Zinc oxide based transparent electronics

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Abstract

This paper will present an overview of the state-of-the-art in zinc oxide based transparent electronics focusing on recent contributions from the Liverpool group on plasma-enhanced atomic layer deposition of ZnO rectifiers, magnesium and niobium doped ZnO thin film transistors, their physical and electrical characterization and modelling.

Transparent electronics is a field gathering considerable interest in recent years, as it offers the possibility of electronics 'anywhere' due to the low cost and relative ease of manufacture. The combination of high electrical conductivity ($10^4\ \Omega^{-1}cm^{-1}$) and optical transparency (> 80%) across the visible spectral range constitute enabling metrics for optoelectronic devices in terms of reduced electrical power consumption and high optical power output. Tin-doped indium oxide ($In_{2-x}SnxO_3$, ITO) fulfils these requirements and has become a benchmark when qualifying the performances of other transparent conductive oxides (TCOs) such as F doped tin oxide or doped zinc oxide.

A number of problems relating to suppression of defects and doping control can be mitigated by the use of compound materials with indium, gallium, zinc oxide (IGZO) favoured for large area displays. Indium in particular however is not an abundant element and is becoming increasingly expensive having experienced a more than tenfold increase in price since 2002. It is becoming clear therefore, that a technology based on indium is not viable for long-term, mass-production in this potentially massive global market. Extensive research activity continues therefore, to be focused on the development of less expensive and non-toxic alternatives to allow control of thin-film resistivity and enhanced transport properties (mobility) [1-4].

The work to be presented will comprise a review of the state-of-the-art in ZnO related technology. Challenges at the materials and device architecture level will be highlighted. Some examples from our recent work follow. We have demonstrated that the use of plasma-enhanced atomic layer deposition (PE-ALD) ZnO films and PtO_x Schottky contacts (Fig. 1) provide a viable pathway for delivering high performance rectifiers for both noise sensitive and high frequency electronic applications [5]. Furthermore, the electrical properties of the ZnO thin films can be systematically tuned by varying the deposition temperature and oxygen plasma time during PE-ALD to optimize the performance of the diode (Fig. 2). Low temperature (80°C) coupled with oxygen plasma time of > 30 s PE-ALD has been found to be the key to produce ZnO films with net doping concentration < 10^{17} cm^{-3} [6]. Our recent work on ALD Nb-doped ZnO [7-9] (Fig. 3) and Mg-doped ZnO [10-11] (Fig. 4) will be presented. The aim was to control the levels of oxygen vacancies and other defects using these high valence materials, to allow control of conductivity whilst achieving good field-effect mobility. We will also present the use of models based on exponential defect state distributions resulting in power-law dependence of thin-film transistor characteristics [12], leading to extraction of physically meaningful parameters from experimental results [8,9,11].

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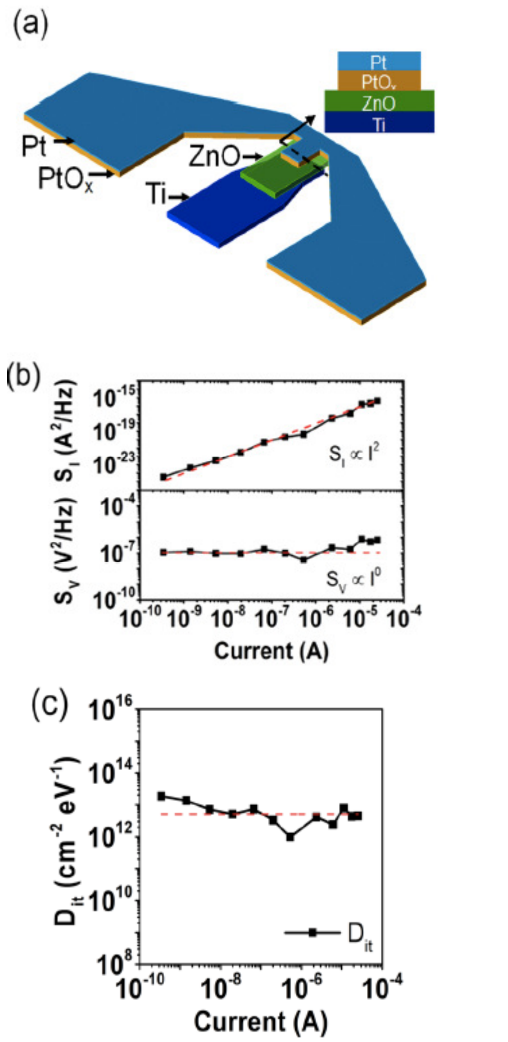

Figure 1. (a) Schematic diagram of the ZnO Schottky diode; (b) Current & voltage noises as a function of current at 5 Hz. (c) Interface trap density vs current [5].

