UltraGaN project: Breakthrough in GaN devices thanks to InAlN/GaN heterostructure

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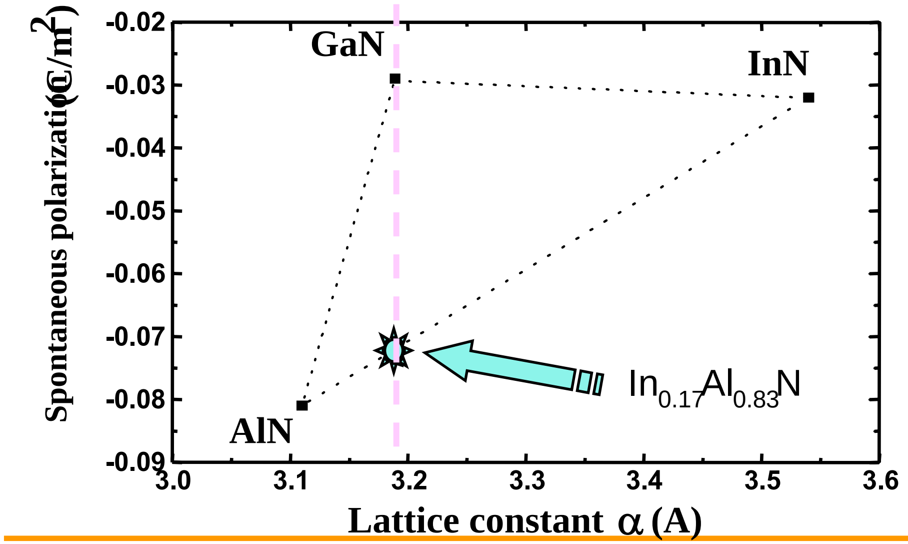
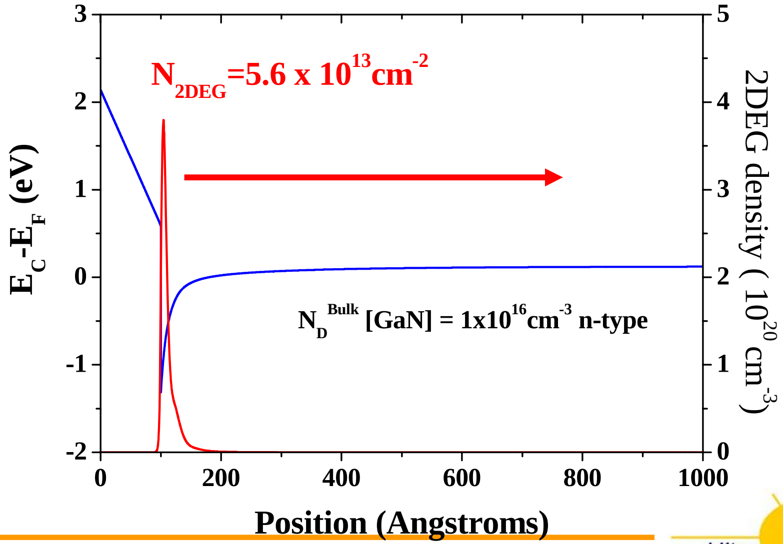
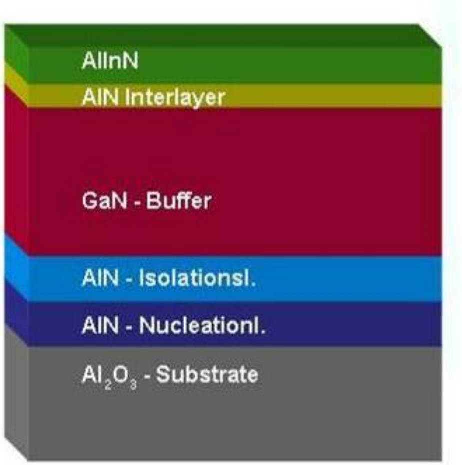
Why we do believe in InAlN/GaN Heterostructure for ultra High Power Microwave Applications ?

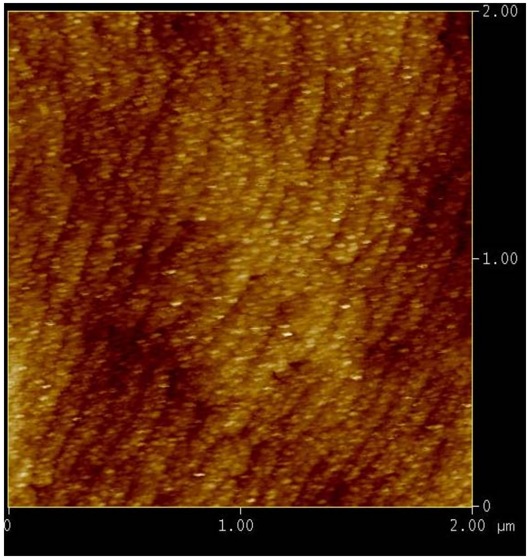
- *$In_{0.18}Al_{0.82}N$ is lattice-matched to GaN*
  - *Strong spontaneous polarisation allowing high density 2-D gas without mechanical stress,*
    - *Improved reliability expected*
    - *Flexibility for choosing barrier layer thickness (gate length – WBG thickness ratio), i.e. higher frequency achievable.*
  - *Stronger spontaneous polarisation, which could triple the AlGaN one.*
    - *Higher 2D gas density (3A/mm expected for 0.25µm gate length)*



