InAlN/GaN HEMTs Technologies for Microwave, Fast switching and Mixed Signal Applications

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Summary

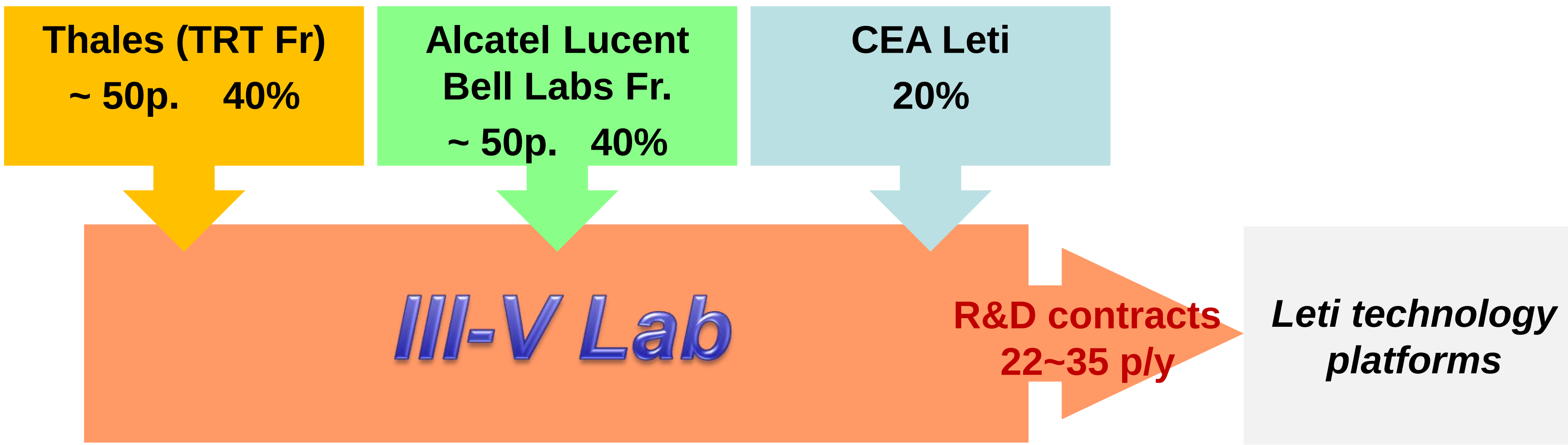
- III-V Lab presentation
- Motivations
- Technology for L & S band applications
- Technology for X to Ka band applications
- Fast Switching applications
- E/D mode devices for mixed signal applications

What is III-V Lab?

- **A jointly owned Alcatel-Lucent / Thales /CEA R&D Lab**
  - French GIE (Groupement d'Intérêt Economique) organization
- **with about 150 R&D experts (incl. 25 from CEA-Leti + ~18 PhD students)**
  - Dedicated to epitaxial growth, device and circuit design and manufacturing
- **performing R&T on III-V semiconductor technology and integration with Si circuits and micro-systems**
  - Optoelectronic and microelectronic materials, devices and circuits
  - From basic research to technology transfer for industrialisation …
  - … or to small scale and pilot line production
- **for complementary Alcatel-Lucent / Thales applications …**
  - High bit rate Optical Fibre and Wireless Telecommunications
  - Microwave and Photonic systems for Defence, Security and Space
- **… and looking for valorisation through external cooperation**

CEA-Leti : third partner in III-V Lab

- 'Alcatel-Thales III-V Lab' becomes 'III-V Lab'
- Access to Leti Si microelectronic and microsystem technology platforms



Main research activities and applications

Opto-electronics

- Tx/Rx photonic integrated circuits for the next generations of optical-fibre communication networks : 10x10Gb/s, 40Gb/s and above, 100Gb/s Ethernet
- IR laser diodes and photonic micro-systems for optronic systems : DIRCM, detection of toxic gases and explosives, microwave links over optical fibres, laser pumping for atomic clocks and cold atoms sensors
- Advanced IR photo-detectors

Micro-electronics

- GaN power HEMT MMIC technology for radars, electronic warfare, and wireless communication systems
- InP HBT technology for fast digital and mixed signal circuits : 40Gb/s and above front-end circuits, broadband ADCs, …

Page 5

III-V Lab implantation

Thales Research and Technology

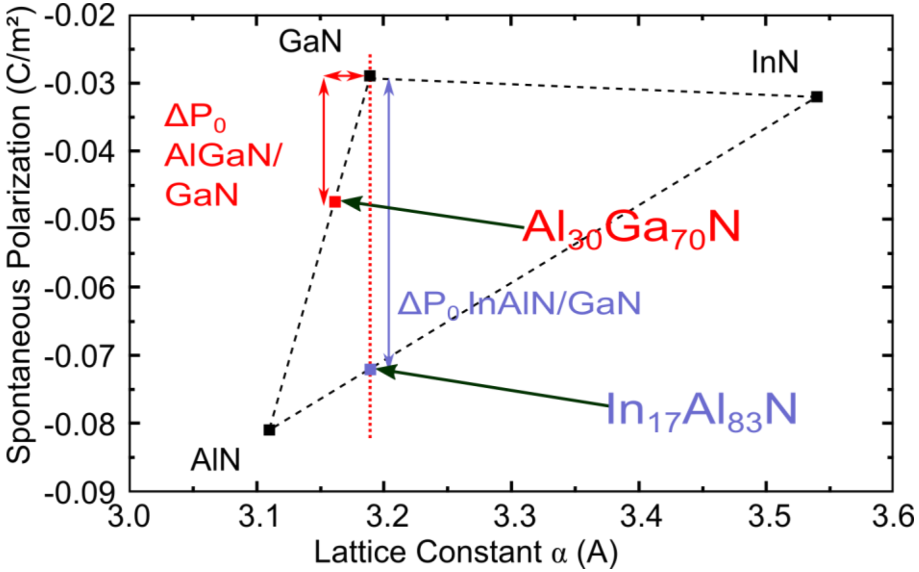
Palaiseau

Alcatel-Lucent /Bell Labs Fr.

Marcoussis

Page 6

Motivations : Why AlInN/GaN HEMTs ?



Spontaneous polarization of GaN, InN and AlN compounds functions of lattice constant

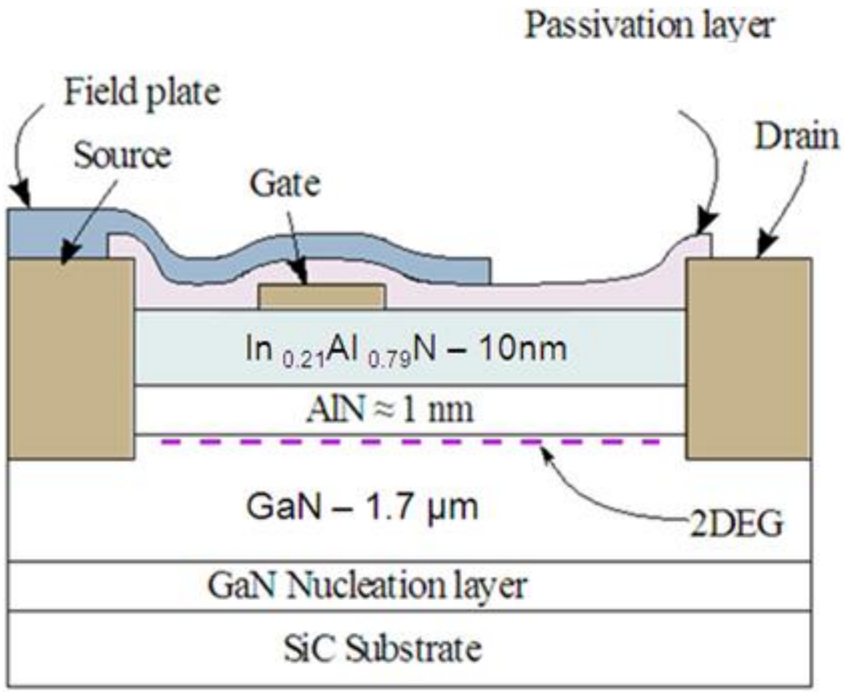
$In_{17}Al_{83}N/GaN$:
- Spontaneous polarization without lattice mismatch

⇨ Spontaneous polarization higher :
More electrons density
More power density

⇨ Lattice match :
Less lag effects ?
Better reliability ?

