

Compound Semiconductor Epitaxy at the Core of Next-gen Connectivity

SEMICON EUROPA
ITF Beyond 5G
15 November 2022

Dr Rodney Pelzel CEng, CSci MIET, FIChemE
Chief Technology Officer

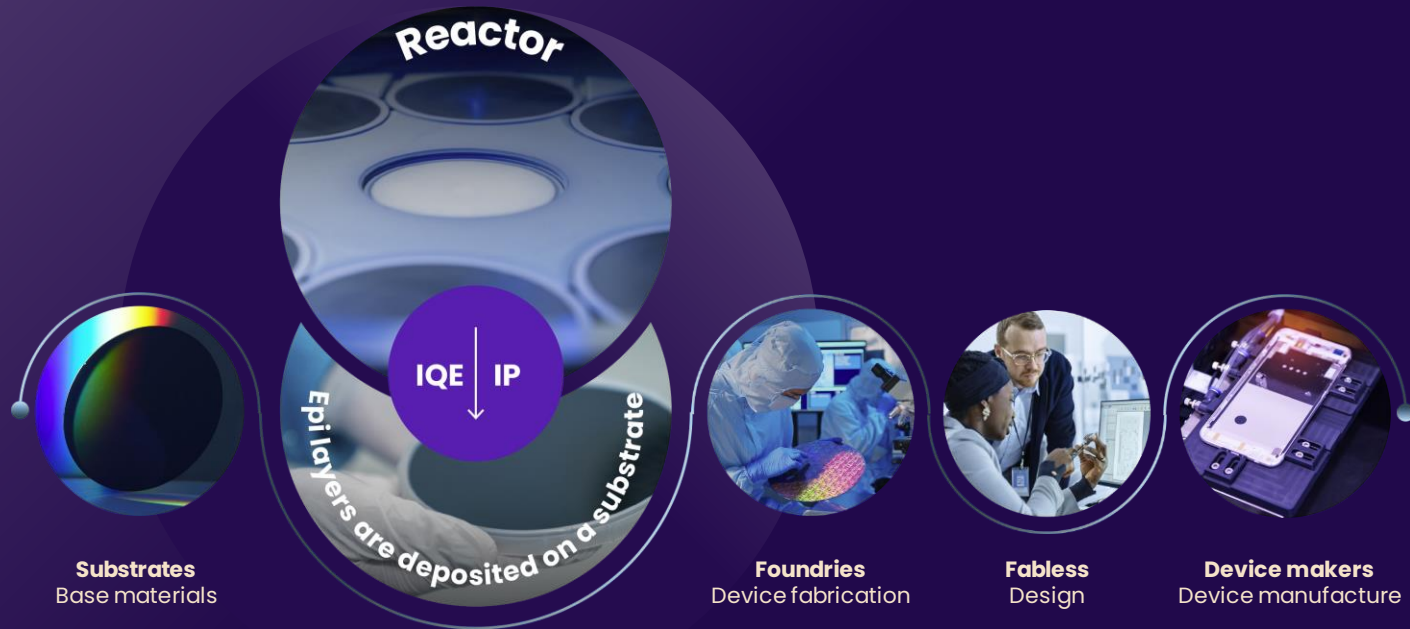


**Architects
of tomorrow**

Uniquely positioned in the global value chain



Epitaxy is where the value is created



Epitaxy is the lithography of compound semiconductors

Lithography



Silicon chips
scaled down in size



Unlocks full
potential of silicon

Epitaxy

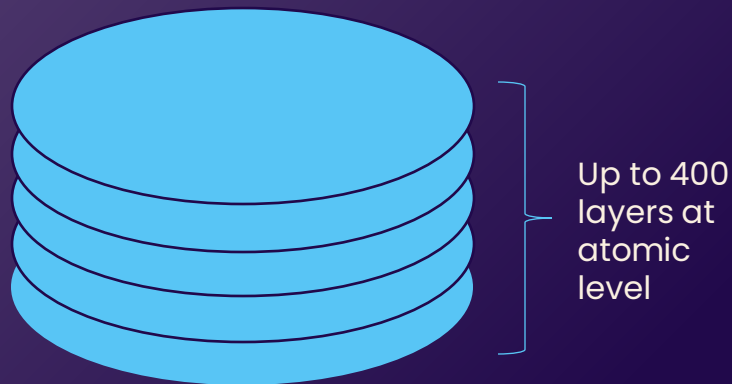


Atomic level control



