Investigations of Metal/Insulator/AlGaN/GaN Structures by Capacitance-Voltage Measurements and Auger Chemical Profiling

B. Adamowicz¹, M. Miczek¹,², T. Hashizume², A. Klimasek¹, P. Bobek¹, and J. Żywicki³

¹Department of Applied Physics, Institute of Physics, Silesian University of Technology, Krzywoustego 2, 44-100 Gliwice, Poland
Phone: +48-32-237-2407, fax +48-32-237-2216, E-mail: Boguslawa.Adamowicz@polsl.pl
²Research Center for Integrated Quantum Electronics and Graduate School of Electronics and Information Engineering, Hokkaido University, West 8 North 13, Sapporo 060-8628, Japan
³High-Tech International Services Inc., Rome, Italy

1. Introduction

Although GaN and AlGaN are promising materials for high-frequency and high-power microelectronics due to their wide bandgaps, high electron mobility, large 2-dimensional electron gas (2DEG) density at AlGaN/GaN interface as well as chemical and thermal stability, there are still problems of large Schottky gate leakage and current collapse. These issues, limiting device performance, are related to the electronic quality of AlGaN surface and subsurface region and can be overcome by surface passivation, the reduction of subsurface defect density, and applying an insulated gate instead of Schottky one [1] as demonstrated in metal/insulator/semiconductor heterojunction field effect transistors (MISHFETs). However, the mechanism of AlGaN surface passivation has not been fully clarified yet and the link between chemical and electronic aspect of passivation is scarcely studied [2,3]. Nitrogen vacancies, oxygen-related defects [2], and carbon traces [3] were proposed to be responsible for gate leakage current and current collapse, respectively.

The purpose of this work is to investigate electronic and chemical properties of AlGaN/GaN heterostructures passivated by SiO₂/Si₃N₄ and SiNₓ/Si₃N₄ bilayers. In this order the electrical characterization by means of capacitance-voltage (C-V) measurements and chemical studies using Auger electron spectroscopy (AES) combined with in-depth profiling were performed. The results, in terms of 2DEG density, C-V hysteresis loop and AES peak evolution versus sputtering for all constituents in the insulator/AlGaN interface region, provided information which seems to be indispensable for better understanding of passivation mechanism and further technology optimization.

2. Experimental

The investigated devices were fabricated on an Al₆xGa₈₋₆xN/GaN/sapphire wafer with the un-doped AlGaN layer passivated by an ultrathin (1 nm) Si₃N₄ film deposited in situ by metal-organic chemical vapor deposition (MOCVD) in order to protect the AlGaN surface during the deposition of a next insulating layer [1]. To fabricate MIS structures a SiO₂ layer was deposited by plasma-enhanced chemical vapor deposition (PECVD) using SiH₄ and N₂O. A SiNₓ film was obtained by electron cyclotron resonance CVD using SiH₄ and N₂. Ohmic Ti/Al/Ti/Au ring contacts were formed using photolithography, wet etching, metal layer deposition, lift-off, and rapid thermal annealing. Finally, Al/Au circular gate contacts with the diameters of 200, 300, 400, and 500 µm were obtained (Fig. 1).

![Fig. 1. A schematic view of the studied MIS devices.](image)

The electrical characterization of the devices were performed by C-V measurements at room temperature at frequency of 100 kHz.

For AES measurements we applied a PHI 600 Scanning Auger Microprobe (property of High-Tech International Services, Rome). The ion sputtering of the passivated AlGaN/GaN structures was performed with a differentially pumped Ar⁺ ion gun (ion energy of 1 keV, incident angle of 30°, pressure of about 4x10⁻¹⁰ Torr). The duration of a sputter time was typically set at 15 s whereas in the sub-surface region of the passivation layer it was 6 s. The AES spectra were recorded at electron beam energy of 10 keV.

3. Results and Discussion

The C-V behavior of the MIS AlGaN/GaN structures with SiO₂ and SiNₓ layers is shown in Fig. 2a and 2b, respectively. The 2DEG density, estimated from C-V curves, is slightly higher (1.8x10¹³ cm⁻²) in the structure with SiO₂ compared to that with SiNₓ (1.3x10¹³ cm⁻²), which could be attributed to a positive charge in SiO₂ [1]. The antilockwise C-V hysteresis loop is narrower in the device with SiNₓ, which suggests its better electronic quality (in terms of density of interface states and/or of traps in insulators).

The theoretical C-V curves were calculated by a numerical solver of Poisson equation using Gummel algorithm and taking into account deep depletion in AlGaN and GaN layer, the AlGaN/GaN interface charge due to piezoelectric and spontaneous polarization, and interface states [4]. The experimental points lie close to the theoretical characteristics (Fig. 2) suggesting good electronic quality of the AlGaN/GaN and insulator/AlGaN interfaces, however it
should be stressed that at room temperature only a small part of interface states in the wide bangaps of AlGaN and GaN is active.

The results of AES measurements for the AlGaN/GaN structure passivated by the SiO$_2$/Si$_3$N$_4$ bilayer are presented in Figs. 3 and 4. The similar data were obtained for the structure passivated by SiN$_x$/Si$_3$N$_4$ bilayer. Fig. 3 shows the detailed evolution of AES peaks of all constituents versus sputtering time. In particular, the visible energy shift of the Si(LVV) peak towards the bulk corresponds to a transition from SiO$_2$ to ultrathin Si$_3$N$_4$ layer. A certain content of oxygen atoms, which are present at the interface can be a source of oxygen-related shallow levels. However, from Fig. 4 it is evident that oxygen content gradually decreases in the range of the insulator/AlGaN interface. It should be also noted that slight carbon contamination was observable only at the outer insulator surface. These findings prove that the applied passivation approach seems to be advantageous compared to the literature reports [3], where the local maximum of oxygen concentration at the insulator/AlGaN interface was observed after different nitride passivation processes.

It seems that good electric characteristics can be partially attributed to relatively low O content and lack of C contamination in the structures and especially in the insulator/AlGaN interface region.

4. Conclusions
We performed electrical (C-V) and chemical (AES) characterization of Al$_{0.4}$Ga$_{0.6}$N/GaN devices passivated by SiO$_2$/Si$_3$N$_4$ and SiN$_x$/Si$_3$N$_4$ bilayers. The higher value of 2DEG density in the structure with SiO$_2$, estimated from C-V curve, was attributed to a positive charge in SiO$_2$. The structure with SiN$_x$ exhibited the narrower C-V hysteresis loop suggesting its better electronic quality. From the AES measurements we obtained the detailed evolution of all elements content versus sputtering time. In particular, the in-depth profiles of AES signal for O, Si and N were determined. On this basis, a decrease of oxygen content towards the insulator/AlGaN interface was revealed.

Acknowledgements
M. Miczek acknowledges postdoctoral research scholarship from RCIQE. The work was partially supported within the project 1561/T11/2005/29 by the Ministry of Science and Higher Education (Poland).

References