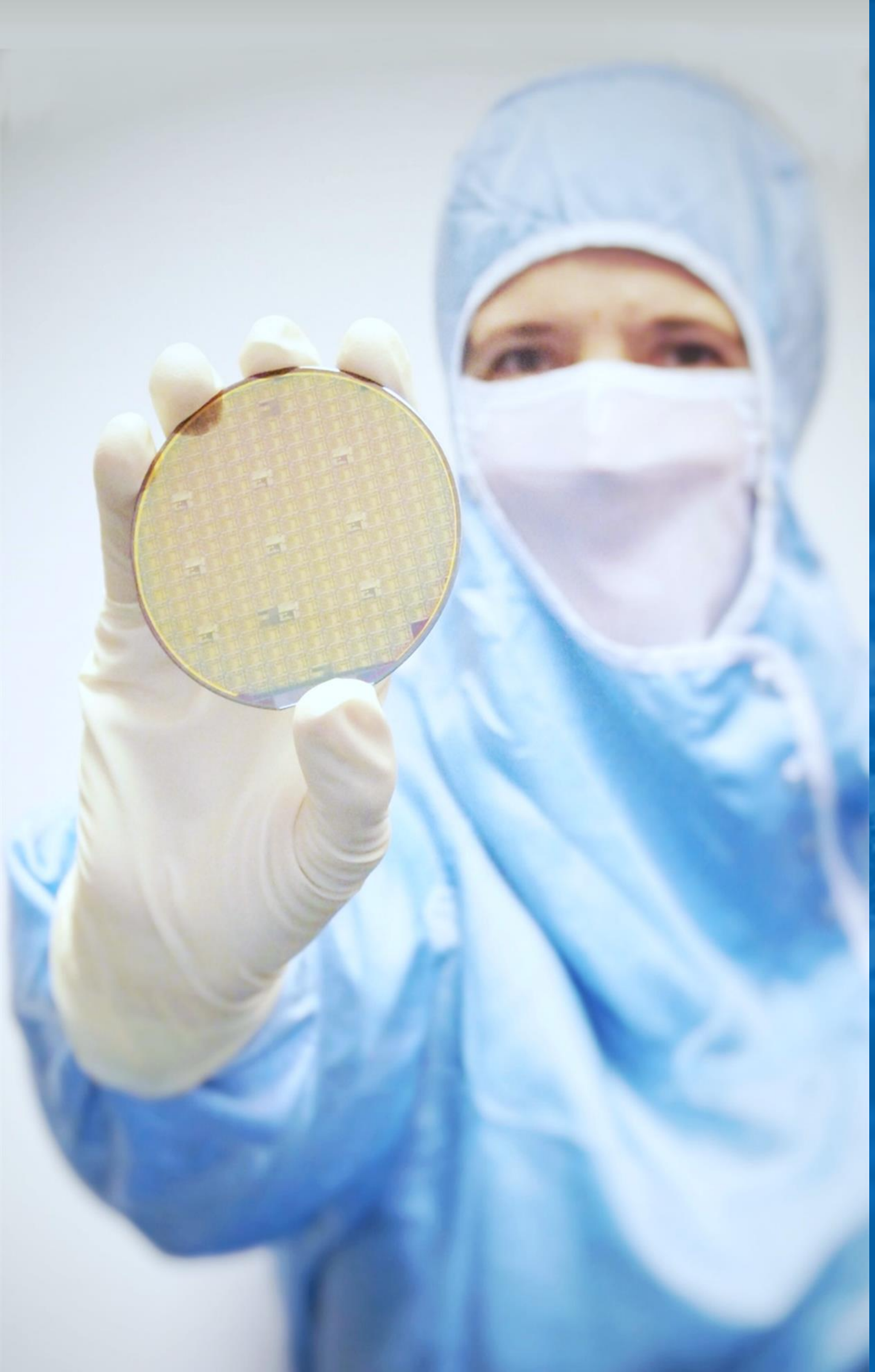


Europe’s Leading Foundry

OMMIC

GaN development and roadmap at OMMIC

Chalmers Winter School 2020

16/01/2020

Outline

- Introduction of OMMIC
- Overview of OMMIC Processes
- Why GaN for mmW MMIC ?
- GaN/Si D01GH technology at OMMIC
- D01GH Electrical Performances
- Some Examples of GaN Circuits
- Development of new GaN Processes
- Summary

Introduction of OMMIC

OMMIC
innovating with III-V'S

1st
6 Inch GaN line in Europe

- Created in 2000
- Former Philips Semiconductor division
- Over 40 years of experience in III-V semiconductors, including GaAs and InP
- Unique GaN Process best suited for upcoming 5G
- Only foundry in Europe offering complete service including Epitaxial Growth, Process Development, MMIC Design & Fabrication, Test & Product Qualification

CORE MARKETS

OMMIC designs and manufactures integrated circuits based on III/V semiconductors (GaAs, InP, GaN) for microwave Tx/Rx Systems from 1 to 400 GHz, addressing ground-based telecom system (2G to 5G)

Introduction of OMMIC

6-inch

GaN Production Line

World's 1st 6'' GaN Line in Production
40 Millions Euros Investment

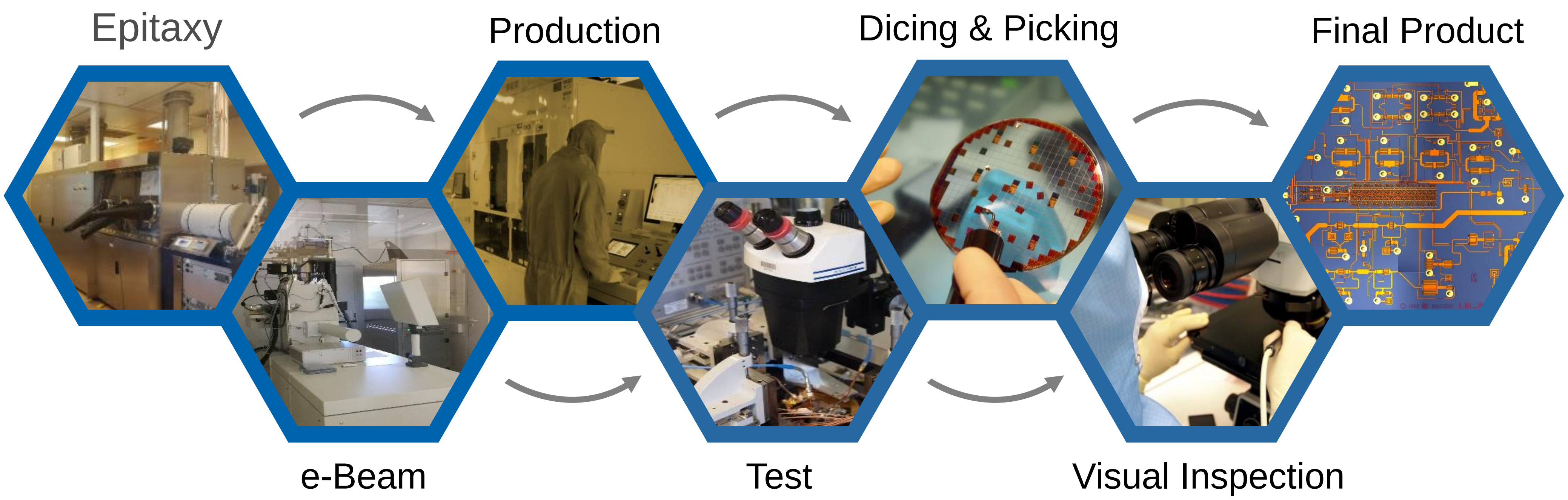
The new 6-inch GaN production line will largely boost OMMIC's production capability by 4 times. Combined with improved production yield and increased work shifts, it is estimated to have 7 times of present production capabilities.

Thanks to improved process automation and 5 work shifts in 2021, lead time will be reduced to 7 weeks

Introduction of OMMIC

PRODUCTION FLOW

OMMIC offers fully open foundry service with its advanced processes available for customers, delivering the best performance product in the market.

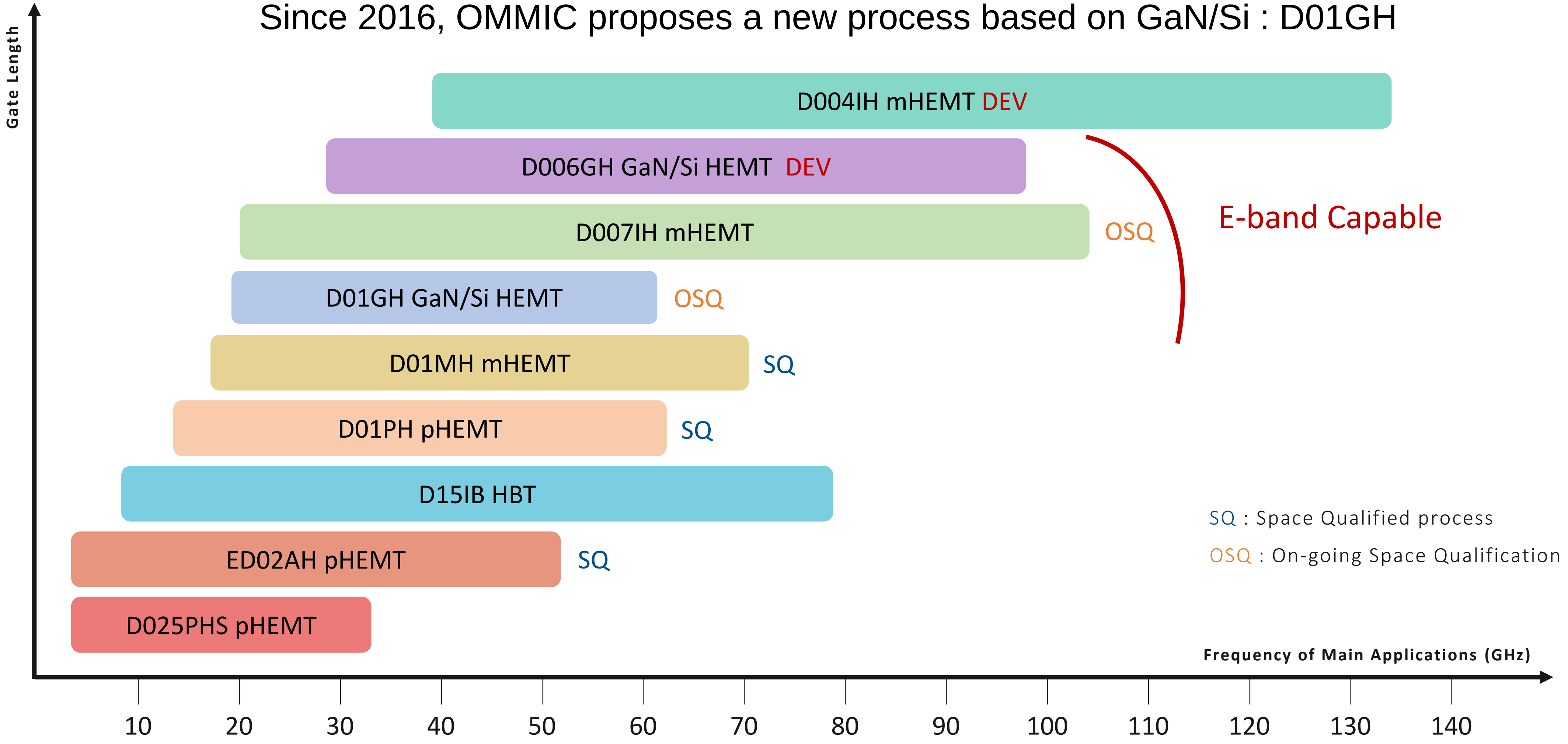


Overview of OMMIC Processes

OMMIC innovating with III-V'S

OMMIC PROCESSES

Since 2016, OMMIC proposes a new process based on GaN/Si : D01GH



Overview of OMMIC Processes

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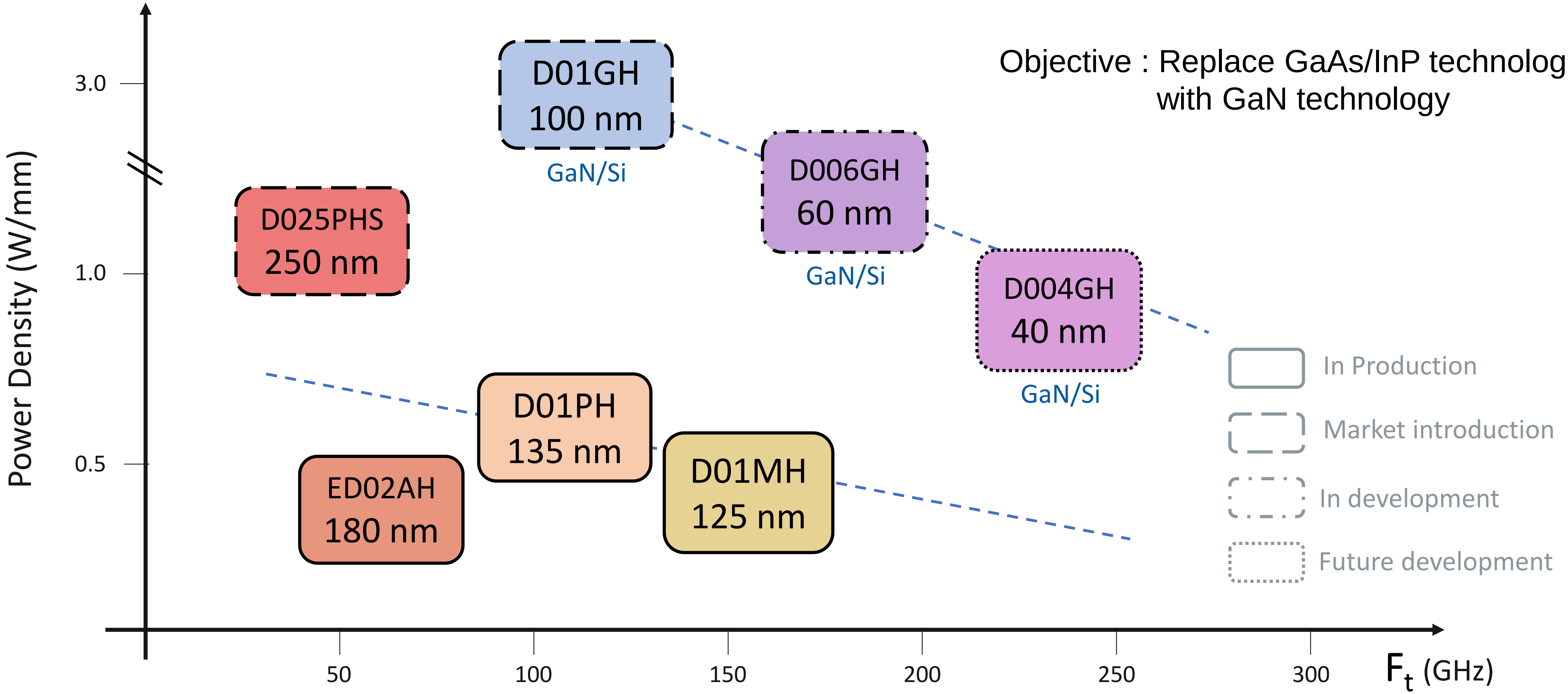
innovating with III-V'S

