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# Characteristics of ZnO/GaN heterostructure formed on GaN substrate by sputtering deposition of ZnO

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**Abstract**

The n-ZnO/p-GaN heterostructures were formed by the growth of n-type ZnO layer using a sputtering method onto p-type GaN substrate which had been grown by a metal organic chemical vapor deposition. The samples showed the mirror-like surface and ultraviolet emission properties. For measurements of high-resolution X-ray diffraction, the samples exhibited the (0 0 0 *l*) peaks corresponding to both ZnO and GaN single crystals. And also, the peaks from interfacial layer of metastable $Ga_2O_3$ appeared eventually. The heterojunction diode fabricated using these heterostructured layers clearly showed the rectifying behavior. However, no relevant but very weak electroluminescence signal was detected. This result is attributed to the existence of metastable $Ga_2O_3$ interfacial layer having lots of interface states acting as nonradiative recombination centers.


*Keywords:* ZnO/GaN heterostructure; $Ga_2O_3$ interfacial layer; Heterojunction diode; Energy band diagram

## 1. Introduction

Wide band gap semiconductor GaN and ZnO are promising materials for the application of optoelectronic devices such as blue light emitting diode (LED), blue laser diode (LD), and ultraviolet photo detector (PD) [1–3]. Both materials have similar physical properties, but ZnO has several advantages over GaN; for example, large exciton binding energy (60 meV) and low power thresholds at room temperature [4,5]. These are useful for the application of ultraviolet (or blue) LD and LED with higher efficiency. However, the practical device application using ZnO is still undergoing inherent problems including lacks of reproducibility on forming the stable p-type ZnO layer and availability on engineering the band gap energy. In contrast, making the high quality p-GaN epitaxial layer and engineering the band gap energy of GaN are practically demonstrated as sufficient as useful for commercial devices. Based on these backgrounds, recently, a study on ZnO/GaN heterostructures has attracted much attention for the purpose of mutualizing the advantages of each ZnO and GaN and piecing out the ambivalences. Moreover, since ZnO and GaN have a similar lattice configuration with a quite small lattice mismatch ratio (∼1.92%), many researches [6–10] concerning ZnO/GaN based-heterostructures have been investigated to realize the higher device performance. For example, Alivov et al. reported that ZnO/GaN heterostructures have the improved current confinement leading to high recombination and high device efficiency [6]. However, with a view to device applications using ZnO/GaN based-heterostructures, more systematic studies concerning the surface and interface properties, the energy band structures, and the carrier transport still remain to be investigated because clarifying these physical phenomena is very important for the application using heterostructured material systems.

In this article, we report data on characteristics of the n-ZnO/p-GaN heterostructure formed with the sputtered n-type ZnO layer on the p-type GaN substrate. Surface properties of ZnO layers grown on GaN substrates were monitored by scanning electron microscopy (SEM), and structural properties of heterostructured ZnO/GaN were examined by high-resolution X-ray diffractometry (HR-XRD). The optical and electrical properties were characterized by means of cathodoluminescence (CL) spectroscopy and measurements current–voltage (*I*–*V*) relationship, respectively.

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## 2. Experimental details

The heterostructure of n-ZnO/p-GaN was formed by the growth of unintentionally doped n-type ZnO layer using an rf magnetron sputtering method onto Mg-doped p-type GaN substrate which had been grown on $Al_2O_3$ (0 0 0 1) by a metal organic chemical vapor deposition (MOCVD). The carrier concentrations of Mg-doped p-type GaN substrates and unintentionally doped n-type ZnO layers were confirmed to be $\sim 10^{17}$ $cm^{-3}$ and $\sim 10^{18}$ $cm^{-3}$, respectively, from Hall effect measurements. To determine the carrier concentration on the top of n-type ZnO on the conductive p-type GaN substrate, we used the modified Hall effect equation [11] for determining the Hall coefficient in cases of bilayer or multilayer. During the growth of ZnO layers, the growth temperature was fixed to 600 °C but the growth ambience was varied by controlling the oxygen partial pressure ($Ar:O_2$ = 50 sccm:0–75 sccm) because the ZnO layers grown at 600 °C showed the well-merged surface configuration without surface segregations but the surface morphology of the layers showed a dependence on the $O_2$ partial pressure ($P_{O_2}$). After growth of n-ZnO/p-GaN heterostructures, we fabricated the heterojunction diode using the heterostructured samples. In order to form a diode structure, etching out the ZnO layer using diluted $HNO_3$ solution and forming the Ohmic contacts to each ZnO and GaN layers were performed sequentially. The Ni/Au was deposited onto p-GaN layers, and the samples were subsequently annealed at 450 °C for 90 s in order to improve the Ohmic properties. And then, Ohmic contacts to n-ZnO were formed by deposition of In and subsequent annealing at 200 °C for 60 s.

