Impact of N_2 plasma power and duration on AlGaN/GaN HEMT

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Surface treatments have been recently shown to play an active role in electrical characteristics in AlGaN/GaN HEMTs, in particular during the passivation processing [1-4]. However, the responsible mechanisms are partially unknown and further studies are demanding.

The effects of power and time N_2 plasma pre-treatment prior to SiN deposition using PE-CVD (plasma enhanced chemical vapour deposition) on GaN and AlGaN/GaN HEMT have been investigated. The low power (60 W) plasma pre-treatment was found to improve the electronic characteristics in GaN based HEMT devices, independently of the time duration up to 20 min. In contrast, high power (150 and 210 W) plasma pre-treatment showed detrimental effects in the electronic properties (Fig. 1), increasing the sheet resistance of the 2DEG, decreasing the 2DEG charge density in AlGaN/GaN HEMTs, transconductance reduction and decreasing the f_T and f_{max} values up to 40% respect to the case using 60 W N_2 plasma power. Although AFM (atomic force microscopy) results showed AlGaN and GaN surface roughness is not strongly affected by the N_2-plasma, KFM (Kelvin force microscopy) surface analysis shows significant changes in the surface potential, trending to increase its values as the plasma power is higher. The whole results point at energetic ions inducing polarization-charge changes that affect dramatically to the 2-DEG charge density and the final characteristics of the HEMT devices.

Therefore, we conclude that AlGaN surface is strongly sensitive to N_2 plasma power conditions, which turn to be a key factor to achieve a good surface preparation prior to SiN passivation.

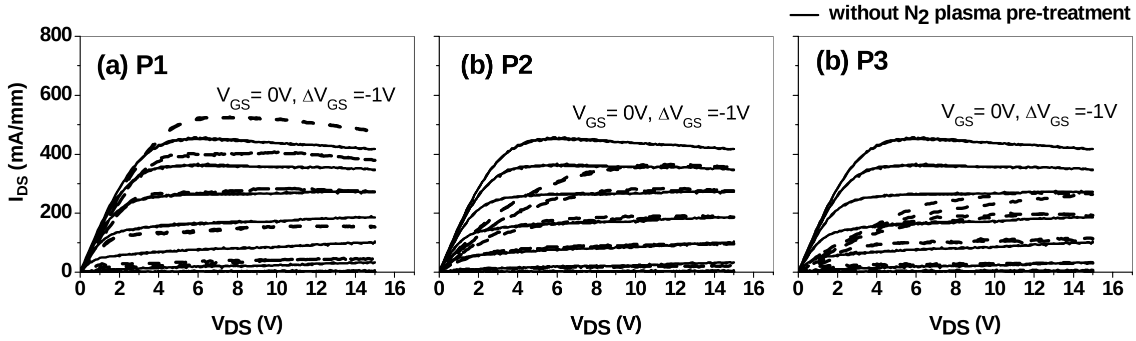

Fig. 1: Pulsed $I_{DS} - V_{DS} - V_{GS}$ characteristics of AlGaN/GaN HEMT passivated with SiN and N_2 plasma pre-treatment at 60 W (a), 150 W (b) and 210 W (c), during 1min. Solid-line corresponds to an equivalent transistor passivated with SiN but without any plasma pre-treatment. (V_{GS} = -5 V to 0 V), ΔI_{GS} = 1 V. The pulses have a width of 500 µs and a period of 10 ms.

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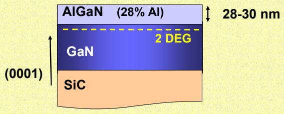
MOTIVATION & OBJECTIVES

- **AlGaN/GaN high electron mobility transistors (HEMTs) are key devices for next generation of high-power, high-frequency and high-temperature electronics applications [1].**
- **Surface treatments have been recently shown to play an active role in electrical characteristics in AlGaN/GaN HEMTs, in particular during the passivation processing [2-5].**
- **The responsible mechanisms of surface pretreatments are partially unknown and further studies are required.**

→ This work focuses on the impact of N_2 plasma treatment power and duration prior to SiN passivation on AlGaN/GaN HEMTs, regarding both the electrical and surface characteristics.

1 EXPERIMENTAL PROCEDURE

☐ **HEMT structure:**



☐ **Devices:**

- **HEMT** (L_G= 1.3 µm)
- **TLM** structures

- **Ohmic contact**: Ti/Al/Ti/Au
- **Isolation**: MESA isolation (Reactive Ion Etching, RIE): Cl-based
- **Gate contact**: Ni/Au or Pt/Ti/Au
- **Passivation**: SiN (PECVD, "Plasma Enhanced CVD")

***In situ* N_2 Plasma pre-treatment**: T= 200ºC, Φ(N_2)~ 10 sccm

P_{RF}= (60 – 210) W
$t_{discharge}$= (1 - 20) min
⇨
- Surface characteristics: AFM, KPFM
- Electrical: I-V (DC, pulsed), RF

2 CHARACTERIZATION OF AlGaN/GaN SURFACE BY AFM

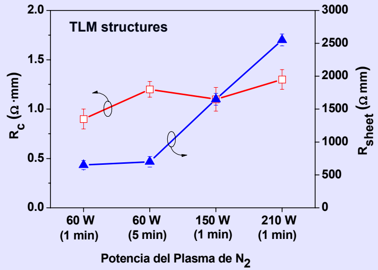
N_2 plasma (1 min)

Root mean square (RMS): ~1.8 nm

4 µm x 4 µm

Similar topography and roughness of GaN-based surfaces after N_2 plasma regardless the power and durantion discharge up to 210 W and 20 min, but R_{sheet} increases dramatically with power plasma.

