Interfacial Charge Properties of ALD/III-Nitride Interfaces

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III-Nitride-based high electron mobility transistors (HEMTs) have been investigated widely for applications in high power and high frequency electronics due to the large bandgap and high electron velocity of GaN. Metal-insulator-semiconductor HEMTs (MISHEMTs) structures can efficiently suppress gate leakage in vertically scaled transistors with ultra-thin gate barriers needed for higher frequency (mm-wave) operation, and could enable ultra-low leakage for loss-sensitive applications such as power switching circuits. In this work, we discuss the presence of fixed interface charges at the dielectric/semiconductor interface, their effect on the energy band profile and electron transport, and methods to reduce this fixed interface charge density.

While the interface trap density and related dispersion in ALD/III-nitride interfaces is less than that seen in III-As semiconductors[1], recent work has shown that a high density of *fixed* charges (~ 1 $\mu C/cm^2$) is induced at ALD-grown Al_2O_3/GaN and Al_2O_3/AlN structures[2,3]. It was shown that this charge is not modulated by electric field, and therefore does not lead to hysteresis, but it does significantly modify the electrostatics in the system. The high interfacial fixed charges reduce the mobility of the 2-dimensional electron gas (2DEG)[4] through remote ionized impurity scatter, and induce high electric fields in the oxide thus increasing tunneling-related leakage currents. This fixed-charge-induced electric field can also lead to substantial leakage for gate dielectric in N-polar III-Nitride HEMTs.

Theoretical investigation of remote impurity scattering for dielectric/AlGaN/GaN structures and the effect dielectric/AlGaN interface charge density, 2DEG concentration, and AlGaN thickness will be presented. Remote impurity scattering was found to be the dominant mechanism when the 2DEG density is below $5x10^{12}$ cm^{-2} and dielectric/AlGaN interface charge density is above $5x10^{12}$ cm^{-2}. The interfacial charge has significant effect on the mobility as the AlGaN cap layer thickness is scaled down below 5nm. We will report experimental transport data for highly scaled dielectric/AlGaN/GaN structures with different fixed interface charge density, and compare results with the theoretical predictions.

Post-metallization anneal (PMA) can be used to reduce the fixed interface charge at the Al_2O_3/GaN interface in Ga-polar, N-polar and non-polar GaN layers. We present experimental data using Al_2O_3 layers of nominal thickness 6 nm, 12 nm, and 18 nm deposited by atomic layer deposition. All samples were then annealed at 700˚C in forming gas for post-deposition anneal. After oxide deposition and gate metallization, PMA was carried out at different temperature: 400˚C, 450˚C and 500˚C. A quantitative analysis of the interface barrier of Ni/Al_2O_3/GaN capacitors was carried out to determine conduction band discontinuity, electric field in the dielectric layer, and interface fixed charge from capacitance voltage (C-V) measurements for each polarity. A linear relationship between the flat-band voltage and oxide thickness was observed, indicating absence of Fermi-level pinning at the Al_2O_3/GaN interface, and non-zero electric field in the oxide, even during flat band conditions in the GaN. The conduction band offset (ΔE_C) was estimated to be 2.1 eV for Al_2O_3/GaN-polar GaN interface. Successively higher post-metallization anneals, were found to decrease the interface charge. The field in the oxide under flat band conditions in GaN was reduced from 1.92 to 0.22 MV/cm corresponding to a large decrease in the interface net charge density from $1x10^{13}$ cm^{-2} to $1x10^{12}$ cm^{-2}. The gate leakage current was also suppressed due to the reduction in the electric field. The reduction of interface charge density using post-metallization anneal was found to occur not only in Ga-polar GaN, but also in N-polar GaN, non-polar GaN, and AlGaN/GaN structures.

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Reference

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Fig.1. Simulation results – remote impurity and phonon scattering models.

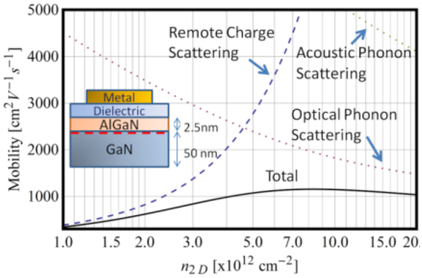

Fig.2. Simulation results – Mobility vs. 2DEG density.