The surface and structural properties of the samples were monitored by SEM measurements using an FE SEM XL-30 system and HR-XRD measurements using a DMAX-2500 system with a Cu Kα radiation, respectively. CL measurements using a GATAN MONO CL system were carried out to characterize the optical properties of the samples. The electrical properties of heterojunction diode were evaluated by measurements of *I–V* characteristics using a conventional semiconductor parameter analyzer.

## 3. Results and discussion

Fig. 1 shows the surface images of ZnO layers grown onto GaN substrates at 600 °C under various mixture gases of Ar and $O_2$; (a) $Ar:O_2$ = 50 sccm:0 sccm, (b) $Ar:O_2$ = 50 sccm:25 sccm, (c) $Ar:O_2$ = 50 sccm:50 sccm, and (d) 50 sccm:75 sccm. As shown in Fig. 1, the surface of ZnO layer grown under no $P_{O_2}$ is wrinkle (Fig. 1(a)), but the aspect of surfaces becomes flatten with an increase in $P_{O_2}$. However, unfortunately, some hillocks (Fig. 1(b)) and pits (Fig. 1(c)) appear at the ZnO layers grown under lower $P_{O_2}$ (i.e., Ar = 50 sccm, $O_2 \leq 50$ sccm). These surface faults disappear from samples grown under $O_2$ overpressure (i.e., $P_{O_2} \geq 1$ (Ar = 50 sccm and $O_2 \geq 50$ sccm)). As shown in Fig. 1(d), the surface of ZnO layer grown under $Ar/O_2$ ratio of 2/3 exhibits a mirror-like surface. Even though the surface of ZnO layers for Fig. 1(a–c) is not mirror-like, it is enough to use them for device applications such as piezoelectric devices or gas sensors. However, in the application of more sophisticated devices such as LED, LD, and PD, the mirror-like surface and

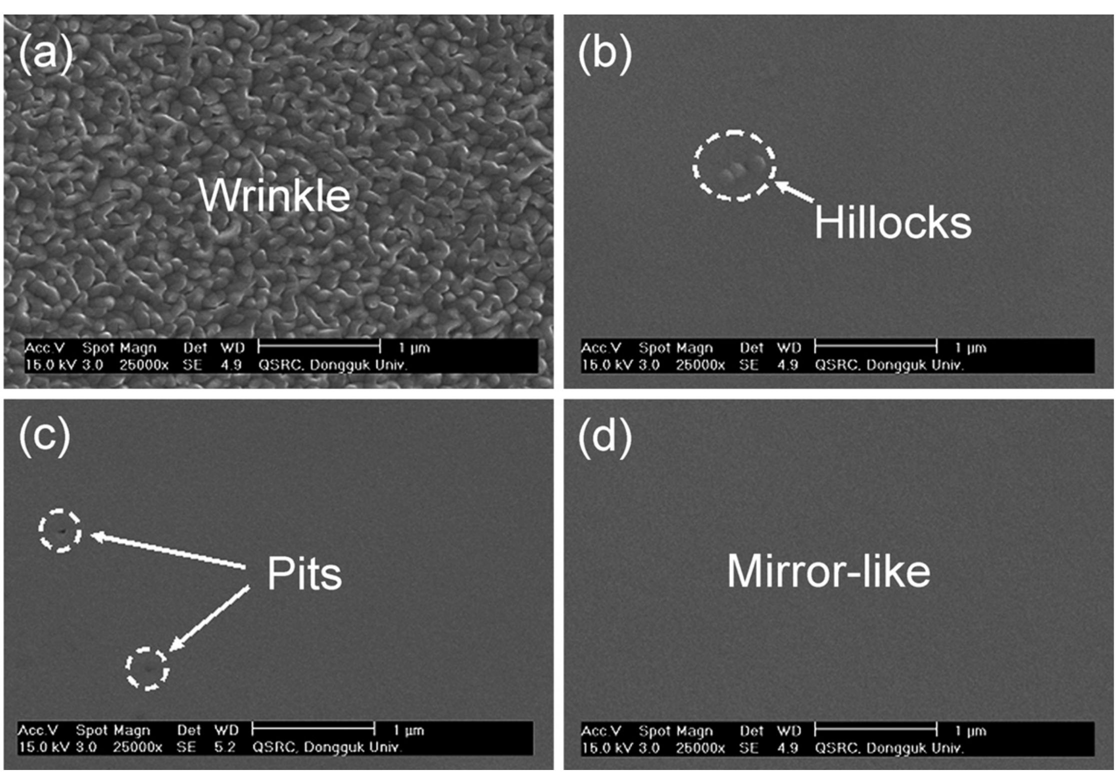


Fig. 1. Top-view SEM images of ZnO layers grown on GaN substrates at 600 °C under mixture gases of: (a) $Ar:O_2$ = 50 sccm:0 sccm, (b) $Ar:O_2$ = 50 sccm:25 sccm, (c) $Ar:O_2$ = 50 sccm:50 sccm, and (d) $Ar:O_2$ = 50 sccm:75 sccm.