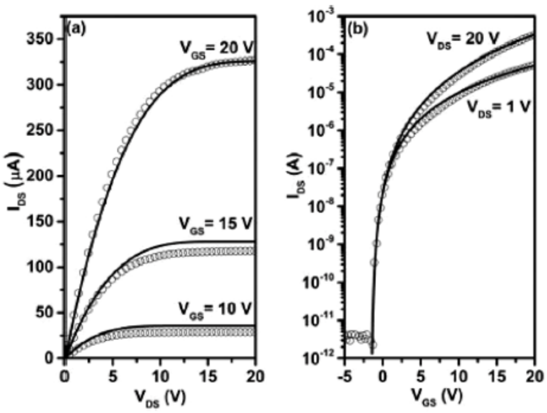

Figure 3. (a) Output characteristics and (b) transfer characteristics of 175°C grown 3.8% NbZnO TFTs [7].

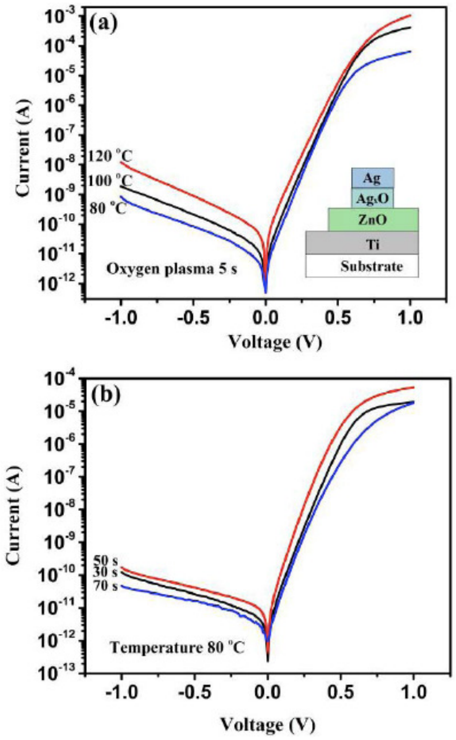

Figure 2. (a) *I-V* plots of Schottky diodes with different PE-ALD ZnO deposition conditions. (b) The ZnO deposition temperature at 80 °C and O_2 plasma times of 30, 50, 70 s [6].

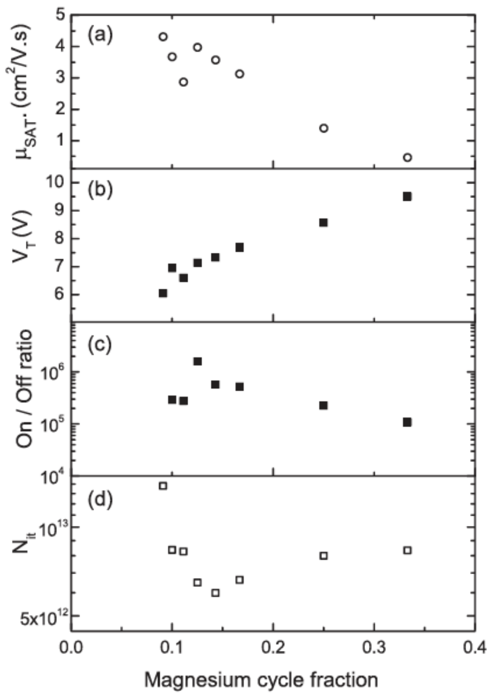

Figure 4. (a) Saturation field-effect mobility, (b) threshold voltage, (c) on/off ratio, and (d) interface trap density for TFTs with varying Mg doping ALD cycle fractions [10].