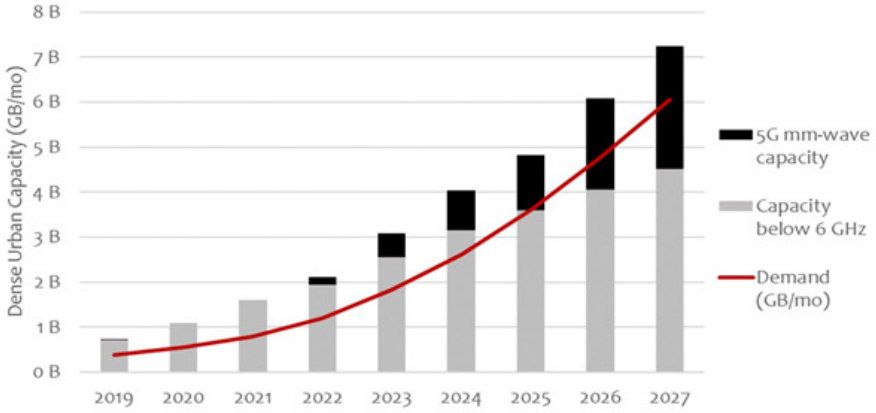
Harnessing the Power of RF GaN-on-Si Technology for Next Generation Connectivity

Nadine Collaert

Overall trends in wireless communication

- Demand for higher capacity is very much alive
- Existing frequency bands <6GHz getting saturated
- New and higher frequency bands come with new challenges
- Operators seeking service diversification beyond data transmission



MobileExperts April 2023

Extreme data-rates and resolution at higher frequencies

COMMUNICATION PERSPECTIVE	FR1	"FR3"	FR2	"FR4"	"FR5"
TYPICAL RANGE	0.1-6 GHz	6-24 GHz	24-52 GHz	57-71 GHz	95-325 GHz
EXAMPLE CARRIER FREQUENCY	3.5 GHz	13 GHz	30 GHz	60 GHz	140 GHz
TYPICAL BANDWIDTH	100 MHz	200 MHz	400 MHz	2 GHz	10 GHz
WAVELENGTH	8.6 cm	3 cm	1 cm	5 mm	2.1 mm
NUMBER OF ANTENNAS ON e.g. 1.5cm x 1.5cm	0	1	9	36	196
SENSING RESOLUTION RANGE/ANGULAR/SPEED	150cm / - / 4.3m/s	75cm / 115° / 1.5m/s	37.5cm / 38° / 0.5m/s	7.5cm / 19° / 0.25m/s	1.5cm / 8° / 0.1m/s

