GaN Technology for Microwave Applications in Ka and Q bands

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CAPABILITIES AND APPLICATIONS OF GaN DEVICES

Microwave and RF 2015

Acknowledgement
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- Thales Com: J.Y. Daden, C. Voillequin

Frequency Rise

- III-V Lab develops InAlN HEMT for wireless data transmission and high frequency power amplification: Ka, Q et E (30->86 GHz) Band.
  - **Civil and military communication (SATCOM)**
  - **Radars and altimeters**
  - **Data backhauling**

- The applications are dual and are interesting both Alcatel-Lucent and Thales mother companies.

- Fierce competition is observed for these markets.

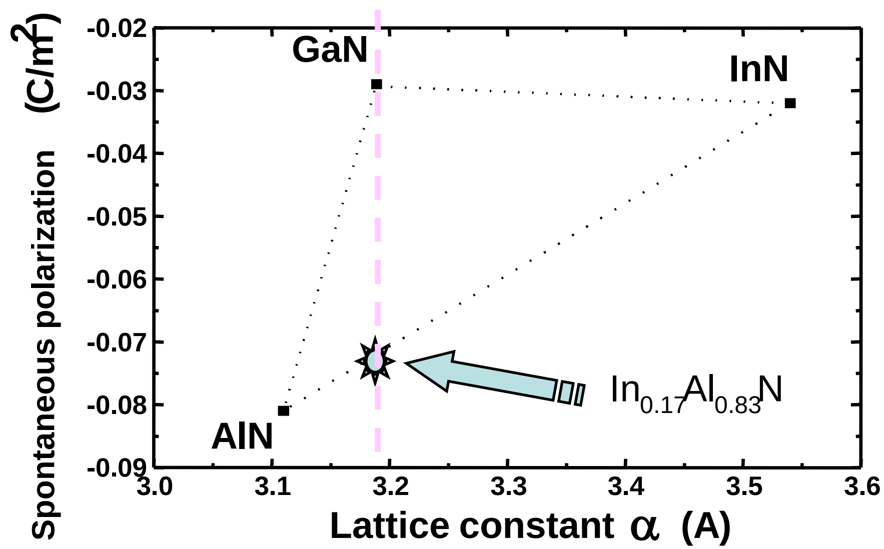
- Challenges :
  - **To increase power gain, efficiency and output power**
  - **To achieve a sufficient level of maturity**
  - **To transfer to manufacturing partners including UMS.**

BACKGROUND

Why did we 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
- Possible higher 2D gas density (3A/mm for 0.25µm gate length)

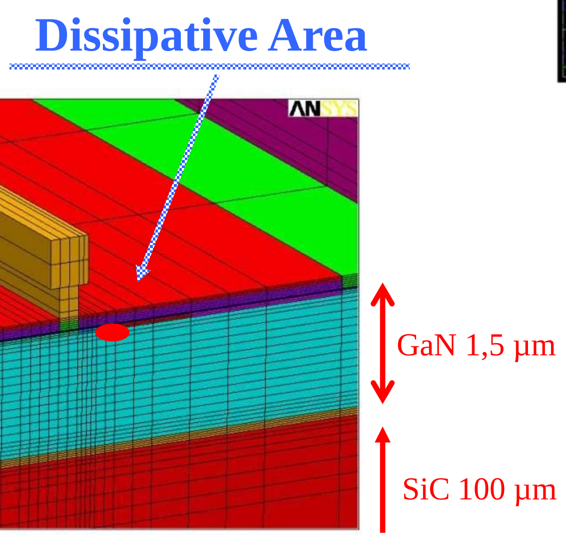


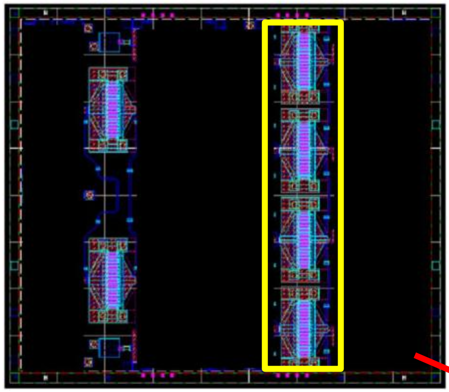
Why SiC substrates ?

▶ 3D-Thermal simulation at transistor and MMIC level

Material	Thermal conductivity (W/K.m) *
GaN	160
SiC	414
Si	155

* : at room temperature





Example of 100µm thick MMIC output power stage 1.92 mm CW – Ts=50°C

Performances at transistor level				
Ps	3W/mm	4W/mm	3W/mm	4W/mm
PAE	40%	40%	30%	30%
Pdiss	4 W/mm	5.4 W/mm	6.3 W/mm	8.4 W/mm
Rth Si/SiC	1.7			
Tj (GaN/SiC)	105	125	140	170
Tj (GaN/Si)	145	180	210	280

Ts=50°C sous la puce 100µm - etage de puissance HPA 1.92 mm (8x4x60)

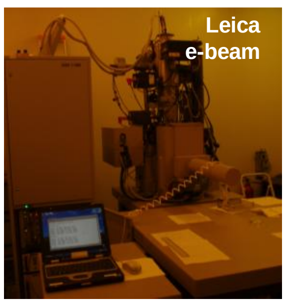
▶ Rth GaN_Si/GaN_SiC ~ 1.7 -> Much lower maximum junction temperatures achieved with SiC substrates compared to Si ones

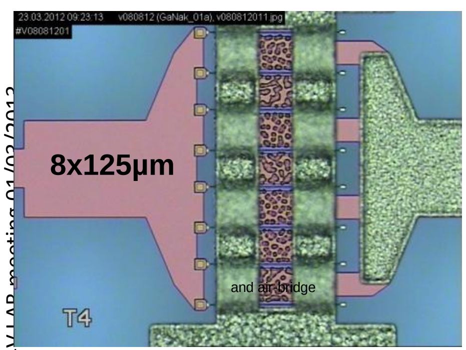
Technology NH15-10
0.15µm InAlN/GaN HEMT

