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# Influence of a Ni buffer layer on the optical and electrical properties of GZO/Ni bi-layered films

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ABSTRACT

Ga-doped ZnO (GZO) and GZO/Ni bi-layered films were prepared on polycarbonate (PC) substrates by DC and RF magnetron sputtering at room temperature in order to determine the influence of a Ni buffer layer on the structural, optical, and electrical properties of the GZO/Ni films. The thickness of the Ni buffer layer was varied between 2 and 5 nm.

As-deposited GZO films that contained the PC substrate show an average optical transmittance of 81.3% in the visible wavelength region and an electrical resistivity of $3.1 \times 10^{-3}$ Ω cm, while GZO/Ni bi-layered films show different optical and electrical properties that are dependent on the thickness of the Ni buffer layer. Although the GZO 100 nm/Ni 5 nm films possessed the lowest electrical resistivity ($7.3 \times 10^{-4}$ Ω cm) and the largest grain size (16 nm) in this study, GZO 100 nm/Ni 2 nm films showed best optoelectrical performance among the films. This superiority was due to the simultaneous optimization of the optical and electrical properties.



## 1. Introduction

The rapidly increasing use of transparent conductive oxide (TCO) films, such as Sn-doped $In_2O_3$ (ITO), for large flat panel displays has prompted increased research and development into inexpensive TCO materials that exhibit adequate optical transmittance and electrical resistivity for various optoelectronic applications [1]. Recently, Al- or Ga-doped ZnO thin films have been widely investigated as a substitute for ITO films due to their relatively low cost, abundance, and non-toxicity [2–4].

Among these elements, Ga is considered one of the most promising because the covalent bonding length of GaO is more similar to ZnO when compared to AlO. This may enable a lower degree of deformation [5]. Furthermore, Ga is less reactive and more resistant to oxidation compared to Al [6]. However, in Ga-doped ZnO (GZO) films, relatively high substrate temperatures are required to simultaneously obtain the necessary electrical resistivity and optical transmittance [7].

One way to improve the optical and electrical properties of GZO films without substrate heating is to use a buffer layer such as GZO/$TiO_2$ [8] or GZO/$SiO_X$ [9] structures. These materials have lower resistivity compared to GZO single-layer films of the same thickness.

In this study, GZO thin films were deposited by radio frequency (RF) magnetron sputtering on PC substrates with and without a nickel (Ni) buffer layer, and the influence of the buffer layer on the optical and electrical properties of the films were investigated using X-ray diffraction (XRD), atomic force microscopy (AFM), UV–Visible spectrophotometer, and Hall Effect measurements.

### 2. Experimental details

GZO and Ni thin films were deposited on a 100 μm thick polycarbonate (PC) substrate without intentional substrate heating via RF and a DC magnetron sputter equipped with two cathodes. RF (13.56 MHz) and DC power were applied to the GZO (ZnO 95–$Ga_2O_3$ 5 wt.%, purity: 99.99%) and Ni (purity: 99.95%) targets, respectively. The sintered GZO and pure Ni targets were both three inches in diameter and 0.25 inches thick. During deposition, the substrate temperature was monitored using a K-type thermocouple in direct contact with the substrate surface; the temperature was maintained at 70 °C.

Prior to deposition, the chamber was evacuated to a pressure of $1.3 \times 10^{-4}$ Pa and sputtering was performed at $2 \times 10^{-1}$ Pa. The GZO/Ni films were obtained by continuously depositing each film layer without exposure of the films to the atmosphere. Table 1 shows the main parameters used for the deposition process in this study. After deposition, the film thickness was confirmed with a surface profilometer (Dektak 5000, Varian).

In order to observe the thin film crystallinity, high resolution XRD (X'pert Pro MRD, Philips) at the Korea Basic Science Institute (KBSI) was used, while a surface root mean square (RMS) roughness investigation was performed with AFM (XE-100,

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**Table 1**
Experimental conditions of RF and DC magnetron sputtering.

| Parameters | GZO | Ni |
|---|---|---|
| Thickness (nm) | 100 | 2, 5 |
| Base pressure (Torr) | $1 \times 10^{-7}$ | |
| Deposition pressure (Torr) | $1 \times 10^{-3}$ | |
| Power density (W/cm$^2$) | RF, 3 | DC, 2 |
| Ar gas flow rate (sccm) | 20 | 10 |
| Deposition rate (nm/min) | 10 | 12 |

Park Systems) on $2 \times 2$ μm areas under ambient conditions. The optical and electrical properties were obtained by Hall effect measurements (HMS-3000, Ecopia) and a UV–Visible spectrophotometer (Cary 100 Cone, Varian), respectively. In addition, the influence of the Ni buffer layer on the optical and electrical performance of GZO/Ni bi-layered films was evaluated with a figure of merit (FOM).

## 3. Results and discussion

Fig. 1 shows the XRD patterns of GZO films with and without a Ni buffer layer. In order to evaluate the optical and electrical performance of TCO films, structural characterization is very important because the optical transmittance and electrical resistivity of TCO films are strongly dependent on the grain size and microstructure. Fig. 1 shows that all the films exhibit a ZnO (002) peak located at $2\theta = 34.14°$, indicating that the *c*-axis is predominantly oriented parallel to the substrate normal. As the thickness of the Ni buffer layer increases, the full width at half maximum (FWHM) of the ZnO (002) peak is decreased. This means that the crystallinity of the GZO film is enhanced by increasing of the thickness of the Ni buffer layer in GZO/Ni bi-layered films [10]. Table 2 shows the grain sizes of GZO single-layer and GZO/Ni bi-layered films. As the Ni thickness was increased from 2 to 5 nm, the grain size also grew from 11 to 16 nm. In a previous study, Kim reported similar results in ITO/Au bi-layered films; the crystallization of the upper ITO film is promoted by an Au buffer layer, which was applied without the intentional substrate heating [11].

