The study of indium zinc oxide, a material that can combine with porous silicon to form white light emitting diodes

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Indium zinc oxide (IZO) is a transparent semiconductor material that has found unique applications in thin film transistors (TFT), invisible electronics, flexible and large displays.[1] An combination of IZO with porous Si (PS) can form a junction, and white light can be emitted when a voltage is applied across the IZO/PS junction.[2] Figure 1a shows the IV curve of the IZO/PS junction. It is seen that IV curve for IZO/PS is a typical IV curve of a diode. Photoluminescence (PL) spectra of PS and IZO/PS (Figure 1b) reveal that photon excited light emission range of IZO/PS is wider than that of PS, covering the range of visible light wavelengths. Typically, the emitted light intensities at these wavelengths are roughly the same, suggesting that the emitted light can be white. Although PL can be generated by the excitation with high energy photons, it is not necessary that the light can be generated by electrical excitation via applying a voltage across the sample. Figure 1c shows the configuration of the sample for applying a voltage across the IZO/PS junction: two conducting copper pads are on the two sizes of the rectangular grey black IZO/PS/Si sample, and the voltage is applied across the IZO/PS junction via the two conducting plates. When a voltage of about 18 V is applied, white light emission can be observed coming from the IZO/PS/Si sample (Figure 1d). We will discuss in more detail on the properties of indium zinc oxide.

A detailed investigation of IZO reveals that the structure, conductivity, band gap, optical transmittance vary with the Zn/In ratio in the sample. Figure 2a shows XRD spectra of IZO samples with different Zn/(Zn+In) ratio. X-ray diffraction patterns of the films reveal that there are no peaks in XRS spectra except for the samples with high indium concentration of In/(Zn+In)>85at% and high zinc concentration of Zn/(Zn+In)>45 at%. The peak observed for the high indium concentration can be assigned to In_2O_3 (211) and the peak for the sample with high zinc concentration corresponds to ZnO (200). For the other samples, only hump in the range of 29^o-35^o can be observed, indicating that amorphous IZO phase was obtained. Electrical conductivity of the IZO samples is determined through Hall effect measurement. The band gaps of the samples are obtained from the Tauc plot for the optical absorption data. Figure 2b shows the carrier concentrations and band gaps of the different IZO samples. It is seen that the carrier concentration varies with zinc concentration. For a high indium concentration (or low zinc concentration) and the existence of In_2O_3 crystallites in the sample, carrier concentration is about twice of those amorphous samples with high zinc concentrations. The optical gaps for both the IZO samples contain crystallite In_2O_3 (high indium content) and ZnO (high Zn content) are about 3.3-3.4 eV. For the other samples with amorphous structure, the gaps are between 2.6 eV to 3.0 eV. For an amorphous IZO sample, an introduction of Al can cause the structural and electronic property change. Figure 1c shows that an increase in Al to 4 at% (sample Al7), In_2O_3 precipitation is induced. The increase of Al concentration to 4at% leads to an increase in resistivity as seen in Figure 2d. Interesting, the In_2O_3 peak disappears but the Al_2O_3 starts to appear with a further increase in Al concentration (see Figure 2c). More interestingly, a sharp resistivity decrease is accompanied with samples Al9 and Al11 (Al concentrations are 10 at% for sample Al9 and 11 at% for sample Al11) as seen in Figure 2c and 2d. A further increase in Al concentration increases Al_2O_3 in the IZO sample but the resistivity turns to be higher. Such a phenomena suggests that an insulator (or semiconductor) – metal transition by the partial crystallization of an amorphous sample.[3] Analysis and discussion will be made at the presentation.

References

[1] T. Kamiya, K. Nomura and H. Hosono, Sci. Technol. Adv. Mater., **11** (2010) 044305.
[2] G. Hu, H. Gong, D.J. Blackwood et al, J. Phys. Chem. C, **113** (2009) 751.
[3] J. Sun and H. Gong, Appl. Phys. Lett, **97** (2010) 092106.