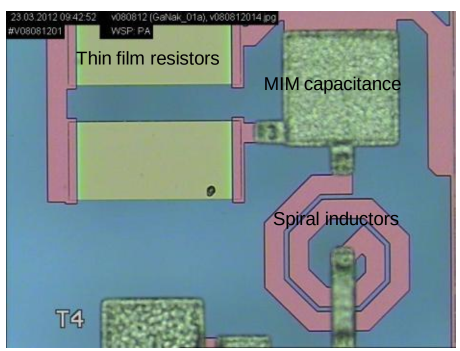
Technological steps	III-V Lab	UMS
Wafer cleaning and surface preparation	✓	
Alignment marks for UMS stepper		✓
Alignment marks for III-V lab : active device process (ohmics, isolation, gate, passivation, numbering)	✓	
Resistances, inter-connection, capacitor dielectric, pillars, bridge, back-side		✓
Measurements	✓	✓

SiC substrate lapping down to 100µm by UMS

For both InAlN or AlGaN heterostructures



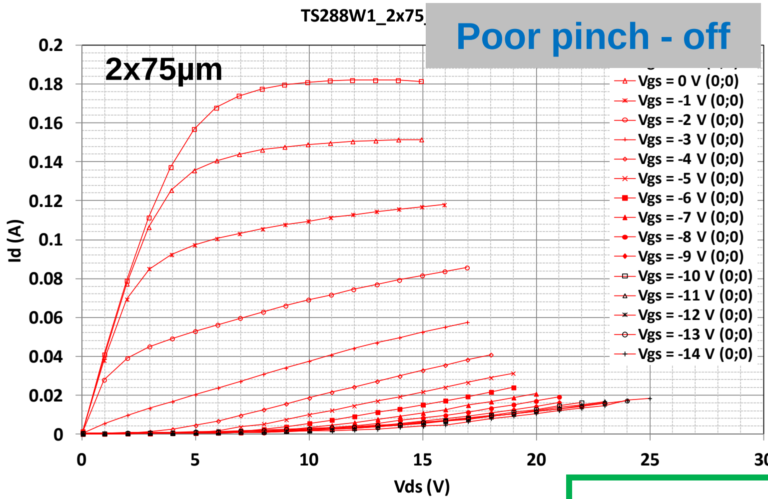


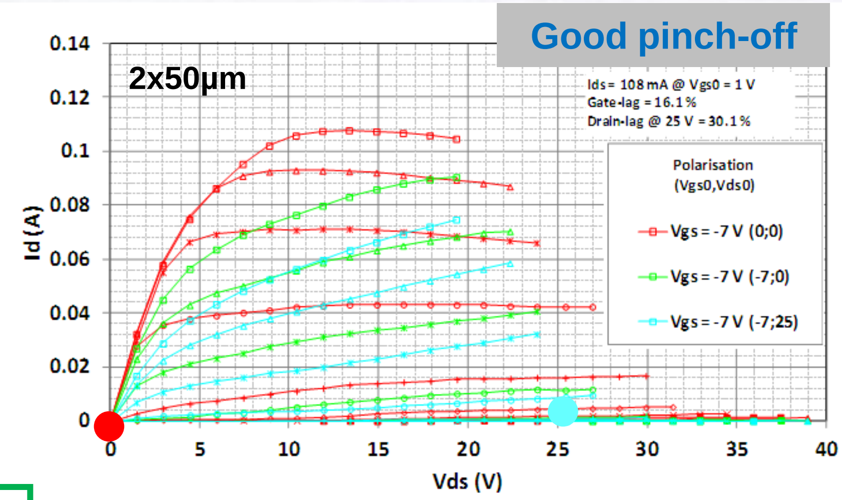


Realization of <u>microstrip MMIC process</u> and <u>multifinger devices</u> shared between III-V Lab and UMS

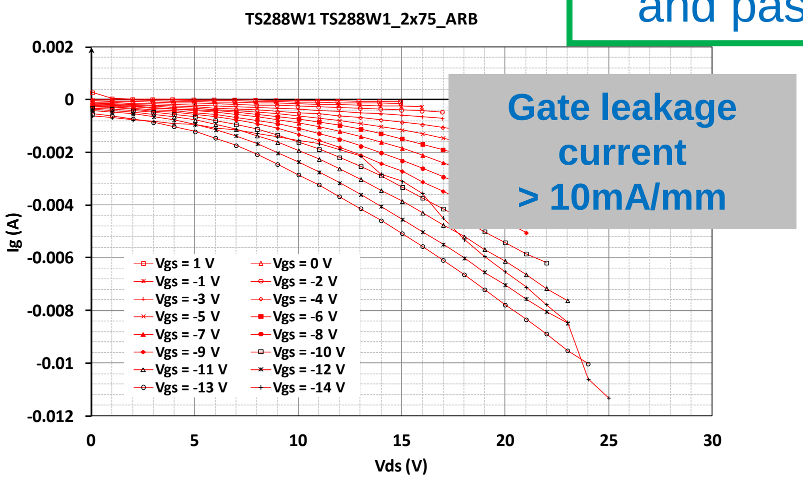
InAlN/GaN 0.15µm HEMT III-VLab Technology

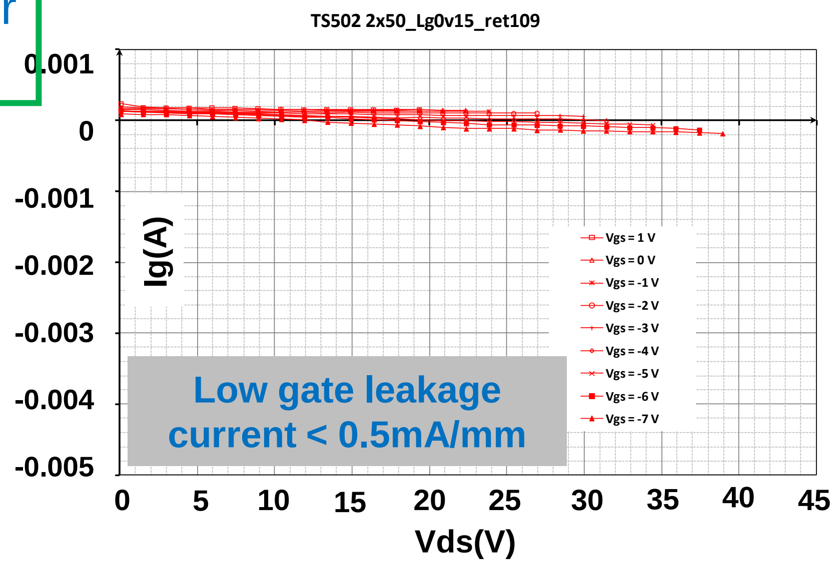
Improvement of pinch-off and gate leakage current