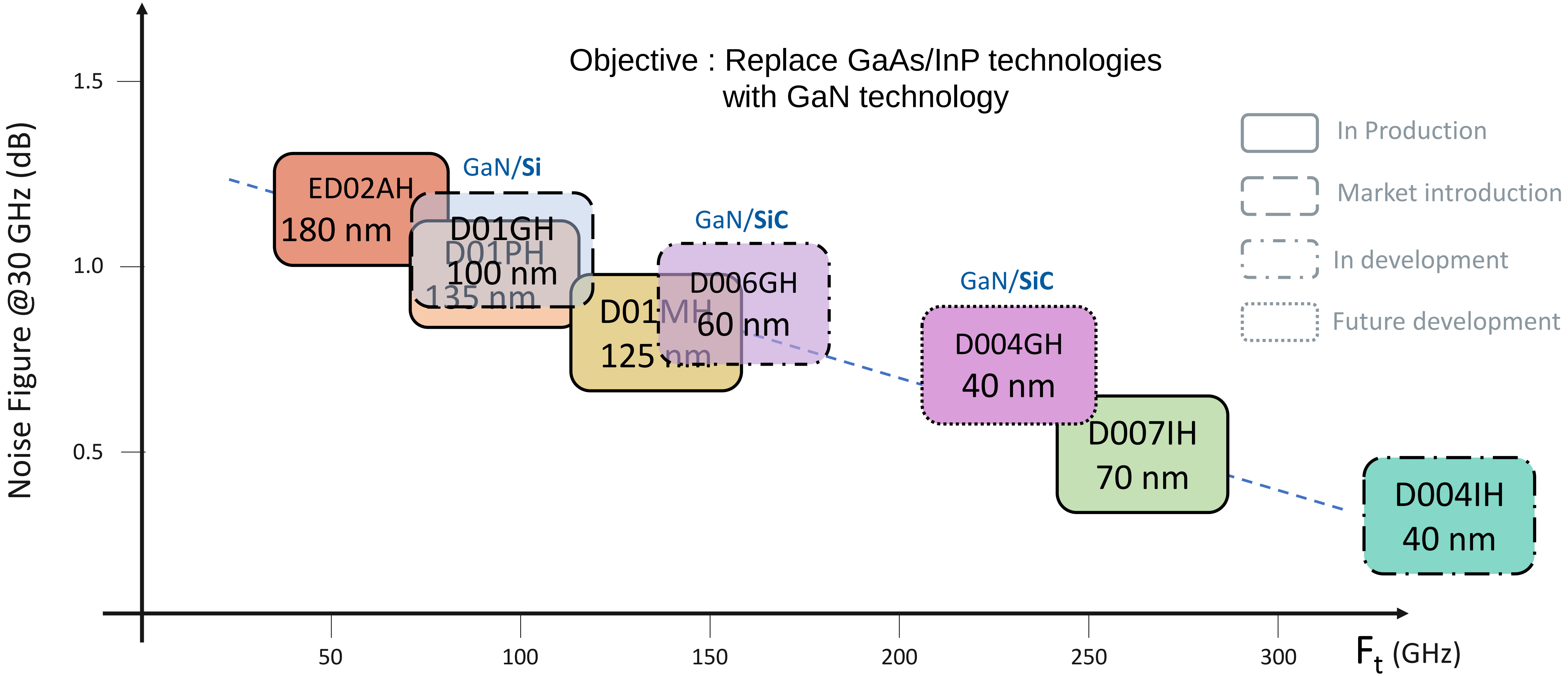
PROCESSES POWER



Overview of OMMIC Processes

OMMIC innovating with III-V'S

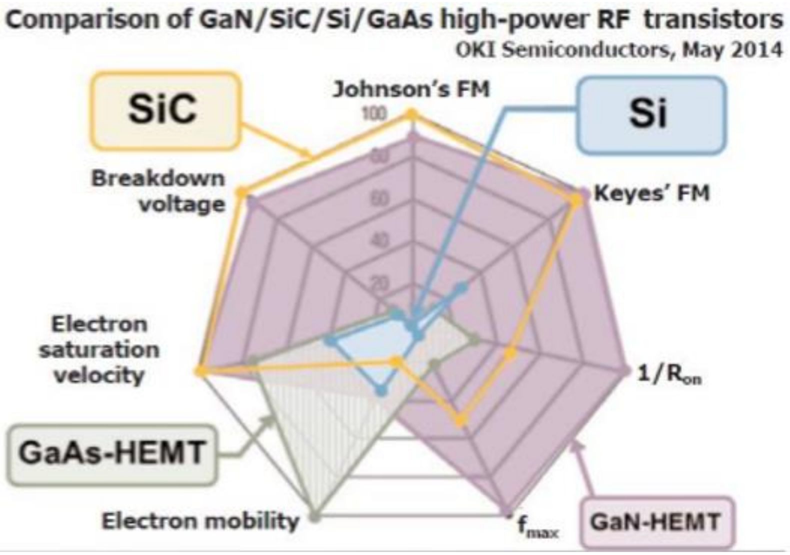
PROCESSES NOISE



Why GaN for mmW MMIC?

GaN's ADDED VALUES

GaN is an ideal semiconductor for **high efficiency**, **wide-band** RF power amplifiers



Semiconductor	Si	InP	GaAs	GaN
Bandgap Eg (eV)	1.1	1.34	1.43	3.4
Breakdown Field Ebr (MV/cm)	0.6	0.45	0.5	3.5
Charge Density n_s ($10^{13}/cm^2$)	0.3		0.3	1
Saturation Velocity v_{SAT} (10^7 cm/s)	1	0.68	2	2.7
Mobility ($cm^2/V.s$)	1300	5400	6000	1500
Thermal Conductivity (W/cm.K)	1.5	0.67	0.5	1.5-3.4

High voltage

High Current

High Frequency

High Jonction Temperature

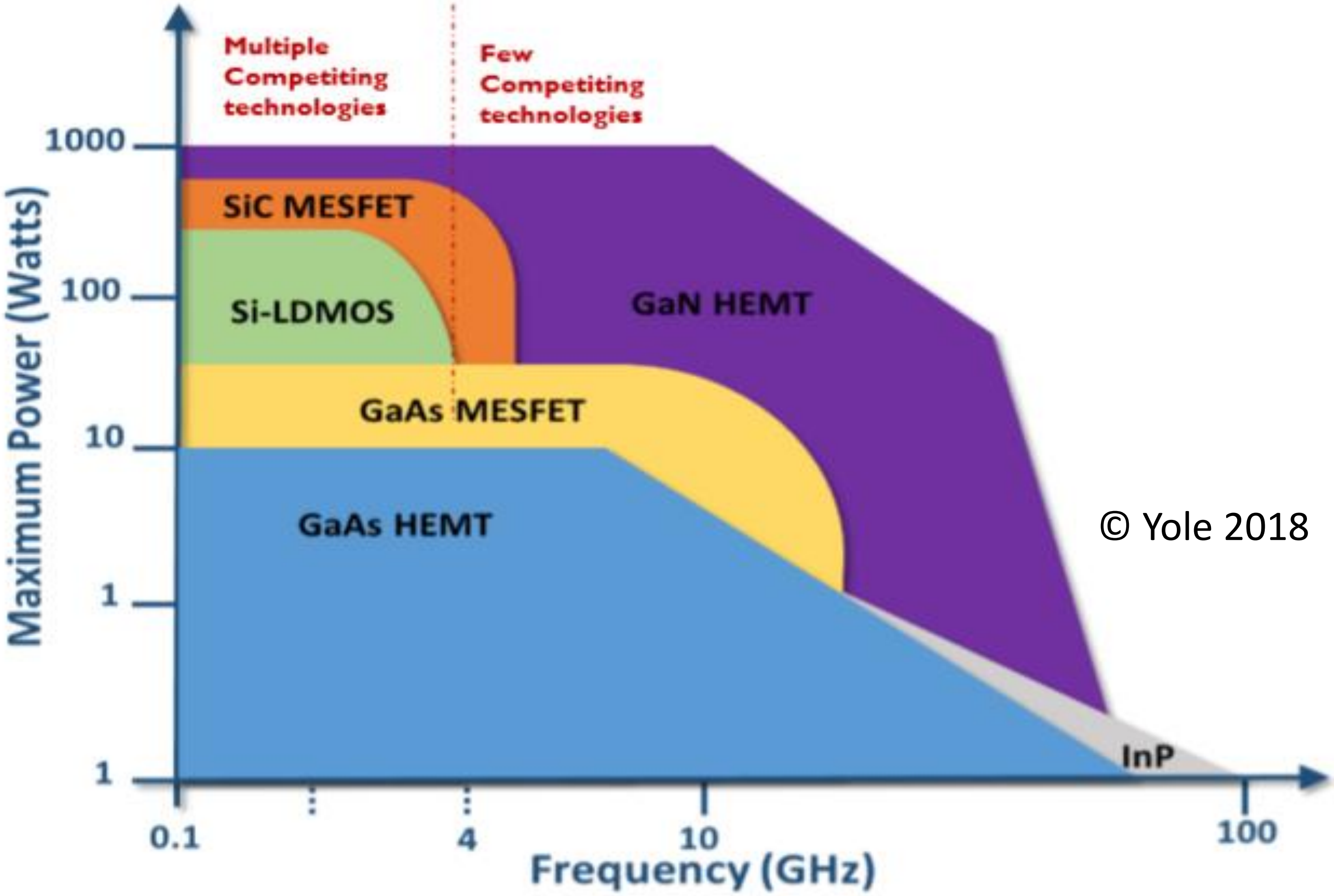
- ✓ High Efficiency
- ✓ High Power density
- ✓ Low capacitance
- ✓ Wide Band-Width
- ✓ Small Size

Why GaN for mmW MMIC?

OMMIC innovating with III-V'S

Power and frequency regions for different semiconductors

GaN enables new possibilities for both high-power and high-frequency



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Why GaN for mmW MMIC?

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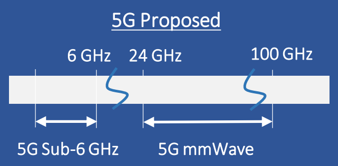
GaN/Si FOR 5G

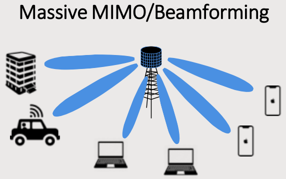
- High frequency
- High efficiency



- Low voltage
- Small size
- High linearization

- Small size
- High temperature
- High reliability

- Ultra-wide band linearization
- Small package/high power



5G

- Only GaN technology can offer enough power at high frequency 28 GHz/ 40 GHz
- OMMIC proposes state-of-the-art GaN/Si technology for higher frequency of 5G application
- OMMIC's 100nm GaN/Si process is unique in the world and perfectly suited for 5G

HIGH FRESQUENCY FIGURE OF MERIT FOR RF CIRCUITS

Remember :

f_T is related to current gain ⇔ How fast transistors can charge (loading) capacitors => fT is more relevant for high-speed circuits

F_{max} is related to power gain ⇔ maximum gain reachable for an amplifier => fmax is more relevant for RF and mmW circuits.