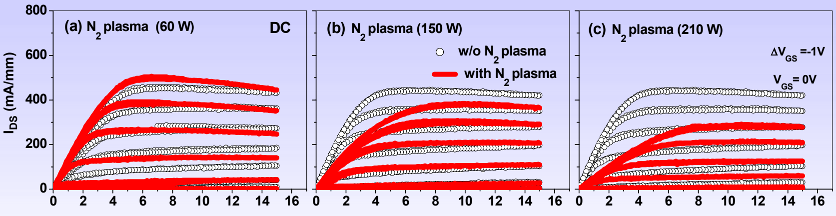
ELECTRICAL CHARACTERIZATION OF AlGaN/GaN TLM STRUCTURES



Energetic ions could induce polarization-charge changes that affect dramatically to 2-DEG charge density, hence increase of R_{sheet}.

3 ELECTRICAL CHARACTERIZATION OF AlGaN/GaN HEMTs

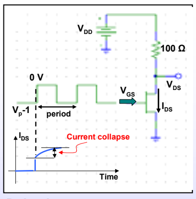
I-V (DC & Pulsed)



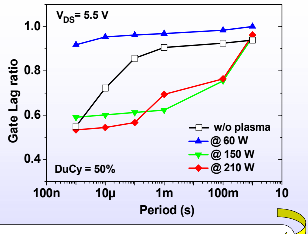
A gradual and **strong reduction** in $I_{DS,max}$ and $g_{m,max}$ up to 33% is observed as the N_2 plasma pre-treatment **power increases**, for both DC and pulsed I-V characteristics in AlGaN/GaN HEMTs.

Gate lag

gate-lag ratio (GLR): defined as the ratio of the pulsed I_{DS} value in steady state to the dc I_{DS} value at V_{DS} = 5.5 V.



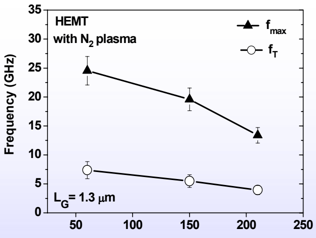
Pulsed measurement set up



☐ N_2 plasma pretreatment has a **direct effect on gate lag** → on the surface trap charges in the active region.

☐ **Drastic current collapse mitigation at low power N_2 plasma**, in good agreement with [5].

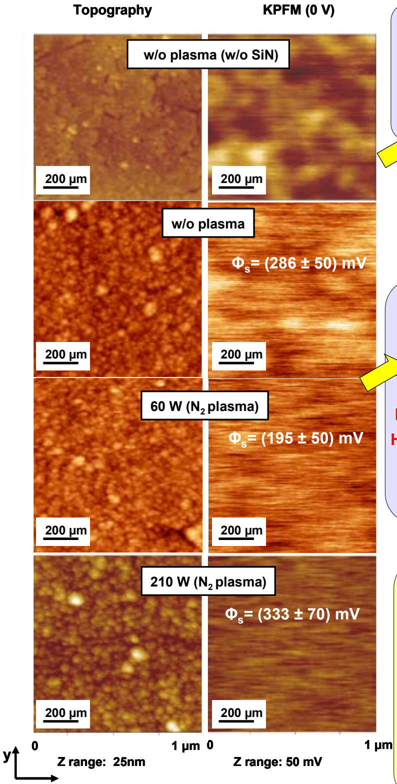
Small signal RF



f_T and f_{max} show a **noticeable reduction** as the N_2 plasma treatment power increases, consistent with the drastic rise in R_{sheet} and drop in n_s.

Discharge power is a critical parameter during N_2 plasma pre-treatment prior to SiN, in order to achieve good AlGaN/GaN HEMT electrical characteristics.

4 CHARACTERIZATION OF AlGaN/GaN SURFACE BY KPFM



Noticeble Inhomogeneity in surface potential (Φ_s) distribution **without N_2 plasma** pre-treatment for both with and without SiN layer passivation.

Likely induced by chemical disorder on the AlGaN surface including the formation of interfacial oxides and/or presence of C [4].

Although Φ_s shows homogeneous distribution using N_2 plasma pre-treatment, the estimated values change with the plasma power

Low power → Lower Φ_S → Higher n_s
High power → Higher Φ_S → Lower n_s

in good agreement with the I-V characteristics in AlGaN/GaN HEMTs & [6].

Two different mechanisms are suggested to be dominant as a function of plasma power:

1. Low power → **N_2 is able to reduce traps on the surface and stabilize GaN-based surface increasing slightly 2DEG.**
2. High power → **energetic ions could introduce electrical changes in the polarization charges reducing 2DEG.**

CONCLUSIONS

- AlGaN/GaN surface is strongly sensitive to **N_2 plasma power**, that turns out to be a **key factor** to mitigate current collapse effects on AlGaN/GaN HEMTs.
- **Low power** (60 W) plasma pre-treatment was found to **improve surface electronic properties**, independently of the time duration up to 20 min, mainly to the reduction of traps in the SiN/AlGaN interface and surface stabilization.
- In contrast, the use of **high power** (150 W and 210 W) plasma pre-treatment led to a drastic **degradation** on HEMT electronic properties, mainly due to the increase of surface trapped charges.
- Surface characterization correlates with electrical results in HEMTs → leading to energetic ions increase **surface states** and induce **polarization-charge changes** that affect dramatically to 2-DEG charge density at high power plasma.

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