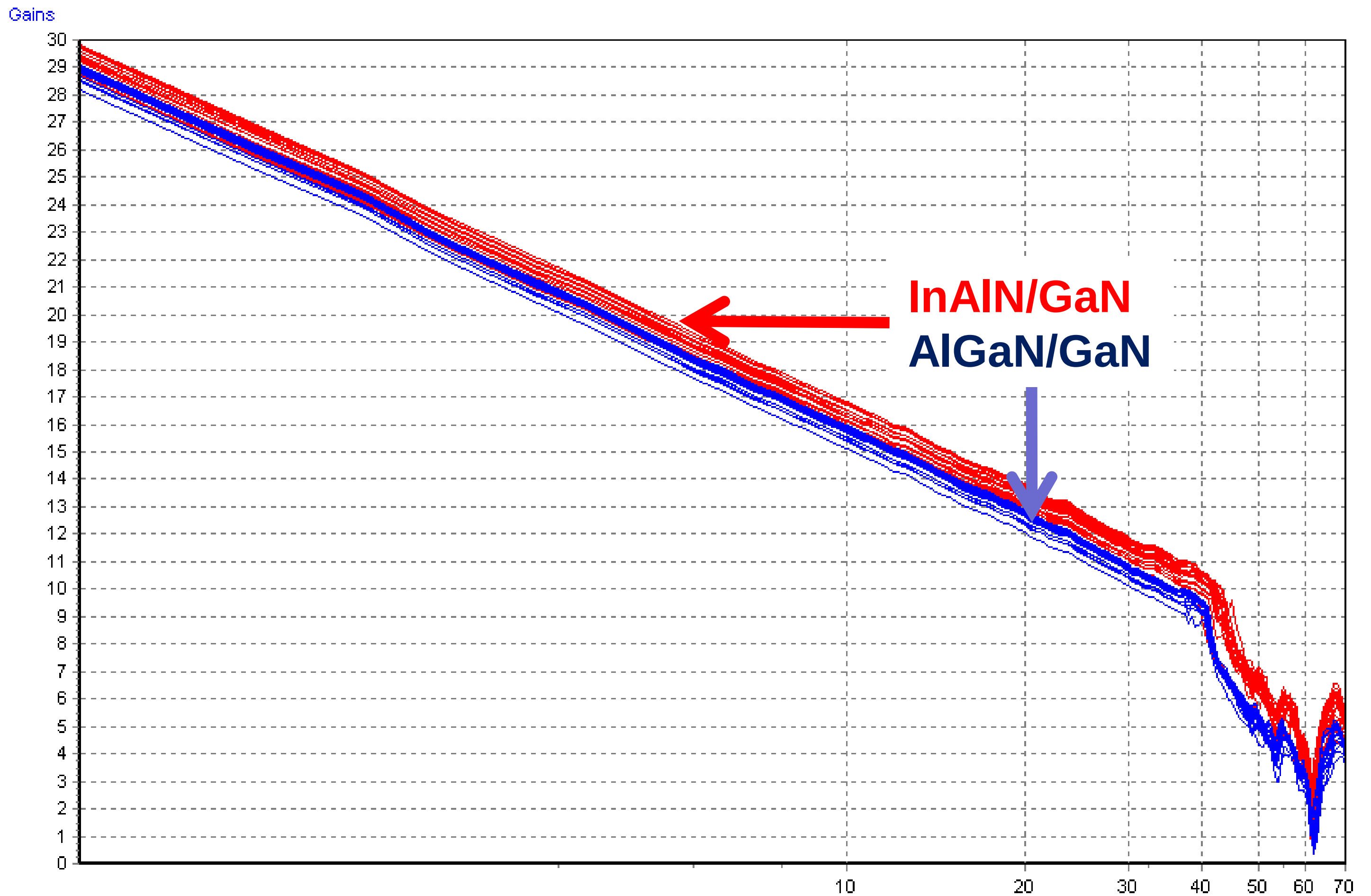


Improved buffer layer and passivation 2

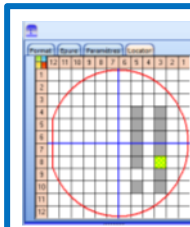




InAlN/GaN small signal power gains
2x50µm x 0.15µm (CPW) 20V-200mA/mm

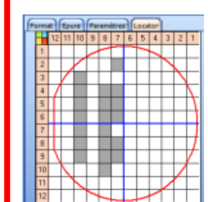


AlGaN



MSG (dB)
12.8dB @ 20 GHz
10.8dB @ 30 GHz
9.5dB @ 40 GHz

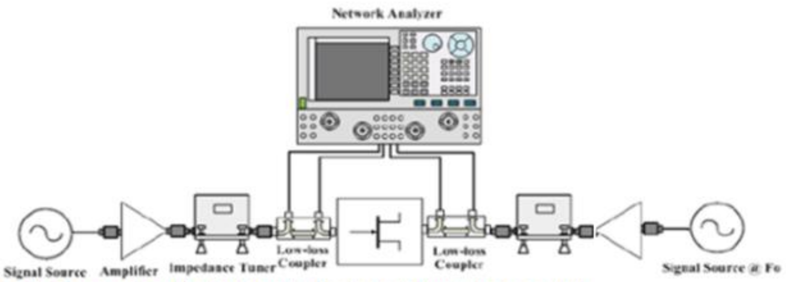
InAlN



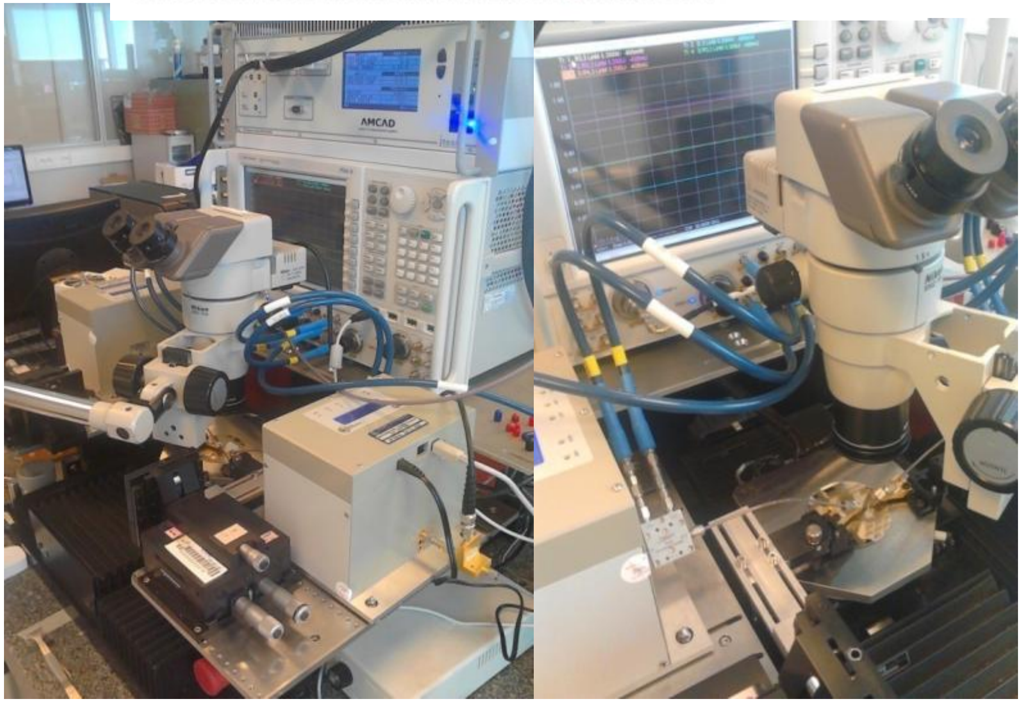
MSG (dB)
13.5dB @ 20 GHz
11.5dB @ 30 GHz
10.3dB @ 40 GHz

Ka-Band III-V Lab Hybrid Power Load-Pull

- **New equipment has been received in September 2014.**