Maximizing RF performance :

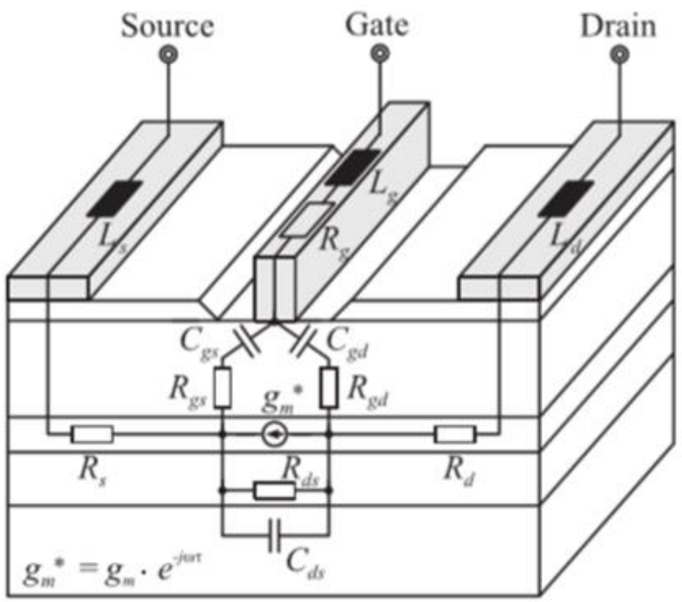
To obtain high power and increase frequencies, it is necessary to improve material growth and the technological process

Material :

⇒ Low defect density
⇒ High charge density (ns)
⇒ high carrier mobility (µ)
⇒ Good electron confinement

Technology :

⇒ Decrease in gate length (Lg)
⇒ Reduction of short channel effects
⇒ Reduction of parasitic elements
⇒ Disappearance of trap effects
⇒ Unalloyed ohmic contacts



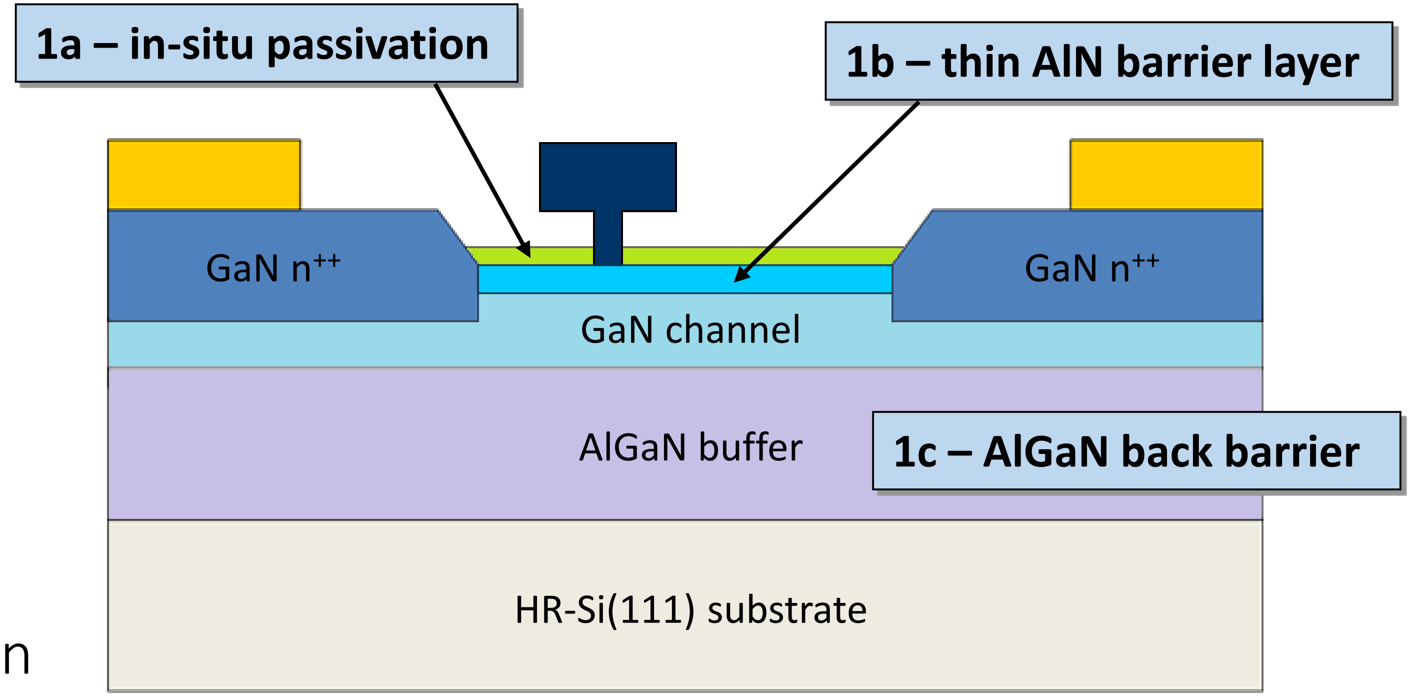
$$f_T = \frac{gm}{2\pi(C_{gs}+C_{gd}+C_{gb})}$$

$$f_{max} = \frac{f_T}{2\sqrt{g_{ds}(R_g+R_s)+2\pi f_T R_g C_{gd}}}$$

GaN/Si Technology at OMMIC

EPITAXIAL STRUCTURE

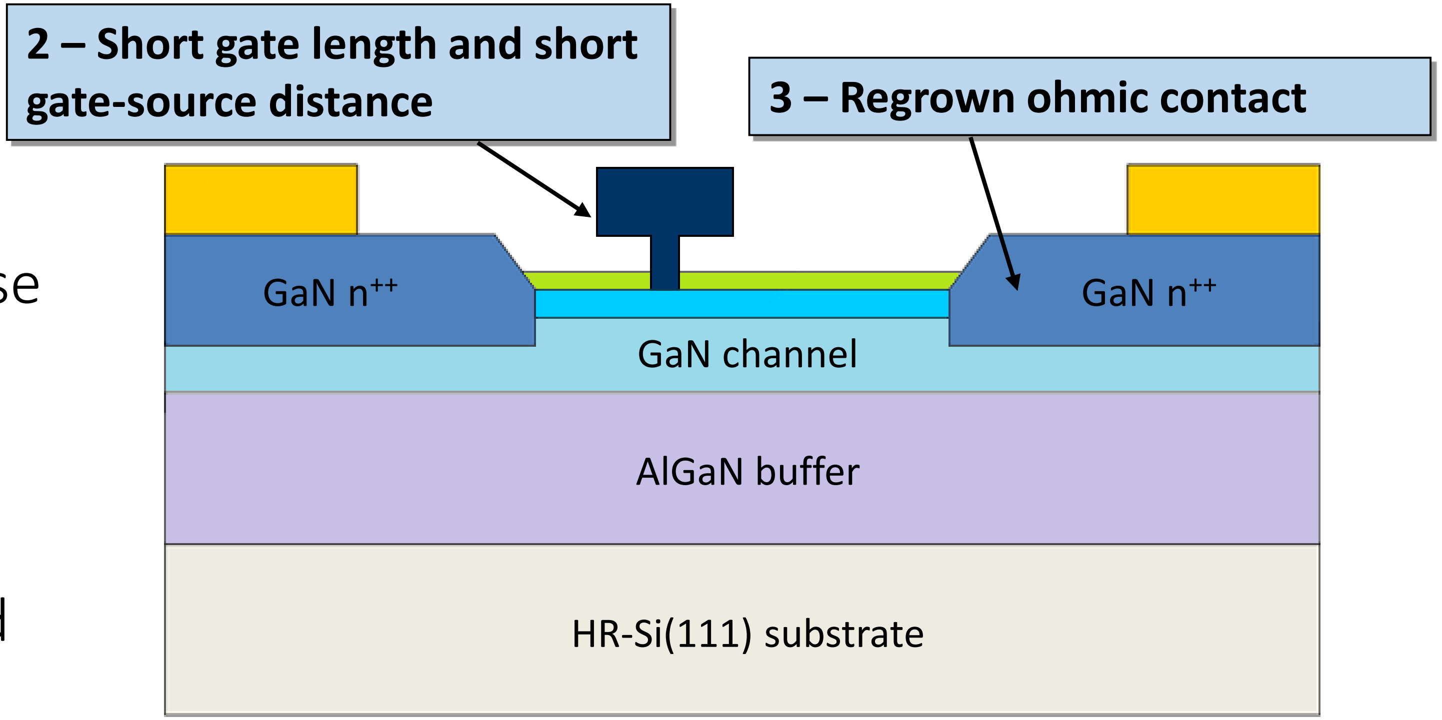
- In situ passivation to avoid trapping / memory effects
- Thin AlN barrier to mitigate short channel effects
- AlGaN back barrier to improve electron confinement.



TECHNOLOGICAL STRUCTURE

- Short gate length **(100nm)** and short gate-source distance **(250nm)** to increase RF performances

- Regrown ohmic contact to minimize access resistance (R_c < 0.1 ohm.mm and R_{ON} < 1 ohm.mm)



WHY GAN/SI SUBSTRATE?

❖ Pros…

- Lower cost, larger diameters
- Lower risk of import/export restrictions (Itar, etc)
- Compatible with heterogeneous integration
- Compatible with 5G global market, thus probably the highest in the coming years.

❖ Cons…

- Higher Rth (approx. x2), but not all applications are impacted
- Higher microwave losses (impact??)

❖ OMMIC policy

- GaN process dedicated to high frequency (Lg, R_S, AlN, Ohmic contact)
- Both Si and SiC will be proposed, with same devices 100nm & 60nm on top
- In the short term (1 to 2 years), only Si is proposed, to address 5G

GaN/Si Technology at OMMIC

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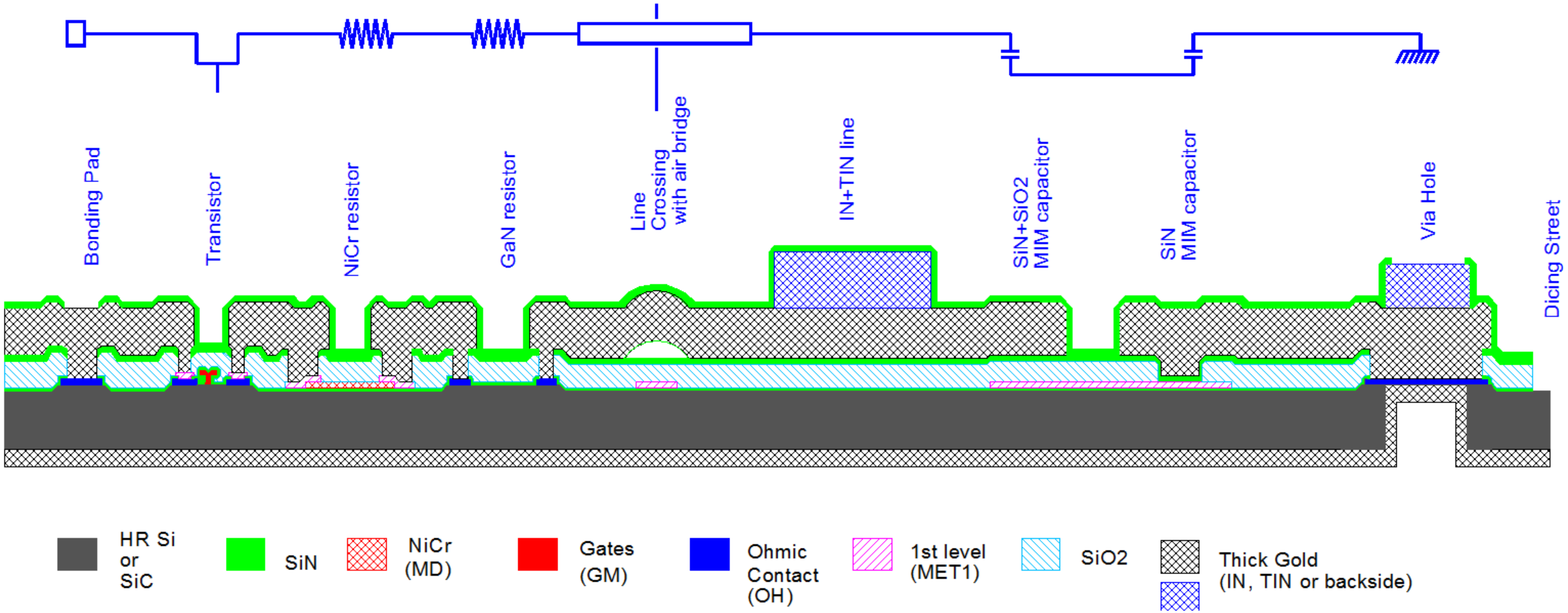
innovating with III-V'S

D01GH MMIC CROS SECTION

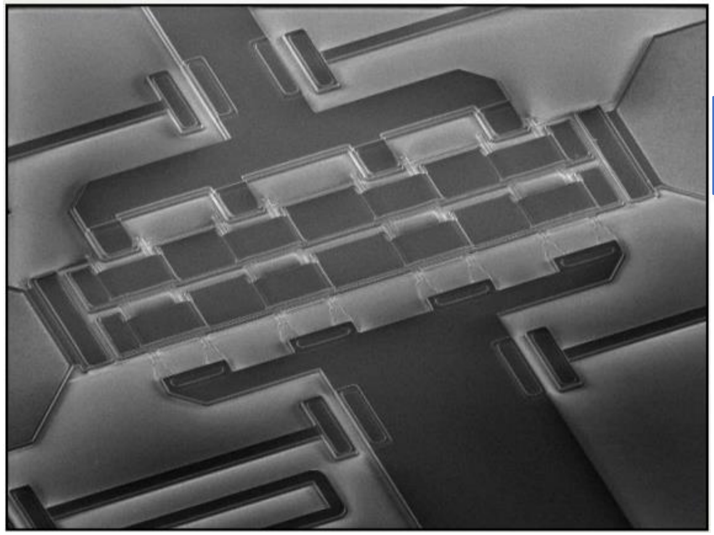


Via holes (Bosch process), air-bridges, NiCr & GaN resistors, SiN & SiO2 MIM capacitors to allow mm-wave designs.
No metal layer of passive components directly on substrate.

