

Effect of plasma surface pre-treatment on plastic substrate for ZnO TFT

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Abstract

Controlling the surface morphologies of ZnO nanostructures is a critical issue for the fabrication of electronic and photonic devices. This study reports the electrical properties of the ZnO nanostructure grown on the plasma surface pre-treated plastic substrates. The ZnO films were grown by using solution method with zinc nitrate hexahydrate $Zn(NO_3)_2 \cdot 6H_2O$ and hexamethylenetetramine $C_{12}H_{16}N_4$ as the main solution under various deposition conditions. The films with plasma surface pre-treatment has stronger (100) peak intensity than that without plasma surface pre-treatment. Also, very uniform grain size of the ZnO nanostructures can be seen. The fabricated enhancement mode ZnO thin film transistors (TFTs) exhibiting good transistor behavior with the drain saturation current of 38.1 μA at $V_{GS} = 35 V$ can be achieved.

Keywords: ZnO nanostructure, plastic substrate, solution method, plasma, surface pre-treatment, TFT.

Introduction

Recently, ZnO semiconductors have been found useful in thin films transistors (TFTs) applications due to its wide band gap of 3.3 eV and a large exciton binding energy of 60 meV at room temperature [1]. So far, most ZnO layer for TFTs have been deposited under high growth temperature, so there is only limited cost production. Solution based processes for ZnO could be low cost, low temperature, mass production and easily fabricated on any substrates. Flexible ZnO TFTs using plastic substrates are lighter and thinner than those based on glass. The quality of the ZnO obtained films, however, is lower than that of VLS- and MOCVD-grown films. Meanwhile, it cannot be post-annealed to improve the quality of the substrate surface. Study the surface pre-treatment on plastic substrate is an alternative to improve the film quality.

In order to improve the adhesion of over-coated layers and reduce the dangling bond on plastic substrate, the plasma pre-treatment at near room temperature is employed. This paper reports a study on the effect of plasma pre-treatment on plastic substrate to the electrical behavior of ZnO nanostructure TFTs.

Experimental

The ZnO films were grown on ITO-laminated PET plastic substrate by using zinc nitrate hexahydrate $Zn(NO_3)_2 \cdot 6H_2O$ and hexamethylenetetramine (HMT) $C_{12}H_{16}N_4$ as main

solutions. The solution and the substrate were placed in Teflon vessel and heated at 95 °C during 10 hours deposition. The concentration of zinc nitrate hexahydrate and HMT solution were fixed at 0.10 M and 0.20 M, respectively. The control of the film morphology was also adjusted by using 0.1 M NaOH solution. Finally, the deposited ZnO films were rinsed and dried using deionized water and dry nitrogen, respectively. The adhesion to the following coating [2] can be increased by plasma pre-treatment on plastic substrate. Here, the used RF plasma power was 40 W. The treatment time was fixed at 1 min and 5 min with the pressure of 0.08 Torr and gas flow rate of 15 sccm, respectively.

The crystallinity of the ZnO films were evaluated by X-ray diffractometer (XRD) (Rigaku D/max-b) using $Cu K_{\alpha}$ radiation ($\lambda = 1.5406 \text{ \AA}$) at rating of 40kV, 20mA. Both of the surface morphology and roughness of the ZnO films were evaluated by atomic force microscopy (AFM) (JEOL – 6500 Japan) and scanning electron microscopy (SEM) (Hitachi - S4100).

The SiO_2 gate dielectric layer was prepared by liquid phase deposition. The SiO_2 powder was added to hydrofluorosilicic acid (H_2SiF_6) and mixed with deionized water. Then, 0.10 M H_3BO_3 was added to the solution and then stirred for 20 minutes. Transistor fabrication began at the ITO bottom gate produced by wet etching on 160 μm thick ITO-laminated of PET substrate. Then, the SiO_2 gate dielectric layer was deposited by using solution method. Finally, before depositing ZnO nanostructure as a TFT channel onto a 200-nm SiO_2 gate dielectric layer, the 175 nm-thick ITO source and drain contacts were sputtered. Meanwhile, the growth temperature was fixed at 95 °C with the concentration of $Zn(NO_3)_2 \cdot 6H_2O$ and HMT kept at 0.01 M and 0.20 M, respectively. The growth time was kept for 10 hours. The thickness of the ZnO films was 120 nm. The transistor dimension is 150 μm in channel length (L) and 1500 μm in channel width (W). The electrical properties of TFTs were measured by using HP 4156B semiconductor analyzer under atmospheric conditions.