  - Much faster than older bench limited to 18GHz,
  - Capabilities to explore large topology variation thanks to active impedance matching,
  - CW and pulses modes possible,
  - Excellent reproducibility and precision.



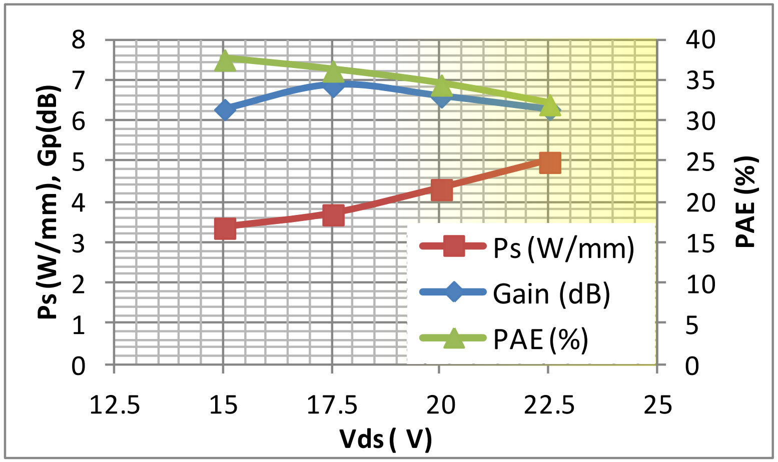
Vector-Receiver Load Pull with active fundamental impedance control

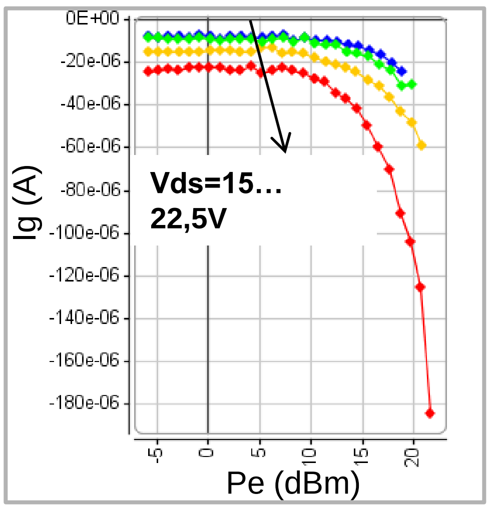


AMCAD Engineering
Advanced Modeling for Computer-Aided Design

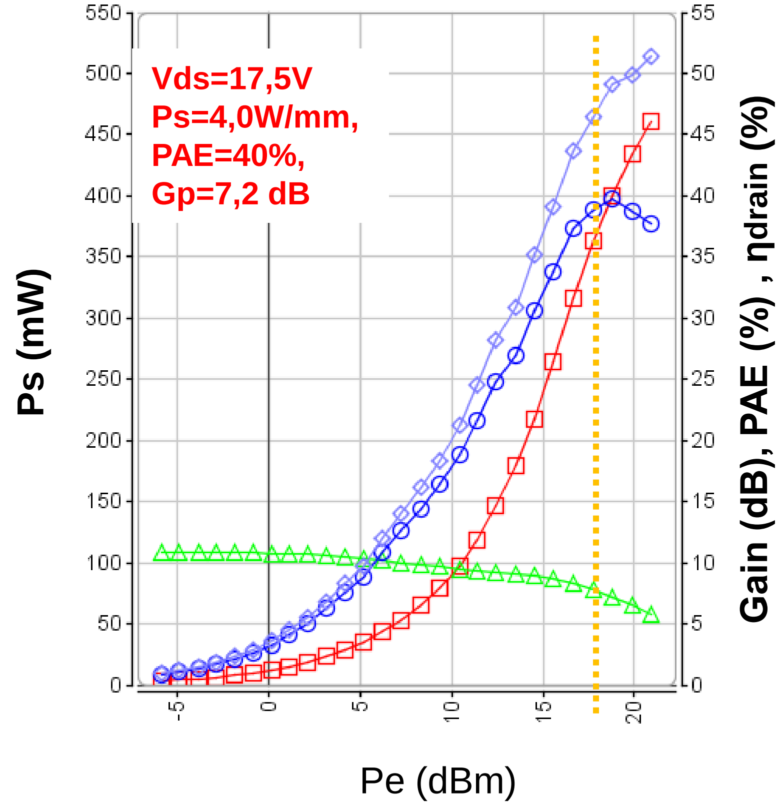
InAlN/GaN Power Load-Pull Characterisation

2x50µmx0.15µm -DC-CW, f0=30 GHz, Ids=200mA/mm (classe AB)





