

Selective Deposition of Low Temperature AlN Ohmic Contacts for GaN Devices

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Abstract

We have developed a low temperature (250°C) plasma-enhanced atomic layer deposition process for AlN on GaN. Due to the polarization effect, this growth technique has produced a large 2DEG channel ($1.8 \times 10^{13} \text{ cm}^{-2}$) and low sheet resistance ($\sim 180 \Omega/\square$). Utilizing the AlN/GaN 2DEG polarization and ultra-thin film thickness (3 nm) we produced a low ohmic contact resistance ($\sim 1 \times 10^{-4} \Omega \text{ cm}^2$). Furthermore, by adjusting the work function of the metal contacts we were able to modify the contact resistance of the device.

INTRODUCTION

Currently, ohmic contacts for GaN based devices have been extensively researched [1]. However, the complex metal stacks and high temperature annealing ranges (800°C-1200°C) increase the difficulty and cost of the overall device. The use of AlN films have been shown to produce a 2-dimension electron gas (2DEG) interface with large confined carrier concentration [2]. By creating an ultra-thin AlN film, the probability of tunneling through the barrier becomes significant. However, through conventional methods these films are difficult to selectively grow [3]. Through the use of low temperature plasma-enhanced atomic layer deposition (PEALD), we were able to accurately control the growth and location of ultra-thin AlN films on GaN. In this abstract we present the electrical characteristics of low temperature PEALD AlN films on GaN for ohmic contacts and MOS applications.

FABRICATION PROCESS

To characterize the contact and sheet resistance of the AlN and ZrO₂ films, devices were fabricated on GaN/Sapphire templates ($\sim 10^{17} \text{ cm}^{-3}$) provided from Kyma Technologies Inc. First, the AlN film ($\sim 3 \text{ nm}$) was deposited using low temperature plasma enhanced atomic layer deposition (PEALD) reactor (Kurt J. Lesker). During the growth of the films, the substrates were maintained at a constant temperature of 250°C. The alternating precursor gases and corresponding dose/purge times were nitrogen plasma (10/7s) and trimethyl-aluminum (0.02/7s). This film growth was optimized through X-ray diffraction analysis (XRD) and x-ray photon spectrometry (XPS). Prior to the deposition of AlN, photoresist was patterned and used as lift-off process. The low temperature process ensured that the photoresist was not drastically affected during the growth.

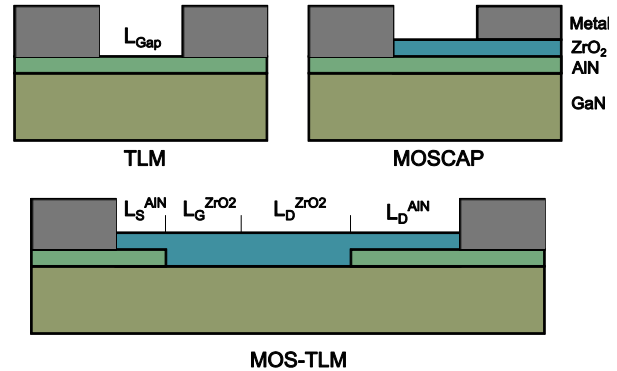


Figure 1 : Device test structures used to evaluate the thin films grown on GaN.

Following the lift-off of the AlN, the high- κ dielectric (ZrO₂) was deposited using the same PEALD process and lift-off technique. The temperature and pressure of the chamber was 100°C and 1.07 Torr, respectively. The alternating precursor gases and corresponding dose/purge times were oxygen plasma (2/2s) and tetrakis(dimethylamido)-zirconium (0.04/5s). The ZrO₂ films were grown for 40 cycles to produce a film thickness of $\sim 6.9 \text{ nm}$. Metal contacts were deposited by RF-magnetron sputtering and patterned into metal oxide semiconductor capacitors (MOSCAPs) and transfer length method (TLM) test structures, as shown in Figure 1. The metals examined in this study were Cr/Au (20/80nm) and Al/Au (20/80nm) stacks.

EXPERIMENTAL RESULTS

To determine the sheet resistance and contact resistance of the film, TLM structures were used by varying the gap between the contacts [4]. This technique allowed for the extraction of both parameters for 25 TLM structures per wafer, shown in Table I. As expected the sheet resistance was independent of the contact metal deposited on top of the AlN. However, the contact resistance was dependent on the metal because the tunneling probability was based on the work function of the contacts.

TABLE I
TLM RESULTS

Contact Metal	AlN Sheet Resistance (Ω/\square)	Contact Resistance ($\Omega \text{ cm}^2$)
Cr/Au	389 +/- 48	$3.8 \times 10^{-4} \pm 0.5 \times 10^{-4}$
Al/Au	346 +/- 62	$3.1 \times 10^{-4} \pm 0.3 \times 10^{-4}$

Gateless MOSFETs, MOS-TLMs, (Figure 1) were fabricated to examine the sheet resistance and interaction between of the AlN and ZrO₂ films with GaN substrate. The dimensions of the AlN and ZrO₂ regions, described in (1) were varied to extract the sheet and contact resistance. The total resistance was describe by the contact resistance (R_c), sheet resistance (R_{AIN} and R_{ZrO2}) and the drain recess (X_{ox}={0, 1/2, 1}) of the AlN.

