

Characteristics of Ti/Pt/Au Ohmic Contacts on *p*-type GaN/Al_xGa_{1-x}N Superlattices

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ABSTRACT

Ti/Pt/Au metallization on *p*-type GaN/Al_xGa_{1-x}N (*x*=0.10 and 0.20) superlattices (SL) were investigated as ohmic contacts. Current-voltage and specific contact resistance measurements indicate enhanced *p*-type doping in the superlattice structures compared to that in GaN. Ti/Pt/Au is shown to be an effective ohmic metallization scheme on *p*-type GaN/Al_xGa_{1-x}N superlattices. A specific contact resistance of $R_c = 4.6 \times 10^{-4} \Omega\text{-cm}^2$ is achieved for unalloyed Ti/Pt/Au on GaN/Al_{0.2}Ga_{0.8}N SL. This is reduced to $1.3 \times 10^{-4} \Omega\text{-cm}^2$ after annealing for 5 minutes at 300 °C.

INTRODUCTION

Ohmic contacts with very low contact resistances are essential for improving the performance of optoelectronic devices fabricated on GaN-based materials. For *n*-type GaN, metallization schemes containing Ti have been very effective in lowering the specific contact resistance (R_c) to less than $10^{-5} \Omega\text{-cm}^2$ [1-3]. In contrast, because of the wide bandgap and the relatively deep acceptor level of the commonly used Mg dopant, it has been very difficult to find ohmic contacts with R_c less than $10^{-3} \Omega\text{-cm}^2$ for *p*-GaN [4]. So far, only three ohmic metallization and processing schemes on *p*-GaN have been reported to yield R_c values less than $10^{-4} \Omega\text{-cm}^2$. One of these schemes requires a post-metallization anneal of 20 minutes at 800 °C [5], while another requires a boiling aqua regia surface etch prior to metal deposition [6, 7]. The third method reduces the resistance of Ni/Au contacts by oxidizing the metallization at 500 °C for 10 minutes and form a thin NiO layer[8]. This work aims at finding a low-resistance ohmic contact on *p*-GaN which requires less aggressive treatments, thereby making the metallization process more compatible with device processing.

Schubert *et al.* proposed that the overall hole concentration in *p*-type GaN can be increased through the generation of valence band edge oscillations in a superlattice[9]. This technique improves the activation efficiency of deep acceptors by allowing them to ionize when tunneling occurs from the larger bandgap material into the adjacent material with a narrower bandgap. Significantly enhanced *p*-type doping efficiency in GaN/Al_xGa_{1-x}N short-period superlattices (SL) has been reported recently [10-11]. In this paper, we

demonstrate excellent ohmic contacts on GaN/Al_xGa_{1-x}N SL with a Ti/Pt/Au contact scheme without any aggressive surface treatment and post-metallization anneal. The results are compared to that obtained from the same metallization on p-GaN.

EXPERIMENTAL DETAILS

The superlattice layers used in this study were grown by MBE on sapphire and consisted of 20 periods each of Mg-doped GaN (10 nm) and Al_xGa_{1-x}N (10 nm). Samples with two different aluminum concentrations, $x=0.1$ and 0.2 , were investigated. Both samples exhibited a mobility of $\sim 1 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$ from room temperature Hall measurements. The reference p-GaN layer used in this study has a $0.3 \mu\text{m}$ doped layer with a nominal bulk carrier concentration of $2.5 \times 10^{17} \text{ cm}^{-3}$ and a mobility of $9 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$ as obtained from Hall measurements at room temperature. Contact resistances were determined using the linear transfer length method (TLM). The structures used for the TLM measurements were fabricated by first patterning the p-GaN and SL samples with $100 \times 650 \mu\text{m}$ mesas. The pattern was then transferred into the samples using reactive ion etching, which electrically isolated the mesas. Rectangular pads were then patterned. Prior to transferring the samples into the evaporation chamber, the surfaces were cleaned in O₂ plasma, followed by dips in a dilute HCl:DI (1:2) solution. Electron beam evaporation was used to deposit Ti (15 nm) and Pt (50nm), while Au (80nm) was thermally evaporated as the last capping layer. Post-deposition heat treatment was carried out while flowing N₂ at 1 atmosphere in a rapid thermal annealing (RTA) system. The contact characteristics were studied using current-voltage (I-V) and four-probe linear TLM techniques at room temperature. For accurate specific contact resistance determination, actual pad distances were determined using scanning electron microscopy (SEM) after metal lift-off.