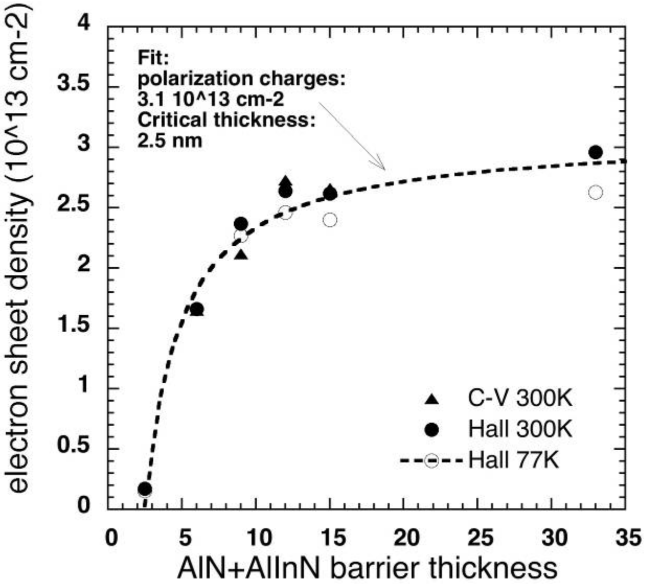


Physical Properties of lattice-matched InAlN/GaN Heterostructure





RMS = 0.6nm (AFM)

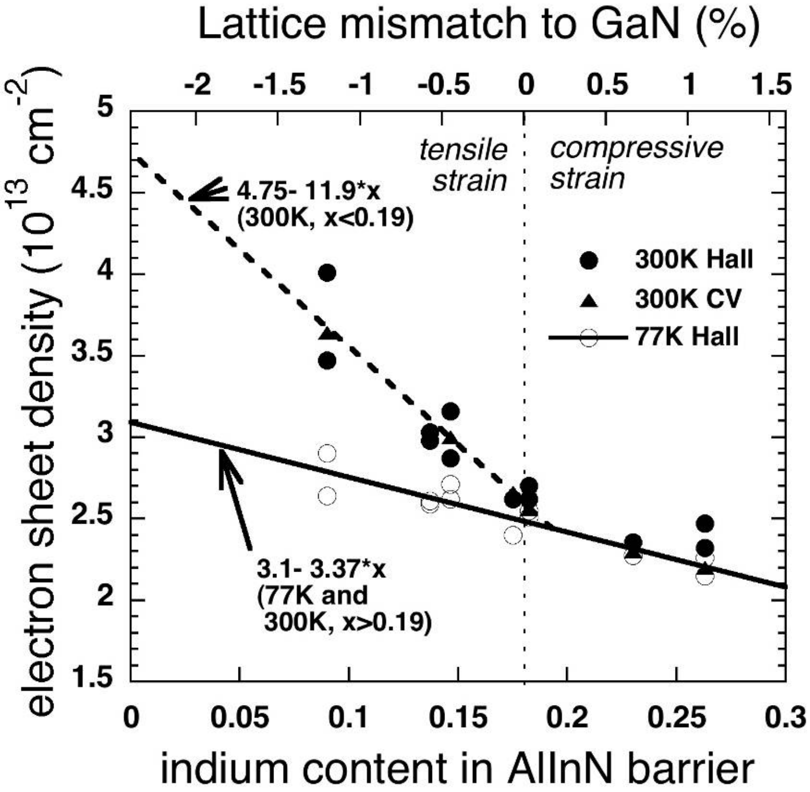


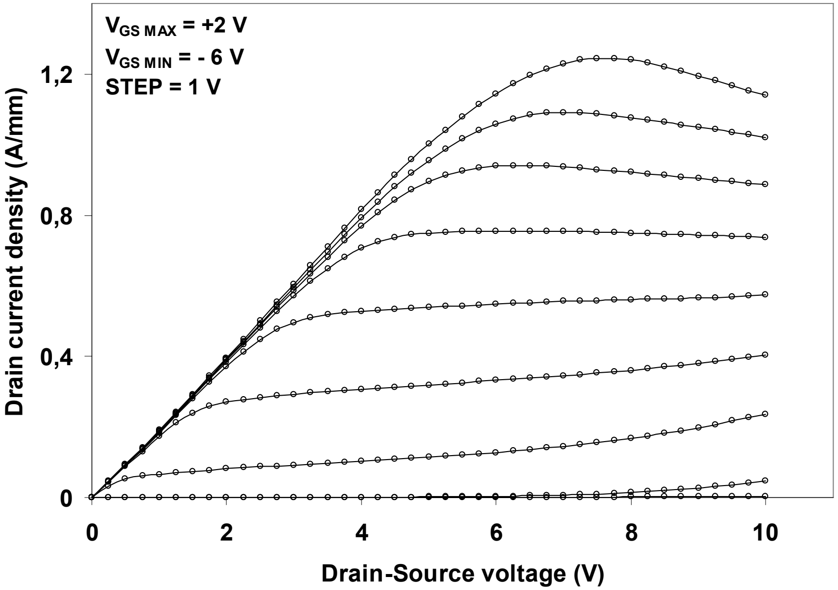
Fit:
polarization charges:
3.1 10^13 cm-2
Critical thickness:
2.5 nm