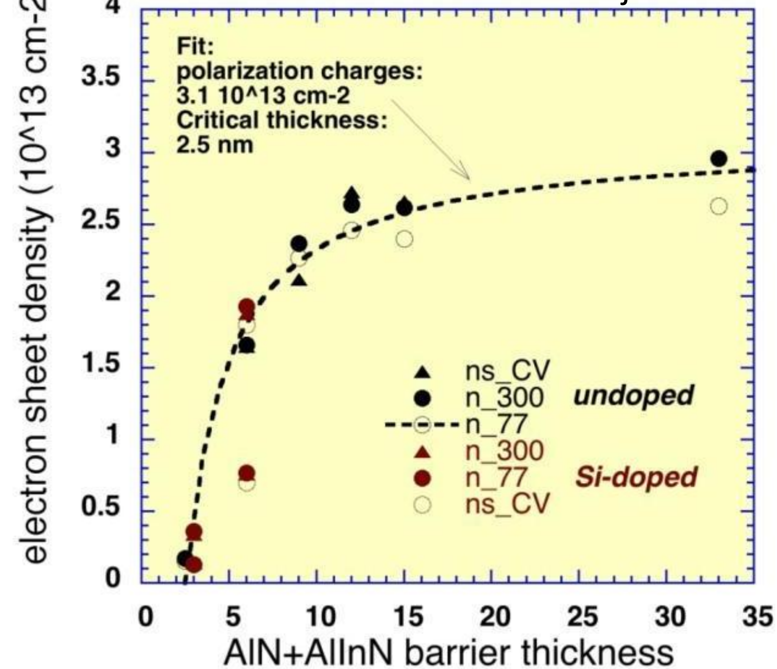
	ΔP_0 (Cm^{-2})	Piezo (Cm^{-2})	Ns (cm^{-2})
$Al_{30}Ga_{70}N/GaN$	$-1.56 \cdot 10^{-2}$	$-0.98 \cdot 10^{-2}$	$1.58 \cdot 10^{13}$
$In_{17}Al_{83}N/GaN$	$-4.37 \cdot 10^{-2}$	0	$2.73 \cdot 10^{13}$

Structure of InAlN HEMTs



Structure of studied HEMT

Source : EPFL-UltraGaN Project



@ 5nm -> 50% of the charges

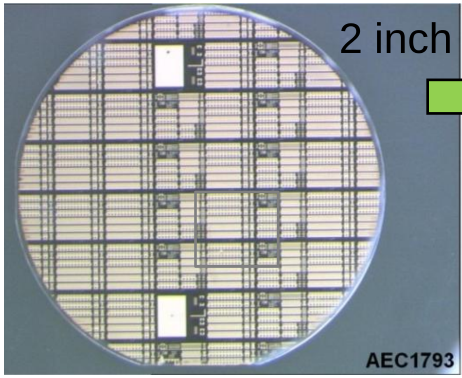
@ 11nm -> 85% of the charges

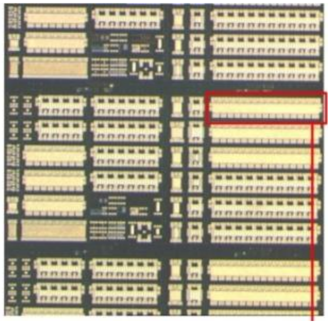
AlN layer enhances sheet carrier mobility