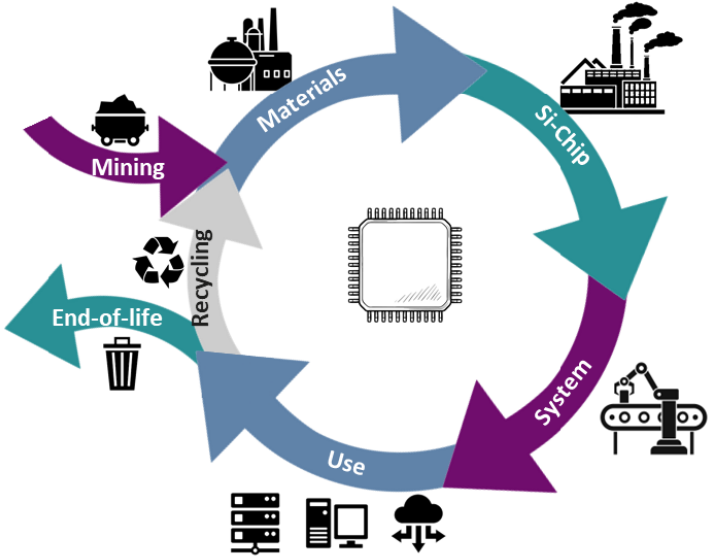
Options to manufacture GaN devices

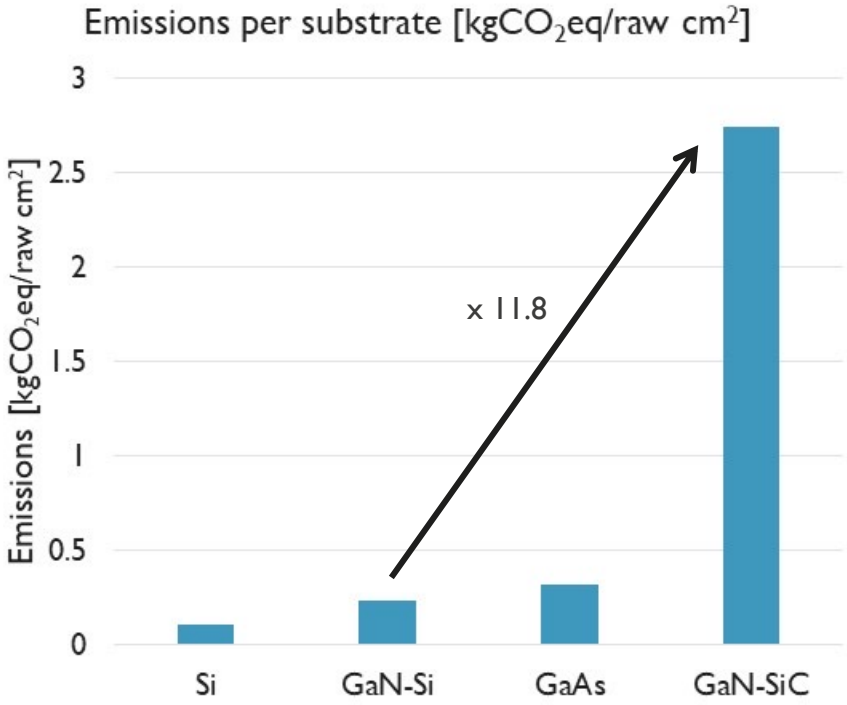
	GaN-on-GaN	GaN-on-SiC	GaN-on-Si
Manufacturability	GaN 2- 4 inch	GaN 4 - 6 inch	GaN 8 - 12 inch
Dislocation density	GaN ~10^7 /cm^2	SiC ~10^8 /cm^2	Si ~10^9 /cm^2
Thermal conductivity	🔥🔥	🔥	🔥🔥
Cost	€€€	€€	€
Environmental footprint		CO_2 CO_2 CO_2	CO_2

imec

GaN-SiC shows much larger emissions than GaN-Si

B. Vanhouche et al, Electronics Goes Green 2024.





From infrastructure to UE

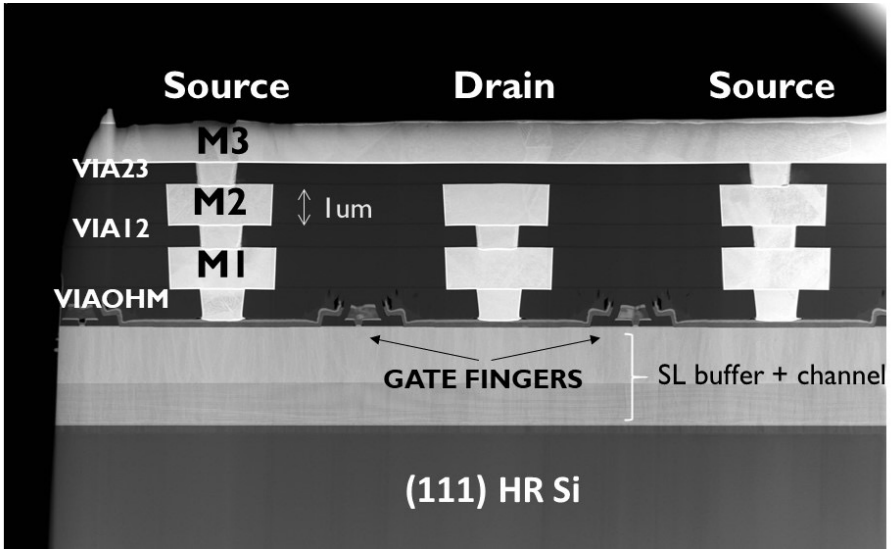
INFRASTRUCTURE

- High-power: ≥ 28V

HANDSETS (UE)