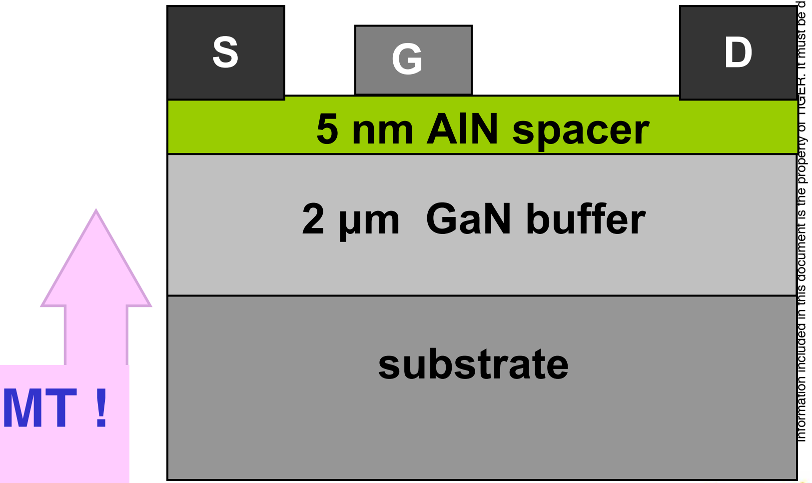
y of TIGE

- ***Low roughness (atomic steps)***
- ***Excellent 2-dimensional growth***
- ***Demonstration of HEMT heterostructure for barrier thickness as thin as 2.5nm !***

Sheet Carrier Density versus Indium Composition







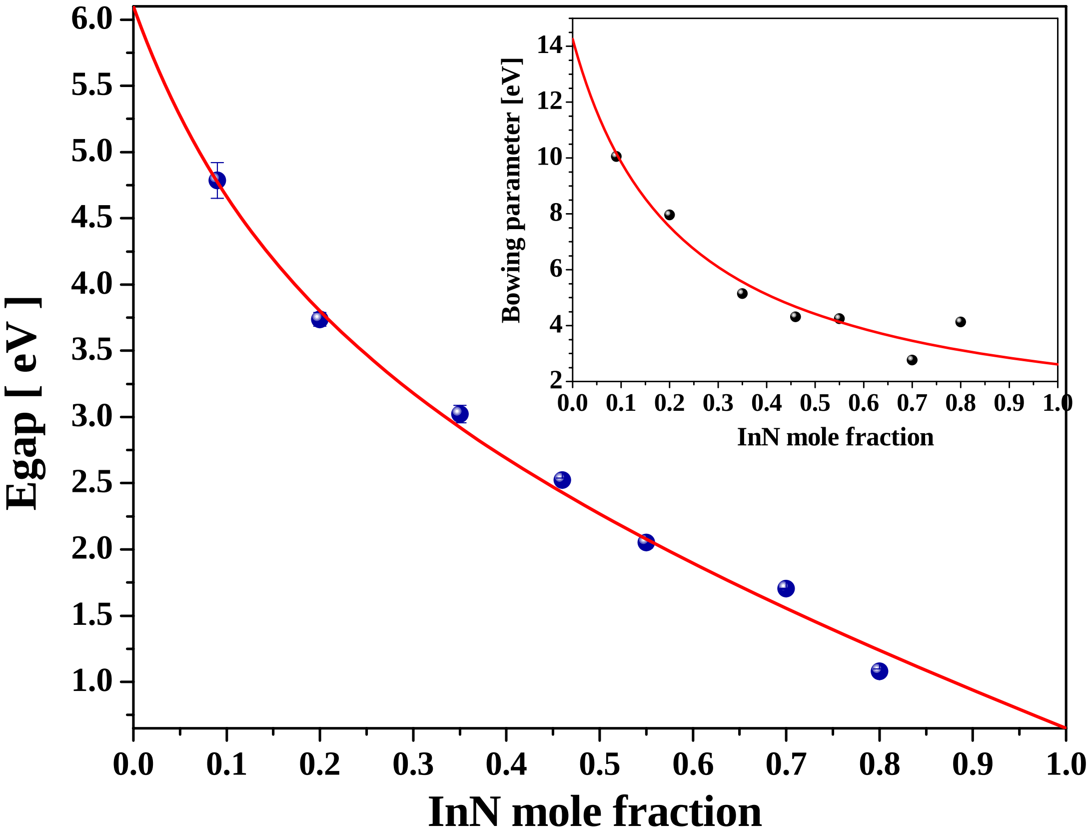
5 nm AlN spacer

2 µm GaN buffer

substrate

Towards MOCVD and MBE AlN/GaN HEMT !

