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## Thermal Stability Enhancement of GaN-based Devices: Towards Highly Reliable MOSHEMT

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Despite superior performance demonstrated by GaN-based power devices [1] as compared to conventional Si- and GaAs-based components, HEMT devices commercialization is still rather limited. This is because the mechanisms such as current collapse, self-heating, strain into the heterostructure, deep traps and surface states still plague the device reliability. Significant improvements have been achieved in GaN technology to efficiently reduce the current collapse, namely by improving the material quality and optimizing proper surface passivation like SiN. However, self-heating and strain relaxation effects strongly affect the device characteristics and result in device degradation [2]. Therefore, investigation and enhancement of the thermal stability of GaN devices are desirable for higher reliability.

In this work, the thermal stability of strained AlGaN/GaN, AlN/GaN and unstrained InAlN/GaN heterostructures on low cost Si substrates are compared for the first time. Two-dimensional electron gas (2DEG) channel and Schottky contacts degradation have been studied by high temperature storage tests up to 900°C for various GaN-based configurations. In order to overcome the problem of gate degradation at high temperature, a novel MOSHEMT by means of a thermally grown oxide is proposed for both exponential gate leakage reduction and thermal stability enhancement.

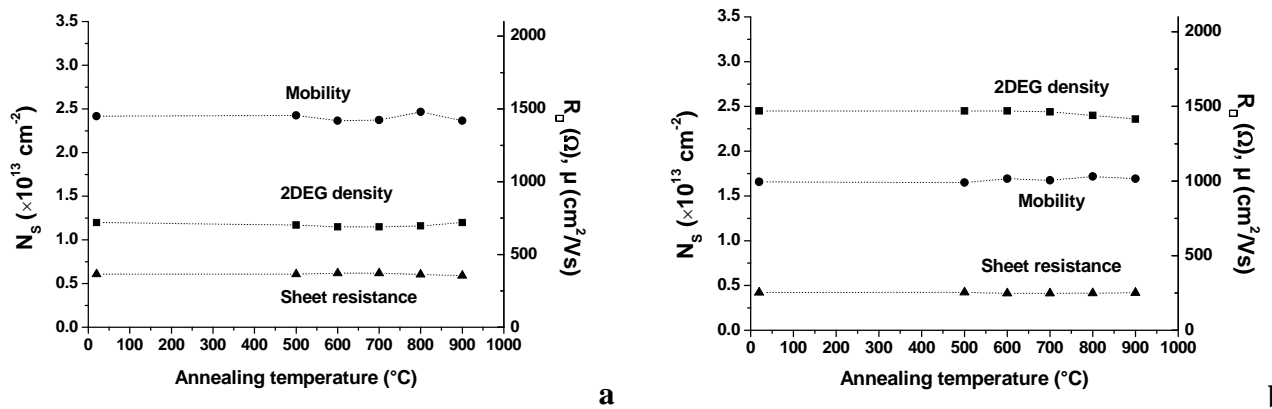
The heterostructure layers employed in this study were grown by MOCVD on (111) Si substrates. They consist of a GaN buffer followed by different undoped barrier layers which are composed of 22 nm Al<sub>0.3</sub>Ga<sub>0.7</sub>N with and without 3.5 nm in-situ SiN cap layer, 4 nm AlN with 3.5 nm in situ SiN cap layer, 30 nm lattice matched In<sub>0.18</sub>Al<sub>0.82</sub>N and lattice mismatched In<sub>0.13</sub>Al<sub>0.87</sub>N barrier layers. Conventional processing was performed up to the ohmic contacts. Prior to the gate deposition the in-situ SiN on the top of AlGaN and AlN barrier layers were removed by dry etching using SF<sub>6</sub>. The InAlN surface was thermally oxidized at 800°C in O<sub>2</sub> (similar to Silicon technology) using oxidation time of 0, 5 and 10 min. XPS analysis revealed a significant peak corresponding to Al<sub>2</sub>O<sub>3</sub> while no InO peak was detected. Finally, Ni/Au circular Schottky contacts with a diameter of 100 μm were deposited. In vacuum the samples have been heated in intervals of 100°C and kept at the temperature for 30 min. At each temperature step the sample was cooled down to the room temperature and data were taken to evaluate permanent degradation. The sheet resistance, the mobility and the density of the 2DEG were characterized using the Van der Pauw Hall measurement. I-V measurements were performed to characterize the Schottky contacts.

