

# Investigation of non-annealed Al ohmic contacts on undoped ZnO synthesized using the “bottom-up” growth method

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We have reported on the non-annealed Al Ohmic contacts on unintentionally doped n-ZnO synthesized using the “bottom-up” growth method. The roughness morphology of the ZnO layer was investigated. Current-voltage characteristic of Al contacts on ZnO layer and its chemical composition were also investigated. The resistivity of Al contacts on ZnO decreases with O/Zn ratio. One possible reason is the Al atoms in-diffused into ZnO surface to form a thin layer of Al<sub>2</sub>O<sub>3</sub>.

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## 1. Introduction

The developments of hydrogen sensors are rapidly growing due to the essential of hydrogen gas in research and commercial field since the last century. Various types of semiconductor materials were chosen to fabricate hydrogen sensor owing to their unique characteristic such as excellent thermal, mechanical and chemical stability. For example, GaN and ZnO is promising candidates to be fabricated as hydrogen sensors [1]. The Schottky diode based hydrogen sensor consists of two types of contacts, one is Schottky, and the other one is ohmic. Pt and Pd are typical Schottky contacts in addition to their catalytic behaviour in hydrogen gas sensing. On the other hand, Al is normally chosen as ohmic contact in high performance devices due to its low resistivity on n-type doped ZnO for [2]. Intensive works from *H.K. Kim et al.* revealed the behaviors of Al based ohmic contacts on Al-doped ZnO (n-ZnO) [2-3]. However, no reports are found to discuss the behavior of Al contact on undoped ZnO. In this report, we have reported on the characteristic of the non-annealed Al contacts on undoped ZnO synthesized using the “bottom-up” growth method. The surface morphology, chemical composition and electrical properties were investigated using atomic force spectroscopy (AFM), energy dispersion x-ray spectroscopy (EDX), and current-voltage (I-V) measurements, respectively.

## 2. Experimental details

Zn thin films were deposited onto glass substrates using thermal evaporation method. Granulated Zn (>99%

purity) was used as the source of evaporation. A few clean microscope glasses were used as substrates. The vacuum chamber was pumped down to background pressure  $5 \times 10^{-5}$  mbar, and the evaporation current was fixed at 5 A. Deposition time was around 0.5 minutes and the thickness for the Zn thin film was about 0.3 micron. After deposition, the samples were transferred into a furnace. The temperature of the furnace was fixed at 600°C prior to oxidation process. Thermal oxidation was performed in air ambient between 15 to 60 minutes. The Al circular-shaped contacts with diameter of 1mm were deposited on the samples by using thermal evaporator. The surface morphology of the sample was investigated by atomic force microscopy (AFM, ULTRAObjective), using non-contact mode. The chemical composition analysis was obtained using energy dispersion x-ray spectroscopy (EDX, JSM-6460 LV). Parameters like accelerating voltage and working distance were fixed in EDX measurements in order to confirm that penetration depth is constant. Current-voltage (I-V) measurement was carried out by Keithley Model 82 with range of bias voltage from -10 V to +10 V. All the characterizations were performed at room temperature.

## 3. Results and discussion

Fig. 1 shows the AFM topography of the sample that undergoes thermal oxidation for 15 minutes. The mean roughnesses of surface morphology (10 μm x 10 μm scan area) for the samples are 247, 206, 368, and 200 nm for the sample oxidized at 15, 30, 45, 60 minutes in air

ambient, respectively. The results indicated that the surface roughness of the samples decrease with oxidation duration except for the sample oxidized at 45 minutes.

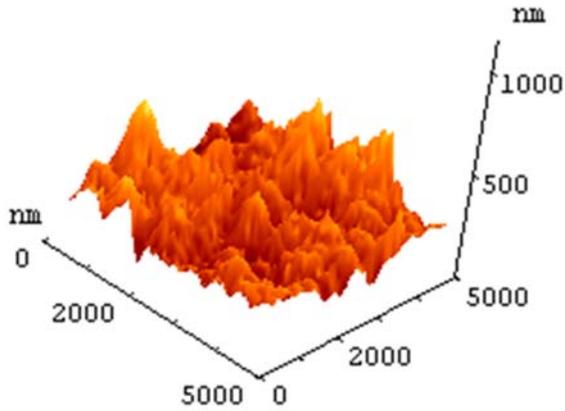


Fig.1. AFM topography of ZnO samples with 15 minutes of oxidation duration.