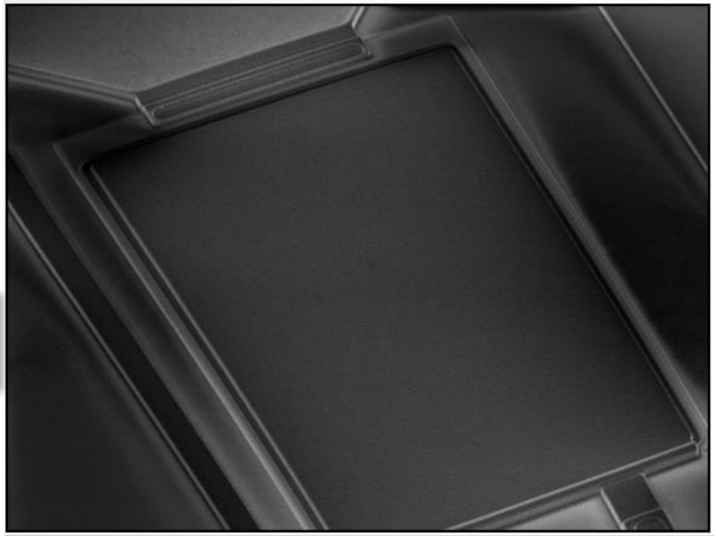
GaN/Si Technology at OMMIC

OMMIC
innovating with III-V'S

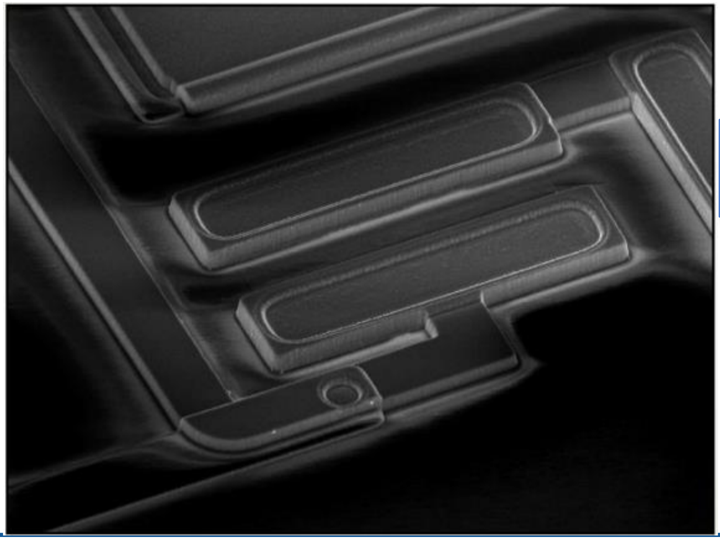
SEM OBSERVATIONS AT END OF PROCESS



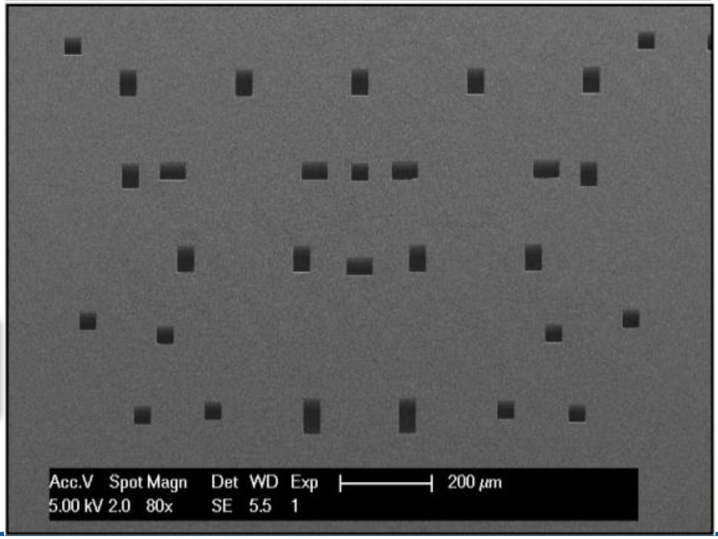
8*50µm GaN HEMT



MIM Capacitor



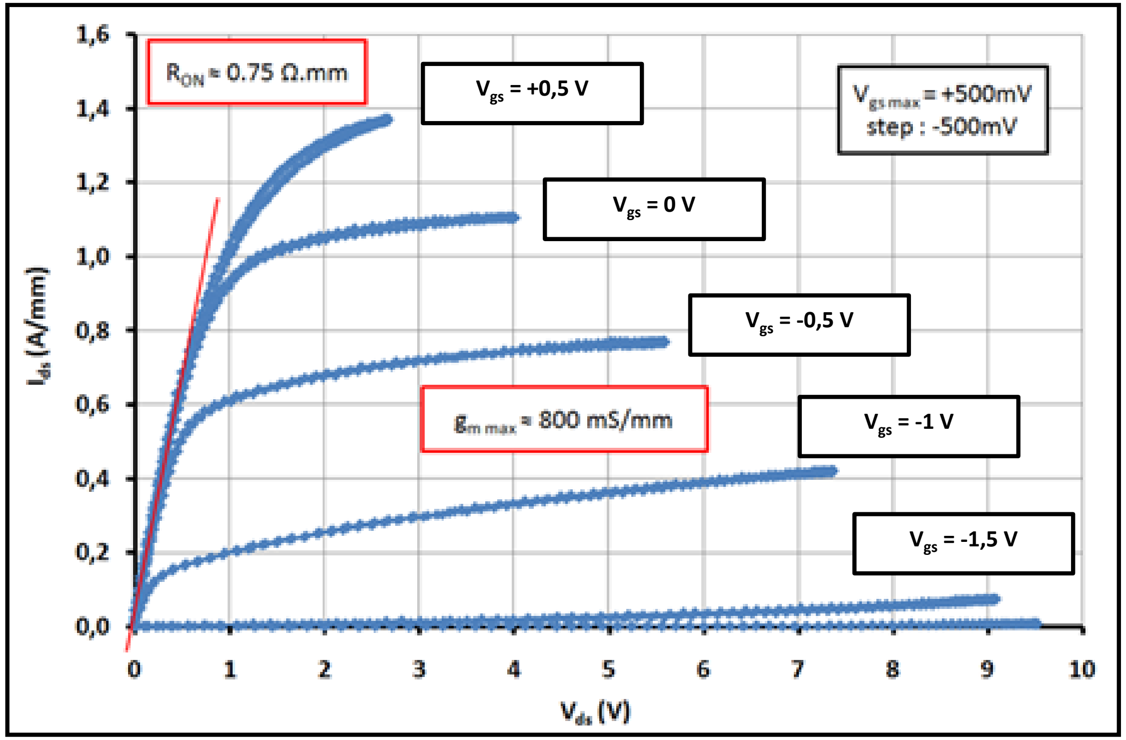
NiCr Resistor

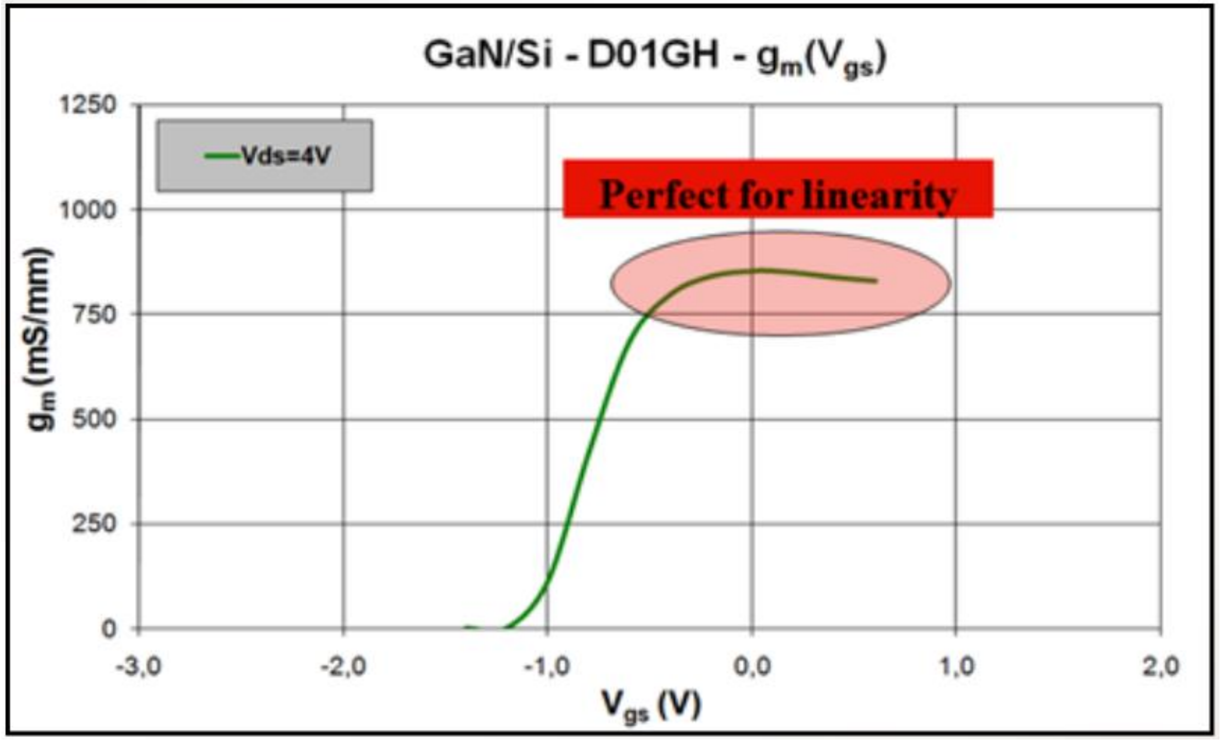


Via-holes

D01GH Electrical Performances

$I_D(V_D)$ and $G_m(V_G)$ characteristics (2*50µm GaN HEMT)



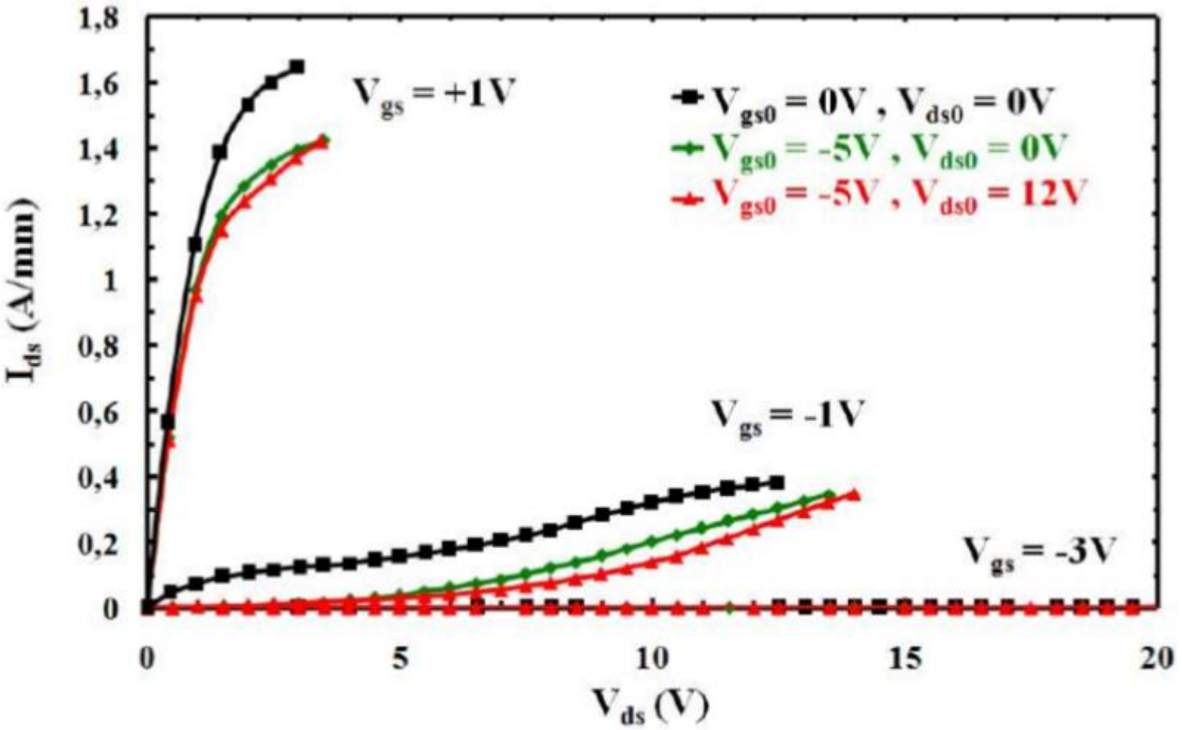


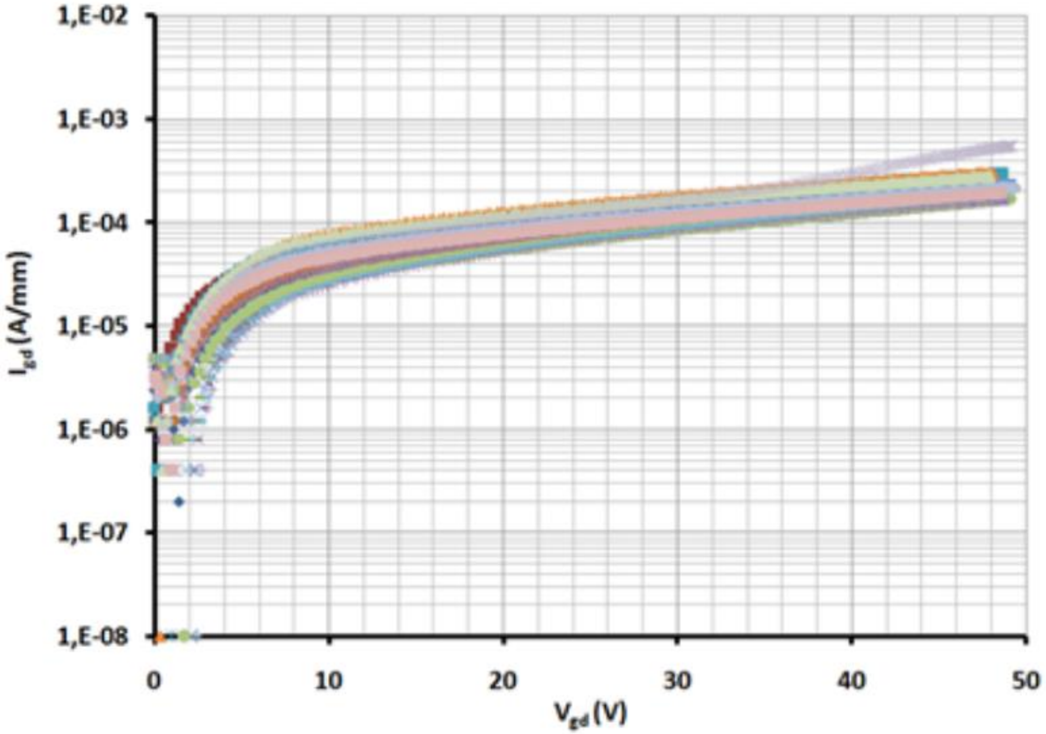
Very low ON-resistance <1ohm.mm and Very high transconductance >800mS/mm

(Regrown ohmic contact & very thin AlN barrier)