Results and Discussion

Figure 1 shows the XRD profiles of ZnO films grown on plasma surface pre-treated PET substrate. It can be seen that the ZnO film shows a very strong (100) peak intensity suggesting most grains have a c-axis parallel to the substrate surface. It was also found that the films have $Zn(OH)_2$ peaks which corresponding to the precursor phase in the growth of ZnO. The films with plasma surface pre-treatment have stronger (100) peak intensity than that without plasma surface

pre-treatment. It implies that most of grain in films with plasma surface pre-treatment lead to significant increase in (100) peaks. The full-width at half maximum (FWHM) of the ZnO films with and without plasma surface pre-treatment is 1568.81 and 2795.03 arcsec, respectively. This indicates the enhancement of ZnO film quality [3].

Figure 2 shows the AFM images of ZnO films grown with and without plasma surface pre-treatment. These images were taken at a 1000 x 1000 nm scan size. The corresponding surface roughness is 0.94 nm and 1.15 nm, respectively. It is found that the ZnO nanostructures prepared by plasma surface pre-treatment shows more uniform and smaller grain size as compared to those without the plasma surface pre-treatment. It implies that increasing the quality of surface morphology of films causes the surface becomes more polar are developed on the surface. Consequently, the surface can react more easily with the solution [4], [5], similar to the report of Shi et al.[6].

Applications to the transistors are also demonstrated as the current-voltage output characteristics shown in Fig. 3. The enhancement mode transistor with the threshold voltage of 20V exhibits good saturation behavior. The drain saturation current of 38.1 μA at $V_{GS} = 35\text{ V}$ can be achieved. In the saturation region, the calculated electron mobility is 4.44 $\text{cm}^2/\text{V}\cdot\text{s}$. The obtained I_{on}/I_{off} and subthreshold slope of the transistor are 7.03×10^5 and 2.5 V/dec, respectively. This indicates that the plasma surface pre-treatment is effective for high quality ZnO films grown on plastic substrates [7].

Conclusions

The plasma surface pre-treatment is effective to improve the preparation of ZnO films on ITO-laminated PET plastic substrate. The enhancement of the ZnO nanostructure quality can be seen. The ZnO nanostructure enhancement mode transistor with good saturation behavior has been demonstrated.

Acknowledgments

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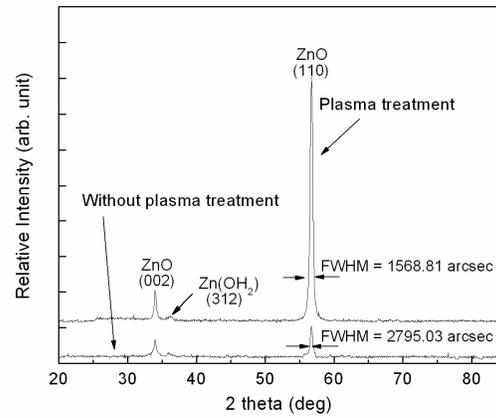


Figure 1 X-rays diffraction patterns of 120 nm thick ZnO films deposited with and without plasma surface pre-treatment.

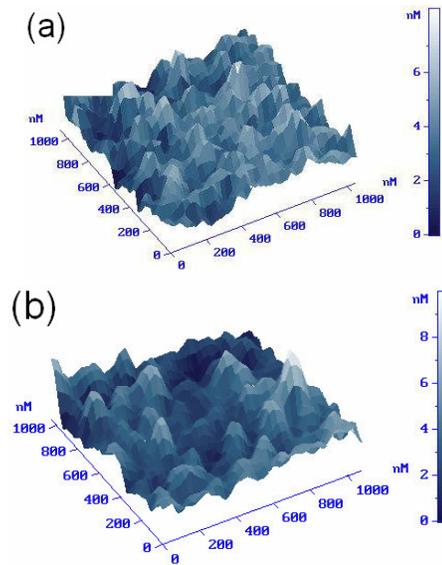


Figure 2 The AFM images of ZnO films (a) with and (b) without plasma surface pre-treatment.

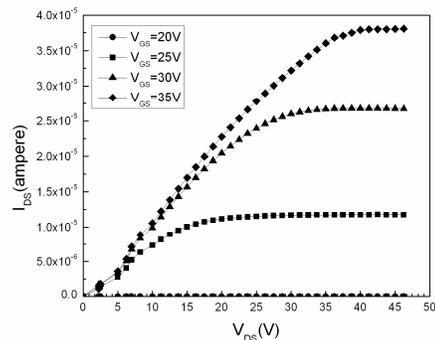


Figure 3 $I_{DS} - V_{DS}$ characteristics for a $W/L=1500/150\ \mu\text{m}$ ZnO transistor fabricated on PET with plasma surface pre-treatment.