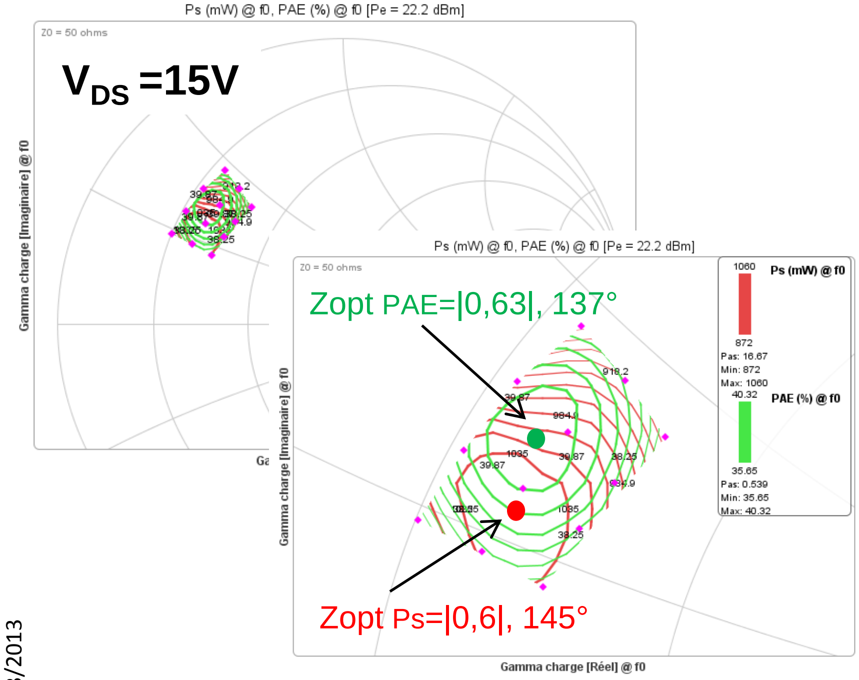
2x50x0.15µm, 30GHz dc/cw

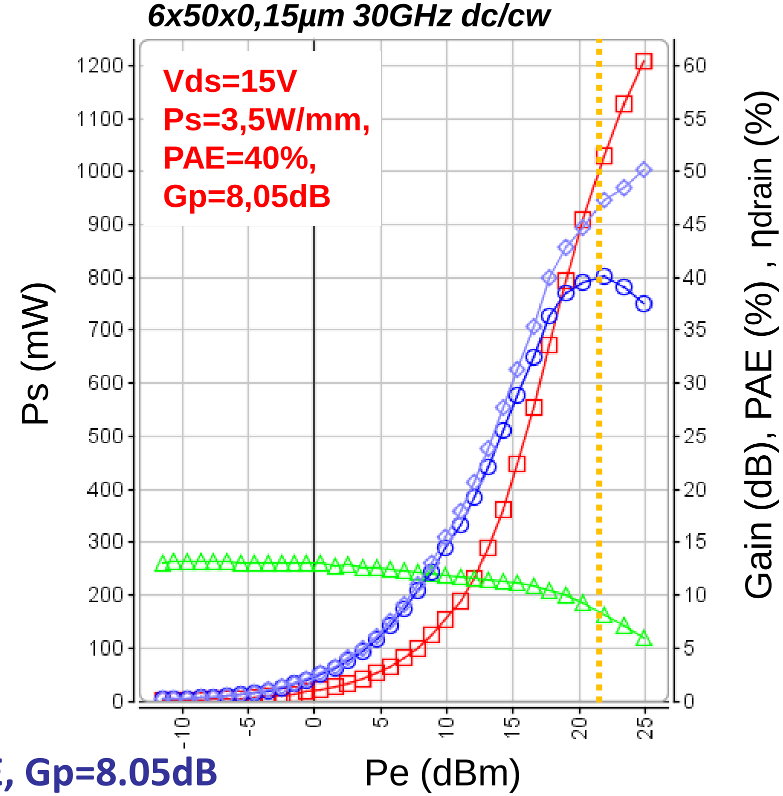


- **Output power depends linearly with Vds**
- **Vds < 20V**
- **4W/mm - 40% PAE - Vds=17.5V**
- **Peak output power 5.12W/mm (34% PAE) at Vds=20V**

InAlN/GaN Power Load-Pull
DC-CW, f0=30 GHz, Ids=200mA/mm (class AB)

6x50µm Lg = 0.15µm (coplanar)





- Max Ps et PAE close, |Γopt|≈0.6
- Vds=15V: Ps=1045mW (3.5W/mm), PAE=40% PAE, Gp=8.05dB
- Vds=17.5V: 1270mW (4.25W/mm), PAE=36%, Gp=7.2dB