D01GH Electrical Performances

D01GH PULSED I(V) AND B-V CHARACTERISTICS



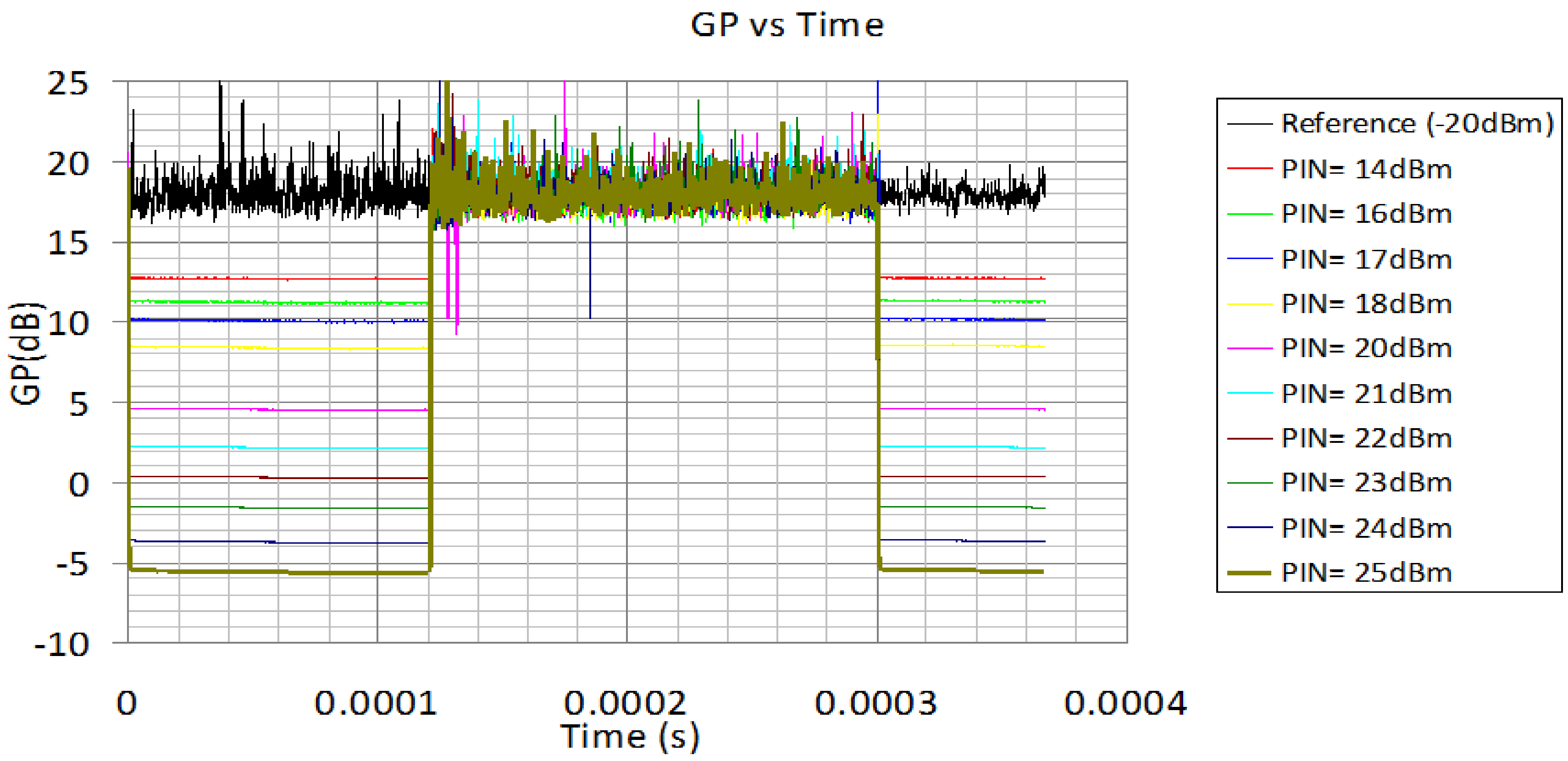


Drain LAG = 2%, Gate LAG = 15% (No traps) and Breakdown voltage >50V

(Back barrier & In-Situ passivation)

OMMIC innovating with III-V'S

D01GH MEMORY EFFECT



No measurable Recovery Time after 24 dBm aggression

- 2x35 µm device
- +25 dBm input power
- 40 % duty cycle
- Low noise bias

In-Situ Passivation

D01GH Electrical Performances

OMMIC D01GH MAIN CHARACTERISTICS

Electrical Characteristic	100 nm
Frequency Cut-off (H21)	105 GHz
Maximum Stable Gain @30 GHz	13 dB
Min Noise Figure / Ass. Gain @40 GHz	1.8 dB / 7.5 dB
RF Power Density	3.3 W/mm (5.7 W/mm meas. peak)
Extrinsic Transconductance	800 mS/mm
Source Resistance	0.18 Ohms.mm
Extrinsic Drain Source resistance Vds=0V (Ron)	0.6 Ohms.mm
Gate Drain voltage for 300µA/mm	40 V
Quiescent Voltage	12 V

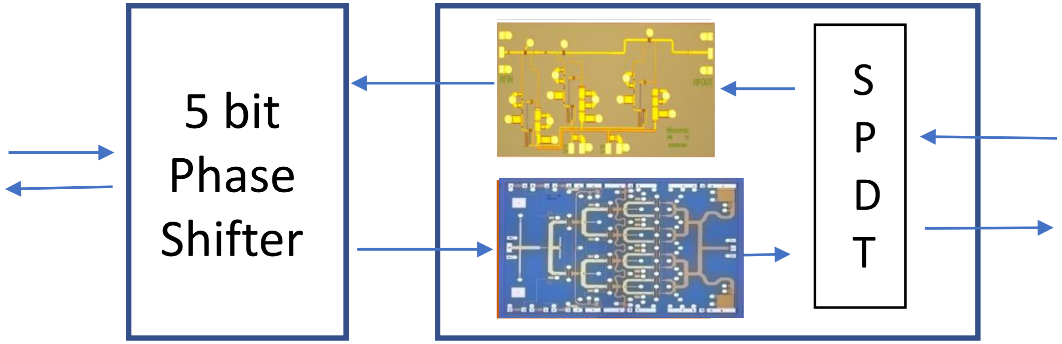
Some examples of GaN Circuits

OMMIC innovating with III-V'S

5G GaN SOLUTION

2017

CGY2260UH/C1 | mHEMT GaAs

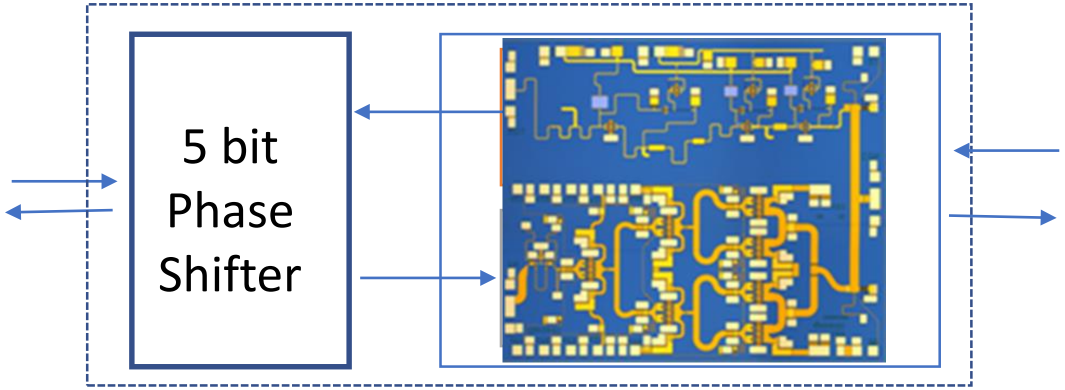


GaAs or CMOS

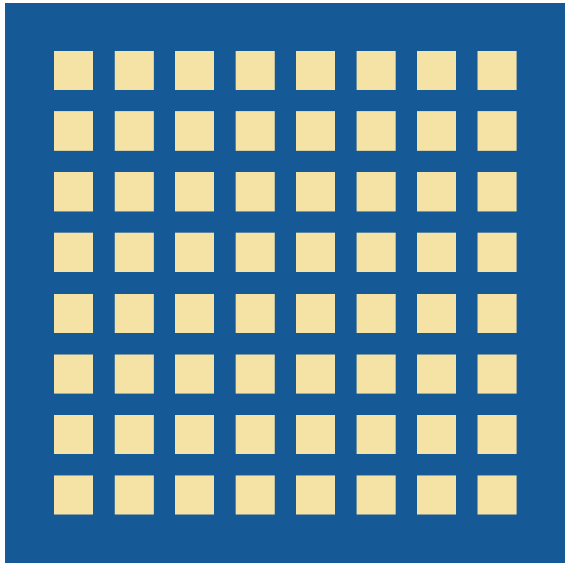
OMMIC D01GH mmW GaN/Si

Two-die Chipset

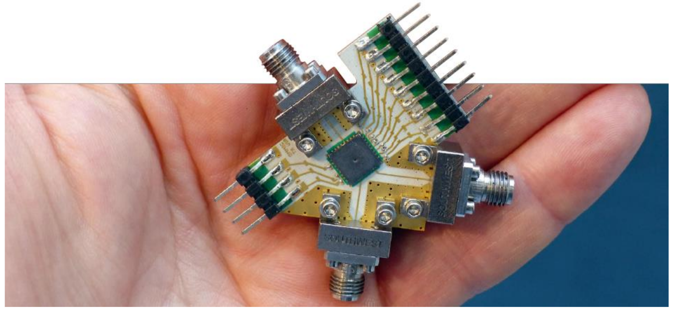
2018



Single Chipset GaN/Si (D01GH)



Massive MIMO Array Antenna



Some examples of GaN Circuits

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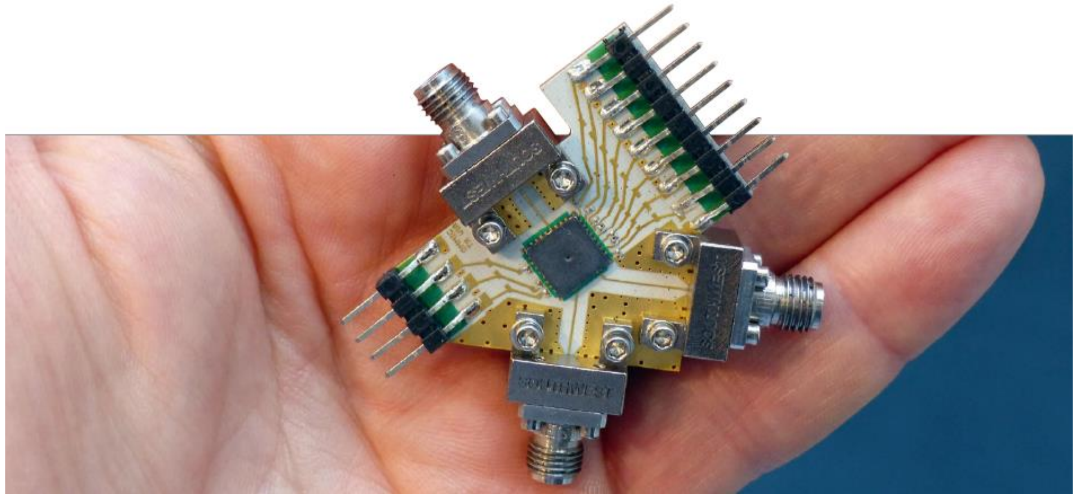
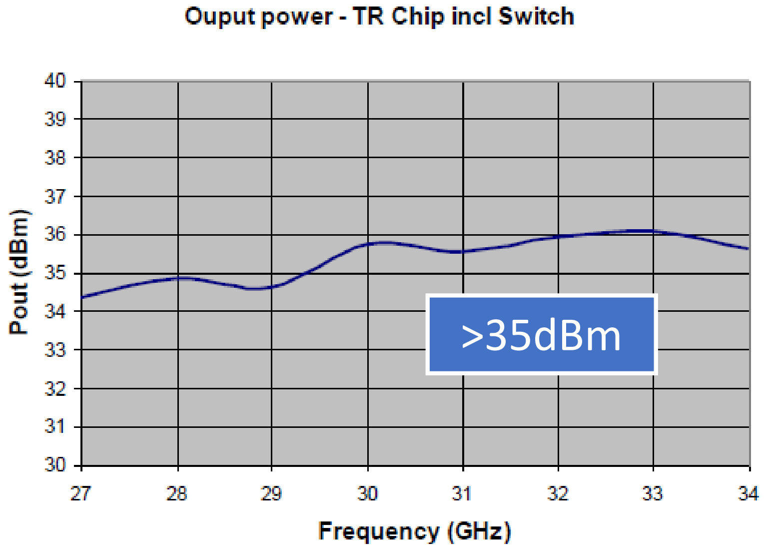
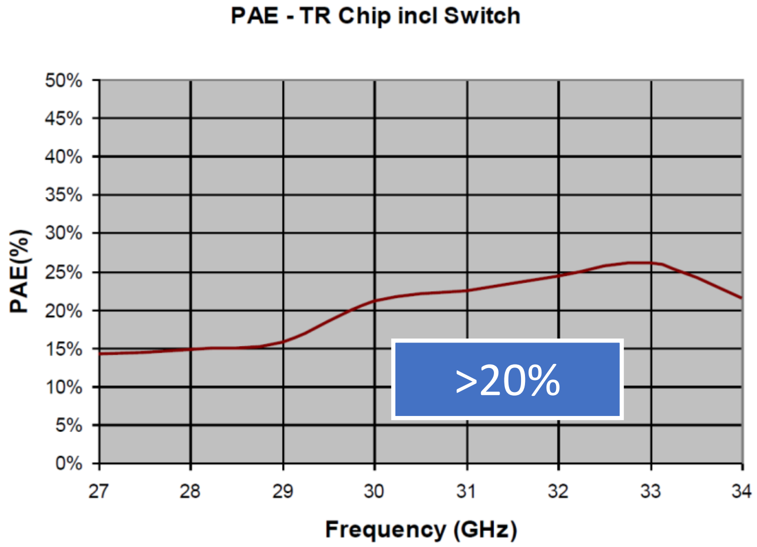
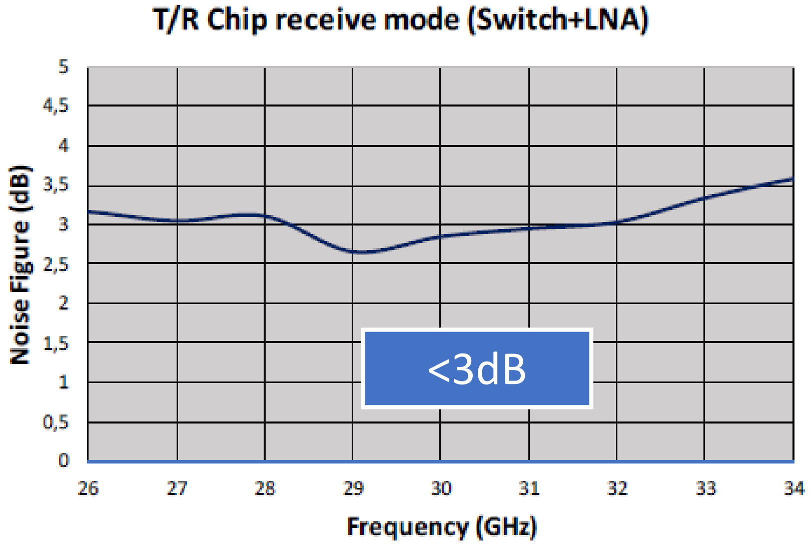
GaN 30GHz T/R Chip D01GH



