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InAlN/GaN MOSHEMT with thermally grown oxide

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InAlN/GaN heterostructures are a new alternative to AlGaIn/GaN HEMT device structures with high 2DEG channel charge density [1] and thermal stability above 1000°C in the lattice matched configuration [2]. High aspect ratio devices with ultra thin barrier layers down to 5 nm, high transconductance (about 500 mS/mm) and high current density have been fabricated without recess [3]. Recently, large signal measurements have resulted in 6.8 W/mm output power at 10 GHz [4]. However, these devices have often suffered from high gate leakage current. Thus, a 5 nm thin Al₂O₃ layer (deposited by ALD) has been inserted to reduce gate leakage [5]. Nevertheless, the properties of such MOSHEMTs with ALD-Al₂O₃ have been found difficult to reproduce and scale due to a high density of interface traps generating extensive current lagging effects.

On the other hand the high thermal stability of InAlN/GaN heterostructures may enable high temperature thermal oxidation comparable to the oxidation of silicon. Thus, in this study, we have investigated the possibility to realize high performance InAlN/GaN MOSHEMTs with thermally grown oxide. Therefore a MOSHEMT technology for proof of concept experiments has been developed, where the HEMT structure has been conventionally processed up to the ohmic contact level and then the entire surface thermally oxidized (see Fig. 1). This step was then followed by gate metal deposition. Therefore, also the ohmic contacts have been subject to oxidation, slightly degrading the contact resistance of the Ti/Al/Ni/Au contacts. Gate length of all structures was 0.25 μm. Finally, a PECVD SiN passivation has been applied.

Used in this study has been a heterostructure with a 10 nm thick lattice matched InAlN. Oxidation was performed in O₂ at 800 °C. Fig. 2 shows the IV characteristics of Ni/Au contacts on the surface before oxidation and after oxidation up to 10 min. As can be seen, the reverse leakage current is in essence reduced exponentially with oxidation time and by 5 orders of magnitude for 10 min oxidation. This points towards a reduction of the leakage current by suppression of residual tunnelling. This may allow to speculate on the oxidation mechanism. A close analysis reveals indeed that the oxidation is diffusion limited (like in the case of Si) with an initial oxidation rate of approx. 1 nm/min (although final verification can only be obtained by TEM cross sections). Thus, a highly insulating oxide film can be grown. This is also seen in forward direction of the IV characteristics by a shift in turn-on voltage from approx. 1.5 V to 4.0 V.

MOSHEMT output characteristics with an oxide grown for 2 min are shown in Fig. 2. The initial maximum open channel current density of 2 A/mm has not been changed by the oxidation treatment. Thus no additional stress is induced in the heterojunction and the polarization discontinuity fully preserved. A peak transconductance of 340 mS/mm, a f_T and f_{max} of 42 GHz and 61 GHz (without T-gate) respectively have been extracted (Fig. 3), indicating no degradation in the small signal channel transport properties.

The open channel current could also be preserved in gate pulse experiments (see Fig. 3). Pulse duration was 500 ns with 10 μs intervals. The quiescent bias points ($V_{DS0} = 0$ V, $V_{GS0} =$ pinch-off voltage) have been chosen to reveal gate lag, avoiding thermal effects. The gate lag characteristics indicate still a low number of traps, which still may to be removed by an additional annealing step.

Although thermal oxides have not been suitable for MOSFET application in the case of III-V semiconductors and also AlGaIn/GaN heterostructures, these initial results on InAlN-MOSHEMTs with thermally grown oxide gate dielectric show already promising small signal and large signal characteristics. The reason is thought to be related to the high chemical and thermal stability of the (In,Al)-oxide with a well defined stoichiometry. Certainly, high resolution analysis is needed to further identify the structural properties. It is thought that this new technology will enable MOSHEMTs with extremely thin barriers, high aspect ratio and improved breakdown conditions as needed for sub-mm wave power devices.

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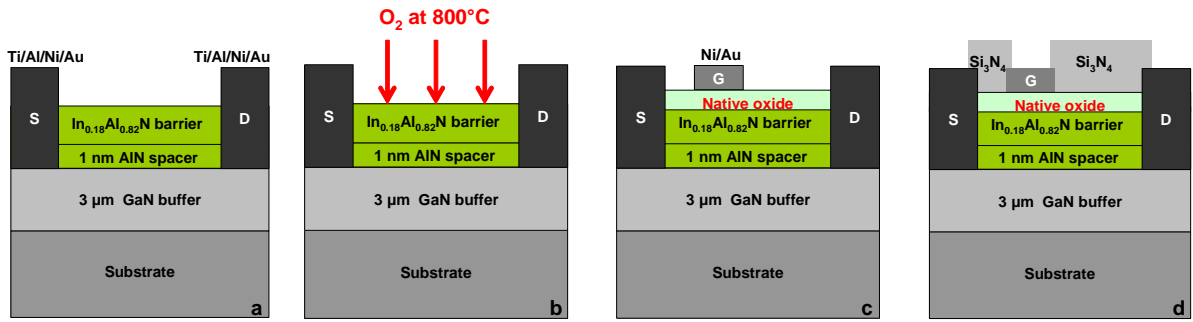


