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Contributed Paper

High Optical Transmittance of Indium Tin Oxide Nanorods Prepared by Electron Beam Evaporation with Glancing Angle Deposition Technique

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ABSTRACT

In this work, indium tin oxide (ITO) nanorods were deposited on glass slides without ITO dense layers by electron beam evaporation. To fabricate the ITO nanorods, the glancing angle deposition (GLAD) technique was introduced with different rotating speeds from 10 to 50 rpm. The grown nanorod layer was investigated by x-ray diffraction (XRD) to study the film quality. Field emission scanning electron microscope (FE-SEM) was used to evaluate the surface morphology with geometry and dimension of nanorods relating to the rotating speed. A UV-Vis spectrophotometer was used for the optical transmittance and it was found that the nanorod morphology was improved to obtain higher transmittance of ITO layers. Furthermore, the rotating speed of the substrate at a fixed angle of 85° also enhanced the transmittance of a nanorod film. The transmittance percentage of ITO nanorods grown on the glass slide is 92% at the wavelength of 550 nm, which is much higher than that of only the ITO dense layer.

Keywords: ITO nanorods, glancing angle deposition, electron beam evaporation

1. INTRODUCTION

Indium tin oxide (ITO) material used as the transparent conductive oxides (TCOs) in either of thin films or nanorod structures is very interesting in many research groups due to many high potential applications on the benefit of the combination of visible light transmission and low specific resistivity [1-4]. There were many researchers who fabricated thin transparent films or nanostructure layers employed as the electrical electrodes for many electronic devices such as solar cells, light emitting devices and photo detectors [5, 6].

However, it is not only ITO material but also has ZnO, AZO and In_2O_3 [7]. These depend on the way how to fabricate them and the electrical properties which are suitable for the electrode of the devices. The main achievement is to meet a high transmittance and a low resistivity of the nanostructure film with uncomplicated techniques. In general, types and shapes of nanostructures are highly dependent on the deposition techniques such as sputtering, evaporation, hydrothermal growth and chemical vapor deposition (CVD). ITO is a commonly used material due to higher transmittance and lower resistivity comparing to other materials. Moreover, it can be coated on various devices by the old techniques such as sputtering and evaporation. To enhance the efficiency of using this material, low dimensional structure such as nanorod is quite interesting in the aspect of advantages which have large surface area and size dependent [8]. There are two further techniques which are set up in the system of either sputtering or evaporation. The first one is oblique angle deposition (OAD) to fabricate inclined columnar structure in nanoscale with the benefit of optical anisotropy and lower refractive index comparing to the dense layers [9]. By this technique, high porosity and anisotropic growth behavior can be achieved due to the self-shadowing effect and limited adatom diffusion [10]. Furthermore, the morphological properties of nanocolumnar films can be controlled when the substrate is rotated around its axis. This is the second technique called glancing angle deposition (GLAD) [11, 12]. The purpose of this paper is to grow the nanorod structures of ITO material prepared by an electron beam evaporation method with GLAD and to characterize their structures in optical properties, surface morphology, and the film quality by UV-Vis spectrophotometer, field-emission scanning electron microscope and x-ray diffraction, respectively.

2. MATERIALS AND METHODS

The substrates used in this work are glass slides and silicon (100) wafers. They were cleaned in ultrasonic bath with acetone for 10 min and then isopropyl alcohol (IPA) for 10 min. The cleaned substrates were rinsed in DI water and dried in N_2. The ITO nanorod films were prepared by electron beam evaporation (DVB SJ-26C) with ion-assisted deposition (IAD) system. The evaporation source material is ITO pallets (indium oxide 90 wt % - tin oxide 10 wt %) with the purity of 99.99%. Prior to deposition, the vacuum chamber was pumped down to obtain a base pressure of 3×10^{-6} Torr. The system was operated for ITO deposition with flowing Ar and O_2 into the vacuum chamber and a working pressure of 2×10^{-5} Torr. The deposition rate of 0.2 nm/s was investigated by quartz crystal monitor (QCM) to get a film thickness of 200 nm. To form nanorod layer, glancing angle deposition (GLAD) technique was used to set the surface normal of a substrate holder at a large tilt angle of 85° with respect to the direction of the vapor flux from the source and also to rotate the holder around its axis. The substrates were fixed on the holder with and without rotation. In case of rotating the substrate, the motor speeds were changed from 10 to 50 rpm at fixed angle of 85°. To get rid of unwanted residue, the substrate was cleaned again in the vacuum chamber by Ar plasma before growing the nanorod on the substrate. The grown samples were investigated by x-ray diffraction (XRD; Rigaku TTRAX III) measurement performed with diffraction angles (2θ) from 20° to 70° and scanning step of 0.02°. The surface morphology and the cross section of ITO nanorods were investigated by field-emission scanning electron microscope (FE-SEM; Hitachi S-4700). Moreover, the optical property to observe the transmittance spectra was recorded by UV-Vis spectrophotometer (Perkin-Elmer; Lambda 900).

3. RESULTS AND DISCUSSION

The structure of ITO nanorod films deposited on the Si (100) wafer was investigated by XRD. The result showed the XRD patterns for ITO material in nanoscale at different rotating speeds of the substrates from 0 to 50 rpm as shown in Figure 1. The diffraction peaks related to the preferred orientation on (440) planes at 2θ = 51.22° and on (222) planes at 2θ = 30.86° where the intensity is lower. From JCPDS, (222) plane is the main peak with high intensity which is different from the obtained results. This can be explained by the fact that the diffusion of the deposited atoms is disturbed with low thickness due to the shadowing effect during the GLAD technique.