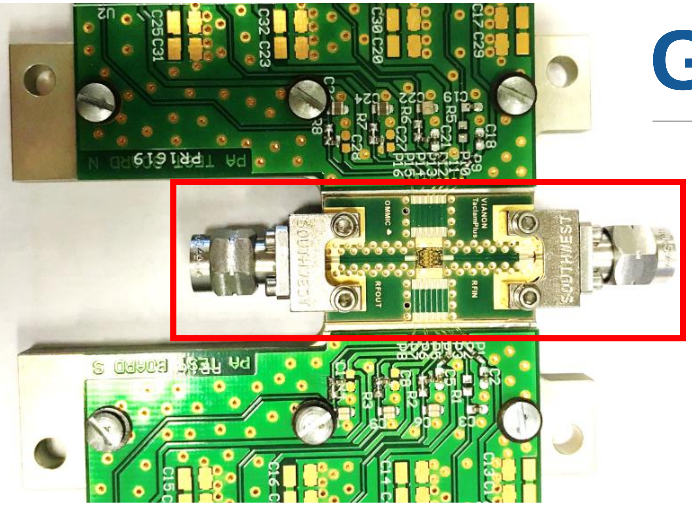




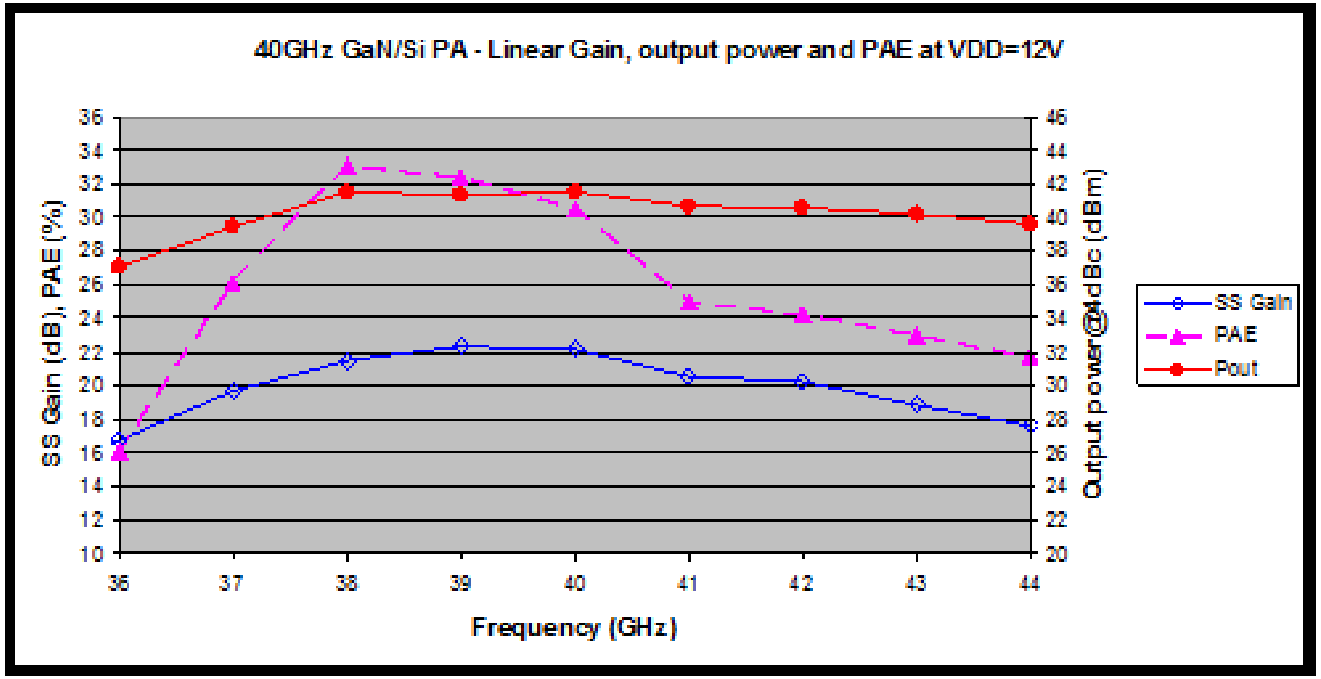


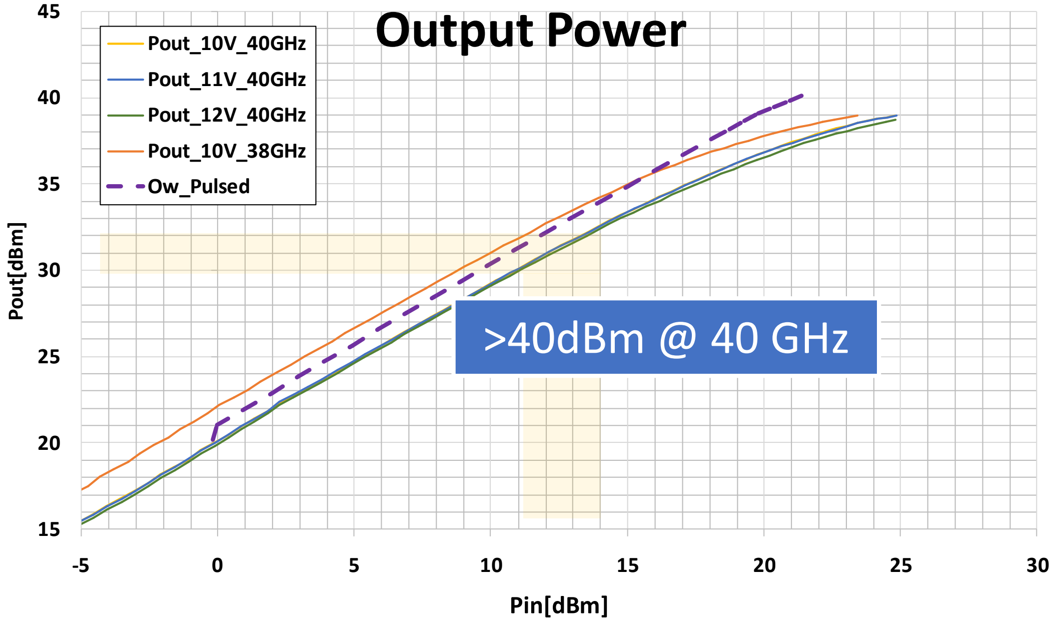
Some examples of GaN Circuits

GaN 37-43GHz 10W PA D01GH



PAE 30% @ 40GHz





>40dBm @ 40 GHz

On Wafer Pulsed *vs.* CW test on fixture

Some examples of GaN Circuits

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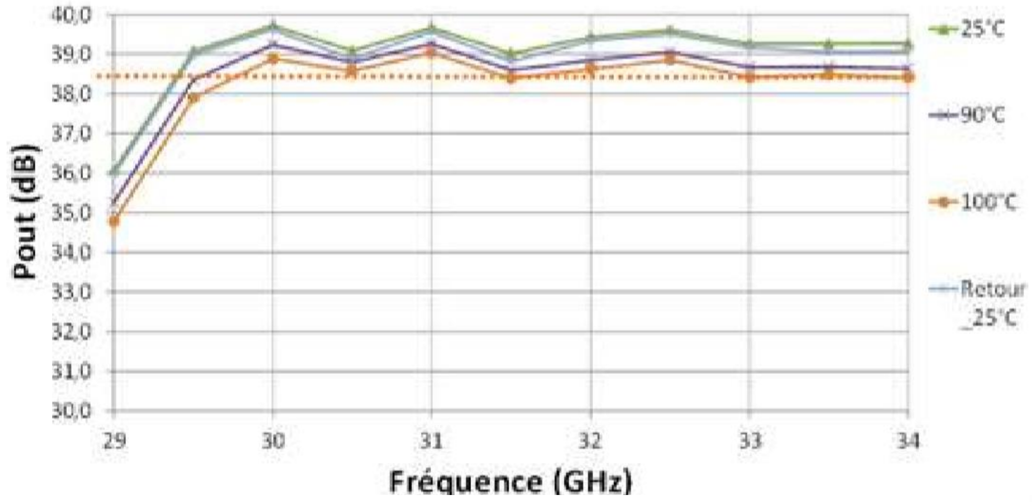
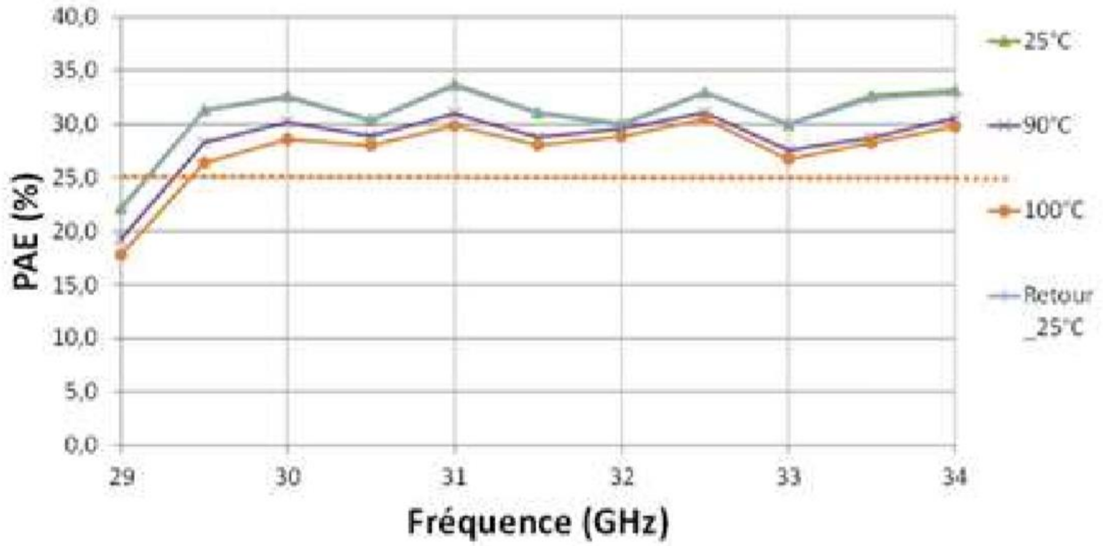
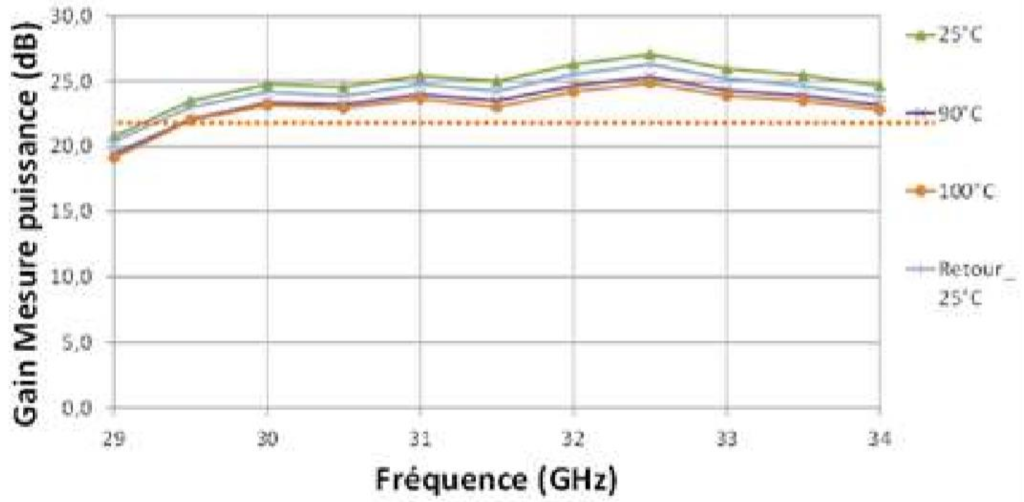
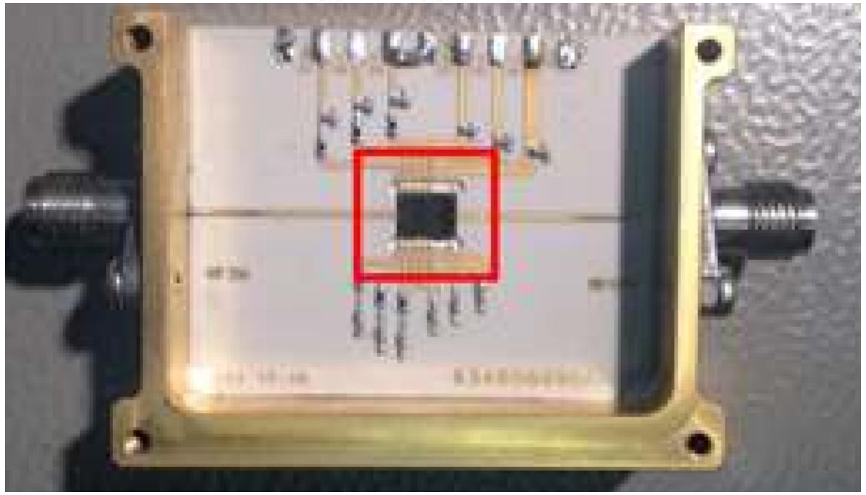
GaN 30GHz 10W PA (vs Temp, CW)