Sheet resistance # 320 Ω/sq. – Sheet carrier density ns # $1.5E^{13}cm^{-2}$

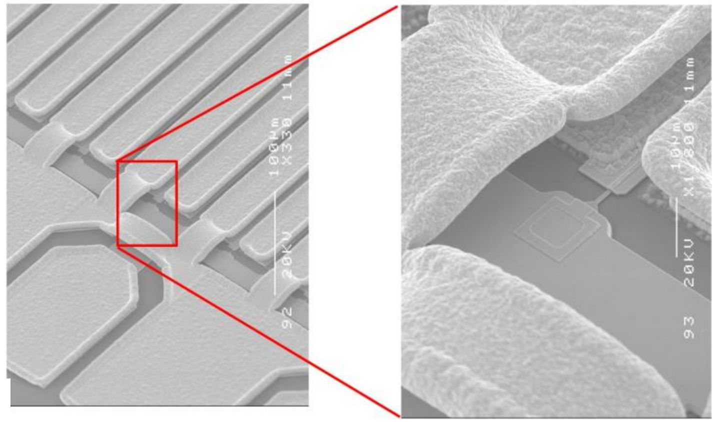
Technology for S-Band Applications

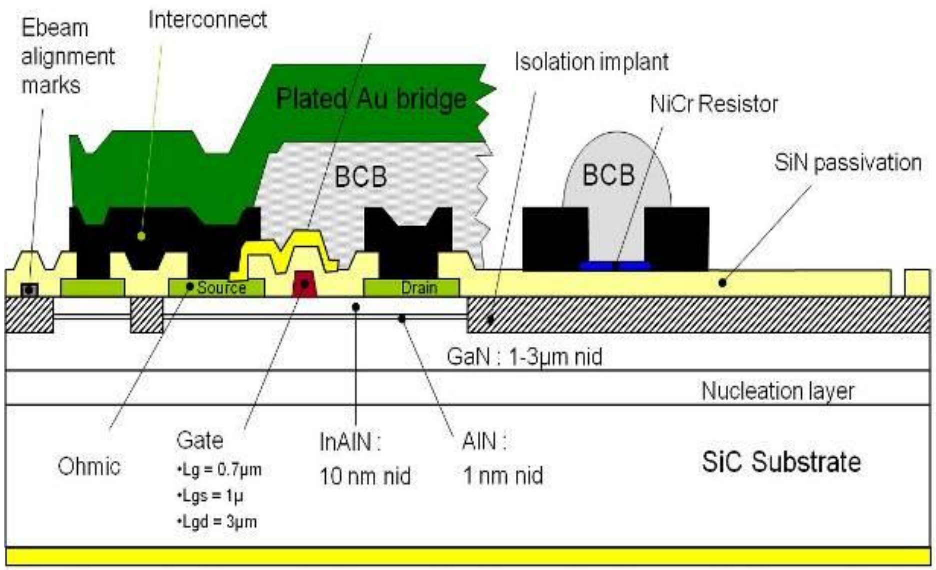
Power Device Manufacturing





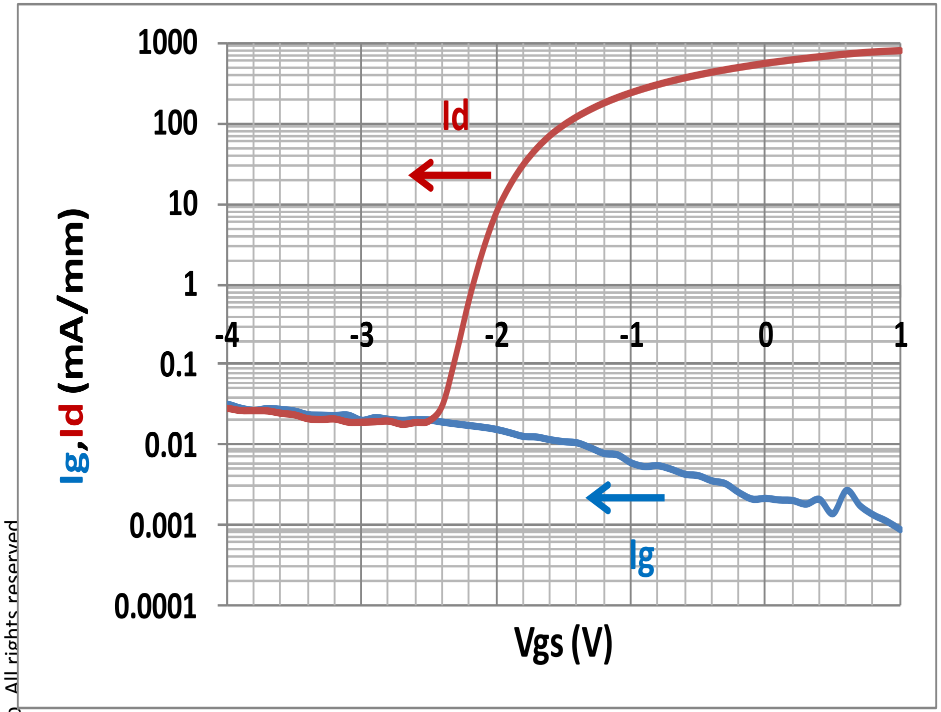
Wg=36mm, 90x400 µm, 1mm x 5mm die

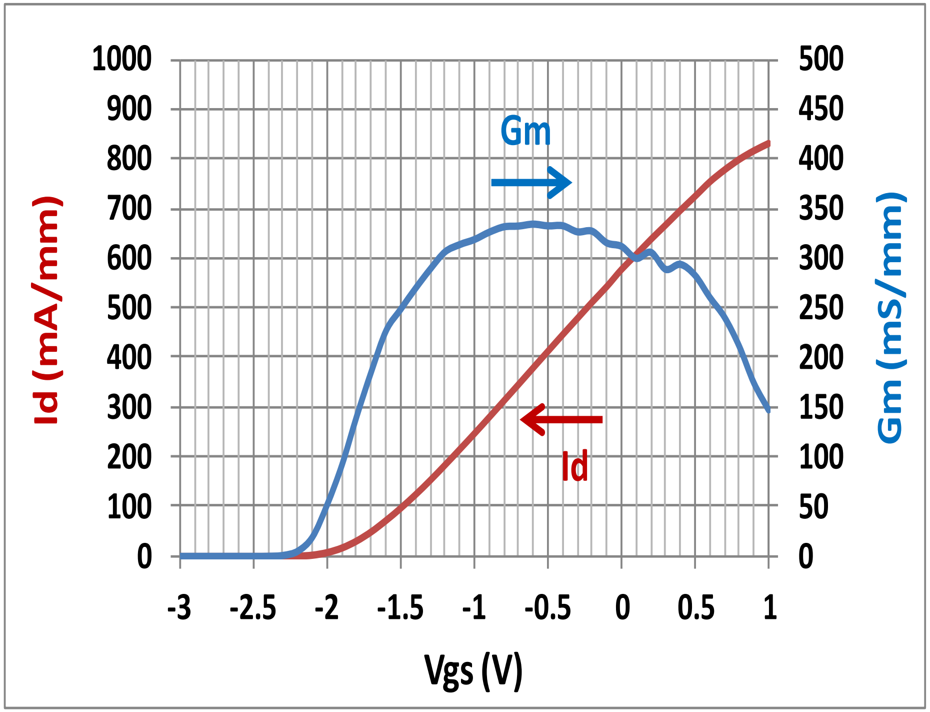




Device cross section

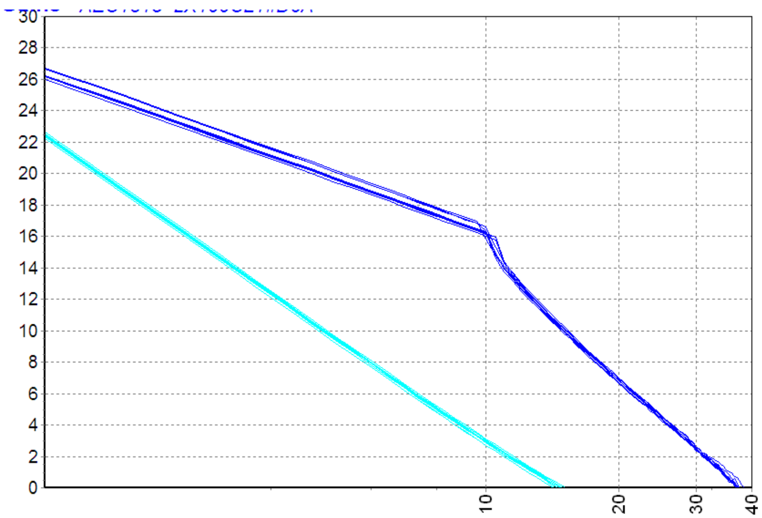
Static results

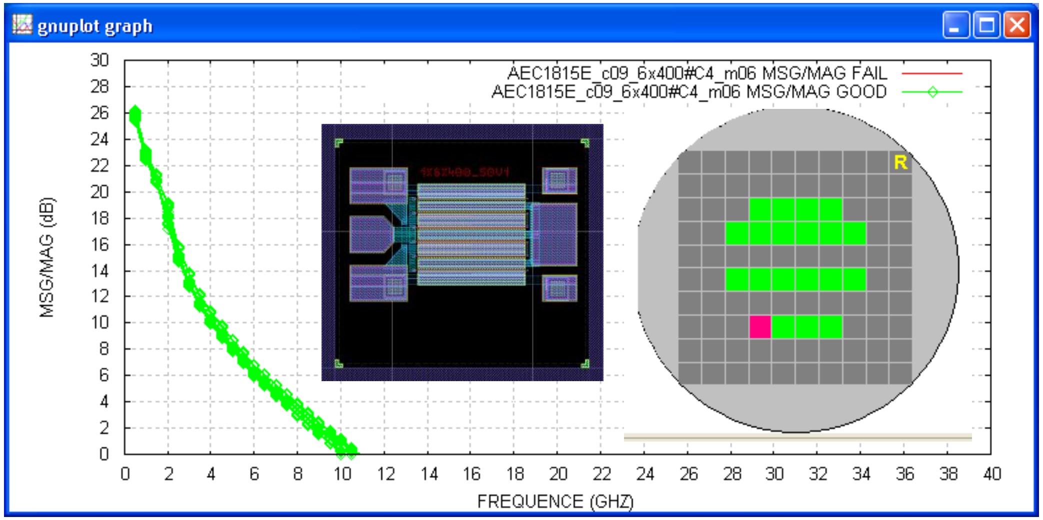




- Idss = 600mA/mm – Ids_{max}= 800mA/mm @ Vds=+1V
- Gm_{max} = 330mS/mm @ Vgs=-0.6V
- Ig < 20 µA/mm @ Vds=10V

