Properties of oxide deposited on c-plane AlGaN/GaN heterostructure

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GaN-based metal-insulator-field effect transistors are very promising for high-voltage power switching applications because of low gate leakage current, low interface state density, and the ability to achieve enhancement mode devices. In this reported work, properties of the SiO_2/AlGaN interface were characterised using capacitors fabricated on polar c-plane (0001) AlGaN/GaN heterostructures for two different oxide deposition conditions. Using capacitance-voltage measurements, it was possible to determine the interface fixed charge density for 500 and 900°C oxide deposition temperatures. The measured interface charge density data will be useful for the design of normally-off AlGaN/GaN transistors with silicon dioxide gate insulator.

Introduction: AlGaN-based heterostructure devices are very attractive for high-power switching applications owing to large bandgap, high breakdown voltages and high-density, high-mobility charge leading to low on-state resistance [1–3]. The lower switching time of such devices reduces power dissipation and higher cutoff frequency allows operating them at higher switching frequencies, reducing the overall size of the power conversion modules. In many cases, in order to design a polar gallium nitride device very precise knowledge of material properties and interface charges is required. Interface properties between dielectric and gallium nitride or aluminium gallium nitride materials depend greatly upon deposition conditions and deposition temperature.

For power switching system designs it is preferable to use normally-off devices. Normally-off AlGaN/GaN devices were realised by the incorporation of the negative charges and the gate recess [4–6]. However, the high polarisation charge in the AlGaN/GaN system makes it difficult to obtain a high positive threshold voltage with low gate leakage and low on-resistance. The use of gate insulators provides a promising method to increase the threshold voltage of transistors while maintaining low gate leakage and low on-resistance.

The SiO_2 on AlGaN/GaN system has been used in the past for MISFET-type devices [7]. However, a careful study of interface charges and barrier height has not been carried out. The interface charges especially play a very important role in shifting the threshold voltage of the transistor, and are therefore crucial in the design of normally-off power-switching AlGaN/GaN HEMTs.

In this work, we estimate the fixed interface charge density at the oxide-semiconductor interface for both high-temperature oxide (HTO) and low-temperature oxide (LTO) using measurements on *C-V* structures.

Experiment: The AlGaN/GaN heterostructure consisted of 30 nm $Al_{0.27}Ga_{0.73}N$ on 1 μm GaN, grown on SiC substrate by metal organic chemical vapour deposition. A 100 nm SiO_2 layer was deposited by low-pressure chemical vapour deposition using dichlorosilane and nitrous oxide precursors at two different temperatures, 500 and 900°C. Ohmic contacts were formed to the structure by etching oxide and annealing the Ti/Al/Ti/Au metal stack. Circular capacitors pads (250 μm in diameter) were deposited on the oxide surface using several metals: Ti, Ni and Pt. The SiO_2 dielectric layer was thinned before metal deposition for some capacitors to yield capacitors with different oxide thicknesses in the range between 20 and 100 nm.

Results: Capacitance-voltage (*C-V*) measurements were performed using an Agilent 4284A impedance analyser at a measurement frequency of 100 kHz. Bias voltage was swept from −60 to +0 V to find the threshold voltage of the depletion of the two-dimensional electron gas (2DEG). The threshold voltage was defined as a voltage when 2DEG starts to disappear, as shown in Fig. 1 for the example of the capacitor with 38 nm-thick SiO_2 layer and Pt electrode. Threshold voltages for the capacitors with different oxide thicknesses and different electrode metals were measured, Fig. 2. The slope of the threshold voltage is proportional to the electric field in the SiO_2 dielectric layer, which is smaller in the case of 900°C (HTO), than the same structure with 500°C (LTO) oxide. This assumes that the electric field in the oxide does not depend on the thickness of the oxide layer.

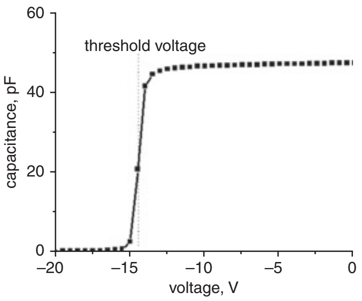

Fig. 1 *Capacitance-voltage characteristic of Pt/SiO_2/AlGaN/GaN capacitor with 38 nm-thick layer of 900°C SiO_2 (threshold voltage −14 V)*

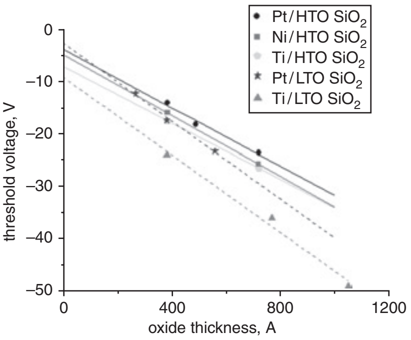

Fig. 2 *Threshold voltage dependence on oxide thickness (two structures with 500°C (LTO) and 900°C (HTO) oxide shown)*

The value of threshold voltage extrapolated to zero thickness of the oxide was following the capacitor electrode metal work function, but the measurement error was too high to determine it precisely. Capacitors with Pt electrodes showed less negative threshold voltage (higher barrier between metal/oxide) than capacitors with a Ti electrode. The potential barrier of capacitors with an Ni electrode was in between.

The linear relationship between threshold voltage and oxide thickness also allows us to determine the field in the oxide at the pinch-off. This field is given by

$$F_{OX} = \frac{n_S - \sigma_S}{\varepsilon_0}$$

where F_{OX} is the electric field in the oxide, n_S is the depleted channel charge, and σ_S is the oxide–semiconductor interface charge. The total depleted channel charge, n_s, was found to be 9×10^{12} cm^{-2} from the *C-V* measurements of the AlGaN/GaN sample before oxide deposition. We have estimated the interface negative charge to be -0.6×10^{12} cm^{-2} and -4.5×10^{12} cm^{-2} for the LTO and HTO cases, respectively. Since the capacitance remains flat between pinch-off and open-channel conditions, we can assume that the interface charge density remains constant at different bias conditions, which is an important factor in the device design.

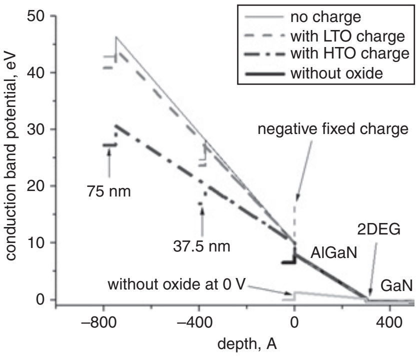

Fig. 3 *Conduction band potential diagrams when 2DEG depleted, calculated for different fixed charges and oxide layer thicknesses (Ti metal electrode used as capacitor plate)*

In Fig. 3, we show calculated band diagrams after inserting these interface charges at the AlGaN/SiO_2 interface. In these band diagrams, we assume that the conduction band offset at the AlGaN–SiO_2 interface is given by the electron affinity difference. The surface barrier is given by the difference between the electron affinity of SiO_2 and the workfunction of the respective metal (in this case Ti).

Conclusion: Metal oxide structures (MOS) were fabricated and characterised on polar, c-plane AlGaN surfaces of AlGaN/GaN heterostructure. Capacitance-voltage measurements of SiO_2/AlGaN/GaN capacitors indicate that dielectric/AlGaN interface has a fixed charge. The amount of the fixed charge depends on the deposition conditions of the dielectric. These results show that tuning of the dielectric/AlGaN surface provides capability to change the threshold voltage of the dielectric/AlGaN/GaN device.

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