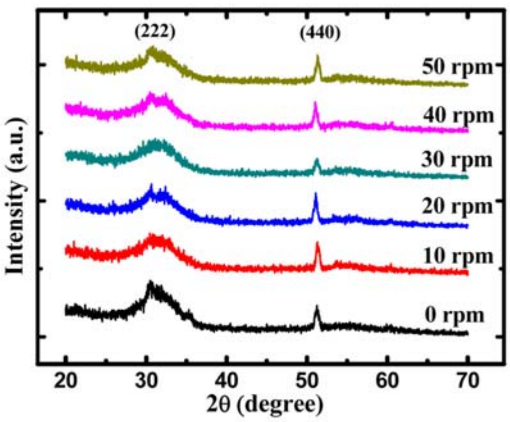

Figure 1. XRD patterns for ITO nanorods deposited at various rotating speeds of the substrate.

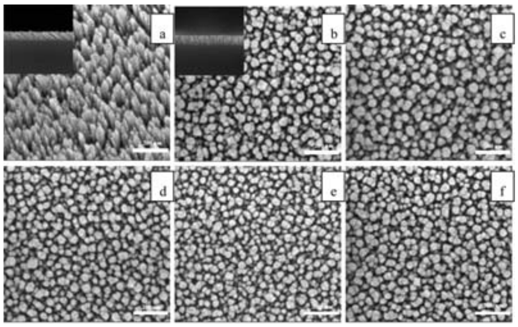

Figure 2. SEM images of ITO nanorods on Si substrate at different rotating speeds (a) 0 rpm, (b) 10 rpm, (c) 20 rpm, (d) 30 rpm, (e) 40 rpm and (f) 50 rpm.

Figure 2 shows the top-view surface of deposited ITO nanorod on Si substrate. The fixed tilt angle of 85° and different rotating speeds of the substrate can form the nanorods with various diameters and geometries. In case of no rotation, the nanorods were inclined in the same direction of the vapor flux of the source as the inset shown in Figure 2 (a). On the other hand, when the substrates were rotated with the speeds from 10 to 50 rpm as shown in Figure 2 (b)-(f) the obtained results show only vertical nanorods. The average diameter of each speed is slightly different but it tends to be bigger and smaller gap between columns corresponding to the increase of rotating speeds as shown in Figure 3. This is due to reducing self-shadowing effect and the particle of material can reach the shadowing regions rather than growing further from the top of nanorods. Moreover, it can be confirmed by the thickness which tends to decrease when the speed is set over 20 rpm. Figure 4 shows the optical transmittance spectra of nanorod structure deposited on the glass slides at different rotating speeds of the substrates. The morphology certainly has an influence on the optical properties of ITO films. The % transmittance at the wavelength of 550 nm of each sample is almost the same around 92 % comparing to that of the commercial ITO dense layer with about 80 % because the nanorod structure can enhance the light extraction limited by the total internal reflection due to high refractive index of material. Moreover, the light can be controlled and propagate into each nanorod to also improve light extraction.

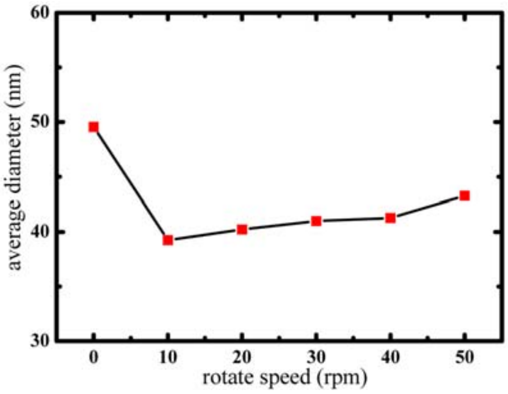

Figure 3. The average diameter of ITO nanorods deposited with various rotating speeds.

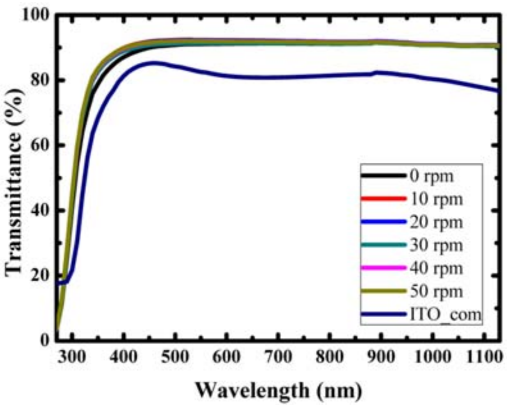

Figure 4. Optical transmittance spectra of GLAD ITO films on glass substrate for different rotating speeds of the substrates.

4. CONCLUSIONS

The ITO nanorod films were fabricated by electron beam evaporation with ion assisted deposition and glancing angle technique. With the growth conditions of nanorods, the morphologies show inclined rods in the direction of the vapor flux of ITO particles for no rotation of the substrate. However, the nanorods are perpendicular to the substrates for all rotating speeds with slightly bigger rod diameters. The thicknesses of the film tend to decrease from 117 to 89 nm when the speeds are set beyond 20 rpm. The ITO material is confirmed by the pattern peak from XRD indicating the preferred orientation on (222) and (440) planes. Moreover, the optical transmittance can be enhanced from 80 % for dense film to 92% for nanorod structure at the wavelength of 550 nm.

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