Small Signal Characterization





F_T= 15 GHz – F_{MAG}=38 GHz

19 dB of MAG @ 2 GHz

Gm # 300 mS/mm

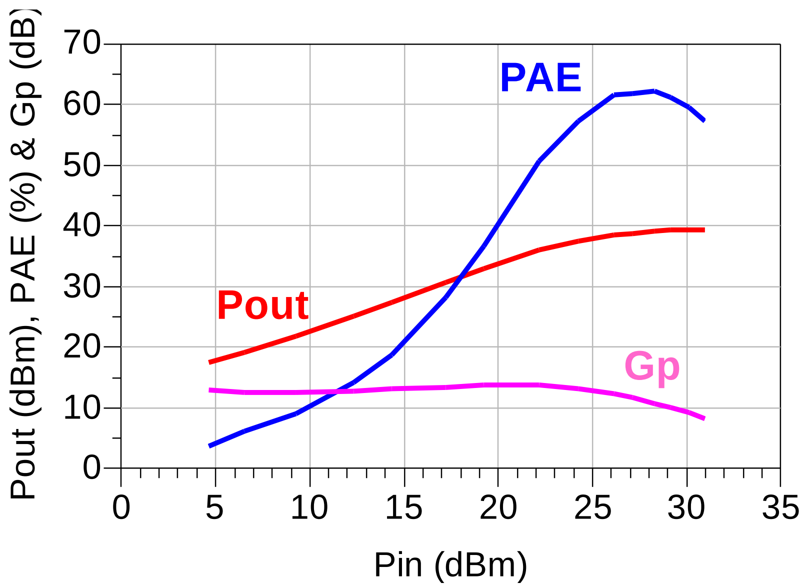
Gd # 3.2 mS/mm

Cgs # 3.4 pF/mm

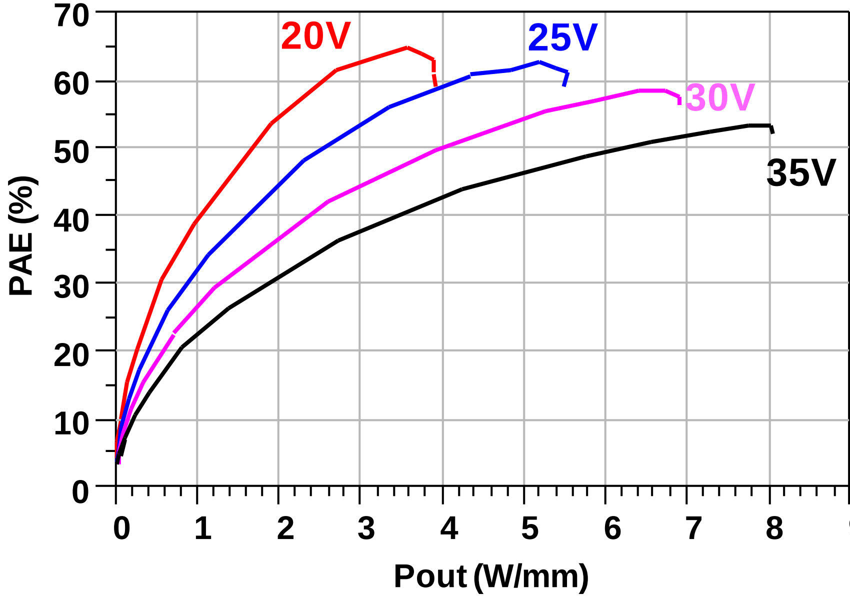
Cgd # 0.110 pF/mm

Cds # 0.450 pF/mm

On wafer large signal characterization : 2mm device @3.5 GHz

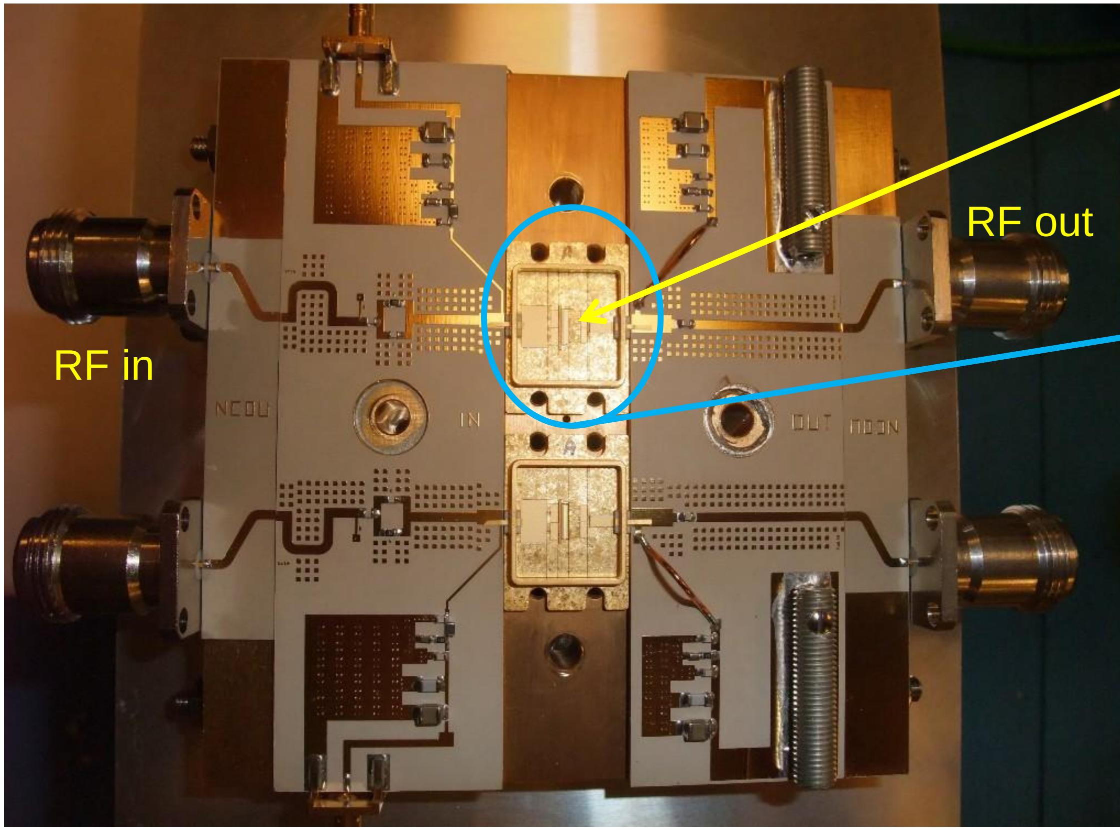


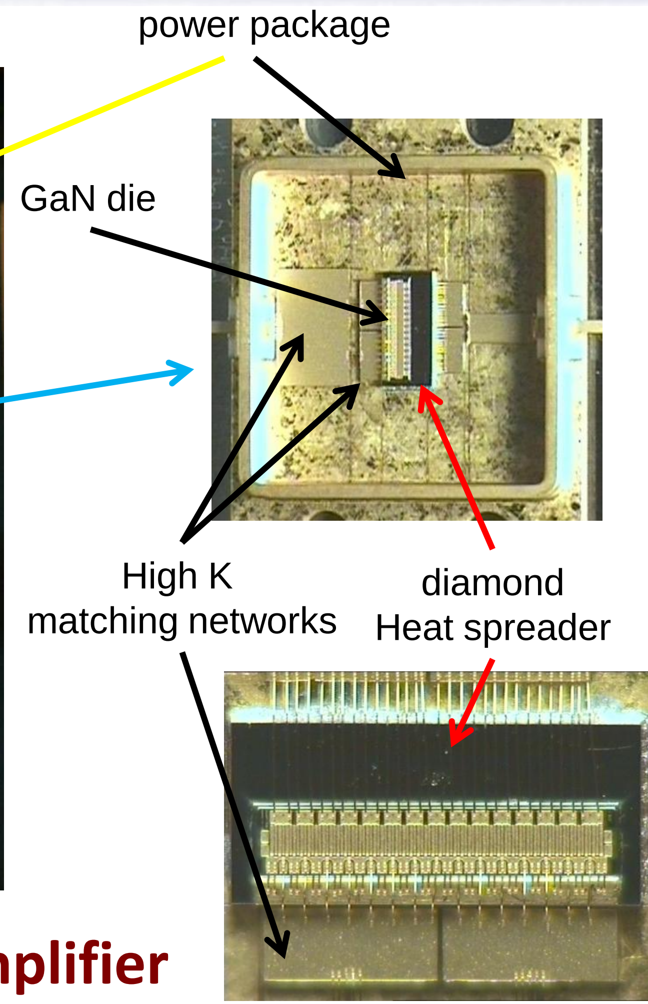
Pout = 39dBm (8W - 4W/mm)
with PAE = 62% and Gp=10.7dB
(Vds0=20V – Ids0=60mA - Zl=17+j18 Ω)



Pout from 4 to 8W/mm with associated PAE from 62% to 53%
(no re-tune at each vds)