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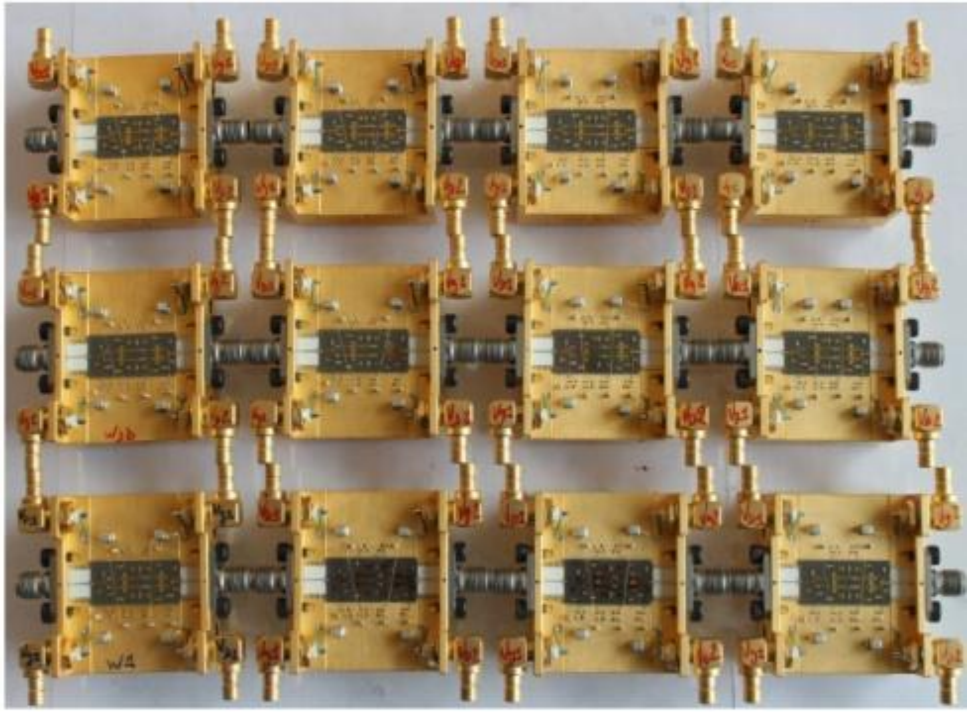
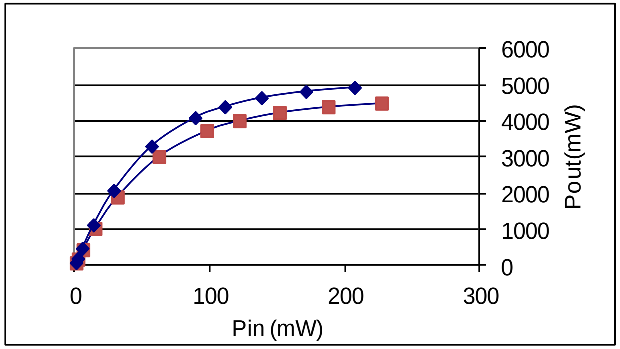
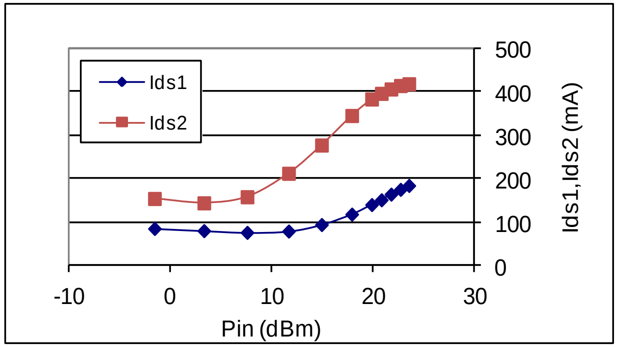
20GHz Hybrid Power Amplifier with flip-chipped HEMT mounting

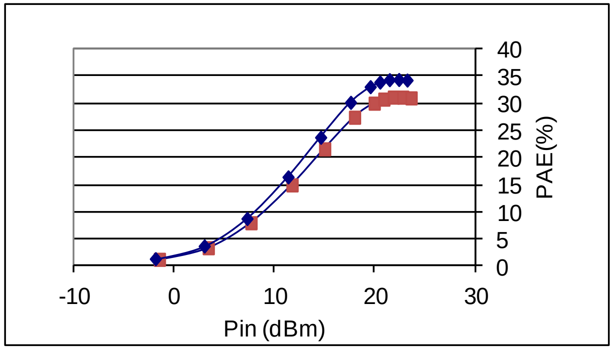
20GHz CW Amplifier
CNES project

- **Vds1= 18 V, Vds2= 25V, classe AB**
- **@Max PAE :**
- **Pout=4.4W, PAE=31%, Gain=13.7dB**









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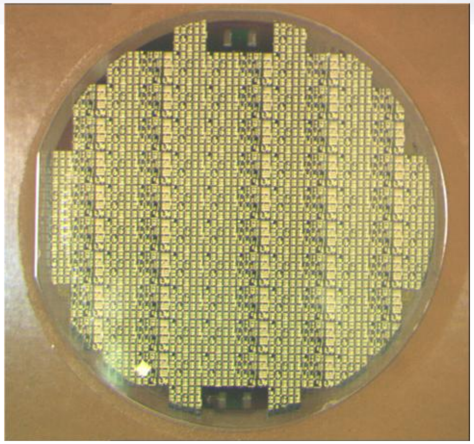
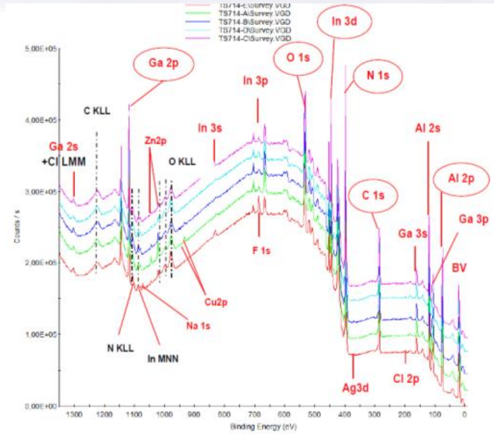
Ka Band Low Noise and High Power Amplifiers

GENGHIS KhAN Project (ANR VERSO 2010)



3'' InAlN/GaN/SiC processed wafer (III-V Lab / UMS)

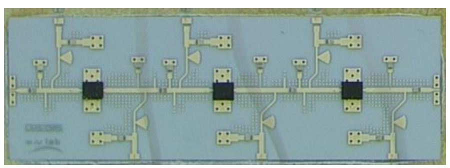


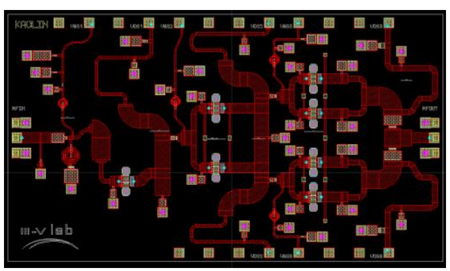
Chemical Analysis of GaN devices (Institut Lavoisier)

Start :01.01.2011
End : 30.09.2014

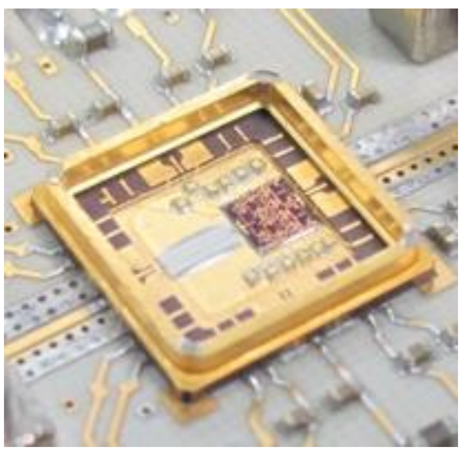
III-V Lab contribution

- Project Management
- InAlN/GaN HEMT development
- Hybrid Ka-Band LNA (LAAS design)
- Ka Band HPA Design





Ka Band amplifiers (LAAS, III-V Lab)

