

Novel Polarization Enhanced Ohmic Contacts to n-Type GaN

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Utilizing a thin n-type $\text{Al}_x\text{Ga}_{1-x}\text{N}$ layer on top of n-type GaN, the metal–semiconductor contact resistance can be decreased drastically compared to bulk n-type GaN. Specific contact resistances as low as $8.5 \times 10^{-5} \Omega \text{ cm}^2$ have been achieved without high temperature annealing. The design of this novel contact is based on polarization fields in the thin $\text{Al}_x\text{Ga}_{1-x}\text{N}$ layer.

Introduction GaN-based semiconductor compounds have been successfully used for short-wavelength light emitters as well as high power/high temperature electronic devices. However, the performance of these devices is reduced because of large contact resistances between metal and III-nitride semiconductor. For n-type GaN, specific contact resistances as low as $10^{-8} \Omega \text{ cm}^2$ can be achieved by using an alloyed Ti/Al/Ni/Au metallization scheme [1]. For p-type GaN, contact resistances as small as $10^{-6} \Omega \text{ cm}^2$ are possible with oxidized Ni/Au contacts [2]. Another approach using p-type AlGaIn/GaN superlattices can reduce the specific contact resistance down to the $10^{-4} \Omega \text{ cm}^2$ range [3].

Because of its wurtzite crystal structure, the III-nitride material system can support spontaneous polarization fields. Additionally, in III-nitride heterostructures significant polarization fields are induced due to piezoelectric effects. Both types of polarization fields bend the conduction and valence bands, resulting in the formation of a two-dimensional electron gas (2DEG) [4, 5]. In the case of a thin $\text{Al}_x\text{Ga}_{1-x}\text{N}$ layer grown on top of n-type GaN, the polarization fields can be utilized to decrease the contact resistance by increasing the tunneling probability through the top layer. Here the $\text{Al}_x\text{Ga}_{1-x}\text{N}$ layer is much thinner than the critical thickness so that the $\text{Al}_x\text{Ga}_{1-x}\text{N}$ layer is pseudomorphically strained. The approach presented here is in contrast to an approach frequently used in the GaAs system, where a *smaller* bandgap material is deposited on top of GaAs to reduce the contact resistance by lowering the metal–semiconductor barrier height [6, 7].

Experiments In this work, uniformly doped n-type $\text{Al}_x\text{Ga}_{1-x}\text{N}/\text{GaN}$ heterostructure and n-type bulk GaN samples (Si: $\sim 10^{17} \text{ cm}^{-3}$) grown by molecular beam epitaxy (MBE) on c-plane sapphire substrates were studied. $\text{Al}_x\text{Ga}_{1-x}\text{N}$ capping layers with different aluminum contents x and different layer thicknesses w are compared to an MBE grown n-type bulk GaN sample without capping layer. Details of the samples are given in Table 1.

As can be seen from the current–voltage (I – V) curve in Fig. 1, at a given voltage, the current densities in the AlGaIn/GaN heterostructures are much larger than in the n-type bulk GaN indicating the presence of a 2DEG. The rescaled I – V curve of n-type

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Table 1

Aluminum content x and $\text{Al}_x\text{Ga}_{1-x}\text{N}$ top layer thickness w of the $\text{Al}_x\text{Ga}_{1-x}\text{N}/\text{GaN}$ samples

sample	x	w (nm)
Al 50	0.5	4.0
Al 30	0.3	7.5
n-type bulk GaN (reference)	0	0

Table 2

Specific contact resistances ρ_c (in $\Omega \text{ cm}^2$) before and after 800 °C annealing in N_2 for 30 s

sample	ρ_c (as deposited)	ρ_c (800 °C annealing (N_2 , 30 s))
Al 30	1.2×10^{-3}	5.5×10^{-5}
Al 50	8.5×10^{-5}	7.6×10^{-6}
n-type bulk GaN	N/A*)	1.0×10^{-4}

*) For n-type bulk GaN sample, the I - V curve is not linear

bulk GaN shows rectifying behavior when compared to the ohmic characteristic of the heterostructure samples (Fig. 2).