Amplifier realization

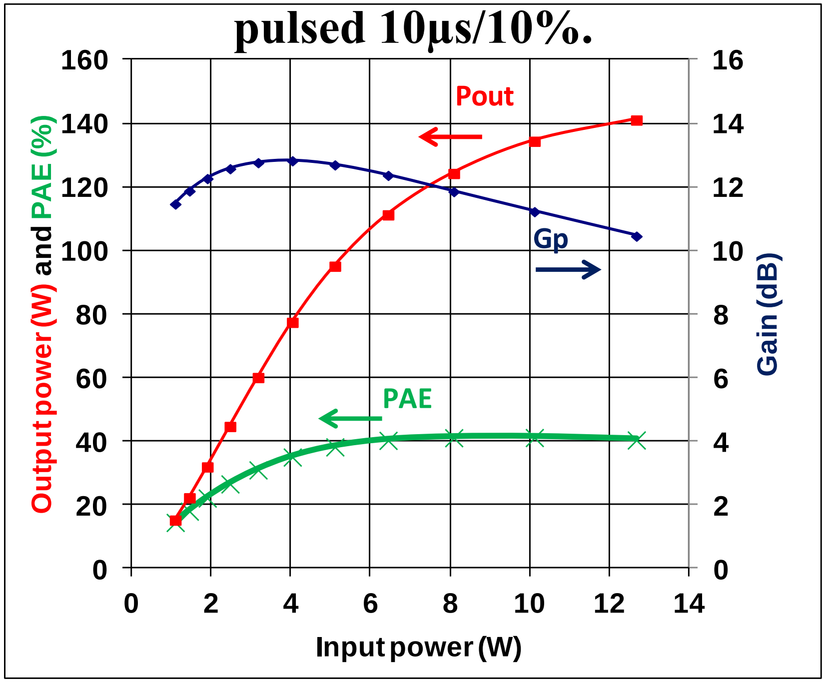




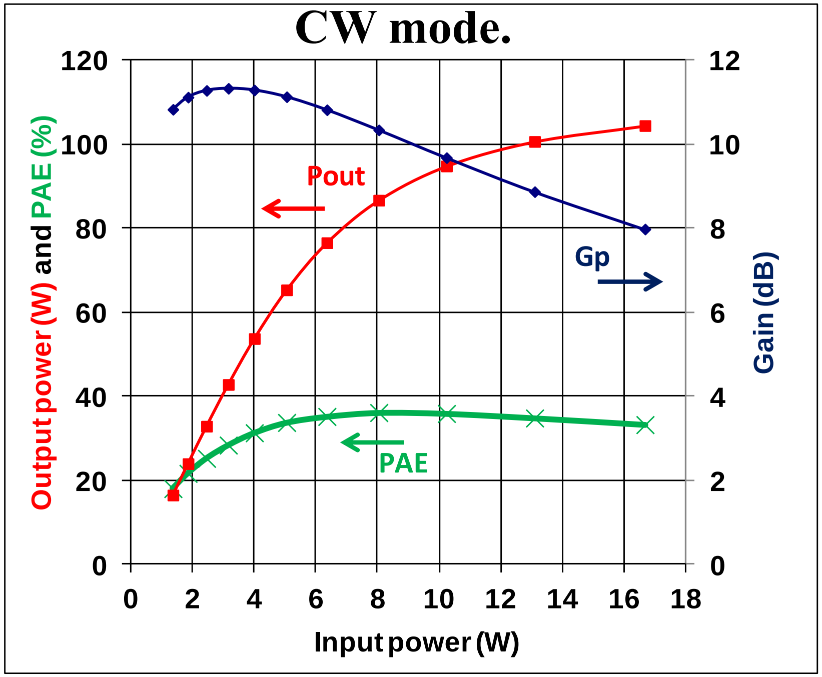
InAlN/GaN based Power amplifier

Can be measured in single ended or balanced configuration

L-Band (2GHz) High Power Packaged Amplifiers Measurements



Vds=30V and Ids_0=0.1A



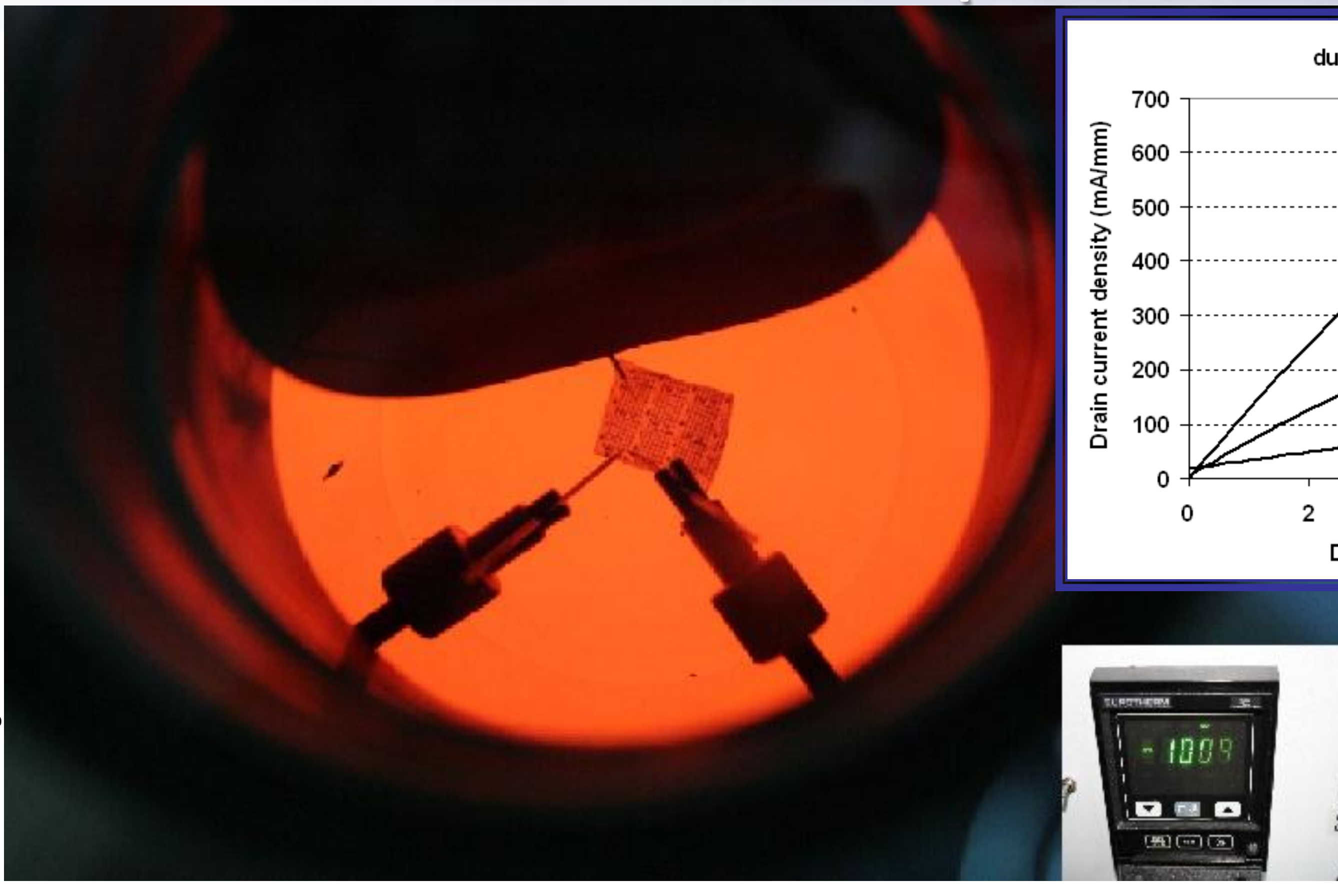
Vds=30V and Ids_0=0.1A.

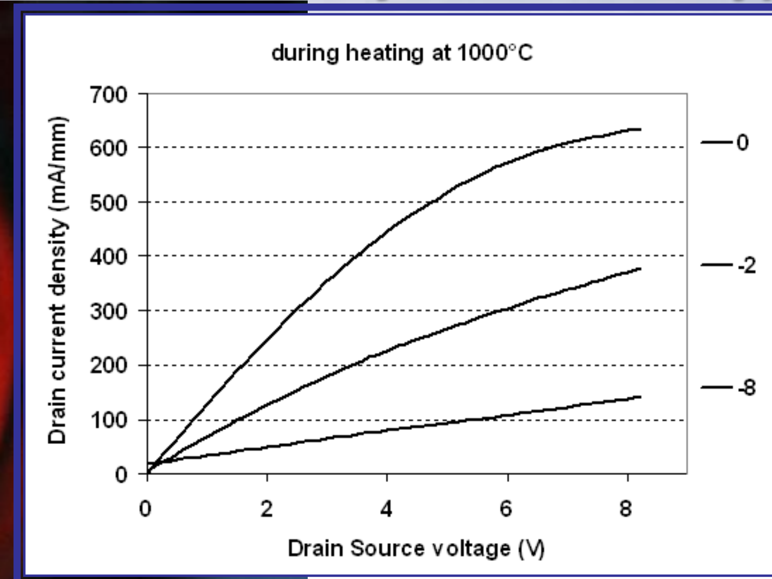
105W - CW reached (Pdiss = 4.5W/mm -> Tchannel = 260°C)

140W - pulsed conditions (Tchannel = 125°C)

III-V lab

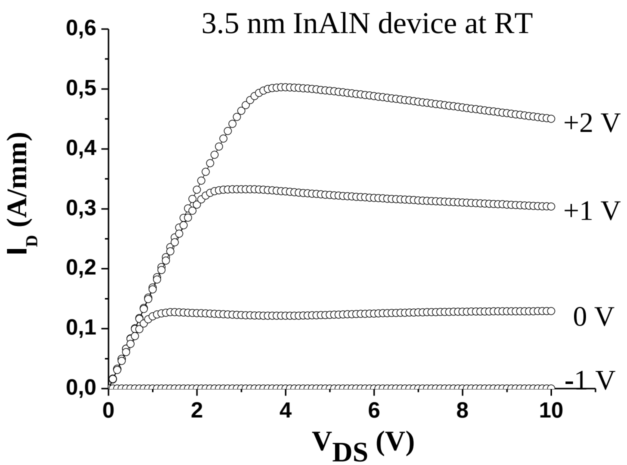
High Temperature DC Measurements (ULM university – Germany)

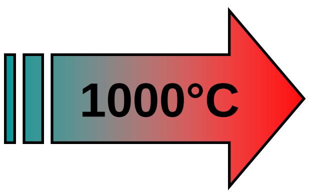


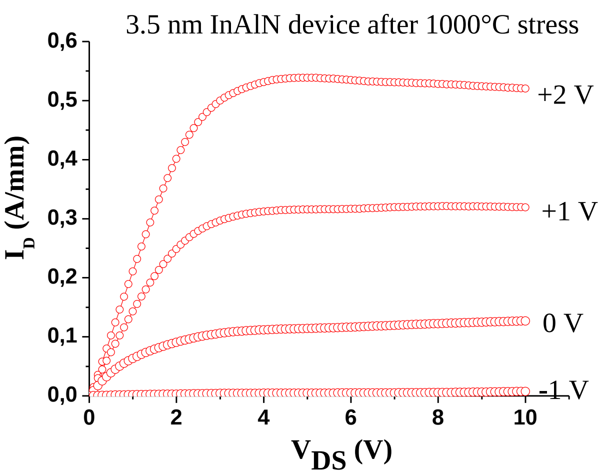


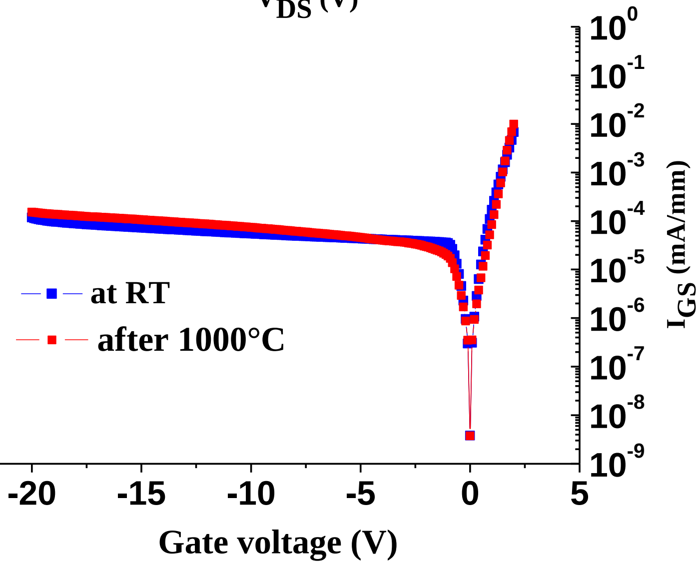
<u>First time</u> a transistor operates up to 1000 C !