RESULTS AND DISCUSSIONS

There are several reasons for adopting Ti/Pt/Au metallization for this study. Based on the Schottky-Mott model of metal-semiconductor contacts, the metal-semiconductor barrier height ϕ_b is related to the work function of the metal ϕ_m and the electron affinity of a *p*-type semiconductor χ_s by $\phi_b = \phi_m - \chi_s + E_g$ – ϕ_m , provided that there is no Fermi level pinning at the M-S interface. Therefore, metals with high work functions are required to reduce the M-S barrier height for wide band-gap semiconductors such as GaN. Pt, with a ϕ_m of 5.65 eV, has the highest work function of all metals and is chemically stable. However, experiments have shown that Pt alone suffers from poor adhesion on GaN and therefore, a thin Ti layer is used to improve adhesion as well as getter surface contamination or oxides. The excellent ohmic contacts obtained here for Ti/Pt/Au shows that Ti has been effective in these roles.

Figure 1 shows the current-voltage characteristics of as-deposited Ti/Pt/Au contacts on all three samples. The as-deposited contact is rectifying on the reference p-type GaN. In contrast, due to the enhanced doping efficiencies, the

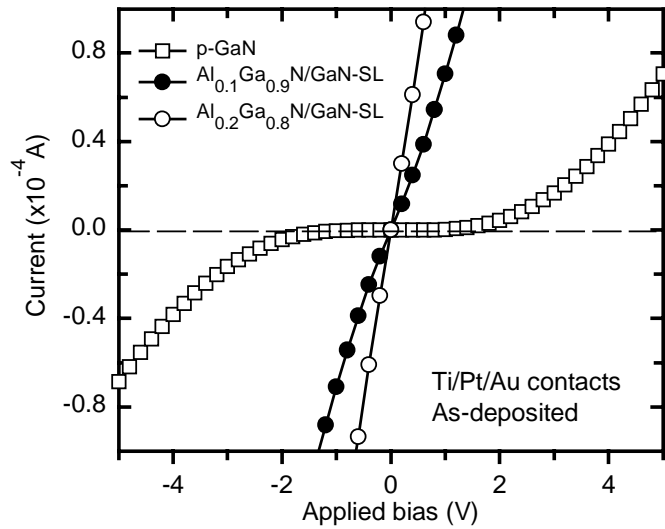


Figure 1. Current-voltage characteristics of as-deposited Ti/Pt/Au contacts on p-Type GaN/Al_xGa_{1-x}N superlattices (x=0.1 and 0.2)

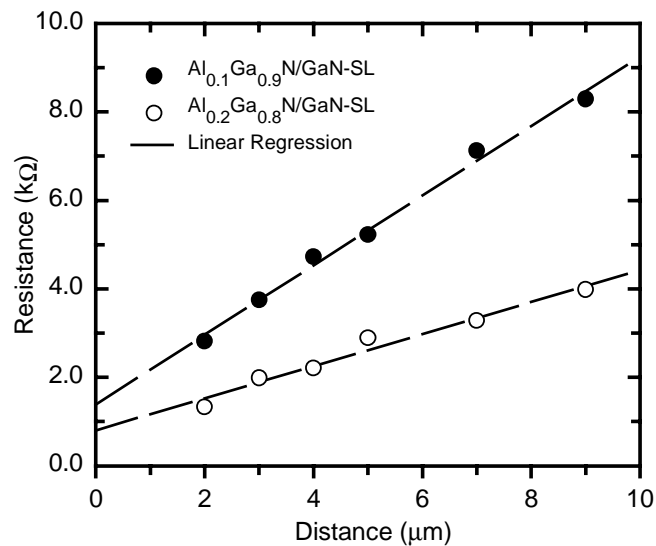


Figure 2. Measured resistance vs. contact spacing plot for the as-deposited Ti/Pt/Au contacts on p-type GaN/Al_xGa_{1-x}N superlattices (x=0.1 and 0.2). Dotted lines are least-square best fits to the different data sets.

I-V curves for GaN/Al_xGa_{1-x}N SL exhibit improved linearity. Figure 1 also reveals that the sample with a higher aluminum mole fraction ($x = 0.2$) was more ohmic in its I-V characteristics. This is consistent with a calculated carrier concentration of $3 \times 10^{18} \text{ cm}^{-3}$ for the SL ($x = 0.1$) versus $5 \times 10^{18} \text{ cm}^{-3}$ for the other ($x = 0.2$). An additional mechanism in support of this observation is that the total polarization charge should be higher in the SL with $x=0.2$ [10].