To determine the specific contact resistance ρ_c , the transmission line method (TLM) is used. Ti (20 nm)/Al (120 nm)/Ni (30 nm)/Au (30 nm) contacts defined by standard photo-lithographic steps are deposited onto the samples with an e-beam evaporator. Prior to the evaporation, the samples were dipped into buffered oxide etch (BOE) for 2 min to remove surface oxide. TLM data before and after annealing in nitrogen ambient at 800 °C for 30 s are shown in Figs. 3 and 4 together with straight lines obtained from fits to the data. The obtained values of the specific contact resistances are shown in Table 2.

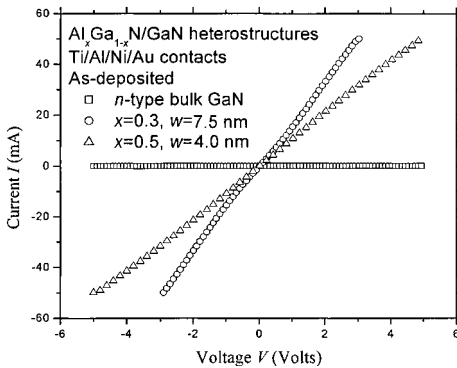


Fig. 1

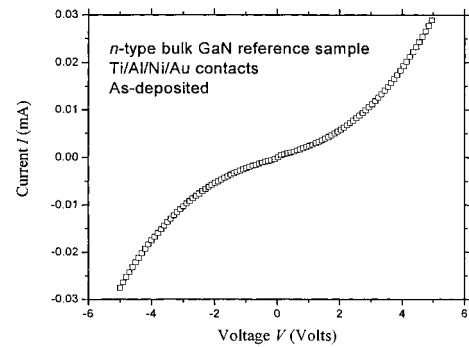


Fig. 2

Fig. 1. I - V curve of the as-deposited Ti/Al/Ni/Au contacts to n-type bulk GaN reference and $\text{Al}_x\text{Ga}_{1-x}\text{N}/\text{GaN}$ heterostructure samples with different aluminum content x and $\text{Al}_x\text{Ga}_{1-x}\text{N}$ layer thickness w

Fig. 2. Rescaled I - V curve of the as-deposited Ti/Al/Ni/Au contacts to n-type bulk GaN reference sample of Fig. 1 shows the rectifying characteristic

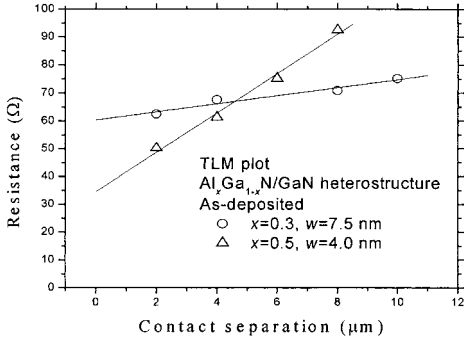


Fig. 3

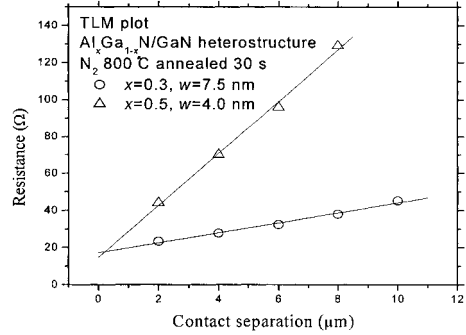


Fig. 4

Fig. 3. TLM data for as-deposited Ti/Al/Ni/Au contacts to n-type $\text{Al}_x\text{Ga}_{1-x}\text{N}/\text{GaN}$ heterostructure samples with different aluminum contents x and $\text{Al}_x\text{Ga}_{1-x}\text{N}$ layer thickness w . The solid line is the linear fit to the data