$In_xAl_{1-x}N$ bandgap versus composition

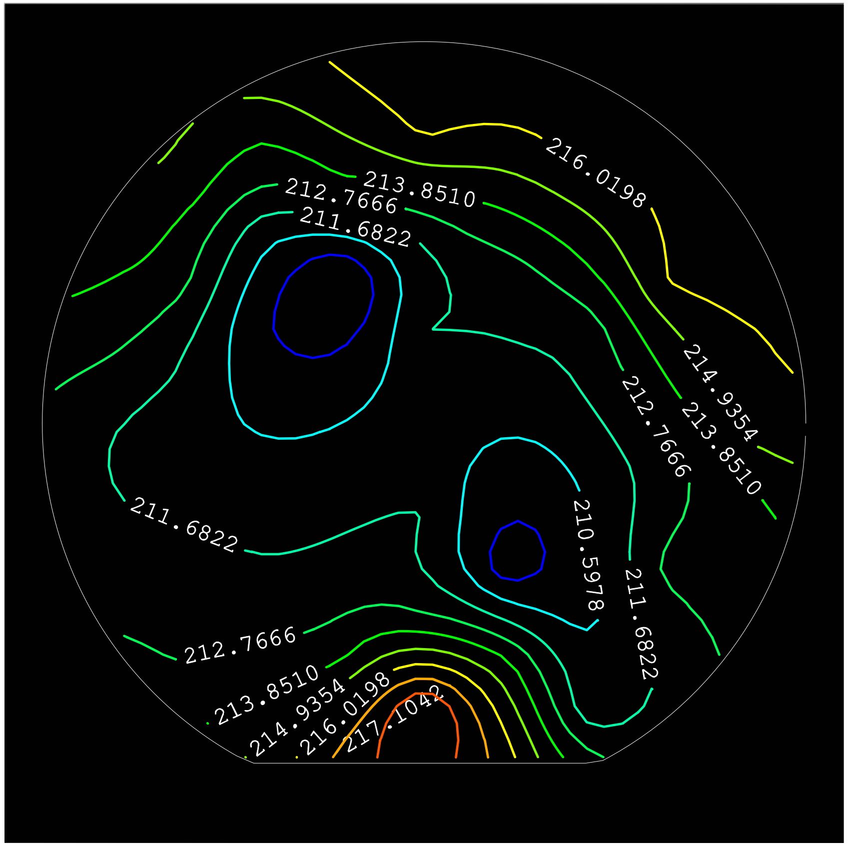


- ***Bowing parameter decreases monotonically with InN mole fraction***

$$b(x) = \frac{a}{1 + b \cdot x}$$ ***with*** $a = 14.3 \pm 1.5$ ***eV and*** $b = 4.5 \pm 0.9$

InAlN/GaN HEMT Wafer Uniformity

- ***Sheet resistance mapping of 2-inch wafer***

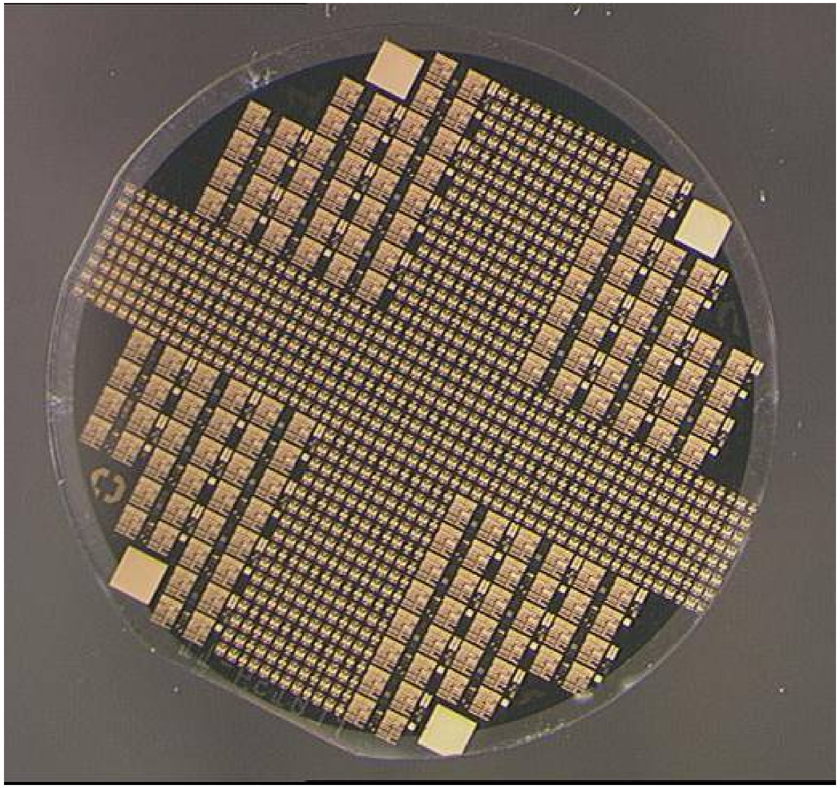


Statistical Summary

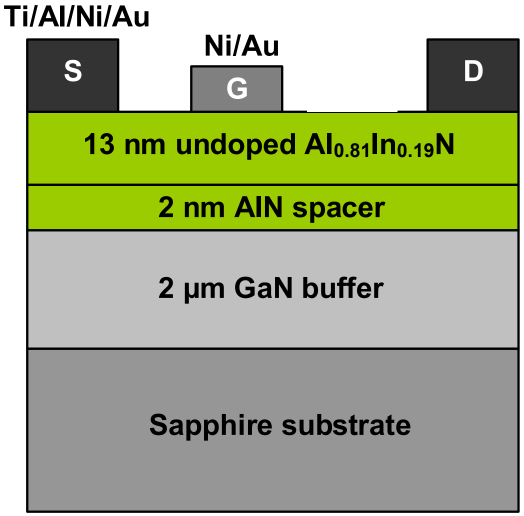
Number of Test Points	55
Average Value	212.9
Maximum Value	219.7
Minimum Value	208.1
Sample Spread (%)	5.56
Std Dev Value	2.3
Wafer Uniformity Value (%)	1.09

$n_s = 2.3 \times 10^{13}$ cm^{-2}
$\mu = 1510$ cm^2 V^{-1}s^{-1}
Barrier thickness = 14 nm