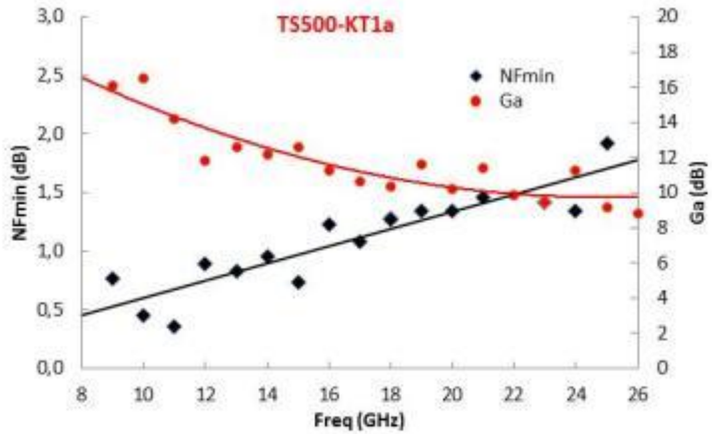


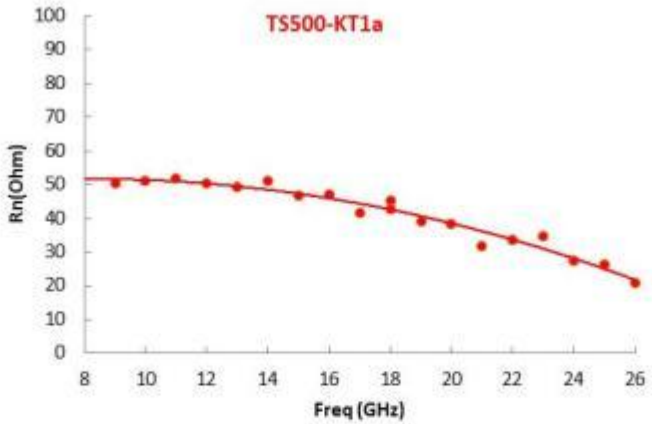
Ka Band package (EGIDE, UMS, TCS)

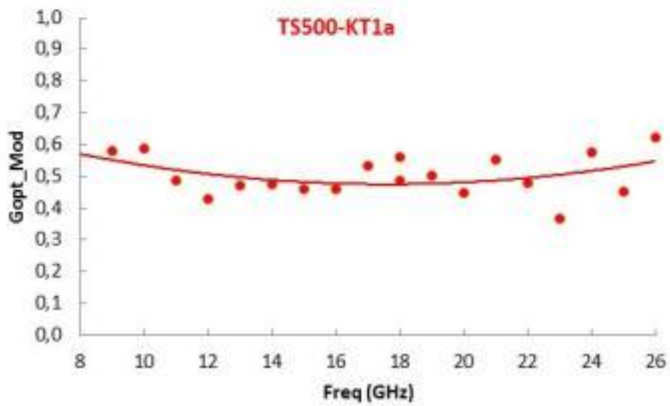
Technology performances (LAAS measurements)

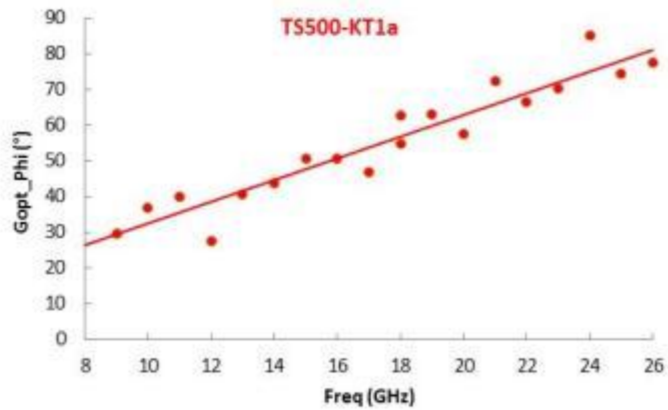
Noise parameters of InAlN/GaN transistors (0,15 µm state of the art)