Thermal stability of 3 nm barrier InAlN/GaN HEMTs







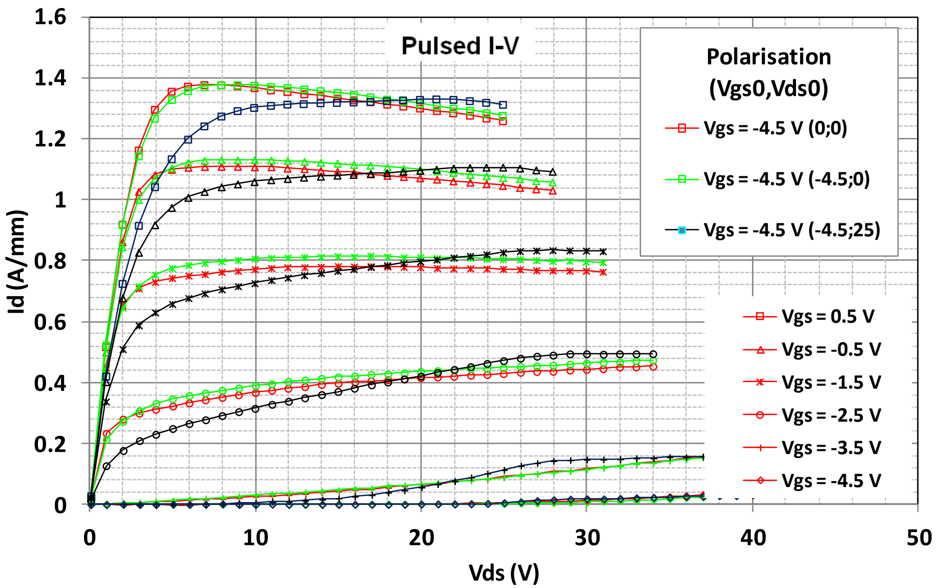


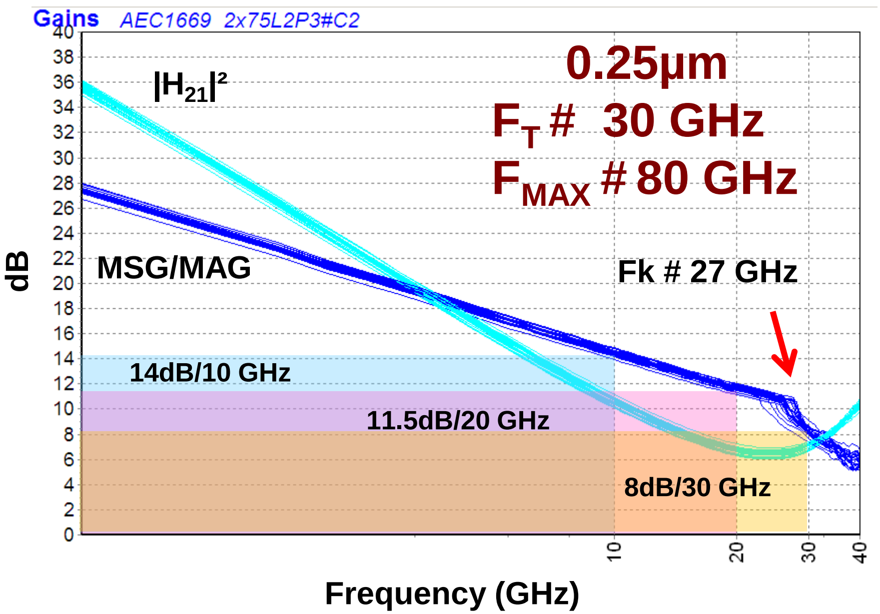
Ultra thin barrier (few nm) InAlN/GaN heterostructure still working after 1000 C for 30min step.
Very promising for high robustness demanding applications.

Technology for X to Ka-Band Applications

0.25µm technology - pulsed I-V and Sij results

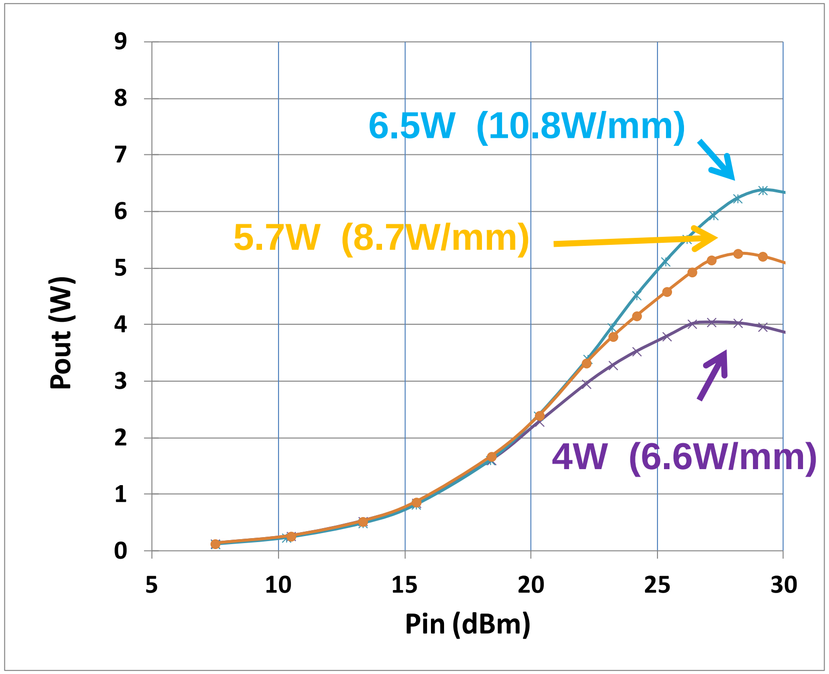
Idss ~ 1.2A/mm and ~1.4A/mm @ Vgs = 0.5V
Gm_{max} ~ 450mS/mm
Vp~ 3.8V