- Low/medium power: ≤ 5V

Imec's RF GaN-Si technology platform



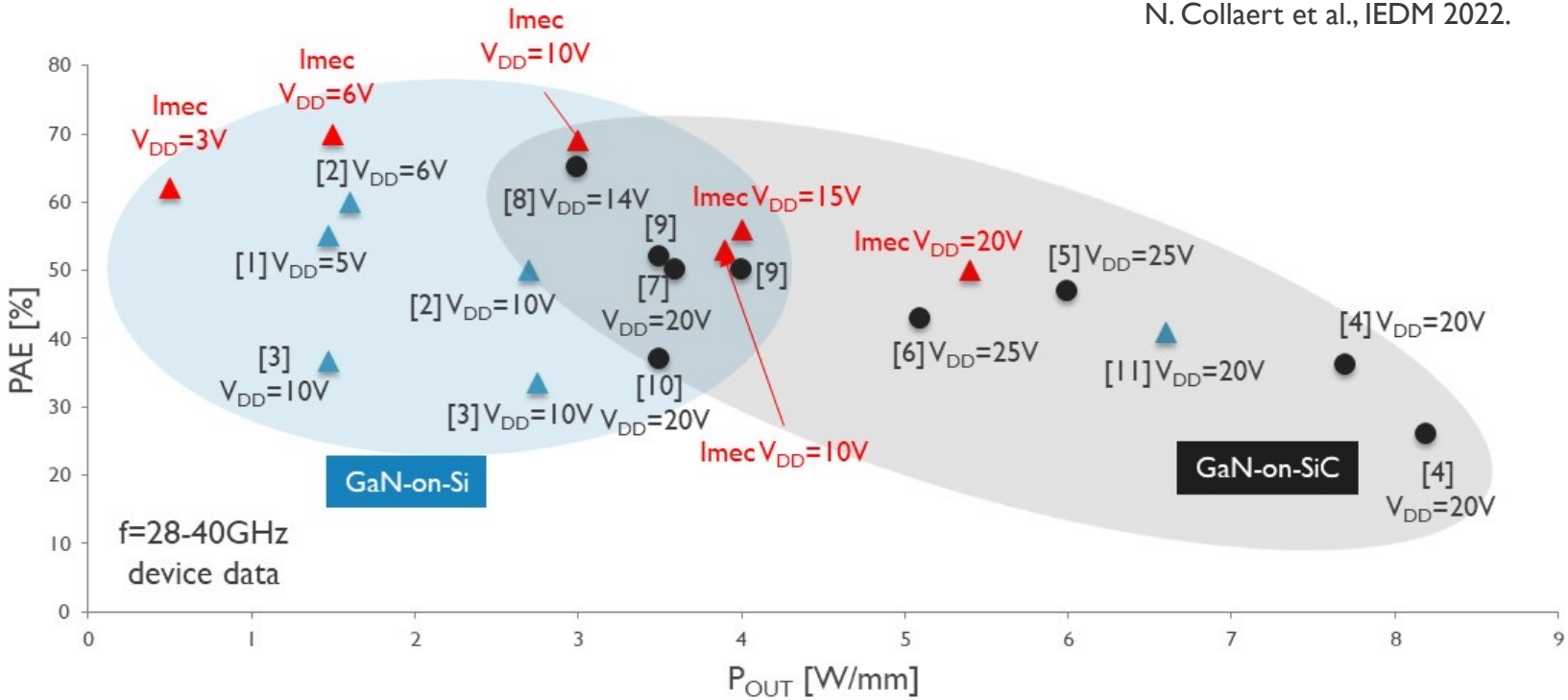
B. Parvais et al., IEDM 2020.

Device key features:

- Substrate: GaN on 200mm HR (111) Si
- HEMT and MISHEMT (SiN & high-k)
- InAlN, AlN and AlGaN barrier
- L_G down to 50nm
- Low resistive ohmic contacts <0.15 Ωmm
- S/D regrowth using MOCVD
- Multi-level Cu BEOL

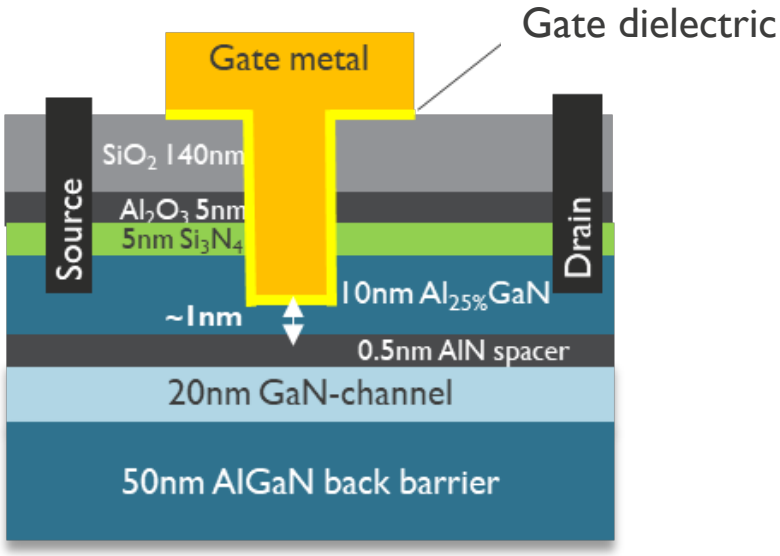
GaN-Si devices can achieve similar performance as GaN-SiC