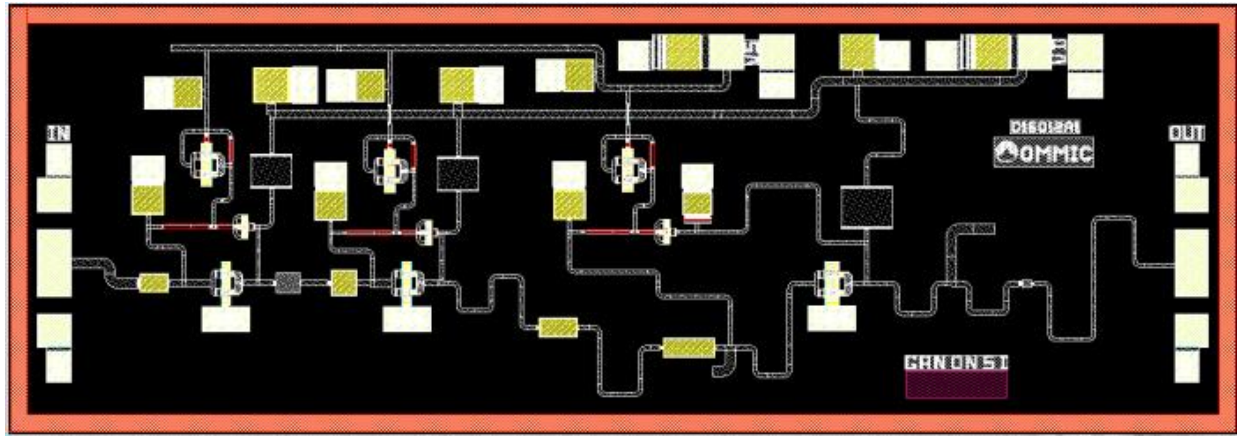




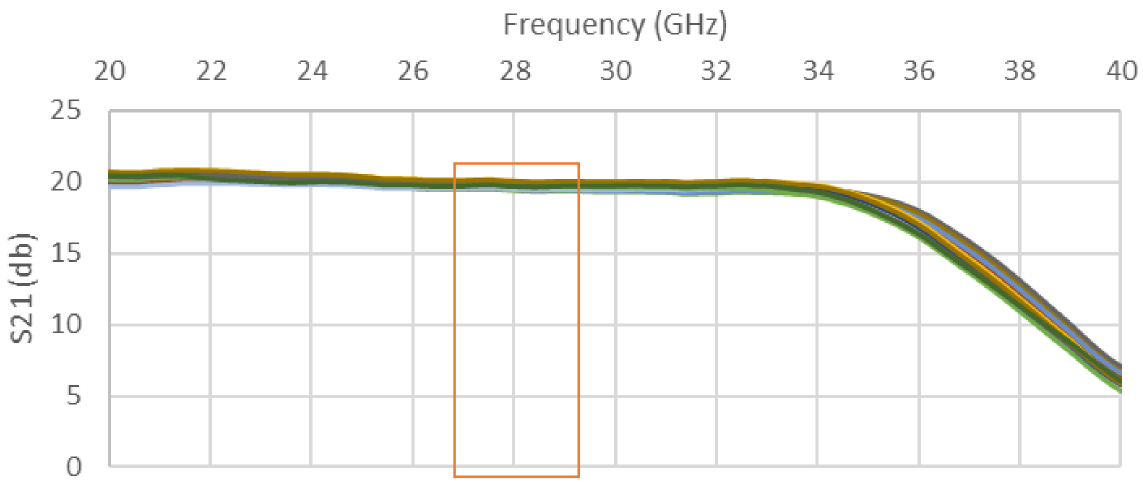
Some examples of GaN Circuits

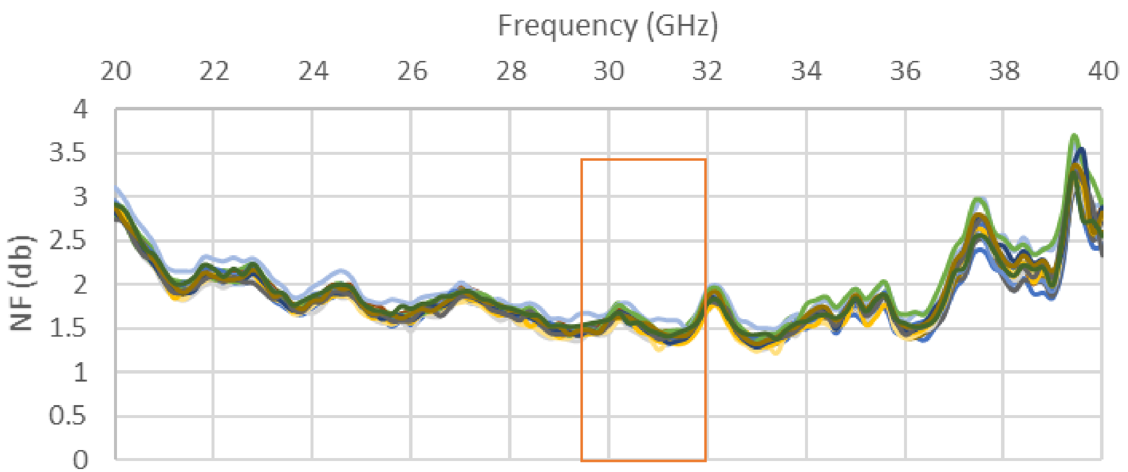
OMMIC innovating with III-V'S

Robust Ultra Low Noise 24-34GHz LNA



- Single VDD/VSS
- Vdd=8,5V / 90mA
- Gain= 20dB
- NF<2dB at Fc
- Robust: >33 dBm during 5 min. with no degradation

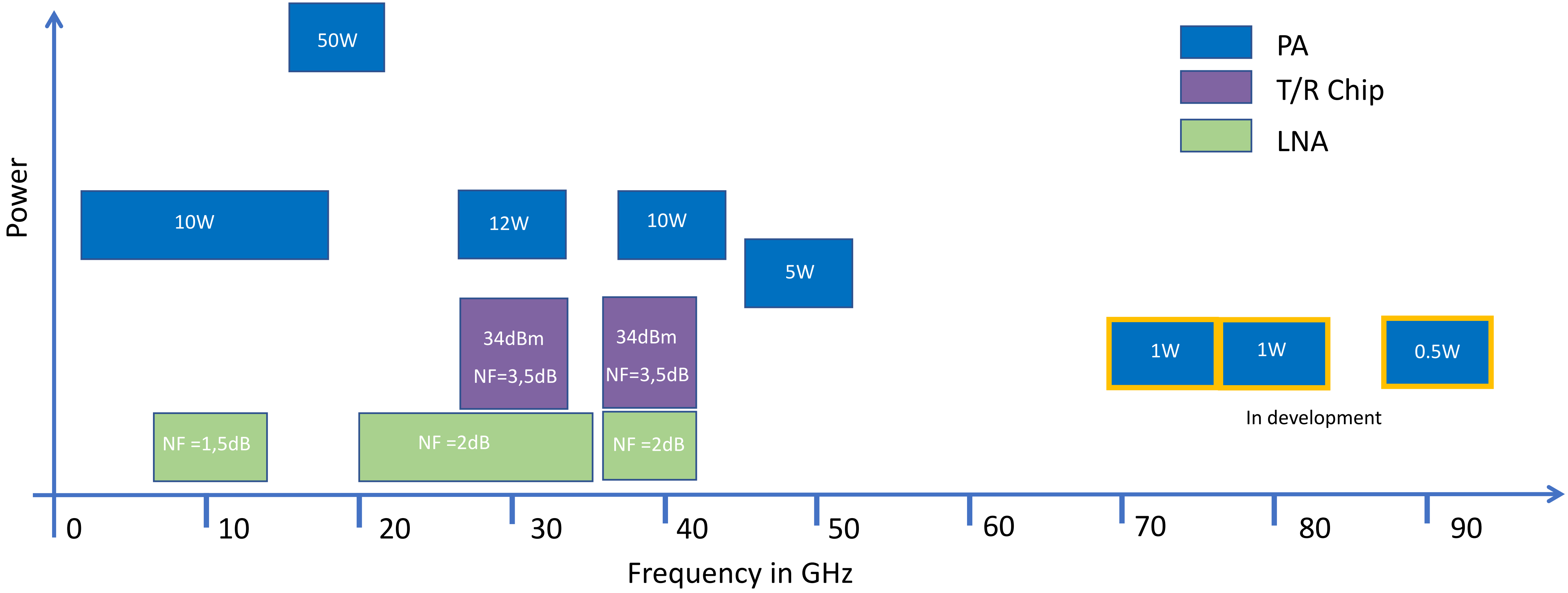




Some examples of GaN Circuits

OMMIC innovating with III-V'S

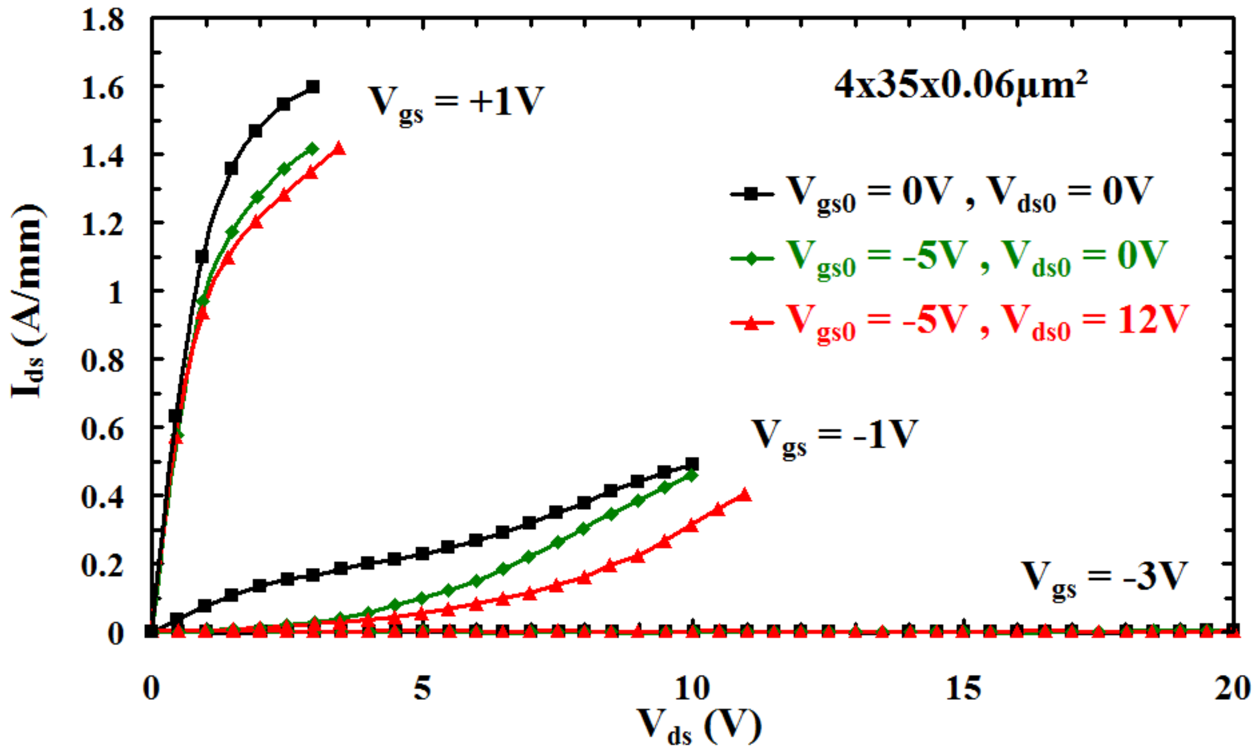
GaN/Si MMIC in mm-Wave

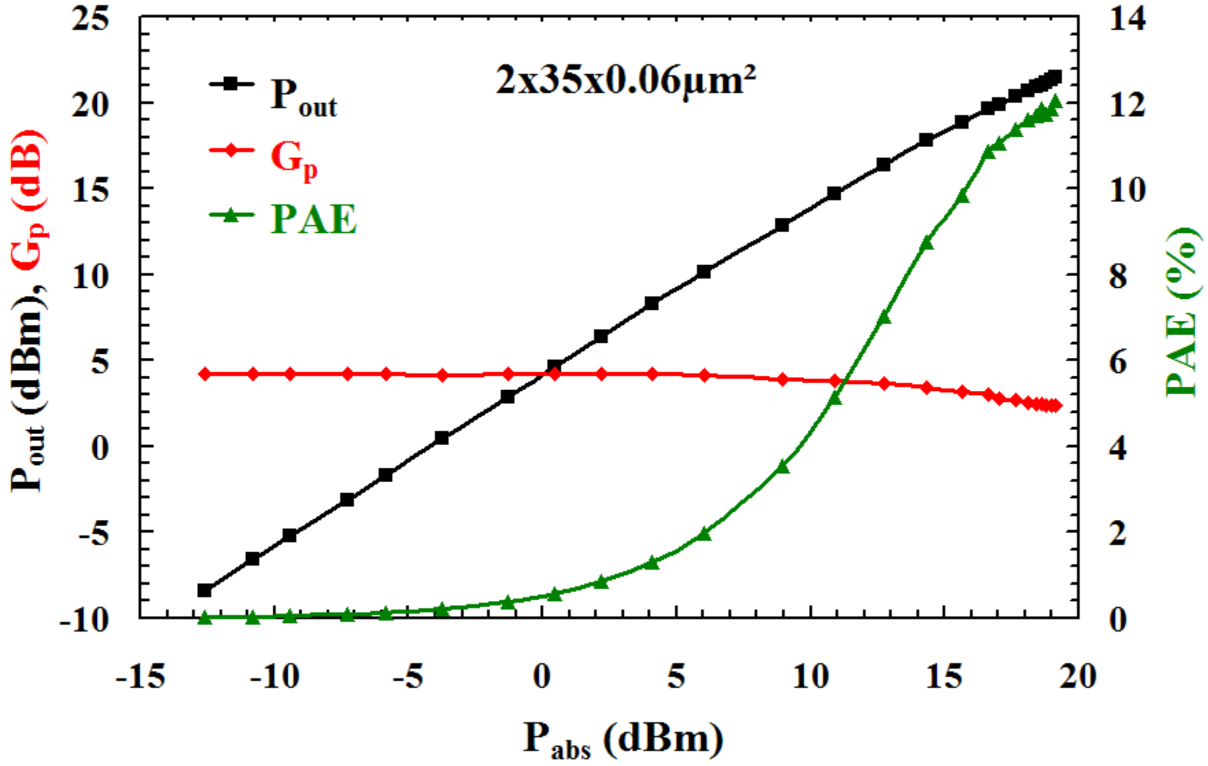


Development of new GaN Process

OMMIC innovating with III-V'S

D006GH GaN/Si Characteristics





P_{out} = 2W/mm @94GHz with an associated PAE of 12% (SoA)