Fig. 1: Technological process for fabricating ultra thin barrier InAlN/GaN MOSHEMT: a) MESA and ohmic contacts b) Thermal oxidation in oxygen at 800°C c) Ni/Au gate contact deposition d) SiN passivation

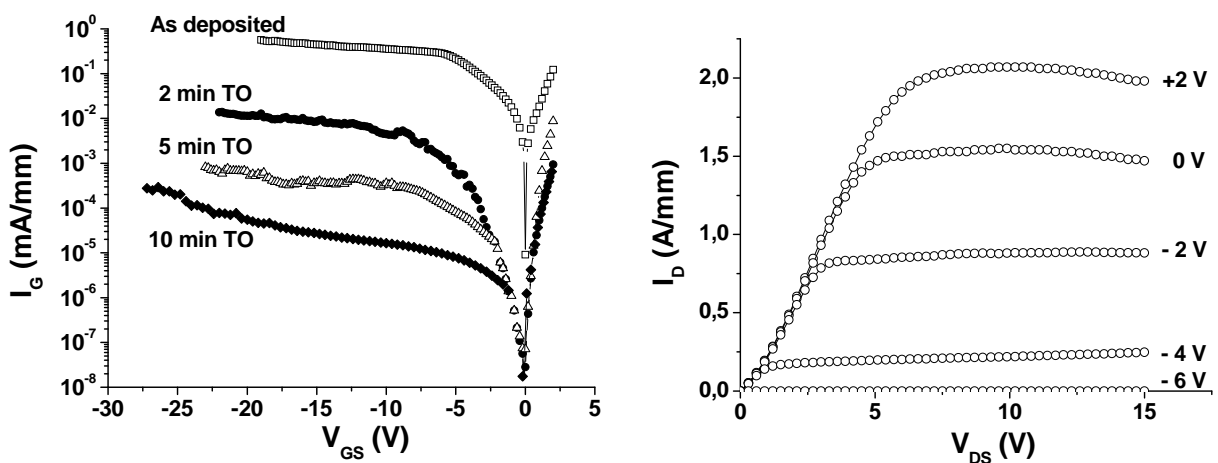


Fig. 2: Gate diode characteristics after various thermal oxidation (TO) times at 800°C (left) and $0.25 \times 50 \mu\text{m}^2$ DC output characteristics at RT thermally oxidized after ohmic contact deposition (right) of a 10 nm barrier of $\text{In}_{0.18}\text{Al}_{0.82}\text{N}/\text{GaN}$ HEMT.

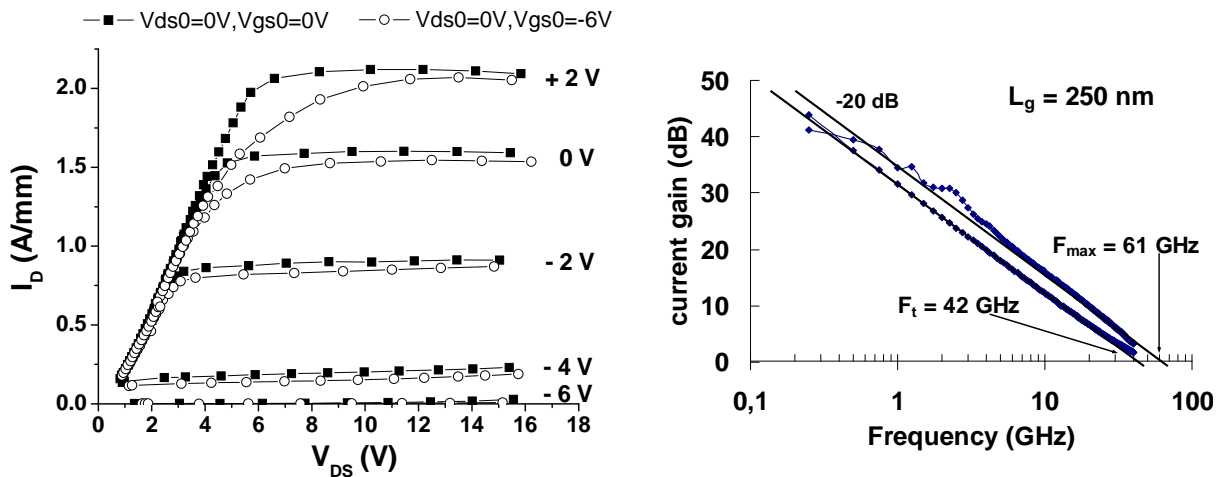


Fig. 3: Pulsed I_D - V_{DS} characteristics (V_{GS} swept from -6 to 2V by step of 2V) at the quiescent bias points $V_{DS0} = 0 \text{ V}$, $V_{GS0} = 0 \text{ V}$ and $V_{DS0} = 0 \text{ V}$, $V_{GS0} = \text{pinch-off voltage}$ (left) and frequency performances (right) of a $0.25 \times 50 \mu\text{m}^2$ 10 nm barrier $\text{In}_{0.18}\text{Al}_{0.82}\text{N}/\text{GaN}$ MOSHEMT on SiC substrate.