Example of HEMT Devices developed in UltraGaN



Optical photography of 2-inch wafer



Ti/Al/Ni/Au

Ni/Au

S

G

D

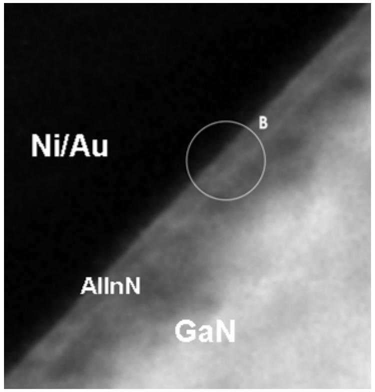
13 nm undoped $Al_{0.81}In_{0.19}N$

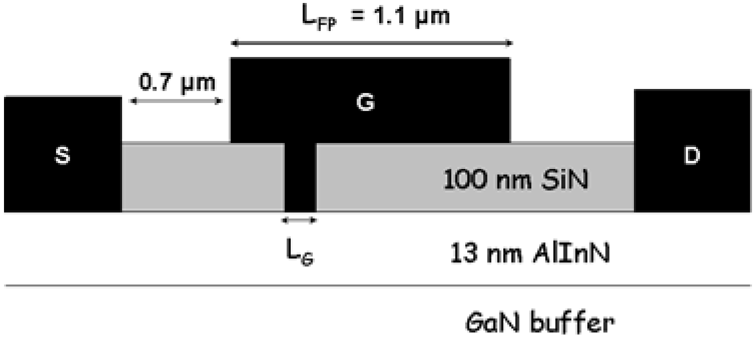
2 nm AlN spacer

2 µm GaN buffer

Sapphire substrate

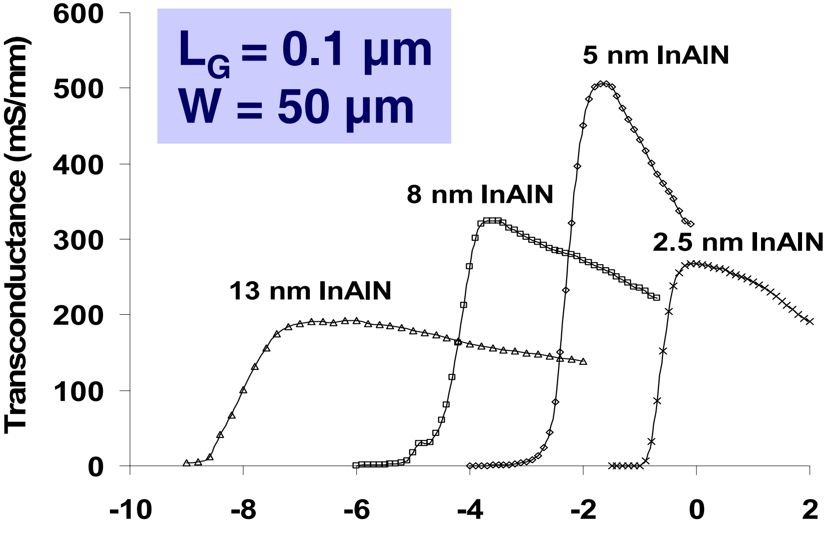
Standard HEMT Device

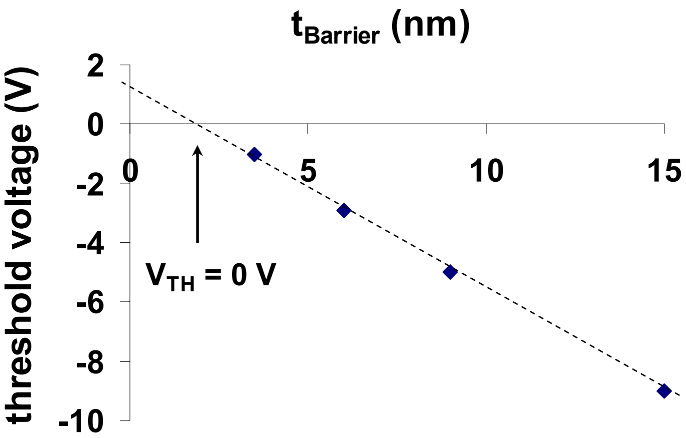




HEMT Device with Field Plate for E-Field spreading

Extremely high transconductance (up to 500 mS/mm) with 5 nm InAlN barrier thickness