NF_{min}=1.3 dB et Ga = 10.2 dB @20 GHz



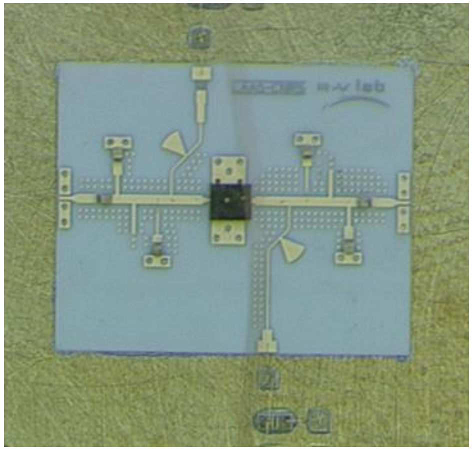




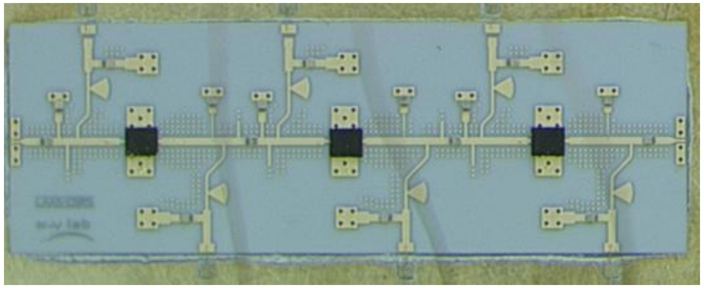


LNA @ 30 GHz

30 GHz LNA

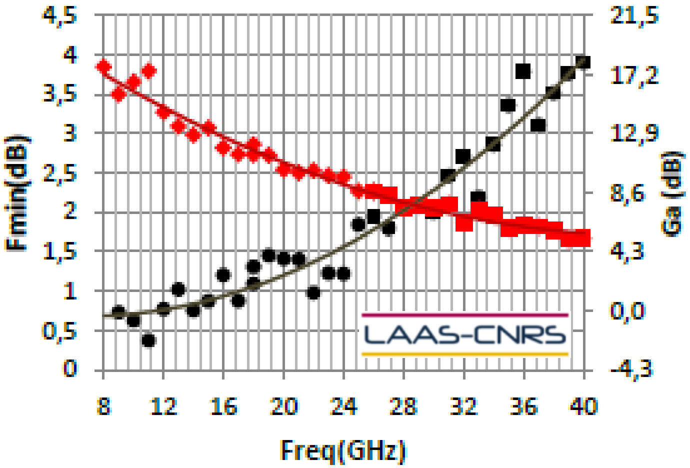


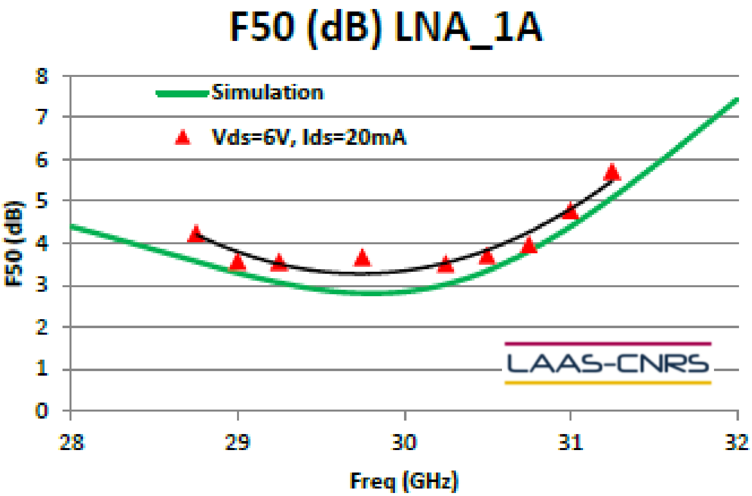
NF = 3.2dB @ 29.5 GHz
Gain = 5.6dB



2x75µm

Vds=6V

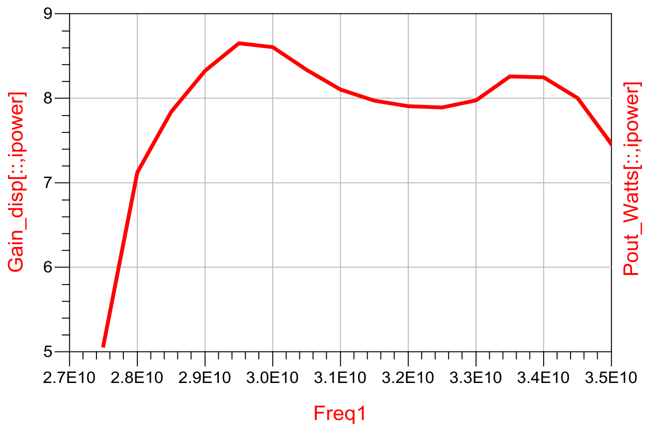


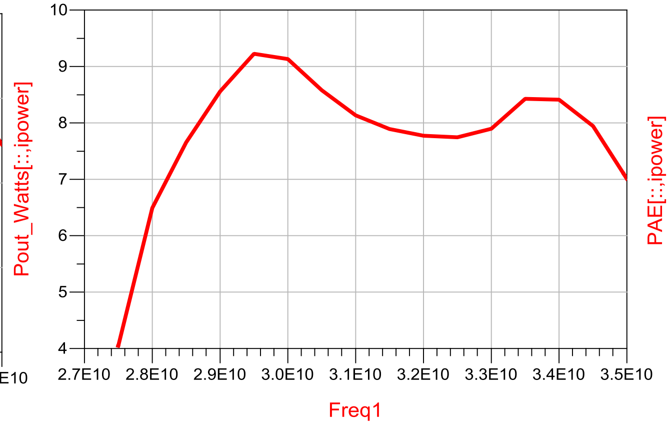


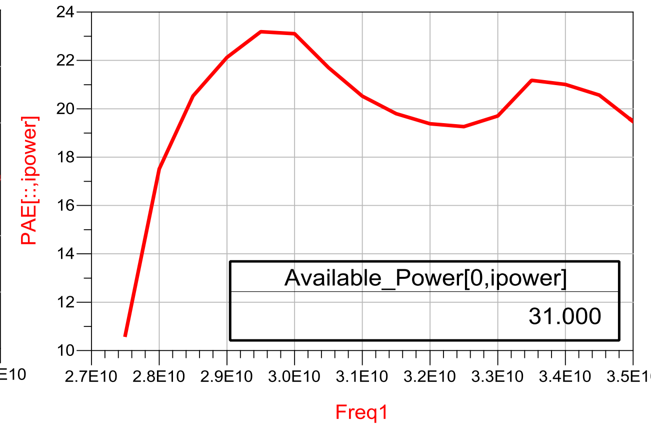
HPA MMIC Design

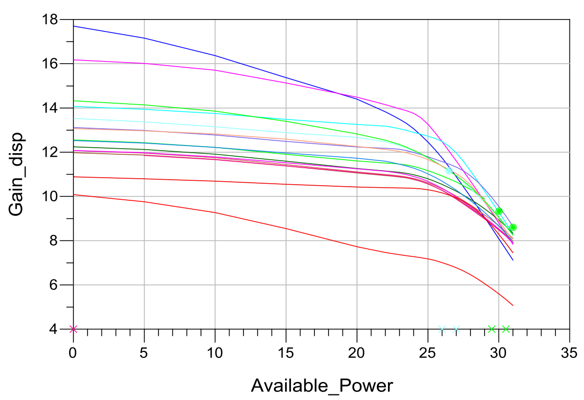
- **Compact NL model : 6x50µm : AlGaN/GaN (March 2014)**
- **3.8W/mm – 33% PAE**
- **Different designs studied:**
  - 2 or 3 stages
  - Balanced architectures
  - [27.5-34.5 GHz] Bandwidth and divided in 2 subbands

2-stage coupled amplifier









- @Pin=31dBm, [28.5-34.5]GHz
  - Pout>7.8W
  - PAE~20-22%
  - Gp>8dB (0.7dB ripple)

Conclusions

- **InAlN/GaN HEMT technology allows high frequency operation,**
- **Important work was carried out during the recent years to reach larger frequencies (heterostructure, gate length, passivation, topology, etc.) supported by experimental and simulations.**

- **Future**
  - Continue effort to mature 0.15µm technology (coming EuGaNiC project),
  - Demonstrate MMIC for Ka and Q Bands (VEGaN-2 project),
  - Push further the gate length reduction (~0.08µm) and optimisation of relevant device modules to address Q-Band and above frequencies.
  - Explore MMIC functionalities enrichment by adding Normally-off device cells.

Thank you for your attention !

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- EDA MANGA
- ANR VERSO Genghis Khan
- EU SPACE AlinWon
- CNES 20 GHz