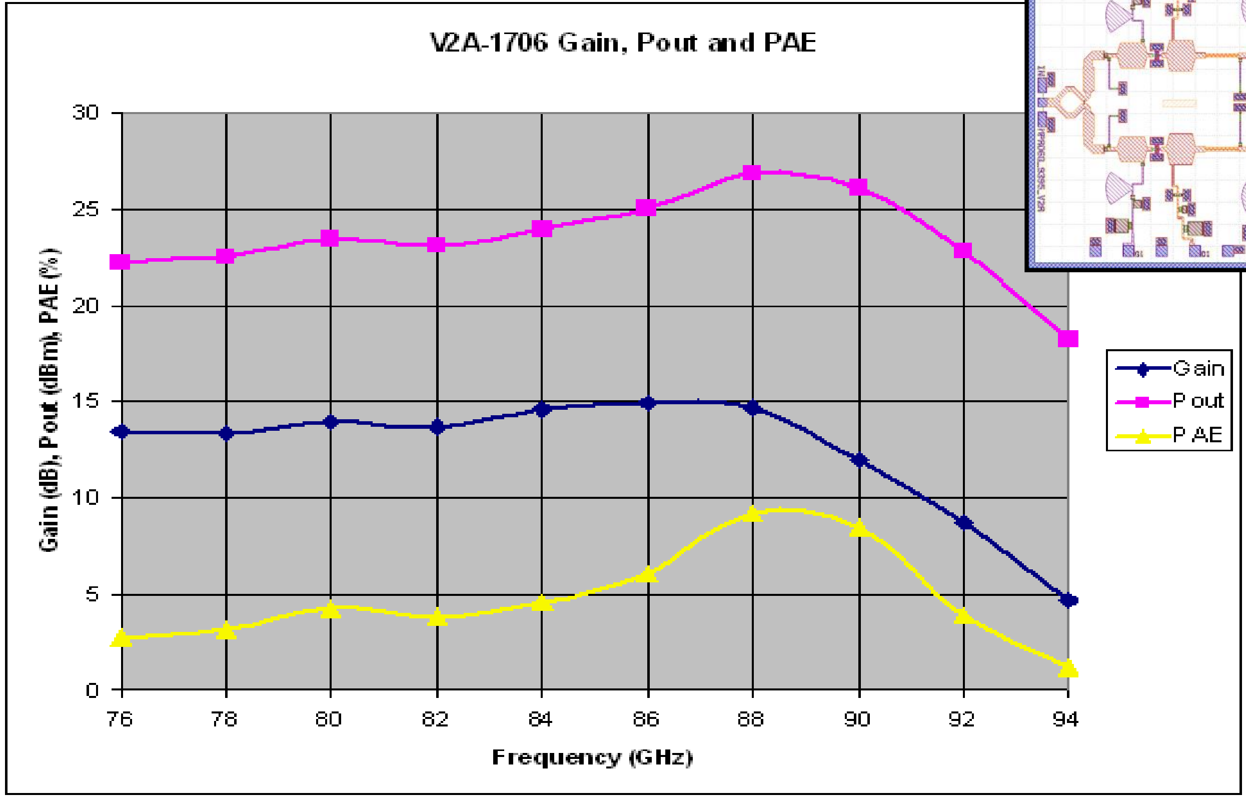
OMMIC D006GH MAIN CHARACTERISTICS

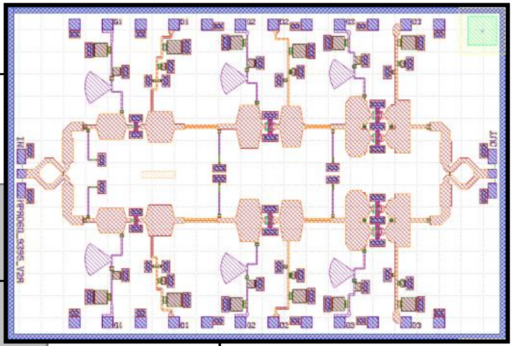
Electrical Characteristic	60 nm
Frequency Cut-off (H21)	190 GHz
Maximum Stable Gain @30 GHz	13.5 dB
Min Noise Figure / Ass. Gain @40 GHz	
RF Power Density	3.3 W/mm
Extrinsic Transconductance	950 mS/mm
Source Resistance	0.18 Ohms.mm
Extrinsic Drain Source resistance Vds=0V (Ron)	0.6 Ohms.mm
Gate Drain voltage for 300µA/mm	40V
Quiescent Voltage	12V

Some examples of GaN Circuits

90GHz 500mW PA D006GH

- **On wafer CW test at FBH-Berlin, design MC2**





- ➢ Gain = 14dB
- ➢ Pout > 27dBm
- ➢ PAE > 8%

GaN/Si Technology at OMMIC

innovating with III-V'S

GAN/Si PROCESS ROADMAP

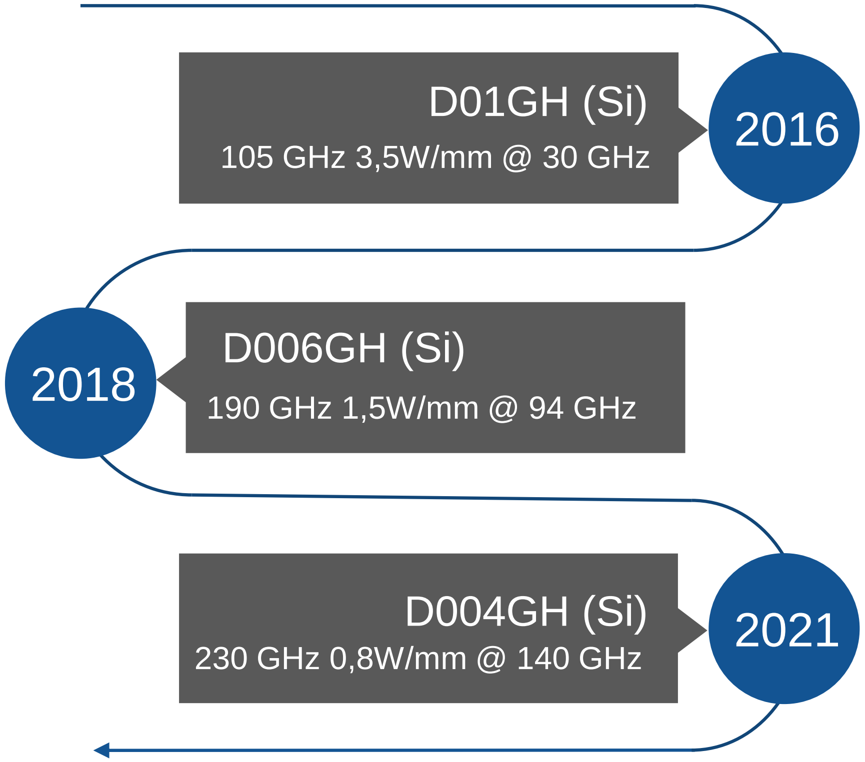
D01GH — D01GH GaN/Si process is already available for OMMIC customer through open foundry service

D006GH — D006GH GaN/Si 60 nm process PDK is already available for download

f_{max} = 250GHz , f_t : 190 GHz , Gate length: 60nm, I_{max} = 1,1 A/mm, Gm = 800 mS/mm, P_{max} =1 W/mm @ 94 GHz, V_{bdg} > 30V, NF_{min} = 1 dB @ 50 GHz

D004GH — D004GH GaN/Si 40 nm process is still in development and will be available in 2021

State-of-the-art and unique 40 nm process for GaN technology



SUMMARY

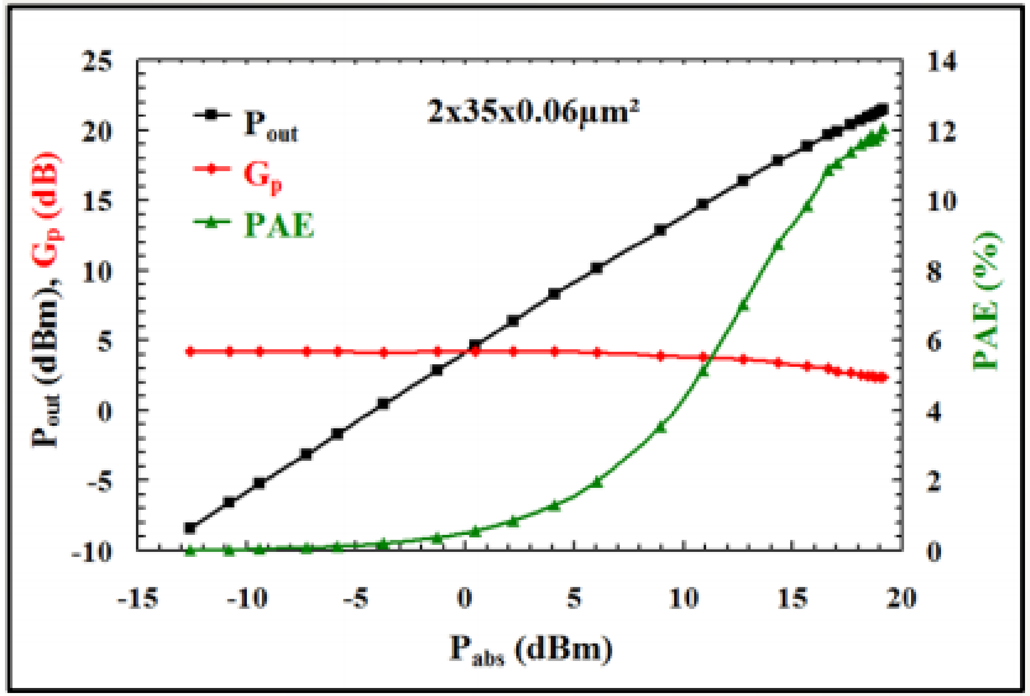
- Due to outstanding physical properties, GaN RF devices show prominent characteristics used in mmW circuits.
- 100nm and 60nm GaN/Si microwave process already exist at OMMIC in 3 and 6 inches. This process enables the same possibilities already explore with GaAs but with more power ☺
- OMMIC GaN/Si reach state of the art performances and excellent reliability with lower cost. Opening possibilities for large volume of production.
- Space qualification of the D01GH process is already in progress.
- For the 2 coming years, only GaN/Si substrate is proposed at OMMIC.
- The next main objective is the development of the 40nm process.

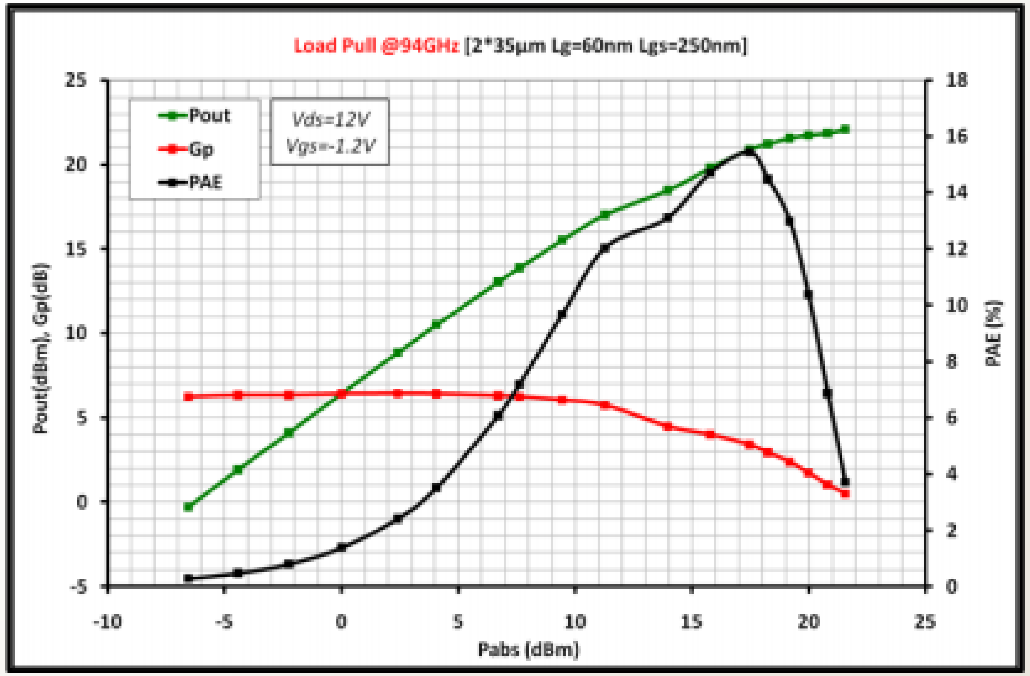
THANK YOU

www.ommic.com

2 Rue du Moulin
94453 Limeil Brevanne
France

- D006GH GaN/Si(C) substrate
  - **2 W/mm @94GHz with PAE of 12% and Gp of 4dB for GaN/Si and Nfmin = 1.6 dB @40GHz**
  - **2.3 W/mm @94GHz with PAE of 15% and Gp of 6dB for GaN/SiC and Nfmin = 1.4 dB @40GH**





OMMIC STRATEGY

Full Replacement of GaAs Solutions

OMMIC plans to replace its GaAs solutions fully by its state-of-the-art GaN/Si technology, offering the best III/V RF solutions, complementary to Silicon RF solutions.

New Cellular Telecom Market

OMMIC aims to enter cellular infrastructure market, especially 5G market with its cutting-edge GaN/Si technology, best suited for the 5G mmWave application.

High-End Space Market

OMMIC continues to serve high-end high value-added space market ,by taking advantage of its avant-garde Hi-Rel process for consumer market.

2015
Unique GaN process for 5G market

2016
Process roadmap for the next 30 years

2016
Strategic partnership with the biggest telecom players

2018
6'' fab ready to serve 5G market

2020
Move to 5 shifts of production

2021
Replace all GaAs products by mmW GaN

GaN/Si Technology at OMMIC

OMMIC
innovating with III-V'S

GaN-on-SiC and GaN-on-Si have begun targeting differnt markets.