Fig. 2 shows the compositional depth profile of GZO 100 nm/Ni 5 nm bi-layered films. Some degree of inter-diffusion between GZO and the Ni buffer layer is observed. In Fig. 2, the observed gallium, zinc, and oxygen atomic percentages were 5%, 35%, and 60%, respectively.

Fig. 3 shows the optical transmittance of GZO single-layer and GZO/Ni bi-layered films. The PC substrates and GZO films that contained the PC substrate show average optical transmittances of 87.7% and 81.3%, respectively, in the visible wavelength range.

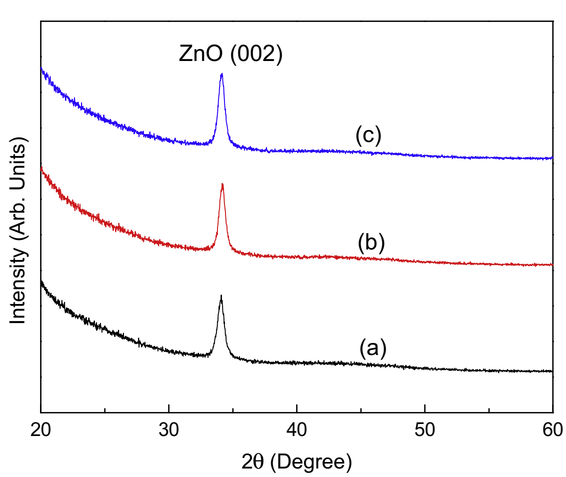


**Fig. 1.** XRD patterns of GZO single layer and GZO/Ni bi-layered films. (a) GZO 100 nm, (b) GZO 100 nm/Ni 2 nm, and (c) GZO 100 nm/Ni 5 nm.

**Table 2**
The grain size of GZO single layer and GZO/Ni bi-layered films.

| Condition | Grain size (nm) |
|---|---|
| GZO 100 nm | 11 |
| GZO 100 nm/Ni 2 nm | 14 |
| GZO 100 nm/Ni 5 nm | 16 |

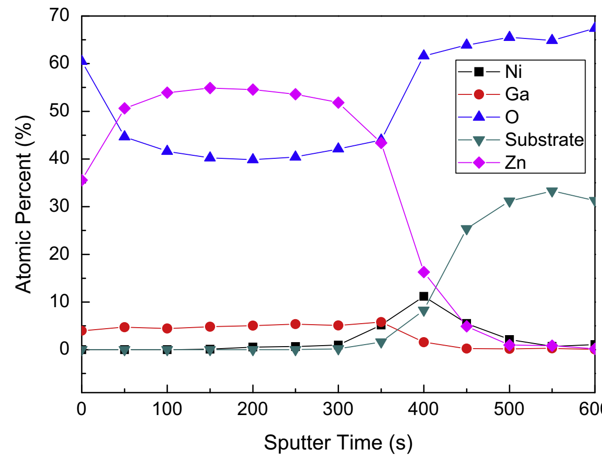


**Fig. 2.** The compositional depth profile of GZO 100 nm/Ni 5 nm bi-layered films.

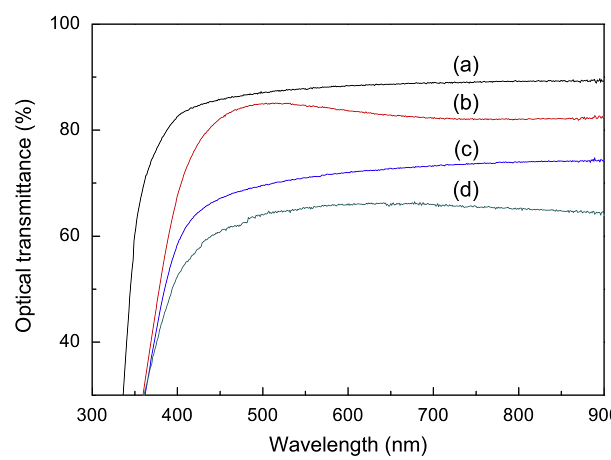


**Fig. 3.** The optical transmittance of GZO single layer and GZO/Ni bi-layered films. (a) PC substrate, (b) GZO 100 nm, (c) GZO 100 nm/Ni 2 nm, and (d) GZO 100 nm/Ni 5 nm.

As the thickness of the Ni buffer layer was increased, the optical transmittance of the films was decreased to 71.7% in the GZO 100 nm/ZnO 2 nm film and 65.2% in the GZO 100 nm/ZnO 5 nm film. We believe that the decrease in the optical transmittance is due to the enhanced optical absorption of the Ni buffer layer in GZO/Ni films.

Fig. 4 shows the AFM images of PC substrate, Ni buffer layer, GZO single-layer and GZO/Ni bi-layered films. This shows that the surface roughness decreased as the thickness of the Ni buffer layer in GZO/Ni films increased. The RMS roughness of the PC substrate, Ni buffer layer and GZO single layer was 1.9, 1.0, and 1.8 nm, respectively. The GZO films with a 5 nm Ni buffer layer showed a lower RMS roughness of 1.3 nm. During buffer layer deposition, Ni film grew preferably in sunken regions of the PC substrate [8]. Thus, the GZO/Ni bi-layered films with a flatter surface were prepared as shown in AFM images and the crystallization of the film is also promoted by a Ni buffer layer.