R. ElKashlan et al., IMS 2023 & accepted to IMS 2024.
N. Collaert et al., IEDM 2022.



[5] M. Mi et al., TED 2017; [6] Y. Zhang et al., EDL 2018;
[7] https://hal.archives-ouvertes.fr/hal-0235688; [8] J.-S. Moon et al., MTTS 2019;
[9] WIN Semiconductor, NP12-01, V_{DD}=28V: [10] UMS GH15, V_{DD}=20V
https://en.sekorm.com/doc/1804392.html ; [11] E. Morvan et al., IEDM 2023.

What do we need to enable low V_{DD} E-mode devices?

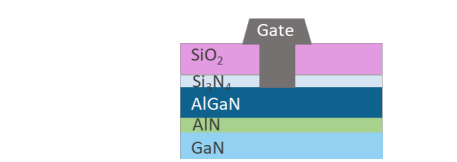


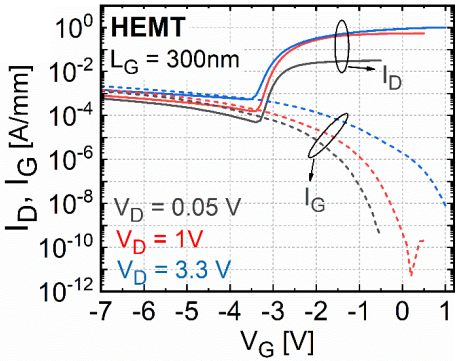
Just example, not optimized stack or device

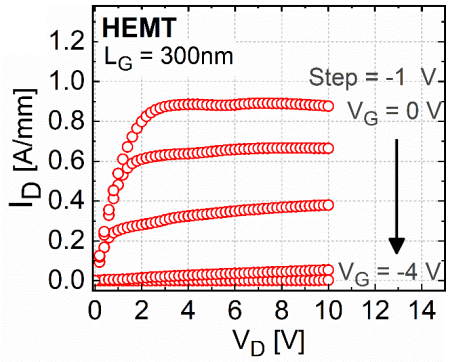
- Optimize active stack
- MISHEMT vs. HEMT
- Gate length scaling and introduction of S/D regrowth

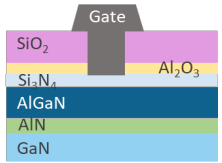
From D-mode to E-mode

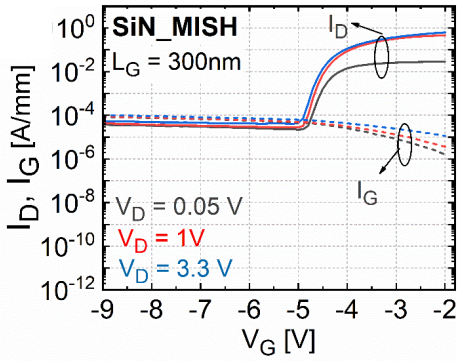
U. Peralagu et al., IEDM 2019.

