KPAN001: Application - OLED (Organic Light Emitting Diode) Research

"*Induced increase in surface work function and surface energy of indium tin oxide-doped ZnO films by $(NH_4)_2S_x$ treatment*" -

Chia-Lung Tsai, Yow-Jon Lin, Ping-Hsun Wu, and Shu-You Chen, Day-Shan Liu, Jia-Huang Hong, Chia-Jyi Liu, Yu-Tai Shih, and Jie-Min Cheng, Hsing-Cheng Chang. JOURNAL OF APPLIED PHYSICS, June 2007

Keywords

Work Function, WF, ITO, OLED, ZnO, Scanning Kelvin Probe, SKP

Abstract

The effects of $(NH_4)_2S_x$ treatment on the surface electronic properties of the thin indium tin oxide (ITO)-doped ZnO films have been examined in this study. Experimental results, found that the formation of S-metal bonds and the removal of oxygen vacancies near the $(NH_4)_2S_x$ -treated ITO-doped ZnO surface could lead to an increase in the surface energy and the work function, meaning that $(NH_4)_2S_x$ treatment might be more helpful to form the uniform deposition of the organic semiconductor on ITO-doped ZnO surfaces and improve the efficiency of ZnO-based organic devices.

Research Area

Among transparent conducting oxides (TCOs) films of indium tin oxide (ITO)-doped ZnO have the remarkable properties of being conductive yet still transparent in the visible and near-IR spectral ranges. The films were used in various applications including organic light-emitting diodes (OLEDs), thin-film transistors (TFTs) and solar cells. An attempt to improve the, intrinsically low, work function of ZnO thereby increasing the luminescent performance was suggested to make it a viable alternative to ITO as the anode film for OLEDs. The purpose of the work described in this study was to present an effective method for improving the surface electronic properties of the ITO-doped ZnO sample using $(NH_4)_2S_x$ treatment. The improvement scheme involves an increase in the surface energy and the surface work function (SWF) of the ITO-doped ZnO samples. In previous studies [it was] found that $(NH_4)_2S_x$ treatment is very useful for changing the SWF of ZnO or ITO.

Figure 1. KP Technology SKP5050 System.

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Use of Kelvin Probe

All samples were ultrasonically and mechanically cleaned in ethanol, acetone and de-ionised water. After drying under dry nitrogen flow some of the 'as-cleaned ITO-doped ZnO samples' were next dipped into a yellow 60 °C $(NH_4)_2S_x$ solution for 3 min, referred to as $(NH_4)_2S_x$-treated ITO-doped ZnO. The Scanning Kelvin Probe (SKP) and x-ray photoelectron spectroscopy (XPS) were used to examine changes in the SWF and the surface chemical bonding states of ITO-doped ZnO samples following $(NH_4)_2S_x$ treatment.

Figure 2 shows the noted SWF image of ITO-doped ZnO films by KP. The model number of the equipment is KP Technology, Scanning Kelvin Probe, SKP. [Since superseded by SKP5050] Before scanning for as-cleaned ITO-doped ZnO samples, the Au surface was scanned by the tip. We find that the Au work function is lower than that of the tip (~114 meV). Next, the $(NH_4)_2S_x$ -treated ITO-doped ZnO samples were placed together. The as-cleaned ITO-doped ZnO is on the right hand side and the $(NH_4)_2S_x$ -treated ITO-doped ZnO is on the left hand side. In Fig. 2, we find that the SWF of the as cleaned ITO-doped ZnO sample is lower than that of the tip (~453 meV) and the SWF of the $(NH_4)_2S_x$ -treated ITO-doped ZnO sample is lower than that of the tip (~104 meV). If the work function of Au is assumed to be equal to 5.1 eV, the SWFs of the as-cleaned and $(NH_4)_2S$ -treated ITO-doped ZnO samples are calculated to be ~4.761 and ~5.110 eV, respectively. It is worth noting the $(NH_4)_2S_x$ -treated sample shows an increase in the SWF shift of ~0.35 eV for the as-cleaned sample and the SWF values (5.11 eV) of the $(NH_4)_2S_x$ -treated ITO-doped ZnO films are higher than those of the commonly used ITO films (4.7–4.8 eV). Park *et al* [3] presented the application of ZnO for the anode film of OLEDs and suggested that one of the main drawbacks of using the ZnO film as the OLED's anode film was reducing luminescent performance compared with that of the device adapting ITO as the anode film, caused by the intrinsic low work function of the film. Thus, the SWF of ZnO is critical to the performance of OLEDs because it affects the energy barrier height at the interface of ZnO with the organic semiconductors, playing a role in reducing the running voltage of the devices