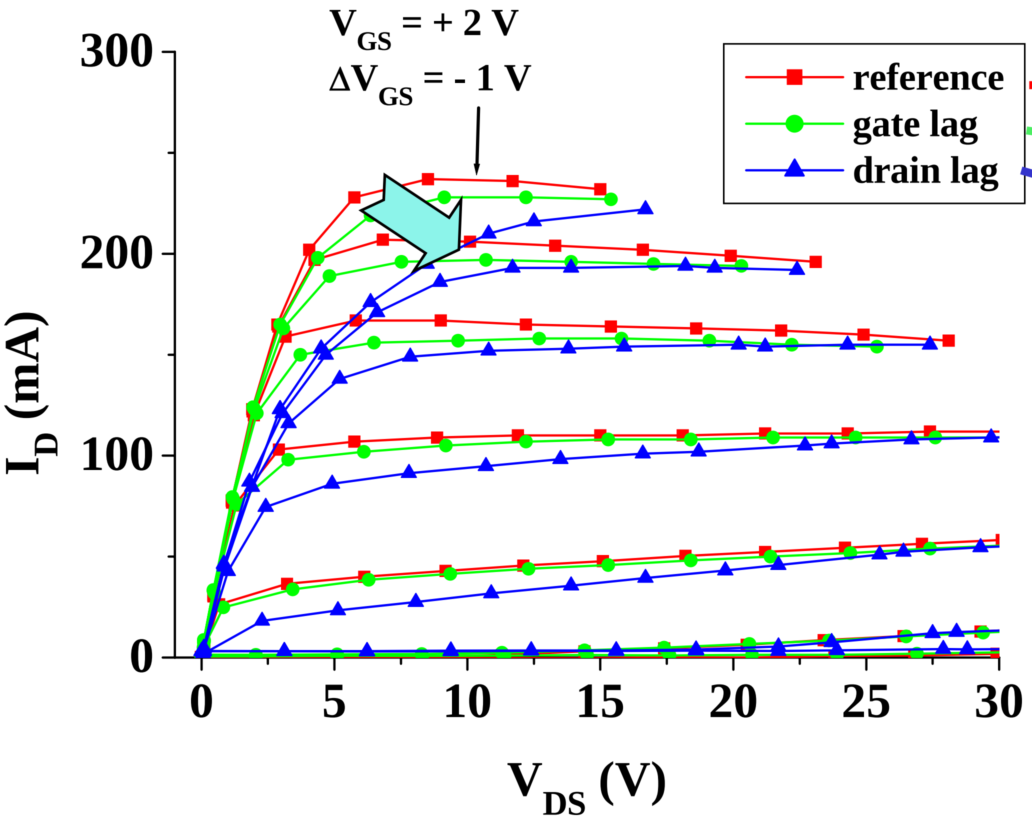
GaN HEMT downscaling can be overcome

Possibility to use ultra short gate length while keeping high aspect ratio

Scaling of V_{TH} fully respected

E-Mode expected for 2 nm barrier thickness

Low trapping effects on 2x0.25µmx75µm InAlN/GaN device Pulse Ids-Vds (500ns pulse legnth – 1% duty cycle)



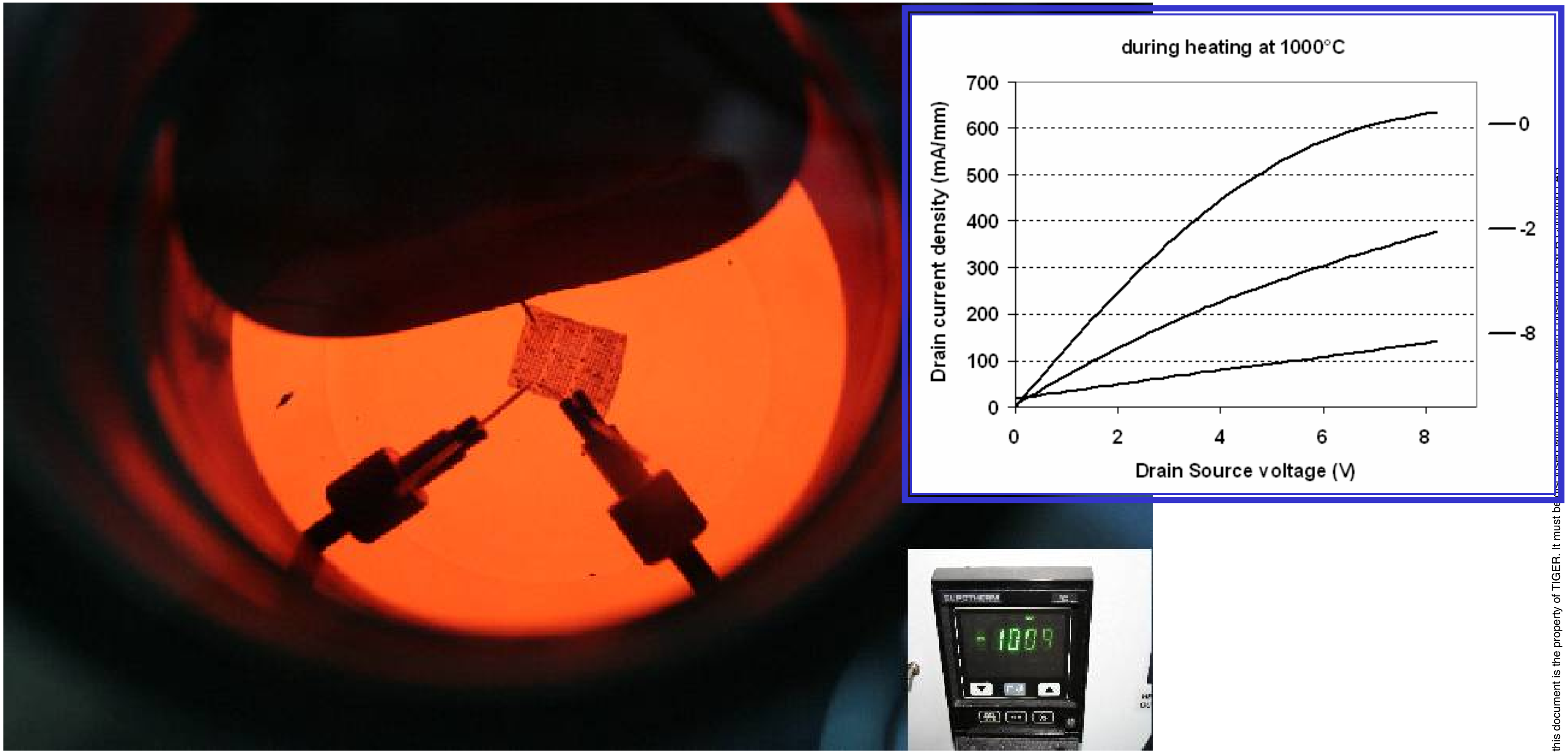
Quiescent Point

	V_{GS}	V_{DS}
reference	0V	0V
gate lag	-4V	0V
drain lag	-4V	+25V

- No gate lag effect
  - Low surface state density
  - Clean interface

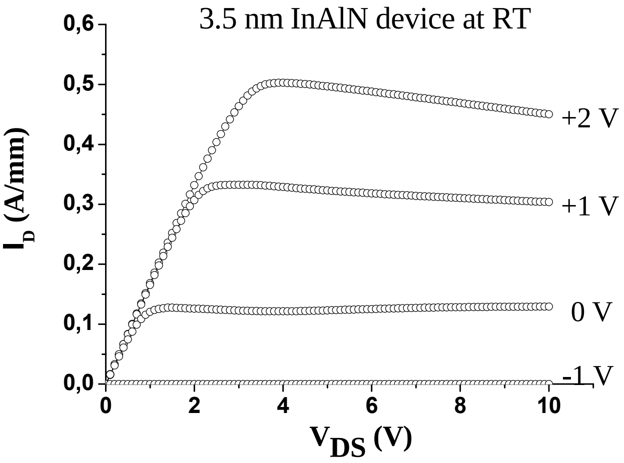
Very reduced Drain + Gate Lag effects similar to best AlGaN/GaN HEMT !