The contact resistivity (ρ_c) and specific contact resistance (R_c) were calculated from the measured resistance vs. contact pad spacing data using the linear TLM method. Figure 2 plots the measured resistance vs. pad distance for the as-

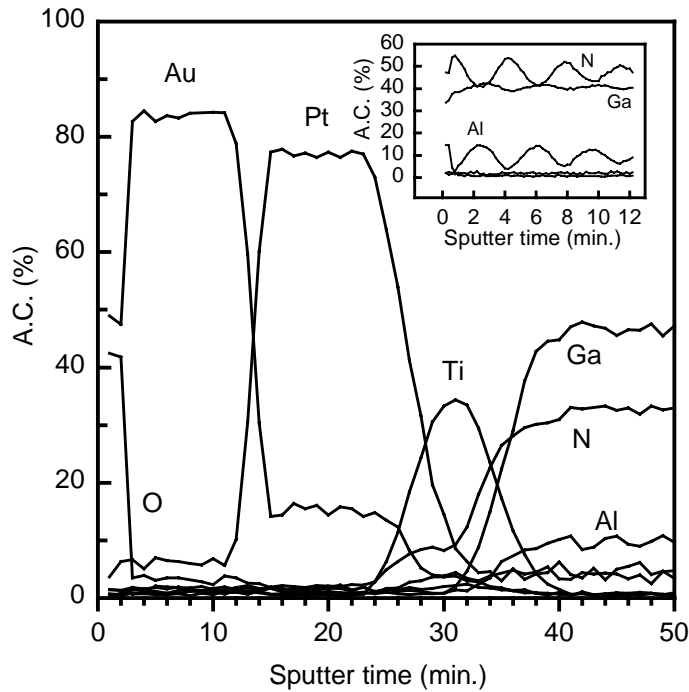


Figure 3 AES depth profile of Ti/Pt/Au contacts after annealing for 5 minutes at 300°C. Inset shows AES depth profile of the as-grown p-type GaN/Al_{0.2}Ga_{0.8}N sample.

deposited Ti/Pt/Au contacts on the two SL samples. Least-square linear regression lines were used to extrapolate the data to the y-axis. The slope of the regression line is a measure of the sheet resistance of the semiconductor. It is clear that the SL with $x=0.2$ has a smaller slope and therefore a lower sheet resistance, again due to the increased carrier concentration coming from its higher Al mole fraction. ρ_c and R_c values can be extracted from the slope of the line, x- and y-intercepts and the pad width. These results are summarized in Table 1. For contacts on semiconductors with $N_A > 10^{17} \text{ cm}^{-3}$, the tunneling

process is expected to predominate. In this case, $R_c \propto \exp[m(N_A)^{-1/2}]$, where m is a parameter related to the contact barrier height and hole effective mass, and N_A , which is the effective carrier concentration. It is clear from this relationship that R_c will be lower for the SL with $x = 0.2$, and R_c of both SL should be much lower than that of the p-GaN, which is consistent with the results shown in Figure 1 and Table 1.

Table 1: Summary of results for as-deposited and annealed (at 300 °C for 5 minutes) Ti/Pt/Au contacts on p-type GaN and GaN/Al_xGa_{1-x}N superlattices ($x=0.1$ and 0.2).

Semiconductor Layer Structure	Contact Resistivity (Ω-mm)		Specific Contact Resistance (Ω-cm ²)	
	<i>as-dep</i>	<i>annealed</i>	<i>as-dep</i>	<i>annealed</i>
p-GaN	Schottky	~200	Schottky	~6×10 ⁻³
GaN/Al _{0.1} Ga _{0.9} N SL	72	62	6.6×10 ⁻⁴	4.7×10 ⁻⁴
GaN/Al _{0.2} Ga _{0.8} N SL	41	24	4.6×10 ⁻⁴	1.3×10 ⁻⁴

Preliminary results on the effectiveness of Ti/Pt/Au contacts on p-type GaN and Al_xGa_{1-x}N alloys after annealing are also included in Table 1. Contacts annealed at 300 °C for 5 minutes showed clear improvement. Figure 3 shows an Auger electron spectroscopy (AES) depth profile of the contact metallization after this treatment. Annealing at temperatures higher than 400 °C resulted in rapid degradation of the contacts. The degradation mechanism is currently still under investigation.

CONCLUSIONS

This study presented the electrical characteristics of Ti/Pt/Au contact on p-type GaN/Al_xGa_{1-x}N superlattices. The results indicate effective increase in carrier concentration by using superlattice structures. Ti/Pt/Au has been demonstrated as an effective ohmic metallization scheme on p-type GaN/Al_xGa_{1-x}N superlattices, which achieved a specific contact resistance of 1.3×10⁻⁴ Ω-cm² on GaN/Al_{0.2}Ga_{0.8}N superlattice after annealing for 5 minutes at 300 °C.

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