Unlocks full potential of
compound semiconductors

Innovation starts at the materials level



Temperature

Pressure



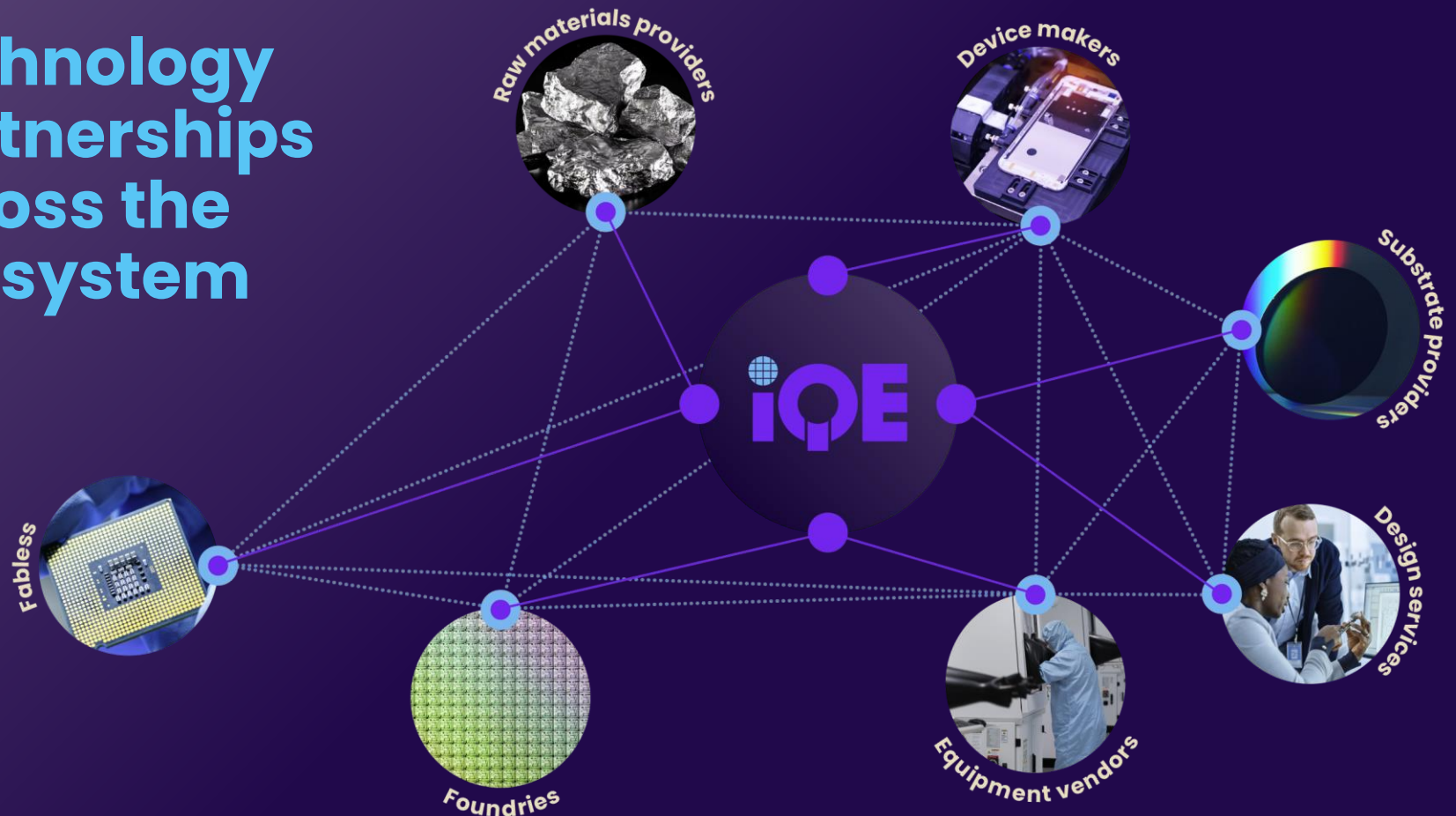
Materials

Time



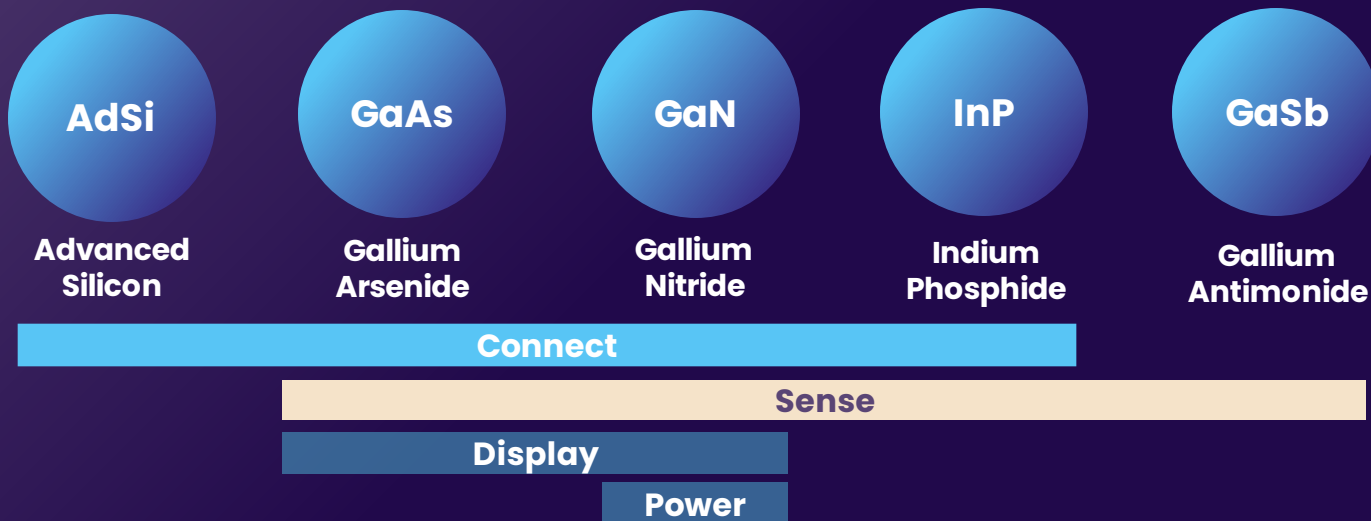
30+ year pedigree
in leading edge epitaxy

Technology partnerships across the ecosystem



Industry leading technology portfolio

Scaled material platforms



Scale across all epitaxy manufacturing technologies: MOCVD, MBE, CVD

Materials platforms unlock diversification

	 Smart Connected Devices	 Communications Infrastructure	 Automotive and Industrial
GaN			
GaAs			
ADSi			
InP			
GaSb			

Connect Products

Enabling 5G, big data and beyond

Current epiwafer products

- PA's handsets FEM: InGaP HBTs/BiHEMTs and GaAs-based PHEMTs
- LNA's for handsets FEM: GaAs-based PHEMTs
- PA's for base stations: GaN HEMTs on SiC and Si
- Transceiver for backhaul and data centre: > 25G DFB and PIN/APD

Next generation epiwafer products

- Handset FEM (improved InGaP HBTs/BiHEMTs & GaN/Si)
- Infrastructure and backhaul - higher speed (> 100G DFB and APD)
- Improved infrastructure PA's (GaN/Si)



