undoped ZnO and ZnO:Y thin films were deposited at room temperature. The thicknesses of the undoped ZnO and ZnO:Y thin films were around 50 nm. Magnetron-sputtered 100-nm-thick Al source and drain were directly fabricated on ZnO and ZnO: Y. The deposition was carried out in a vacuum chamber evacuated to a base pressure of 5.6×10^{-6} Torr. High purity Ar was used as the sputtering gas. Al was fabricated at a constant power of 75 W, gas flow of 50 sccm, and pressure of 1 mTorr. The schematic diagram of the undoped ZnO and ZnO:Y TFTs is shown in Fig. 1. Riggaku (Japan, D/max-II with Cu-K_α radiation) X-ray diffraction (XRD) was employed to study the crystallographic orientations of the films. The surface morphologies of the undoped ZnO and ZnO:Y thin films were examined using field-emission scanning electron microscopy (FE-SEM, S-4200 Hitachi, Japan). The chemical compositions of the films were determined by X-ray photoelectron spectroscopy (XPS) SIGMA PROBE (ThemoVG, U.K.) with Al anode material; the operating power was 300 W. Current–voltage (I-V) measurements were performed using a semiconductor parameter analyzer (Keithley 4200).

3. Results and discussion

Fig. 2 shows XRD patterns of the undoped ZnO and ZnO:Y thin films. Both undoped ZnO and ZnO:Y thin films show (002), (102), and (103) diffraction peaks; the (002) diffraction peak revealed the highest peak intensity, which indicates that the films have a preferred *c*-axis orientation. The (002) diffraction peak positions of the undoped ZnO and ZnO:Y thin films were found to be 34.06° and 33.98°, respectively. The lower 2θ position of the (002) peak of the undoped ZnO thin film suggests that the film suffered from stress, which may be due to the low activation energy of the incoming particles from the target to the substrate at RT. However, the peak position in the ZnO:Y thin film is marginally shifted to a lower 2θ value (from 34.06° to 33.98°), which may be due to larger ionic radius of Y^{3+} (0.92 Å) than that of Zn^{2+} (0.74 Å). It is assumed that the surplus Y impurities tend to be positioned at interstitial positions. This may be because of the insufficient activation energy of impurity atoms. Also, there is an increase in peak intensity along with reducing FWHM of the (002) peak from 1.42 to 1.30°. The increasing of the intensity of (002) diffraction peak is related

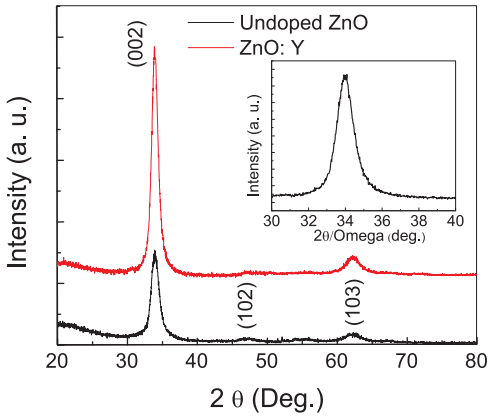

Fig. 2. XRD patterns of magnetron sputtered undoped ZnO and ZnO:Y TFTs fabricated at RT.

to the improvement in the crystalline quality of the film. The inset of Fig. 2 shows XRD 2θ/omega scan measurement of ZnO:Y thin film. A wide peak position angle from 33.91° to 34.08° was observed. The crystallite size (t) was determined using the Scherrer formula [10].

$$t = \frac{0.9 \times \lambda}{B \cos \theta_B}$$

where λ is the X-ray wavelength (1.54060 Å), θ_B is the Bragg diffraction angle, and B is the FWHM of the (002) diffraction peak. The crystallite sizes of the undoped ZnO and ZnO:Y thin film were found to be 6.8 and 13.16 nm, respectively. The SEM micrographs of the undoped ZnO and ZnO:Y thin films are shown in Fig. 3(a) & (b). The surface morphology of the film revealed a homogeneous surface that was made up of grains. The ZnO:Y thin film showed larger grain size than the undoped ZnO thin film. The improvement of grain size is in agreement with previous reported results [11]. The estimated grain size of undoped ZnO and ZnO:Y thin films determined from SEM micrographs are 3.86 and 5.81 nm, respectively, consistent with the particle sizes calculated from the XRD results.

Fig. 4(a) & (b) shows the O_{1s} XPS spectra of the undoped ZnO and ZnO:Y thin films. Gaussian fitting was used in the deconvolution of the O_{1s} peak. The O_{1s} spectrum of undoped ZnO thin films exhibited a wide spectrum with peaks centered at 530.66 and 532.33 eV are due to the oxide lattice with and without oxygen vacancies, respectively [12]. The band at 530.66 eV arises from the oxygen bonds with oxygen vacancies [13]. The higher band around 532.33 eV is attributed to chemisorbed or dissociated oxygen or OH species on the surface of the film [14]. However, the ZnO:Y thin film O_{1s} spectrum shows peaks at 530.8, 531.57, and 532.51 eV. The peak observed at 531.57 can be associated with O^{2-} ions in oxygen regions. The loosely bound oxygen on the surface of the ZnO thin film containing these species is drastically reduced in the ZnO:Y thin films. The area of the oxygen bonds with oxygen vacancies, which indicates the relative quantity of oxygen related defects decreases. The individual fraction of oxide lattice with oxygen vacancies of undoped and ZnO:Y thin films obtained by the semi-quantitative analytical results is examined to be 1.02 and 0.99, respectively. The fraction of hydroxide related peak is obtained 0.86 and 0.55 for undoped ZnO and ZnO: Y, respectively. The fraction of O^{2-} ions in oxygen regions of ZnO:Y is found to be 0.63. The fraction of both oxide lattices with oxygen vacancies and hydroxide on the surface decreases, which could be correlated to the device performance of ZnO:Y TFT. It is speculated that the reduction of oxygen bond with oxygen vacancies related defect densities and highly reduced oxygen bound on the surface of the ZnO in the ZnO:Y thin films may lead to enhanced the mobility of ZnO:Y TFT.

It has been reported that an appropriate amount of rare earth elements can improve the performance of ZnO thin films. According to