This might be due to the covalent bonds of Zn – O was changing to counter the unstable polar surface energy from crystal [4]. Fig. 2 shows the I-V characteristics of non annealed Al ohmic contacts on all samples. The contact resistivity,  $R_c$  of the samples were calculated and listed in Table 1 by using equation (1).

$$R_c = \left( \frac{\partial J}{\partial V} \right)_{V \rightarrow 0}^{-1} \quad (1)$$

The values of O/Zn ratio from EDX measurements were listed in Table 1 also. The Al atoms from contact diffuse into the ZnO surface even without annealing process. Majority of the Al atoms diffuse into the ZnO surface hence increases the carrier concentration at the ZnO surface [5].

Table.1. Oxidation duration, Al contact resistivity, and O/Zn ratio of the samples.

Oxidation duration (min.)	Resistivity( x $10^7 \Omega$ )	O/Zn ratio
15	2.63	0.83
30	2.52	1.08
45	4.53	0.80
60	2.57	0.88

The enthalpies of formation for ZnO ( $H_{298}^o = -350kJ / mol$ ) are much larger than enthalpies of formation for  $Al_2O_3$  ( $H_{298}^o = -1676 kJ / mol$ ) [6]. The out-diffusion of the oxygen atom into Al metal layer formed a thin  $Al_2O_3$  interlayer in between Al contact and ZnO layer. On another way round, Al atoms in-diffused into ZnO surface layer and form a highly conductive (Al-

ZnO) layer. The value of  $R_c$  related with the high doping concentration of semiconductor with tunneling effect at the interlayer can be expressed as equation (2) [7].

$$R_c \propto \exp\left(\frac{1}{\sqrt{N_D}}\right) \text{ (high doping)} \quad (2)$$

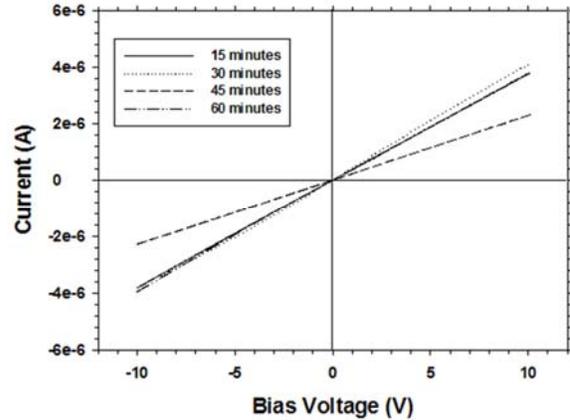


Fig. 2. I-V characteristics of non-annealed Al ohmic contacts on ZnO.

Fig. 3 indicates the behavior of contact resistivity of the samples versus value of O/Zn ratio from the sample. The resistivity of the Al contact on ZnO, decreases with O/Zn ratio. This may be due to the rate of formation of  $Al_2O_3$  thin layer is relatively low as compared to the formation of a highly conductive layer (Al-ZnO). Alternatively, tunneling effect has taken part, thus contributing to the lower contact resistivity.

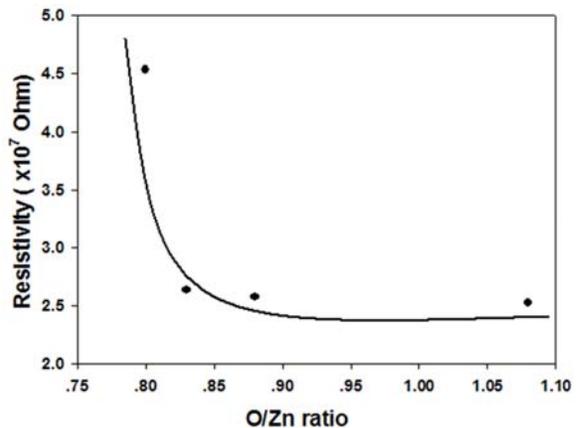


Fig. 3. The characteristics of contact resistivity versus O/Zn ratio.

#### 4. Conclusions

In summary, non-annealed Al ohmic contacts on undoped ZnO synthesized using the “bottom-up” growth method were investigated from the standpoint of EDX

measurements, I-V characteristic, and AFM topography. The maximum mean roughness of the samples is 368 nm over a 10  $\mu\text{m}$  x 10  $\mu\text{m}$  scan area. The sample with 30 minutes oxidation duration has the lowest resistivity. The resistivity of the Al contact on ZnO decrease with O/Zn ratio. The reason might be the possibility of tunneling effect due to Al atoms in-diffused into ZnO surface to form a highly conductive (Al-ZnO) layer.

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