GaN capability



Architects
of tomorrow

Leveraging the versatility of GaN

Underpins today's business and creates waves of innovation for growth

Connect

Communications
Infrastructure



Smart Connected
Devices



GaN device
CAGR
= 14%

\$724m

2022

2027

\$1.4b

Power

Smart Connected
Devices



Automotive
& Industrial



GaN device
CAGR
= 50%

\$182m

2022

2027

\$1.4b

Display

Smart Connected
Devices



Automotive
& Industrial



GaN device
CAGR
= 158%

\$7.3m

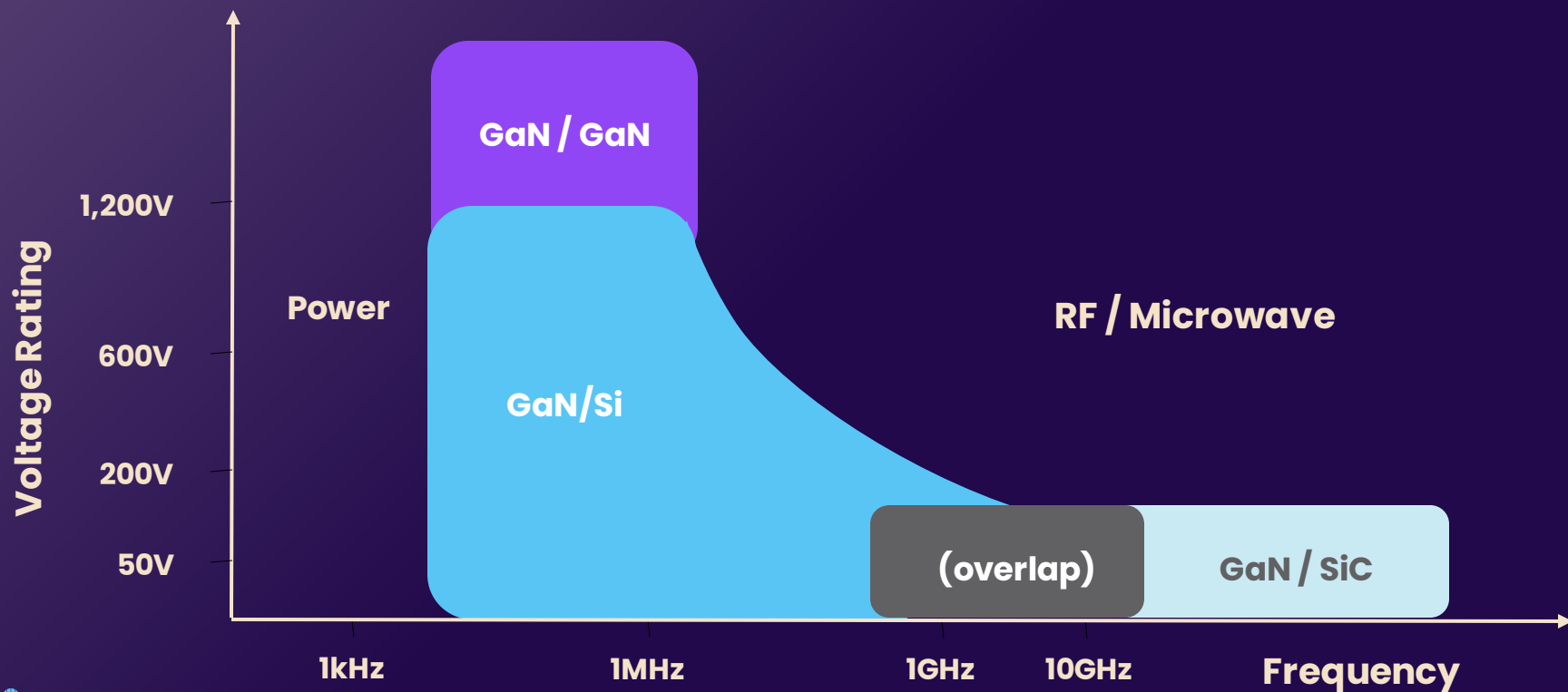
2022

2027

\$834m

Source: Yole Intelligence Q4 2022

Different markets, different substrates



All GaN is not created equally

Different markets require different material solutions

Geopolitical prudence requires local capability for each materials solution

- Demonstrated capability across all substrate types for multiple markets
- Global footprint with Production and R&D capability in the US and UK