We observed an irreversible degradation of the 2DEG properties for the uncapped AlGaN/GaN heterostructures at 700°C which is consistent with previous reported studies [3]. On the other hand, when capped with in situ SiN, the same heterostructure is found to be fully stable up to 900°C (Fig. 1.a). Even the highly strained AlN/GaN using in-situ SiN does not degrade at such high temperatures. It appears that the in-situ SiN prevents the strain relaxation of the barrier layer [4]. In the case of unstrained In<sub>0.18</sub>Al<sub>0.82</sub>N/GaN, no degradation of the 2DEG behavior is noticed while the lattice mismatched In<sub>0.13</sub>Al<sub>0.87</sub>N/GaN showed a drop of the 2DEG density at 900°C from  $3.26 \times 10^{13} \text{ cm}^{-2}$  to  $2.8 \times 10^{13} \text{ cm}^{-2}$ , confirming the role of the strain relaxation effect in the material degradation at high temperature.

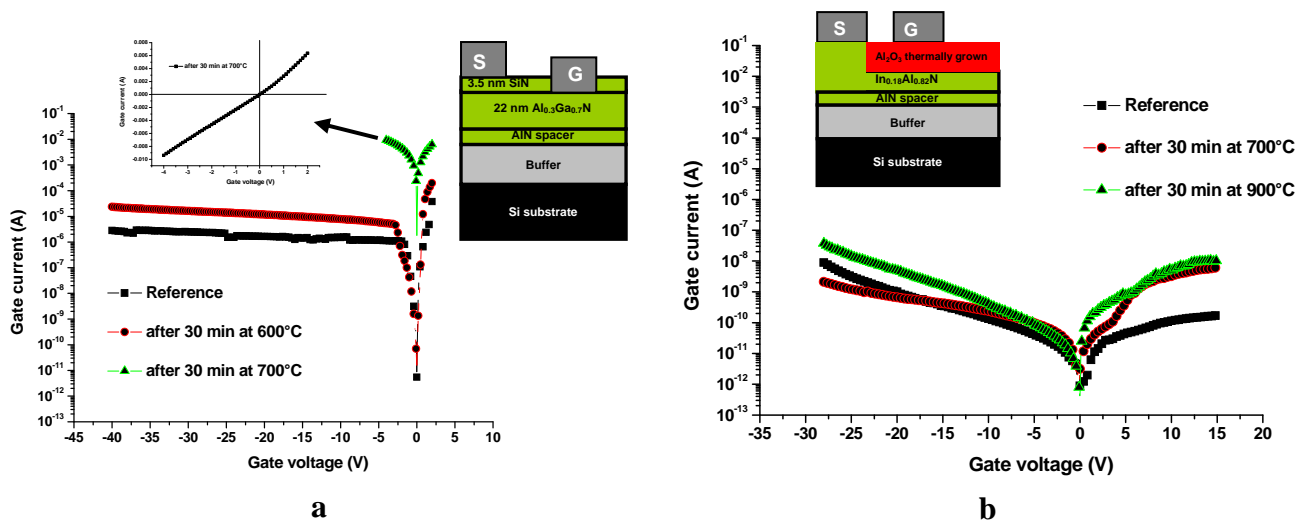
Fig. 2 shows the Schottky contact characteristics as a function of the annealing temperature of

strained SiN/AlGaN/GaN and unstrained Al<sub>2</sub>O<sub>3</sub>/InAlN/GaN heterostructures. 10 diodes have been characterized for each sample. Even though the material properties of SiN/AlGaN/GaN system are stable at 700°C, a dramatic increase of the leakage current is observed giving rise to an almost ohmic contact (see inset of Fig. 2.a). This is attributed to the diffusion of the gate metal into the barrier layer [5]. Similar degradation at 700°C has been obtained with SiN/AlN/GaN devices. However, we clearly observed that the use of the InAlN native oxide (Al<sub>2</sub>O<sub>3</sub>) enables not only an exponential reduction of the gate leakage current and thus a significant increase of the gate breakdown voltage as a function of the oxidation time but also an enhanced device thermal stability up to at least 900°C (see Fig. 2.b). It has to be pointed out that for 10 min thermal oxidation the turn-on voltage is shifted from 1.5 V to more than 15 V as compared to the reference sample while marginal gate leakage degradation occurred after 30 min at 900°C, illustrating the highly insulating oxide film property. This new concept is expected to allow reliable GaN-based MOSHEMTs for power applications.

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**Fig. 1:** 2DEG densities ( $N_s$ : square), mobility ( $\mu$ : circle) and sheet resistances ( $R_s$ : triangle) as a function of annealing time in (a) SiN/Al<sub>0.3</sub>Ga<sub>0.7</sub>N/GaN, (b) unstrained In<sub>0.18</sub>Al<sub>0.82</sub>N/GaN



**Fig. 2:** Post stressing I-V characteristics of Ni / semiconductors with 30 min. Thermal stressing at different temperatures (a) on strained Al<sub>0.3</sub>Ga<sub>0.7</sub>N/GaN and (b) unstrained In<sub>0.18</sub>Al<sub>0.82</sub>N/GaN with 10 min thermal oxidation prior to the gate deposition