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Original

# Transistor characteristics of zinc oxide active layers at various zinc acetate dihydrate solution concentrations of zinc oxide thin-film

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**Abstract**

This paper presents a technique involving a sol-gel deposition method applied to the deposition of zinc oxide thin film for a transistor as a semiconductor layer. This method was used for manufacturing the essential thin films of II-VI semiconductors. Zinc oxide (ZnO) bottom-gate (BG) thin-film transistors (TFTs) have been successfully fabricated at low temperatures. We investigated the electrical characteristics of ZnO thin-film transistors at various concentrations of ZnO solution: 0.02 M, 0.03 M, 0.04 M, and 0.05 M. All of the ZnO films exhibited a hexagonal wurtzite polycrystalline structure with (002) preferred orientation. Atomic force microscopy (AFM) revealed the formation of grains or clusters as a result of the accumulation of nanoparticles, and the grain size increased with increasing solution concentration. The coated ZnO films were employed as the active channel layer in thin-film transistors, and the impact of the solution concentration on the device performance was examined. As the solution concentration was increased, the field-effect mobility increased from $1 \times 10^{-4}$ cm$^2$/V-s to $1.2 \times 10^{-1}$ cm$^2$/V-s, the threshold voltage increased from 4.8 V to 11.1 V, and the $I_{on}/I_{off}$ ratio increased from $10^4$ to $10^6$. The on-off ratio ($I_{on}/_{off}$) was found to be $10^6$. The 0.05 M ZnO solution performed optimally.



*Keywords:* ZnO; Zinc acetate dihydrate solution; Thin-film transistor; Concentration

## 1. Introduction

Matrices of thin-film transistors (TFTs) in next-generation displays not only require semiconductors with high performance, but also require them to feature high optical transparency, and low-temperature and solution processability (Ameer 2012; Bermudez-Reyes et al., 2012; Grundmann et al., 2010). To date, hydrogenated amorphous silicon (a-Si:H)-based TFTs have been widely used as pixel switches in displays (Spear & Le Comber, 1993). However, amorphous silicon with deposition requires a high-cost vacuum process. More important, the poor transparency of silicon makes it unsuitable for transparent applications, and transparency is a key criterion for future display technology. Consequently, metal oxide semiconductors, such as In, Ga or Zn oxides (Park et al., 2012), have gained considerable interest as alternatives for amorphous silicon.

Generally, metal oxide thin films have been used as electrodes in flat panel displays such as $In_2O_3$, $SnO_2$, and ZnO. Indium is currently the most commonly used material, but it is costly and toxic. Compared to the high price of In, Zn is inexpensive. In the recent years, ZnO thin films have been considered favorable candidates to be metal oxide materials because of their efficient visible transmittance, optimal conductivity, and low-cost fabrication (Cho et al., 2010).

Zinc oxide (ZnO) is a II-VI *n*-type compound semiconductor that possesses several favorable characteristics, including a wide energy bandgap (3.3 eV) (Chu et al., 2012; Lee et al., 2003; You & Lin 2012), large free exciton binding energy (60 mV), wide range resistivity ($10^{-4}$ to $10^{12}$ Ω cm), high carrier mobility, high transparency at room temperature, and excellent photoelectric, piezoelectric, and thermoelectric properties (Tsay et al., 2010). ZnO has a natural *n*-type conduction because of a large number of native defects, such as oxygen vacancies and zinc interstitials. ZnO crystallizes in a hexagonal wurtzite structure exhibiting non-central symmetry; therefore, it demonstrates piezoelectricity (Anand et al., 2010). The conduction band of ZnO is primarily composed of large, metal-based 4s orbitals that expand spatially into isotropic shapes, thus enabling the direct overlap between neighboring metal orbitals. The unique properties of the conduction band have led to recent interest in using ZnO as a channel material for TFTs, and as a replacement for conventional Si-based materials and organic semiconductors (Kim et al., 2009). ZnO-based TFTs have received a considerable amount of attention for the following practical applications: active matrix organic light emitting di-

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ode (LED) displays; radio frequency identification tags; low-end smart cards; and sensing devices on polymer substrates by using organic field-effect transistors.

ZnO-based films are prepared using various deposition techniques, such as pulsed laser deposition, sputtering, atomic layer deposition, and chemical vapor deposition (CVD), all of which usually suffer from the following problems: high cost, low throughput complex operating conditions, and high energy consumption. By contrast, solution-based deposition processes, such as the sol-gel process, chemical bath deposition, and the aqueous solution growth method, have offered comparatively simple, low-cost, and large area thin-film deposition techniques (Cheng et al., 2011). The sol-gel method not only enables easy fabrication of a large area thin film at a low cost, but also easily controls the film composition and uniformity of thickness (Bahadur et al., 2007; Bari et al., 2009; Gayen et al., 2011).

The primary aim of this work is to investigate the fabrication of ZnO films in a zinc acetate sol-gel solution under electroless conditions, as well as its impact on the electronic properties of TFTs (Cheng et al., 2007; Srinivasan et al., 2008). A series of ZnO films are formed at various concentrations of zinc acetate dihydrate solution (Hoffman et al., 2003; Muthukumar et al., 2001; Pearton et al., 2005). The film nanostructure is investigated using a wide range of characterization techniques, such as atomic force microscopy (AFM) and X-ray diffraction (XRD). In addition, the saturation mobility ($\mu_{sat}$), on/off current ratio, and threshold voltage of the ultra-thin *n*-type ZnO transistor, with respect to long-term reliability, was carefully investigated based on bottom-gate and top-contact transistor architecture (Hirao et al., 2008).