$$R_{tot} = 2R_c + R_{AIN}^S \frac{L_{gs}}{w} + R_{ZrO_2}^G \frac{L_g}{w} + R_{ZrO_2}^D \frac{X_{ox} L_{gd}}{w} + R_{AIN}^D \frac{(1 - X_{ox}) L_{gd}}{w} \quad (1)$$

The different dimensions of the gate-drain region allowed us to extrapolate the slope and determine the sheet resistance between the AlN/GaN interface and the ZrO₂/GaN interface. The intercept of (1) was used to extract the contact resistance, which was only dependent on contact metal used on the surface of the AlN. As expected and observed with the TLM structures, the Al/Au stack produced a lower contact resistance than the Cr/Au. This was due to the alignment of the Fermi level with the work function of the metals. The larger work function contact metal, Al, allowed for higher tunneling probabilities through the AlN films which in-turn produced a lower contact resistance of >20%.

TABLE II
CR/AU MOS-TLM RESULTS

Contact Metal	L _{AIN} = L _{gd}		L _{AIN} = 1/2 L _{gd}			L _{AIN} = 0	
	AIN Ω/□	R _c (Ω cm ²)	AIN Ω/□	ZrO ₂ Ω/□	R _c (Ω cm ²)	ZrO ₂ Ω/□	R _c (Ω cm ²)
Cr/Au	167	1.69x10 ⁻⁴	208	631	1.31x10 ⁻⁴	673	1.42x10 ⁻⁴
Al/Au	184	1.18x10 ⁻⁴	158	636	1.04x10 ⁻⁴	688	1.21x10 ⁻⁴

Following the extraction of the contact resistance and sheet resistance, the 2DEG polarization created from the AlN was determined from TLM capacitance-voltage (C-V) measurements, shown in Figure 2. By pinching off the 2DEG channel we were able to determine the total charge density (0.8x10¹³cm⁻²) caused from the AlN film. Similarly, the MOSCAPS C-V measurement, shown in Figure 2, was used to extract the 2DEG polarization charge density

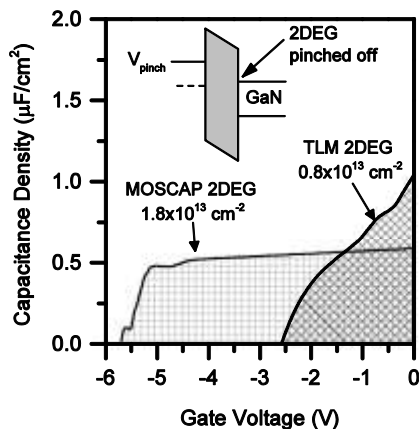


Figure 2: Capacitance-Voltage measurements used to determine the 2DEG carriers produced by the AlN/GaN polarization.

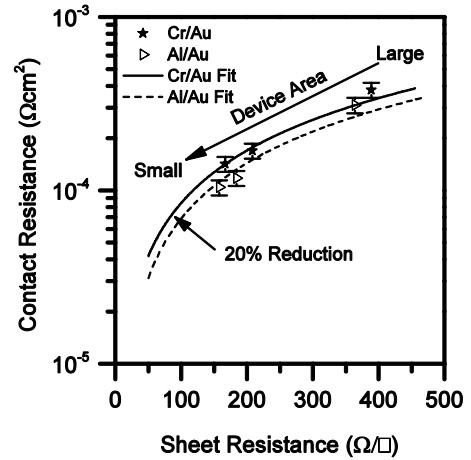


Figure 3: Area dependence of the sheet and contact resistance.

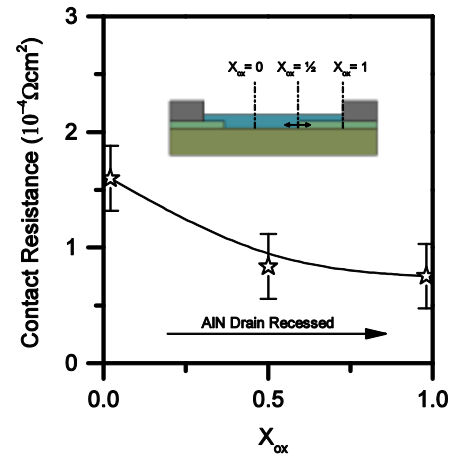


Figure 4: Improvement of the contact resistance as selective AlN regions are reduced.

(1.8x10¹³cm⁻²), again independent of metal contacts. Using the extracted sheet resistance and 2DEG concentration, we were able to confirm that the films peak electron mobility was in the range of 700-800 cm²/Vs. Furthermore, the MOS-TLMs were used to confirm that the sheet resistances of the non-polarized 2DEG ZrO₂/GaN regions were consistent with the expected sheet resistance for the GaN substrate (> 650 Ω/□).

The polarization of the films was found to be dependent on the dimension of the AlN growth region, shown in Figure 3. The total polarization charge was found to improve as the growth area was reduced from full wafer deposition to selective deposition <400um². Furthermore, the AlN drain recess produced low contact resistances, Figure 4, as the AlN was shortened.

Through a low temperature selective PEALD deposition technique, we have produced a large 2DEG and low ohmic contact for GaN based devices. This modest technique provides insight into the future of fabrication for GaN based devices.

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