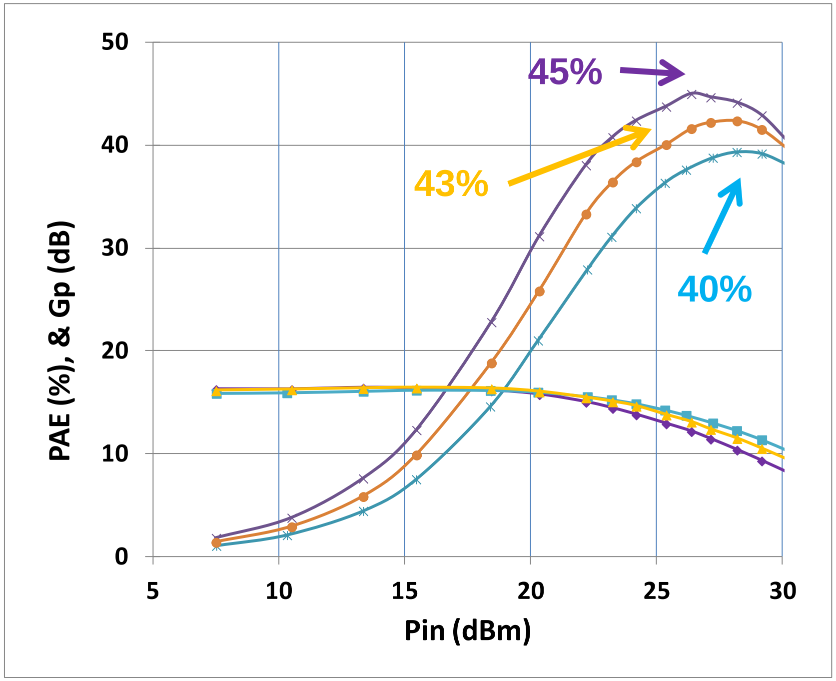




Pulsed I-V measurements

Load-Pull measurements @ 10 GHz 250µs pulsed

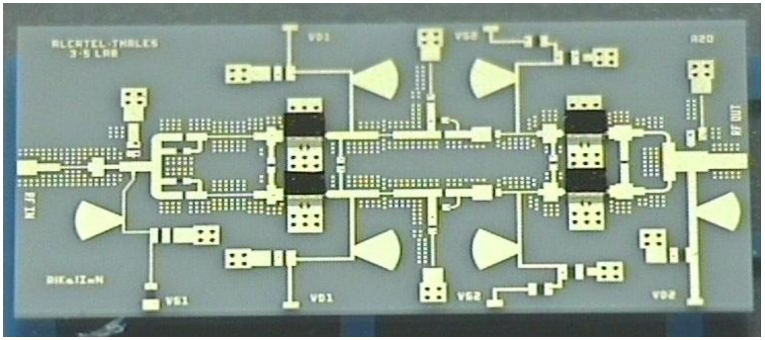


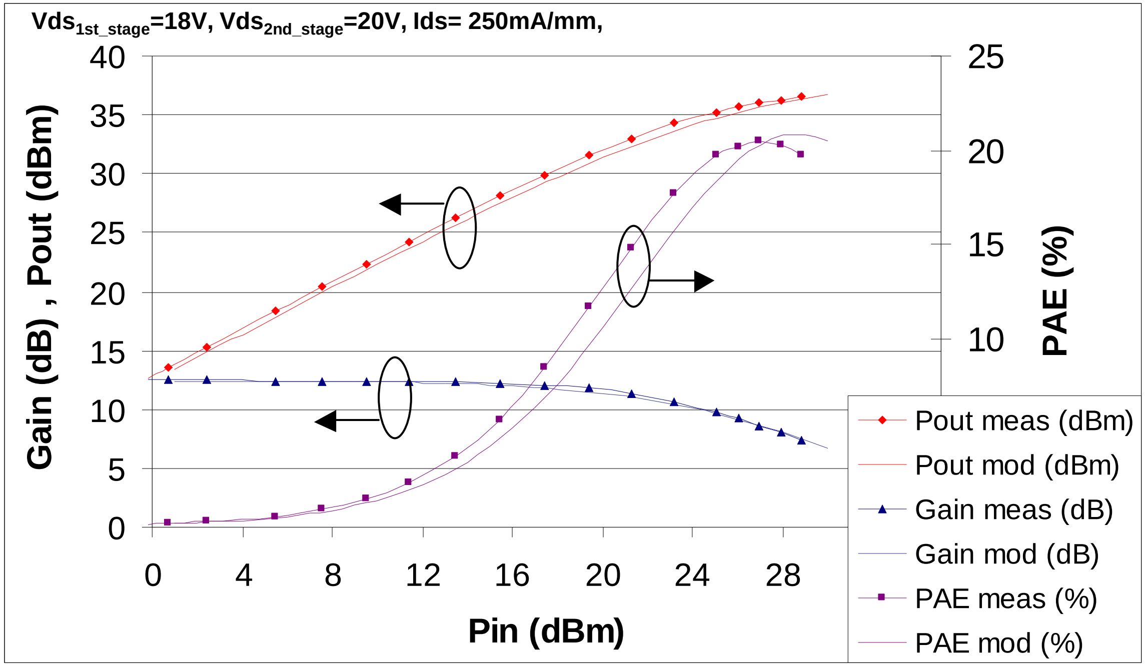


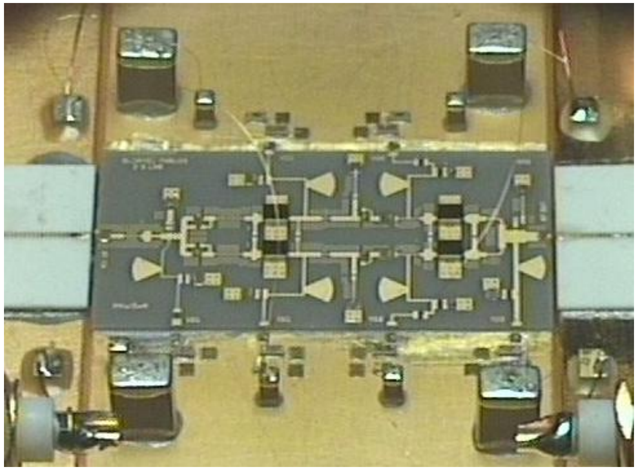
8x75µm - A-Class (500mA/mm) Vgs_0=-2.1V

Vds from 20V to 30V
Output power from 6.6W/mm to 10.8W/mm
PAE from 45% to 40%

World first demonstration of 20 GHz CW InAlN/GaN Power amplifier







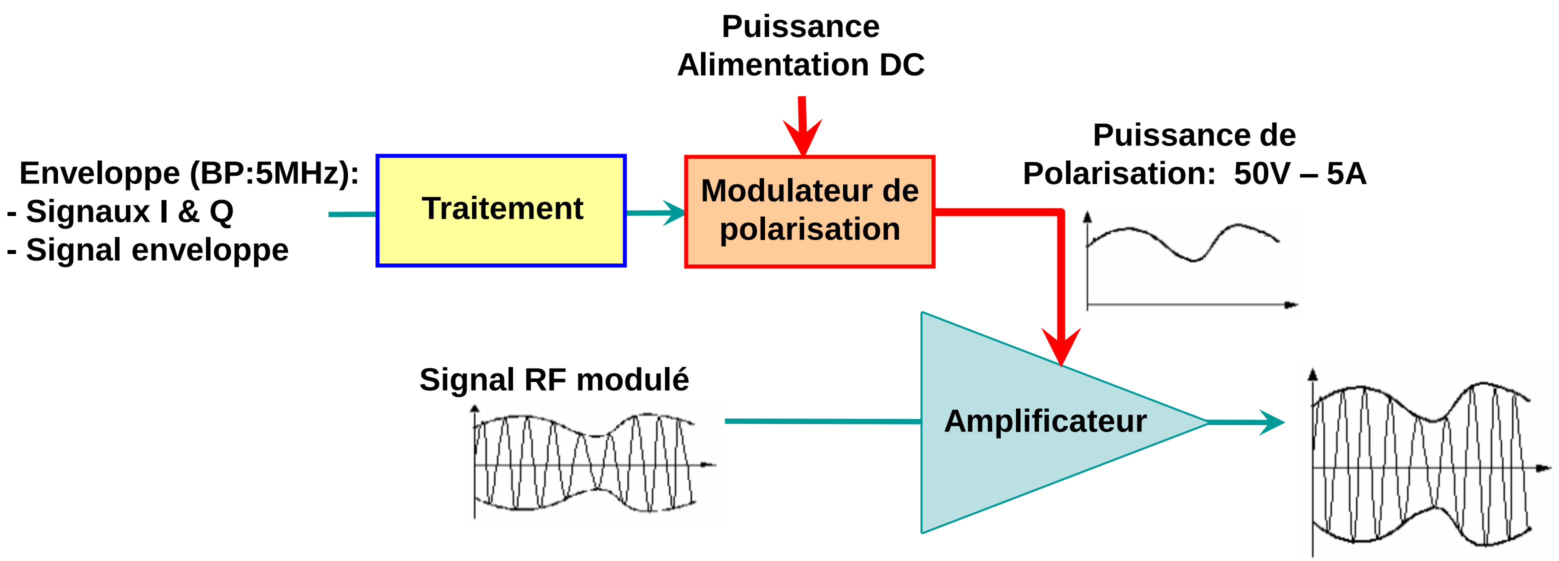
20 GHz AlInN/GaN amplifier
In test JIG

20GHz : Pout = 4.5W with 20% PAE and 12B of linear gain

Good comparison with the simulation

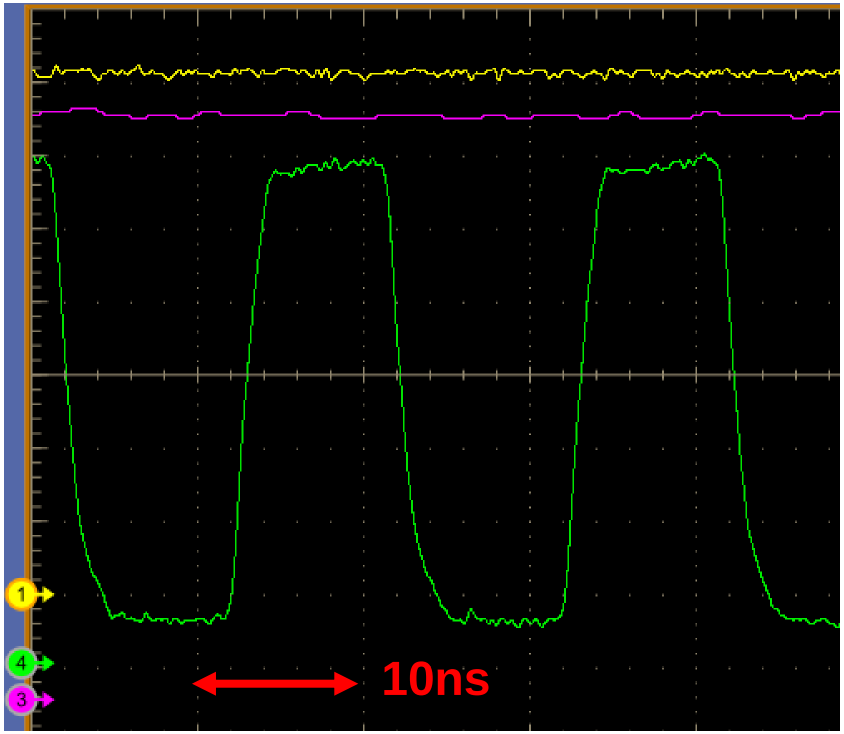
Technology for Fast Switching Applications