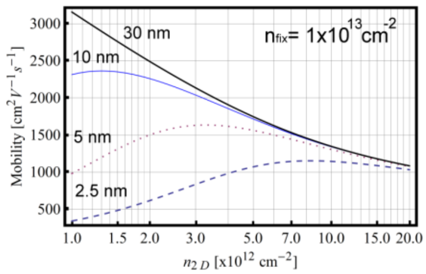

Fig.3. Simulation results – Mobility vs. Interface charge

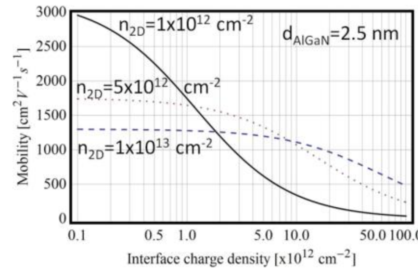

Fig.4. C-V profiles and flatband voltage for Al2O3 on Ga-polar GaN with different PMA temperature.

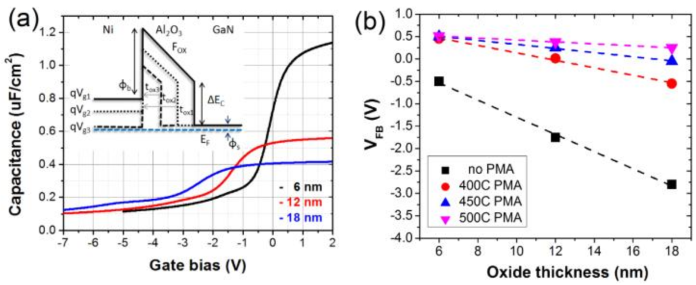

Fig.6. Gate current density vs. gate voltage with different PMA temperature.

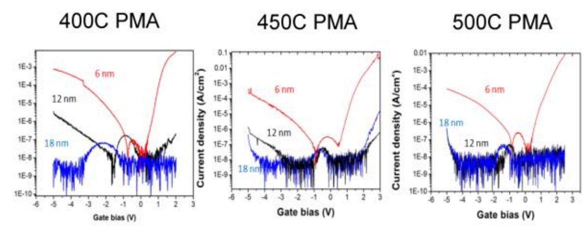

Fig.5. C-V profiles and flatband voltage for Al_2O_3 on (a) (b) N-polar GaN and (c) (d) m-plane GaN with different PMA temperature.

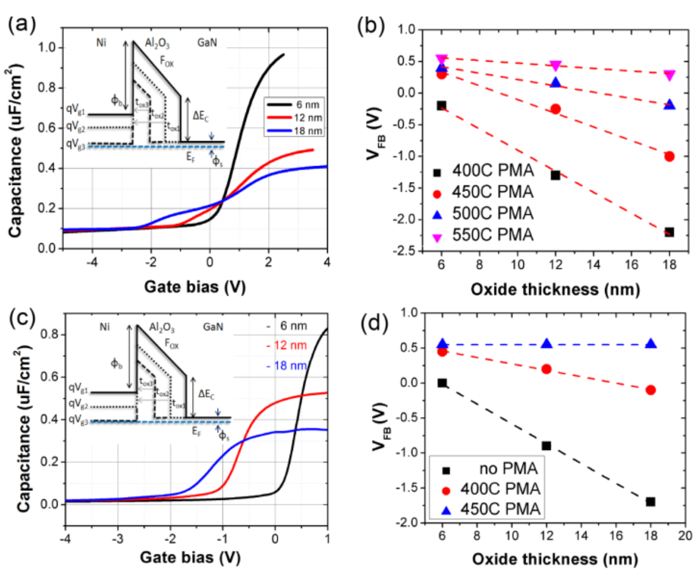

Fig.7. C-V profiles for 15nm Al_2O_3 / 19nm $Al_{0.3}Ga_{0.7}N$ / GaN MISHEMT with different PMA temperature.