Ni-based ohmic contacts to surface-treated *p*-type GaN

Sang-Heon Han, Ja-Soon Jang, Seong-Ju Park, and Tae-Yeon Seong*

Department of Materials Science and Engineering, Kwangju Institute of Science and Technology (K-JIST), Kwangju 500-712, Korea, *e-mail: tyseong@kjist.ac.kr

[1] Introduction

GaN-based materials have been extensively investigated, since the realization of short wavelength light emitting diode and laser diode.[1-2] The formation of high quality ohmic contacts is one of key factors for the successful fabrication of high performance optoelectronic devices. The Ni-based metallization schemes, such as Ni/Au, Ni/Cr/Au, and Ni/Pt/Au, have been reported to result in good ohmic contacts to *p*-GaN.[3-5] However, there is lack of the detailed studies of top layer effects on the electrical and structural properties of the Ni-based contacts. In this work, we have investigated Ni, Ni/Ru and Ni/Au metallisation schemes to find out the effects of the top layer on the contact properties.

[2] Experiment

Metalorganic chemical vapor deposition was used to grow a 1-μm-thick *p*-GaN:Mg ($N_a = 4.6\text{x}10^{17}$ cm^{-3}) on a 2-μm-thick unintentionally doped GaN/(0001) sapphire substrate. The GaN layers were ultrasonically degreased with RCA cleaning for 5 min. Prior to the fabrication of TLM patterns, the samples were ultrasonically treated with a boiling buffered oxide etch (BOE) for 20 min. TLM patterns were defined by a photolithograhphic technique. The patterned samples were then treated in BOE for 30 s. The Ni (15 nm), Ni/Ru (15 nm/15 nm), and Ni/Au (15 nm/15 nm) films were deposited by electron-beam evaporation. Some of the samples were rapid-thermal-annealed in a N_2 ambient. Current-voltage (I-V) measurement was performed using parameter analyzer (HP 4155A). Glancing x-ray diffraction (GXRD) and Auger electron spectroscopy (AES) were used to investigate interfacial reactions. Atomic force microscope (AFM) was used to assess the surface morphology of the contacts.

[3] Results and Discussion

The I-V characteristics of the Ni, Ni/Au, and Ni/Ru contacts on the surface-treated *p*-GaN are shown in Fig. 1. The as-deposited contacts show nonlinear behavior, Fig. 1(a). However, the I-V characteristics are improved with increasing annealing-temperatures up to 500 °C, Fig. 1(b). It is shown that the Ni/Ru contacts exhibit better I-V characteristics than the Ni and Ni/Au contacts. Specific contact resistances were determined from plots of the measured resistances versus the spacings between the TLM pads; it was measured to be in the range of 8.42×10^{-3} – 8.42×10^{-3} Ωcm^2 for the as-deposited contacts. For the samples annealed at 500 °C, it was in the range of 3.45×10^{-3} – 1.56×10^{-3} Ωcm^2. The specific contact resistance is given in Table I. It is noted that the specific contact resistances of the Ni/Ru contacts are lower than those of the Ni and Ni/Au contacts, and the Ni/Au contacts are better than the Ni single contacts. This indicates that the top layers have an effect on the electrical properties of the Ni-based contacts.

In order to investigate the effective Schottky barrier height (SBH) of the Ni-based contacts, the I-V method was employed. The I-V relation is given by[6]

$$I = I_0 \exp(qV/nkT)\,[1 - \exp(-qV/kT)] \quad (1)$$

$$I_0 = AA^{**}T^2 \exp(-\phi_b/kT) \quad (2)$$

where I_0 is the leakage current at zero bias, A the contact area, A^{**} the effective Richardson constant which is defined by $A^{**} = (4\pi qk^2 m_h^*)/h^3$, and n the ideality factor. Calculations showed that the SBH was in the range of 0.526 - 0.517 eV for the as-deposited contacts. For the annealed contacts, it was in the range of 0.493 - 0.484. The calculated SBHs are listed in Table I. It is clearly shown that the observed SBHs of the contacts are dependent on the type of the top layers (i.e., Ru and Au on the Ni layer), although the Ni layer is in contact with the *p*-GaN surface in these samples.

To investigate the top-layer dependence of the electrical properties of the contacts, glancing x-ray diffraction (GXRD), Auger electron spectroscopy (AES) depth profiling, and x-ray photoelectron spectroscopy (XPS) have been performed. From the GXRD and AES results, it is shown that the different electrical properties of the Ni, Ni/Au, and Ni/Ru contacts could result from different interfacial reactions between metals and GaN, the presence of oxide, and the thermal stability of the top layers. It is further shown that these effects could result in a large difference in the light-transmittance and thermal stability of the contacts. In addition, we have successfully demonstrated light-transmittance better than 90 % (at 470 nm) by optimizing the Ni-based contact structures. Details will be described and discussed using the I-V-T, AES, and TEM data.

[4] Conclusion

The electrical and structural properties of the Ni-based ohmic contacts to *p*-GaN have been investigated as a function of annealing temperature and film thickness. It is shown that the specific contact resistance and effective SBH of the contacts are dependent on the type of the top layers on the Ni layer. The observed differences in the electrical properties of the contacts are explained in terms of interfacial reactions, oxide, and thermal stability of the top layer. Finally, it is shown that the optimized Ni-based contacts show light-transmittance higher than 90 % (at 470 nm) and a contact resistance of ~10^{-3} Ωcm^2.

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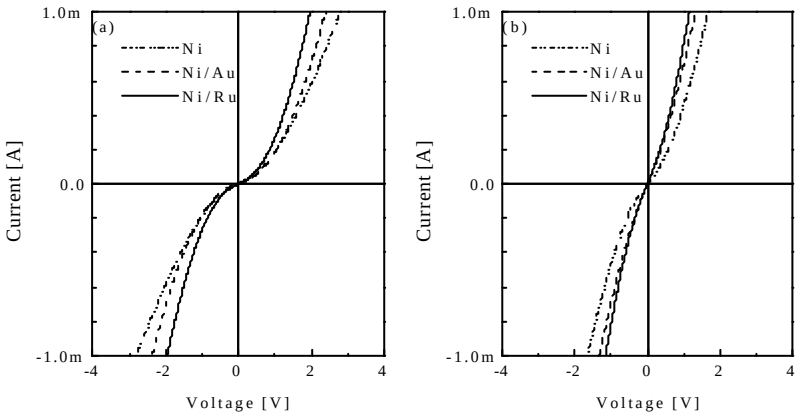

Figure 1. The I-V characteristics of the Ni, Ni/Au, and Ni/Ru contacts (a) before and (b) after annealing at 500 °C.

Table I. Summary of the electrical properties of Ni, Ni/Au, and Ni/Ru contacts on *p*-GaN.

	Specific contact resistance [Ωcm^2]		SBH [eV]	
	As-deposited	Annealed	As-deposited	Annealed
Ni	0.00841	0.00345	0.526	0.493
Ni/Au	0.0052	0.00248	0.522	0.487
Ni/Ru	0.00362	0.00156	0.517	0.484