Enveloppe Tracking

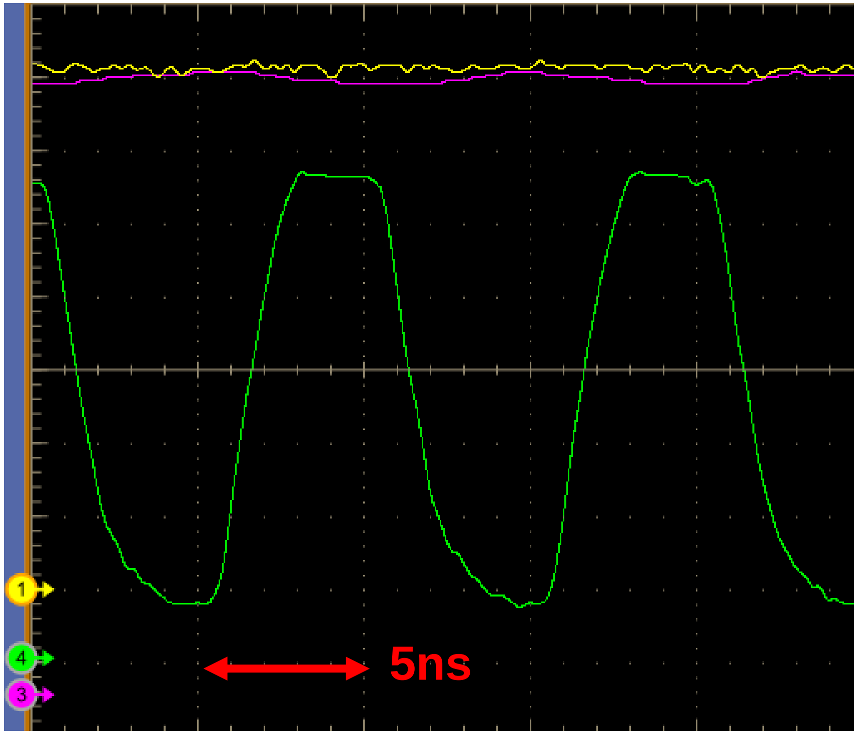


Cellule de commutation
Mesures à Vdd=50V, fcommut=50 & 100MHz

- **Mesures:**
  - Rch=500 Ohms, Vdd= 50V, DC = 50%



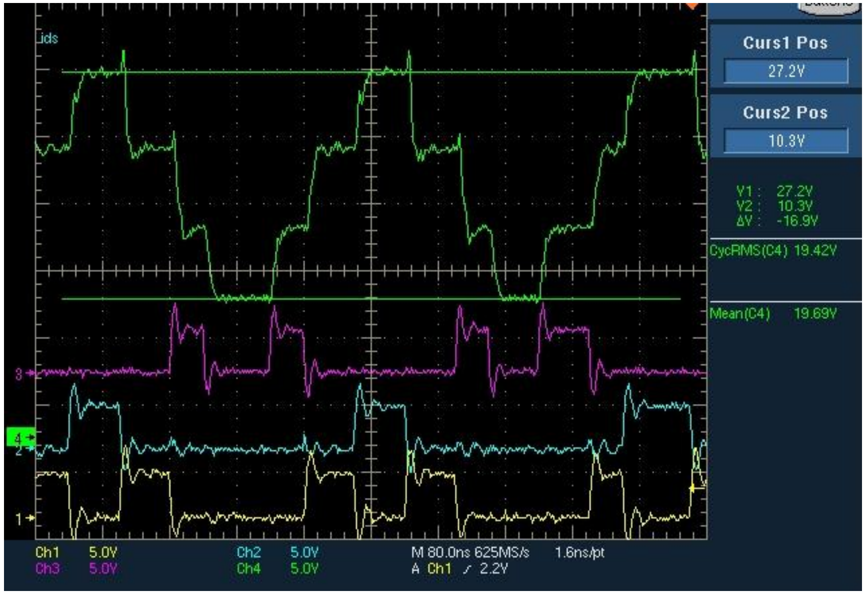
Fcommut= 50 MHz



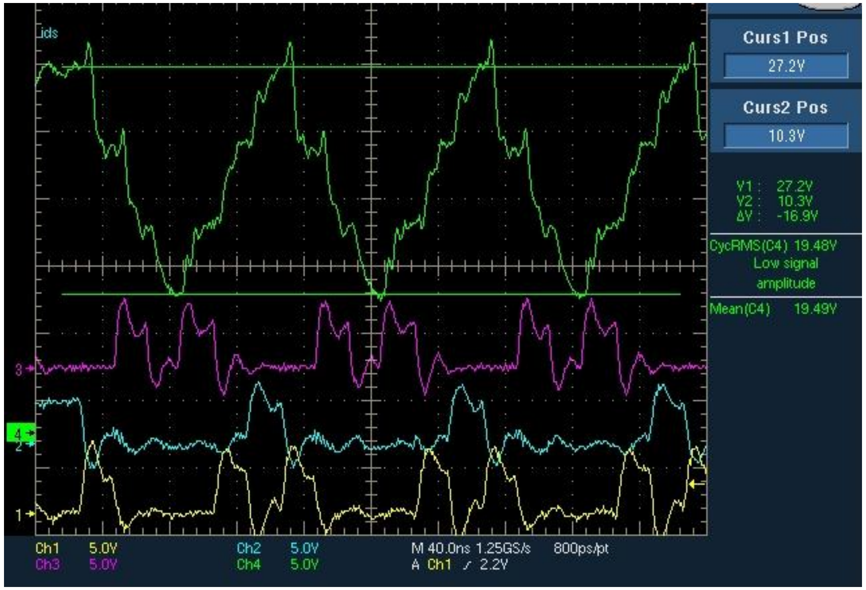
Fcommut=100MHz

- **Mesures d'un signal sinusoïdal ➔ fcommutation=6*Fenveloppe**

Fenv=3MHz (Fc=18MHz)



Fenv=8MHz (Fc=48MHz)



Technology for Mixed-Signal Applications

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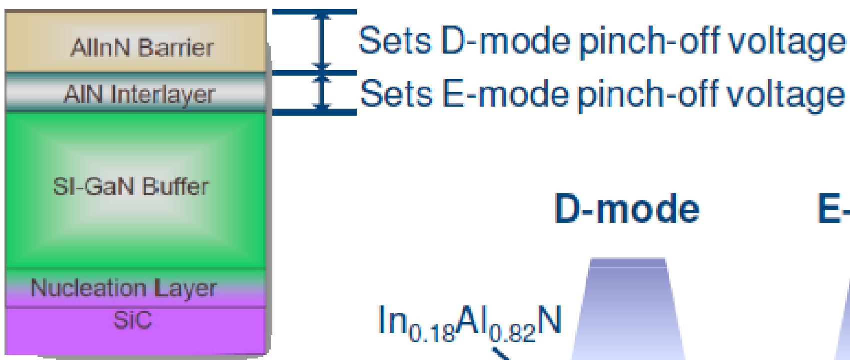
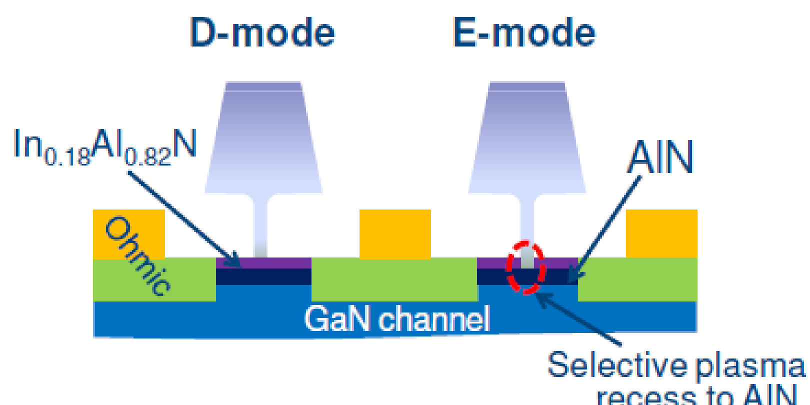
InAlN/AlN/GaN E/D Approach





- E-mode device is an AlN/GaN HEMT
- InAlN provides low access resistance

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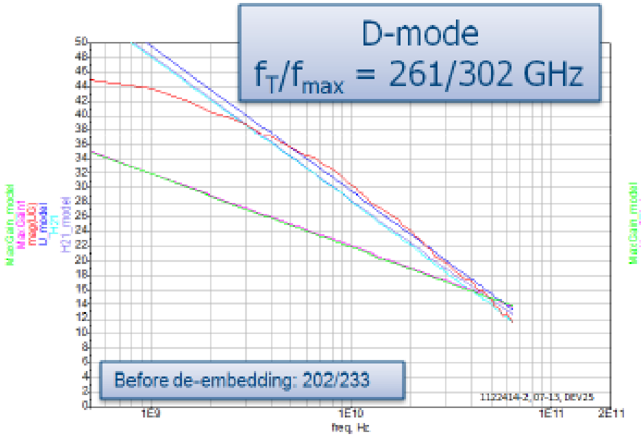
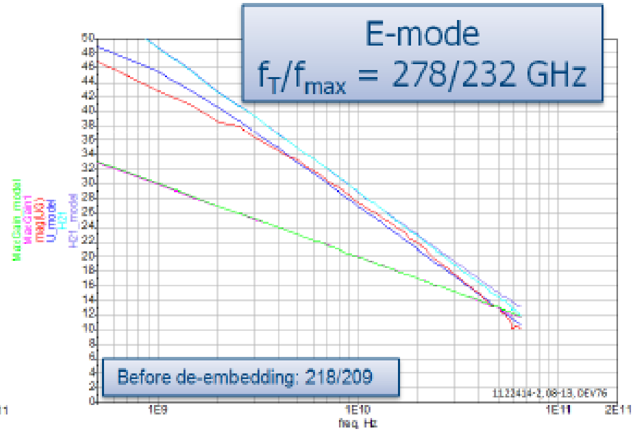
Small Signal Characteristics

Devices from same wafer

l_g = 30 nm, l_{sd} = 160 nm, 2x50 μm





		FT4(GHz)	Fmax(GHz)	Gm(mS)	Cgs (fF)	Cgd(fF)	Ri (ohm)	Rg(ohm)	Rs(ohm)	Rd(ohm)
0713_#25	D-mode	261	302	118	52	9	4.8	6	2	4
0813_#76	E-mode	278	232	155	54	17	6.6	6	2	2.6

WMA Advances in InAIN/GaN Device and Microwave/MMW Circuit Technology IMS2013, Seattle, June 2-7, 2013 32

Merci de votre attention !

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