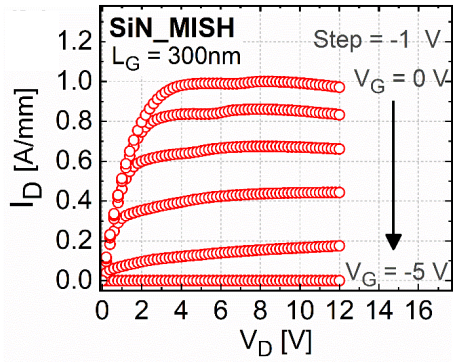


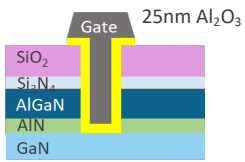


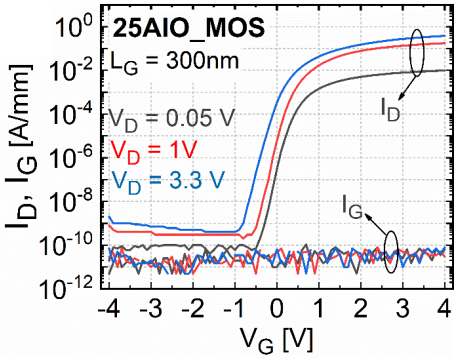


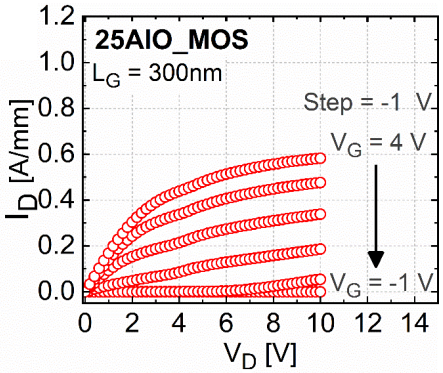






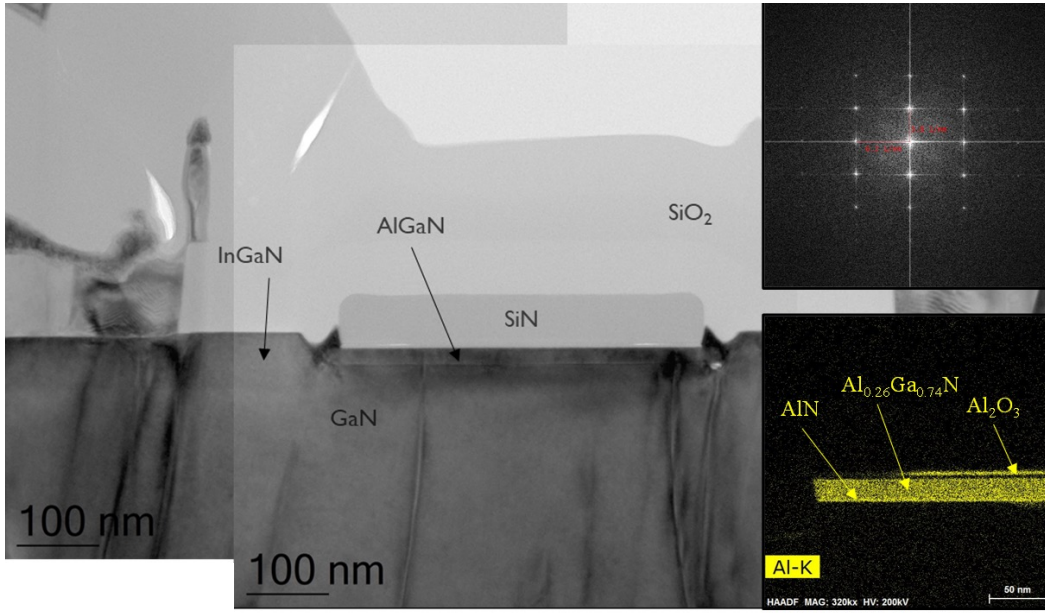






Enabling S/D regrowth

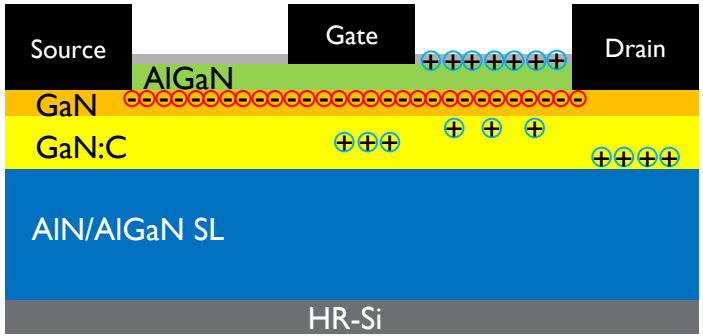
S. Banerjee et al., ICNS 2024.