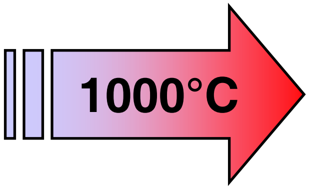
High Temperature DC Measurements

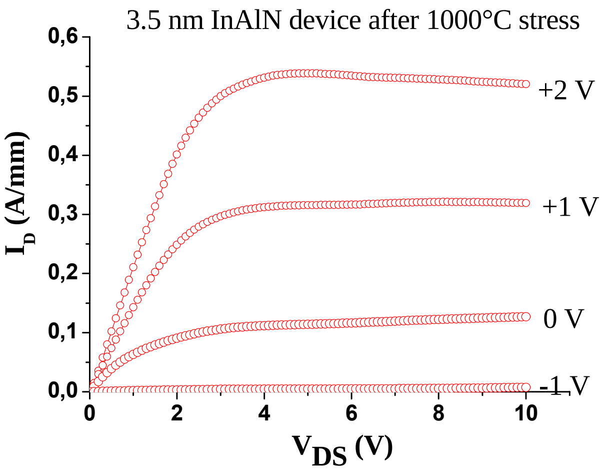


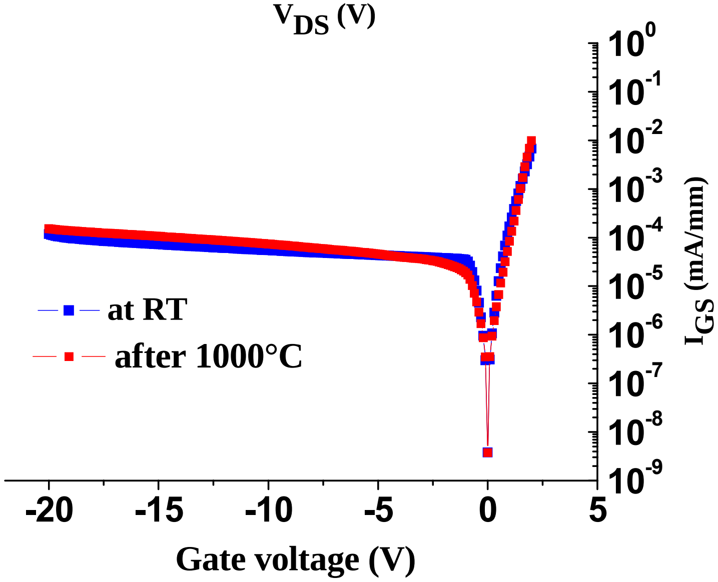
First time a transistor operates up to 1000°C !