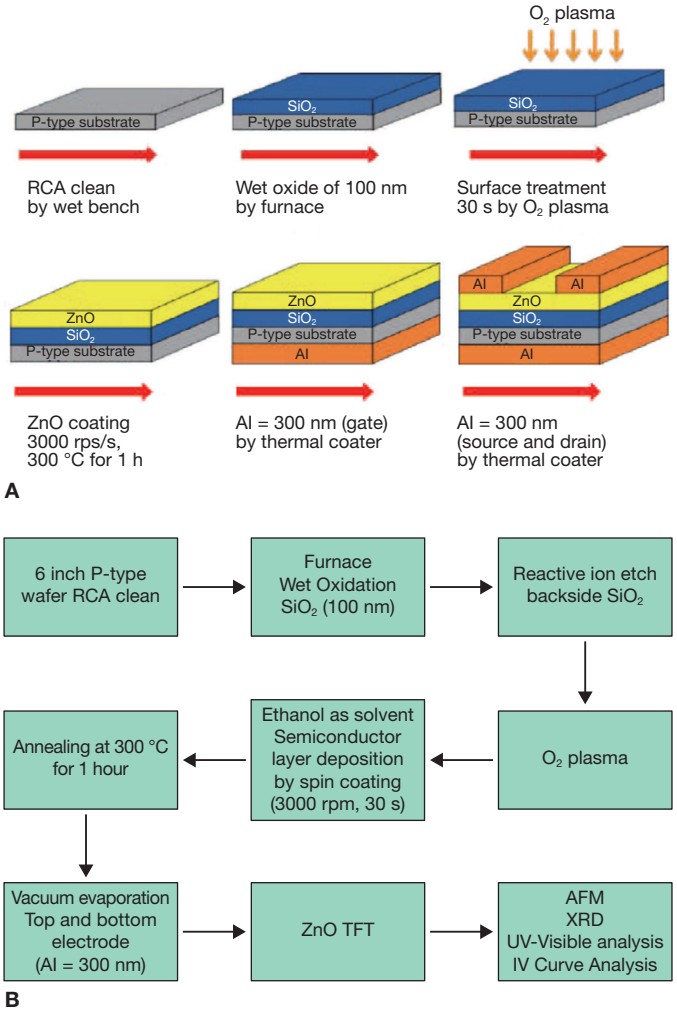


Fig. 1. A: the cross section views and process parameters of ZnO TFT under process sequence flows. B: the process details of ZnO TFT under process sequence flows.

## 2. Experimental details

A fabrication process flow chart of the ZnO-TFTs is shown in Figure 1A and B. The channel width *(W)* and length *(L)* of the ZnO TFTs were 70 and 2000 µm, respectively. Bottom-gate TFTs with the ZnO channel, which were formed using the sol-gel method at atmospheric pressure. A 100-nm-thick wet oxide layer was deposited using a horizontal furnace to form the gate dielectric on the silicon substrate.

As shown in Figure 2, the ZnO solution sample formed channels of TFTs, and ZnO solutions of 0.02 M, 0.03 M, 0.04 M, 0.05 M, and 0.06 M were prepared using the sol-gel method. The ZnO sol was prepared in ethanol by blending zinc acetate dihydrate [$Zn(CH_3COO)_2 \cdot 2H_2O$], stirred at 50 °C for 30 min, and sonicated for 30 min to attain a homogeneous solution. Under the same conditions for the solution, 0.05 M was considered the maximum solubility, because the solution concentration at 0.06 M produced a precipitate. The bottom picture of Figure 2 presents the transparency of test samples. It proved that the zinc oxide thin films are transparent (Lee et al., 1996; Lim et al., 2008; Rendón et al., 2012; Vázquez-Cerón et al., 2007; Wu et

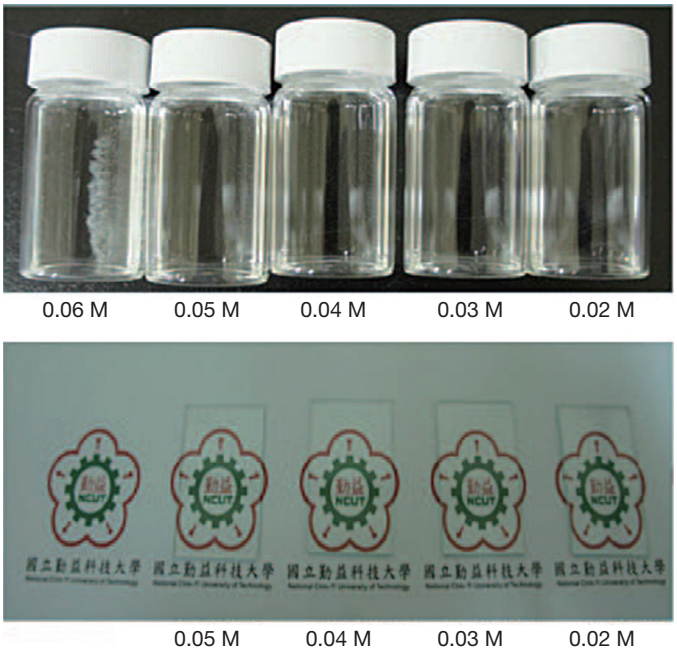


Fig. 2. Solution samples of ZnO concentration from 0.06 M to 0.02 M, spin coating on the glass are transparent.