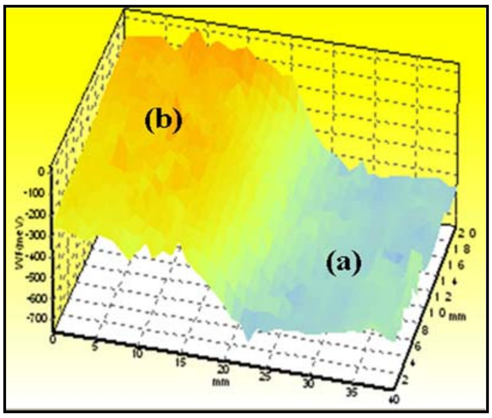

Figure 2. SWF images of (a) as-cleaned and (b) (NH4)2Sx- treated ITO-doped ZnO films.

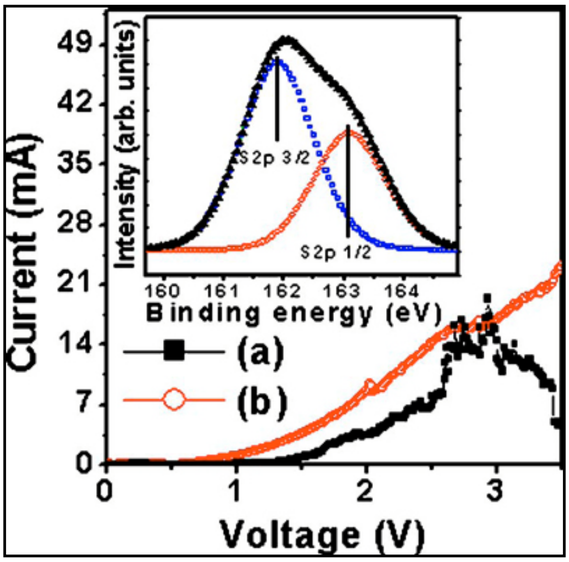

Figure 3. *I-V* characteristics of (a) as-cleaned and (b) $(NH_4)_2S_x$-treated ITO-doped ZnO/PF/Ca/Al devices

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Conclusion

The surface electronic properties of $(NH_4)_2S_x$ - treated ITO-doped ZnO samples have been investigated by XPS, optical transmittance, contact angle, PL, and Kelvin Probe. It is found that the removal of *V*O-related defects and the formation of S-metal bonds induced an increase in the surface energy and the SWF of ITO-doped ZnO samples. The induced increase of the SWF of ITO-doped ZnO samples by $(NH_4)_2S_x$ treatment could be useful for heightening the efficiency of ZnO based OLEDs. In addition, $(NH_4)_2S_x$ treatment may be more helpful to form the uniform deposition of the organic semiconductor on ITO-doped ZnO surfaces, owing to the induced high surface energy. It is hoped that continuing research like this will allow more rapid and knowledgeable development of improved contact schemes and their capabilities.

Reference

1. Original publication: "Induced increase in surface work function and surface energy of indium tin oxide-doped ZnO films by $(NH_4)_2S_x$ treatment" - Chia-Lung Tsai, Yow-Jon Lin, Ping-Hsun Wu, and Shu-You Chen, Day-Shan Liu, Jia-Huang Hong, Chia-Jyi Liu, Yu-Tai Shih, and Jie-Min Cheng, Hsing-Cheng Chang.

   Full text available from:
   Journal of Applied Physics 101, 113713 (2007) [DOI: 10.1063/1.2745366]

2. Correspondent Author: Yow-Jon Lin, Institute of Photonics, National Changhua University of Education, Taiwan, Republic of China – rzr2390@yahoo.com.tw

3. SHK Park, JI Lee, CS Hwang and HY Chu. Japan, Journal of Applied Physics, 2005

Testimonial

"*Measurement of the work function at the semiconductor surfaces is an important characterisation method and is widely accepted for providing information on the surface band bending, interfacial barrier heights and contact resistivity. These measurements are important both for research, device characterisation and process monitoring. KP Technology Scanning Kelvin Probe (SKP) provides the most compact and inexpensive instrument available in air ambient. It is an easy-to-use, open architecture SKP system with excellent sensitivity."*

- Professor Yow-Jon Lin
National Changhua University of Education, Institute of Photonics
Changhua 500, Taiwan, R.O.C