Thermal stability of 3 nm barrier InAlN/GaN HEMTs







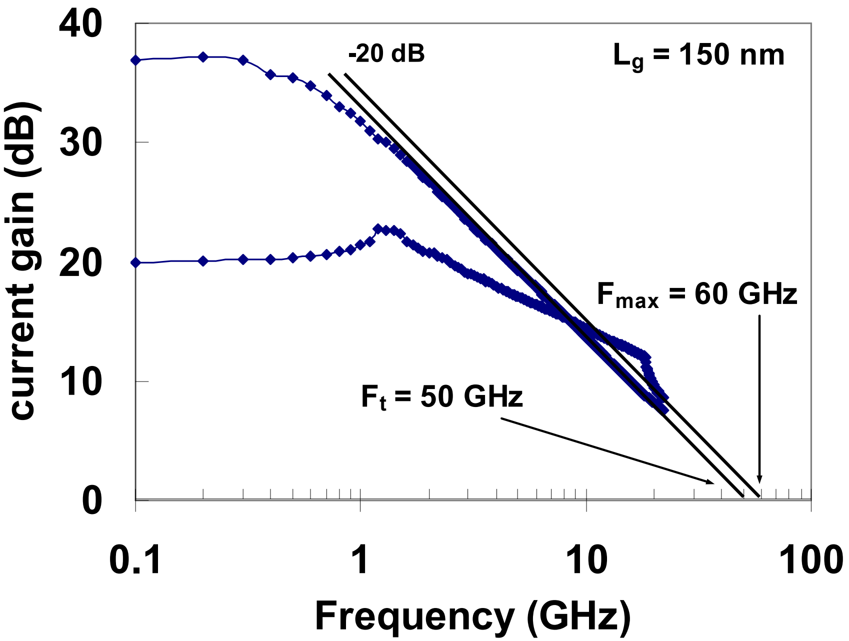


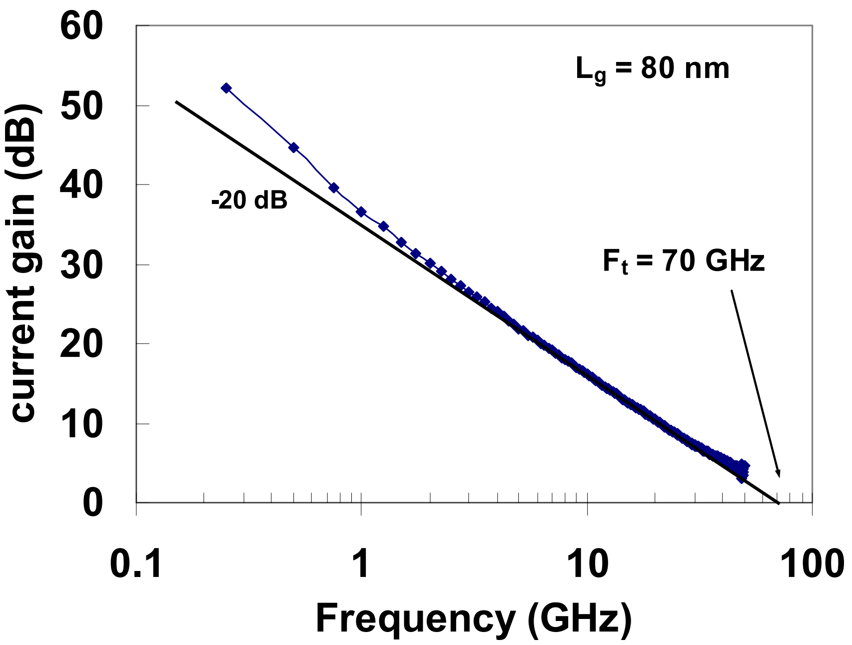
Ultra thin barrier (few nm) InAlN/GaN heterostructure still working after 1000°C for 30min step.

Very promising for high robustness demanding applications.

Title : UltraGaN project
Date : 14-11-2007
Authors : S. Delage et al.

Microwave measurements



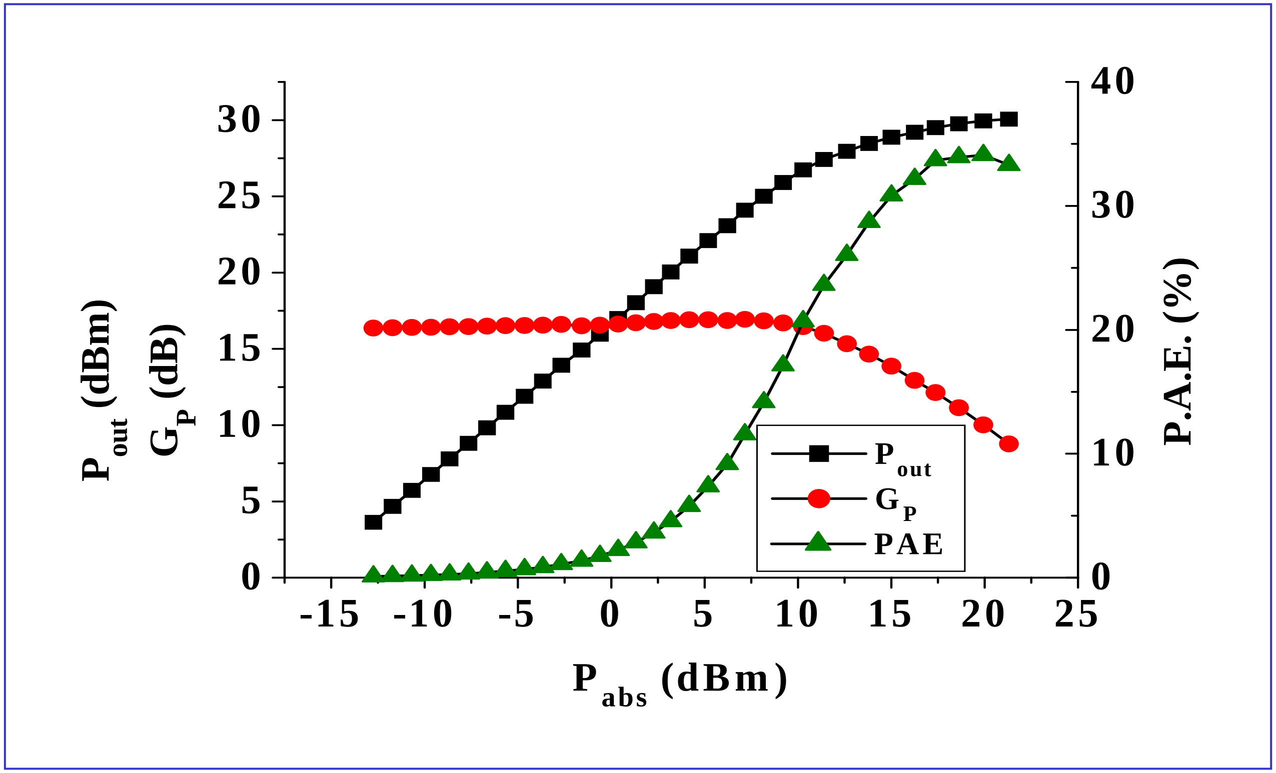


No T gate!

Favourably comparable to the best AlGaN/GaN device frequency performances

Capability of this structure to operate at high frequency

CW 10GHz 6.8W/mm Load-Pull Characteristics (without field – plate)



Vds = 30V – Vgs = -1.5V – 2x75µm – Lg=0.25µm
World record using InAlN/GaN HEMT

UltraGaN Highlights at M24

- **<u>Can InAlN/GaN be an alternative to AlGaN/GaN HEMT ?</u>**

- **ULTRAGAN answer: Yes!**
  - **No stress, if lattice-matched**
  - **Stress-free heterostructure with even double n_s**
  - **High thermal and chemical ceramic-like stability promising high robustness**
  - **HEMT demonstrated with barriers down to tunnelling thickness**
  - **Low dispersion effect leading to high power operation**

2nd EU FET-Cluster meeting

November 13-16, 2007

Las Palmas de Gran Canaria (Spain)

Thank you for your attention !

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http://www.ultragan.eu