AlGaN/GaN MIS-HEMT Gate Structure Improvement Using Al_2O_3 Deposited by PEALD

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AlGaN /GaN heterostructures are very promising for the elaboration of high-power and high frequency devices because of their excellent electrical properties such as a high breakdown voltage, a high electron saturation velocity and a high mobility of the 2D electron gas. The Metal Insulator Semiconductor (MIS) gate structure with the introduction of high dielectric constant (high-k) materials as a gate dielectric represents one of the most promising ways to achieve viable power electronic devices [1,2]. Among various insulators commonly used in the world of microelectronics, Al_2O_3 is mostly used for its deposition simplicity and has already lead to obtaining very good results, though it often needs post deposition treatments and surface pre-conditioning [3].

This work is focused on the capacitance/voltage C(V) and drain-current/gate-voltage $I_d(V_g)$ measurements analysis for two different atomic layer deposition (ALD) techniques. In both cases, tri-methyl aluminum (TMA) was used as a precursor, but in one case water is used as oxidizer while oxygen plasma is used in the other. MESA etching isolation and ohmic contacts using Ti/Al annealed at 900°C were realized before a 10nm Al_2O_3 deposition, and a Cr/Au gate was used. The C(V) measurement were carried out on 400µm diameter diodes and Id(Vg) measurements were performed on 1mm width circular transistors with a 100µm gate length.

As we can see in Fig.1, two distinct behaviors appeared depending on the oxidation process used during the ALD. The one using H_2O showed a stepped C(V) curve while the one using oxygen plasma led to a smooth and steep non-stepped on/off transition. The threshold voltage (V_{th}) was also increased from ~9V to ~5V. In the latter case, the same sharp behavior and steady capacitance below V_{th} was also obtained for frequencies as low as 1kHz, while the H_2O samples led to negative capacitance below 50kHz.

Regarding $I_d(V_g)$ measurements, we see in Fig.2 the same increase in V_{th} as before, as well as a drastic gate leakage current (I_{leak}) reduction for the plasma oxidized sample. We were thus able to obtain a threshold slope of 80mA/decades between the on and off state.

Regarding C(V) and $I_d(V_g)$ results, the V_{th} improvement can be linked to a reduction of trapped charges through the O_2-plasma ALD deposition technique compared to H_2O ALD. Furthermore, the better quality of the O_2-plasma oxide is confirmed by stable low frequency measurements, while the negative capacitance with H_2O deposition is characteristic of a leaky behavior.

Those trapped charges can be associated to the carbon contamination of the AlGaN surface. The improvement of the results between the two deposition techniques may come from a better carbon removal at the surface during the first cycles of plasma assisted ALD. This was confirmed through XPS analysis. If we look at Fig.3, we can see the carbon level using PEALD is lower than the one for thermal ALD for samples with the same thickness of high-k deposited. Comparing to the AlGaN reference, the carbon level is slightly higher after high-k deposition due to a residue of CH_3 inside the Al_2O_3 coming from the TMA precursor. As for the stepped behavior in the C(V) curves, it can be associated to a detachment at the gate periphery as shown on fig4. XPS analysis of thick Al_2O_3 layers has also shown that CH_3 removal is more efficient using PEALD.

In this study, we have shown that using O_2-plasma instead of water during the oxidation steps of the Al_2O_3 ALD deposition drastically improves our device performances (threshold voltage and gate leakage current). Furthermore, these good results can be easily achieved without any specific surface preparation or post-deposition treatments.

References

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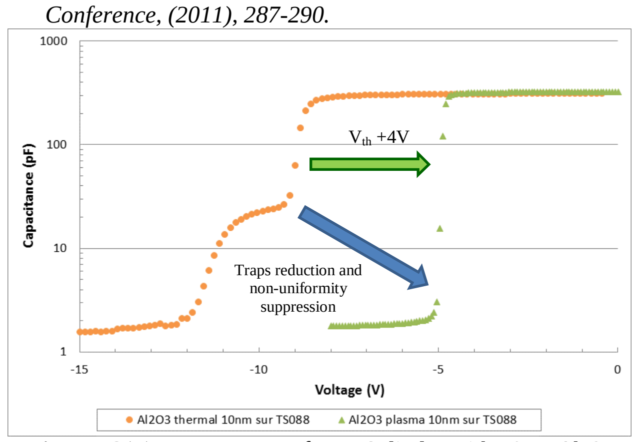

Fig. 1 : *C(V) measurements for MIS diodes with 10nm Al_2O_3 deposited by thermal and plasma enhanced ALD.*

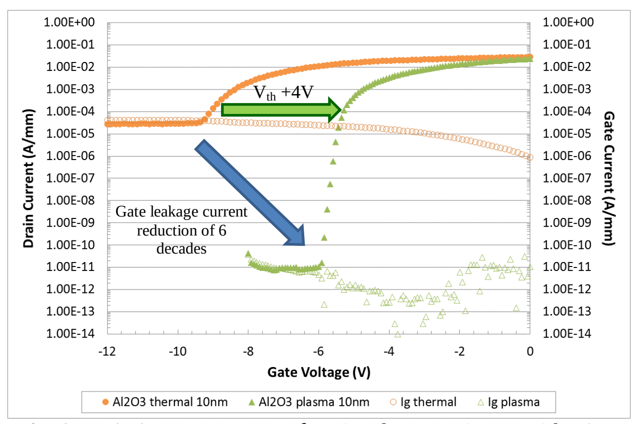

Fig. 2 : *$I_d(V_g)$ measurements for circular transistors with 10nm Al_2O_3 deposited by thermal and plasma enhanced ALD.*

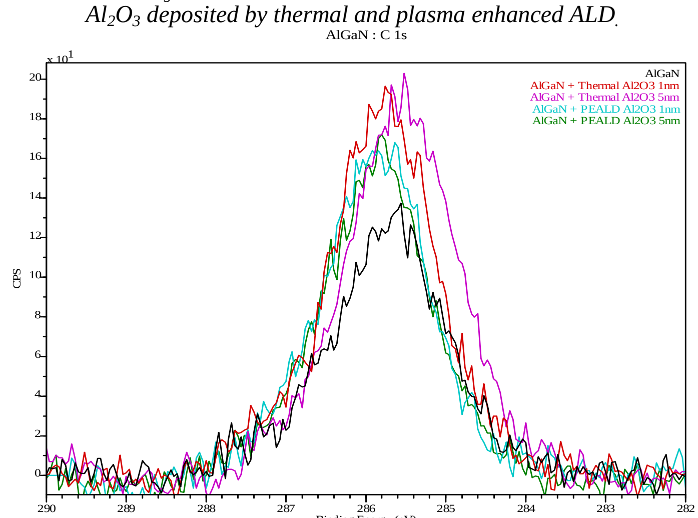

Fig. 3 : *C1s XPS spectra for different thicknesses of Al2O3 deposited by thermal and Plasma Enhanced ALD on AlGaN*

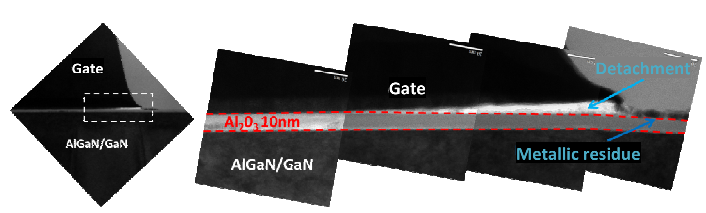

Fig. 4 : *TEM image of the gate detachment at the gate periphery for thermal ALD*