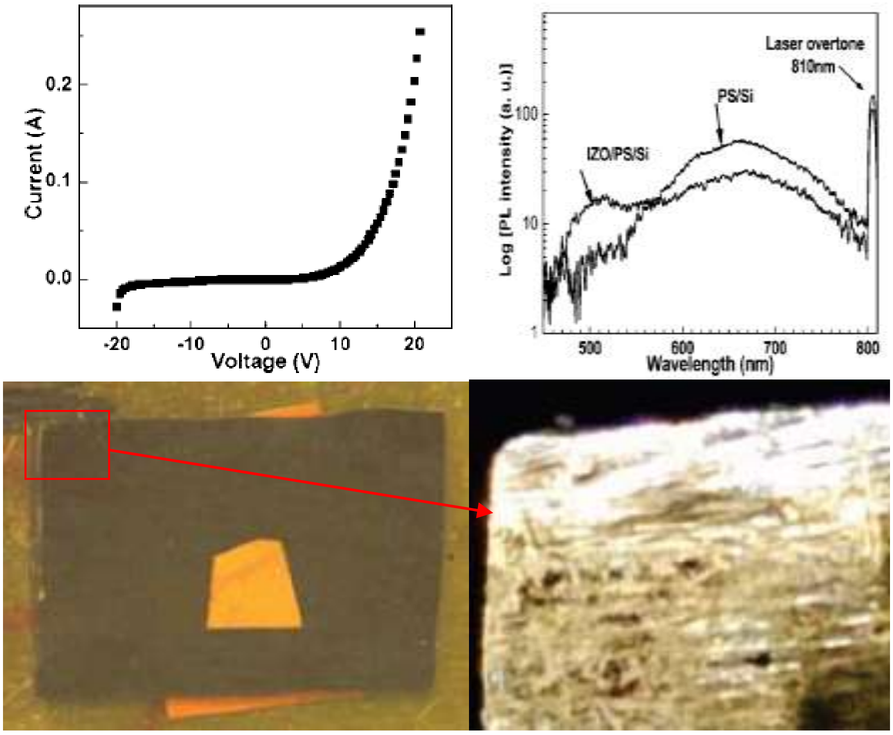

Figure 1 (a) Current-voltage characteristics of an IZO/PS junction, (b) Photoluminescence of PS and IZO/PS, (c) a IZO/PS sample with electrodes below and above, (d) shows white light emission from a part of the IZO/PS sample when 18 V voltage is applied across the IZO/PS junction.

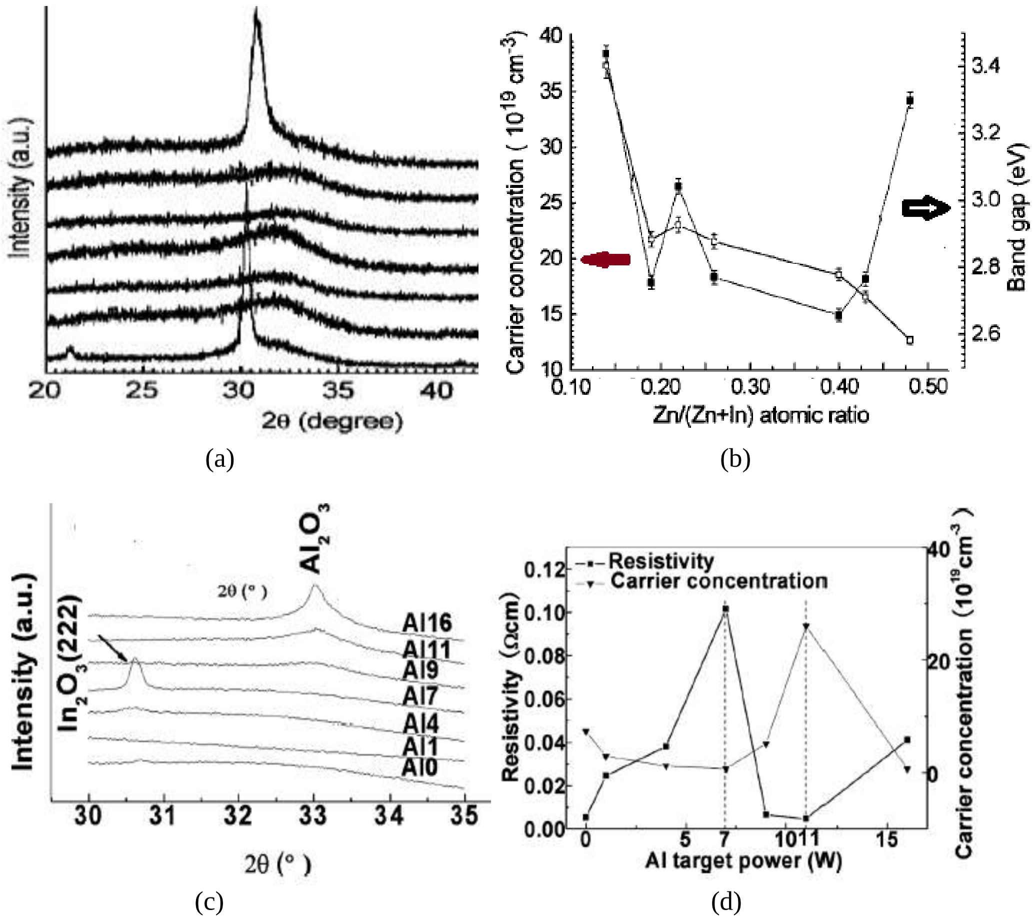

Figure 2 (a) XRD of IZOs with increased Zn concentration (from top to bottom); (b) Carrier concentration and band gap variation with Zn concentration in indium zinc oxide; (c) XRD pattern of an amorphous IZO with different Al incorporation; (d) Resistivity and carrier concentration of the Al incorporated IZO samples.