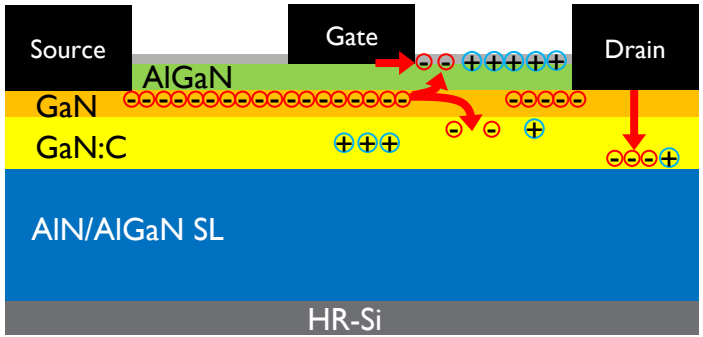


- R_{total} can be reduced to <0.1 Ωmm
- Challenges related to selectivity, intermixing and non-uniformity in composition

Main sources of dispersion

V. Putcha et al., IRPS 2020, 2021 & 2022.
B. O'Sullivan et al., accepted to IRPS 2024.

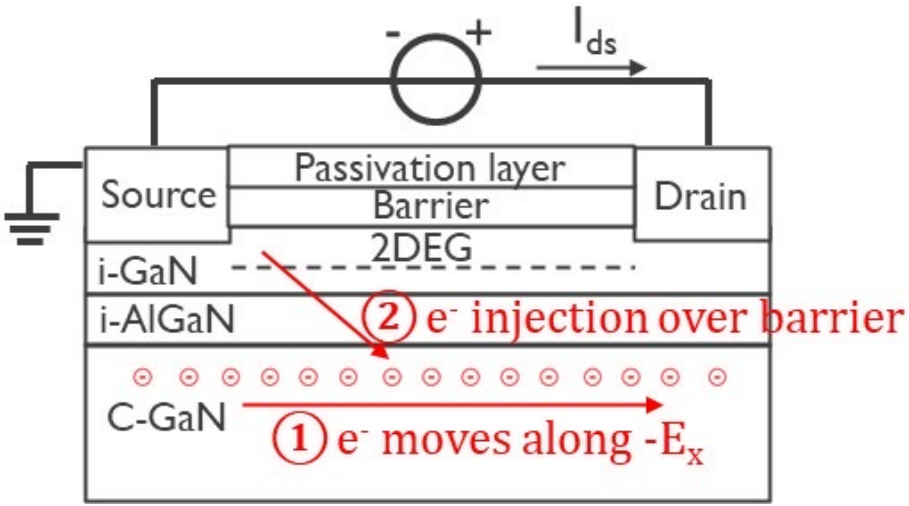


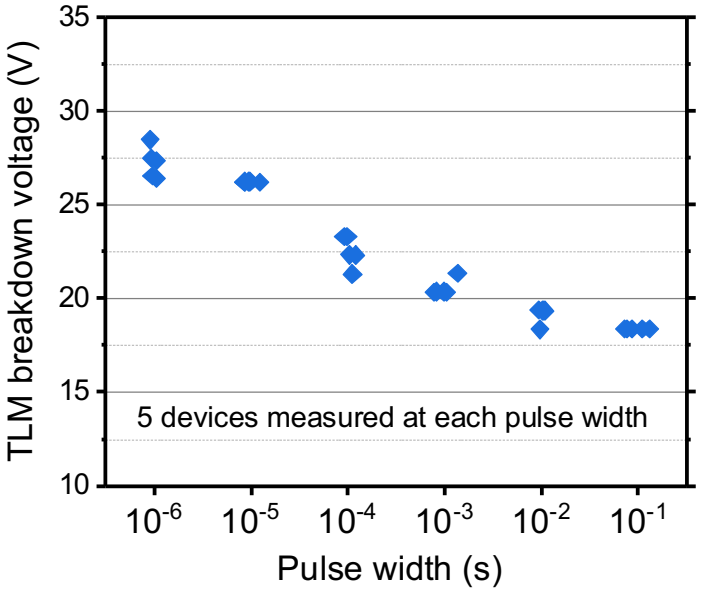


- Following sources of dispersion have been identified:
  - Surface states: localized and reversible charge trapping in defects located near the corner of the gate.
  - Barrier defects
  - Deep level buffer defects
  - C_N defects (C-GaN layer) can get ionized

Charge movement in back barrier responsible for early breakdown

H.Yu et al., IEDM 2023.





Key take-aways

- RF GaN-Si shows very promising performance shown for low/medium power and high-power RF applications
- For handset applications, the search for a high performing and reliable E-mode device is still on
- Understanding the impact of non-idealities related to defects and thermal on RF FOM continues to be key
- Co-design of electrical, thermal, package, IC, antenna is key ⇒ availability of EDA tools
- RF STCO/DTCO methodology needed to guide the technology development

Acknowledgements

- The research team of the advanced RF IIAP program
- Imec's Core program partners
- The European Commission and Regional authorities for their support of European collaborative projects

Thank you

embracing a better life