Fig. 4. TLM data for 800 °C annealed Ti/Al/Ni/Au contacts to n-type $\text{Al}_x\text{Ga}_{1-x}\text{N}/\text{GaN}$ heterostructure samples with different aluminum contents x and $\text{Al}_x\text{Ga}_{1-x}\text{N}$ layer thickness w . The solid line is the linear fit to the data

Discussion As can be seen in Table 2, the contact resistances for the heterostructure samples after annealing are significantly smaller than for the n-type bulk GaN reference. The lowest resistances were obtained for sample Al 50 with the large Al content and smallest thickness of the $\text{Al}_x\text{Ga}_{1-x}\text{N}$ top layer. These results can be understood based on the bandstructure modifications caused by the polarization field in the thin $\text{Al}_x\text{Ga}_{1-x}\text{N}$ layer and the induced bound charge at the heterostructure interface. A band diagram calculated self-consistently using a software package solving the one-dimensional Schrödinger and Poisson equation [8] is shown in Fig. 5. The tunneling width in the heterostructure is given by the thickness w of the $\text{Al}_x\text{Ga}_{1-x}\text{N}$ layer and can be made small enough for tunneling to be the dominant charge carrier transport mechanism.

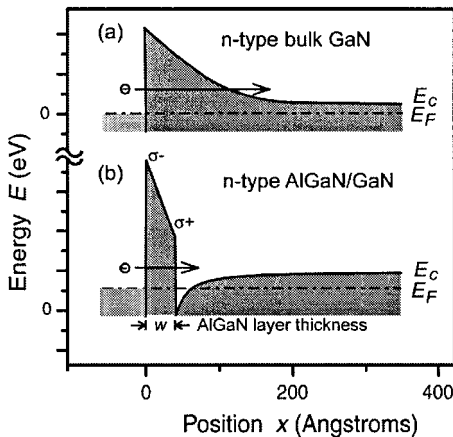


Fig. 5. Calculated band diagram for n-type GaN (top) and the AlGaIn/GaN heterostructure (bottom) with a metal contact at the surface ($z = 0$). The Schottky barrier height is given by the formula $U(z = 0) = (1.3x + 0.84)$ eV [4]. E_C and E_F are the bottom of the conduction band and the Fermi level, respectively. The bound charge densities induced by the polarization field at the surface of the AlGaIn layer and at the heterostructure interface are denoted by σ^- and σ^+

By applying the zero-order Wenzel-Kramer-Brillouin (WKB) approximation, the tunneling probability through the AlGa_xN layer is given by

$$T = e^{-\int_0^w 2\hbar^{-1} \sqrt{2m^* [U(z) - E]} dz} \quad (1)$$

where w is the layer width and $U(z)$ is the height of conduction band. E is the electron energy usually set to zero and m^* is the effective electron mass in Al_xGa_{1-x}N. For thin top layers the tunneling probability is increased and the contact resistance between metal and semiconductor is reduced. Large aluminum content increases the Al_xGa_{1-x}N layer band bending and decreases the $[U(z) - E]$ term. However, it has to be taken into account that the barrier height increases at the same time.

A similar approach may also be feasible for metal contacts to p-type GaN by utilizing a thin In_xGa_{1-x}N top layer with a thickness comparable to the hole tunneling width.

Summary In this work, GaN samples with thin Al_xGa_{1-x}N top layers of different thicknesses and aluminum contents are studied. The contact resistances decrease with increasing thickness of the Al_xGa_{1-x}N layer. Specific contact resistances as small as $8.5 \times 10^{-5} \Omega \text{ cm}^2$ have been obtained without annealing. These results can be explained by the effects of polarization fields in the Al_xGa_{1-x}N top layer on the hetero bandstructure causing tunneling to be the dominant charge carrier transport mechanism.

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