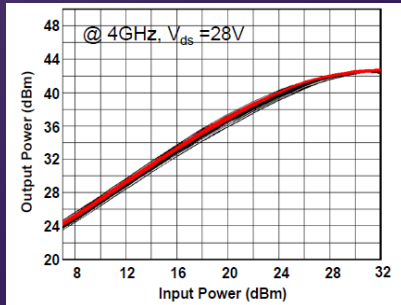
Think GaN
think IQE

RF		Power Electronics		Display		
GaN/SiC	GaN/Si	GaN/GaN	GaN/Si	GaN/GaN	GaN/Sapphire	GaN/Si
4"	4"	2" 4"		4"	4"	
6"	6"		6"		6"	6"
8"	8"		8"			8"

IQE is the multi-market, global GaN supplier

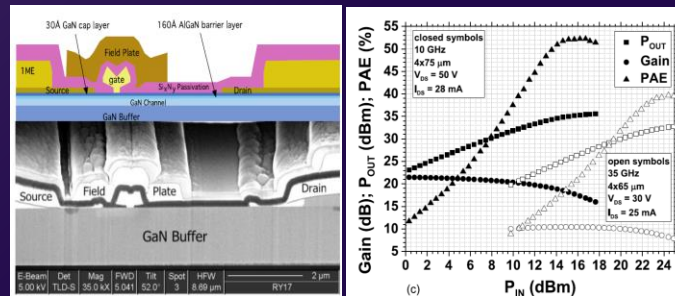
GaN for RF

- SiC and Si substrates
- First to scale from 4" to 6" SiC substrates, 8" SiC now becoming available
- Participant in numerous projects targeting leading-edge GaN performance
- Leader in production on 8" Si
- IQE is leveraging its pedigree in RF to enable GaN solutions for the PE and μ LED growth markets



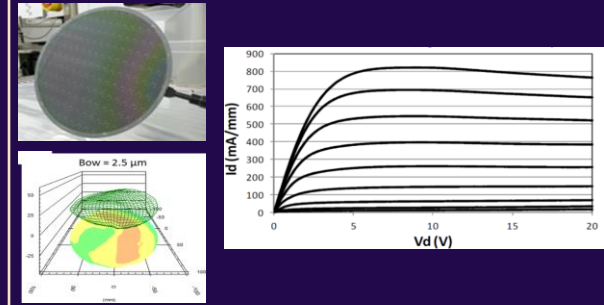
Data for 0.2 μ m MMIC on SiC
parity between 4" and 6"

Isaak et al, CS MANTECH 2014



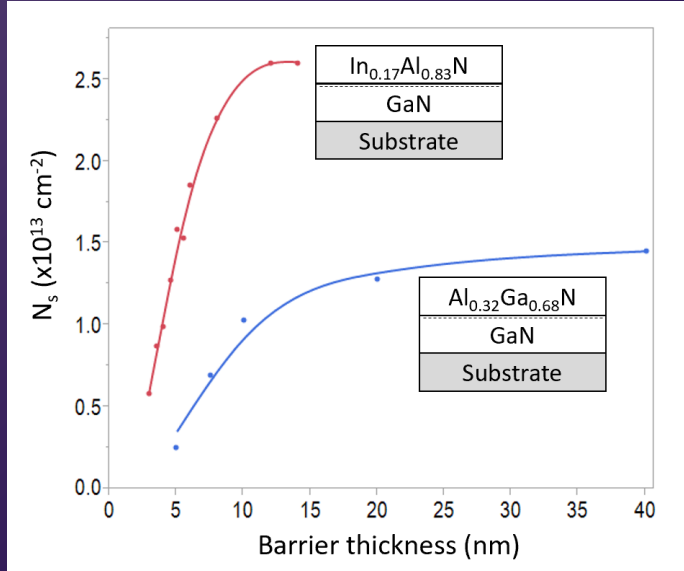
7.7 W/mm @ 35 GHz, 30 V
12.5 W/mm @ 10 GHz, 60 V

Fitch, et al, IEEE Electron Dev Lett, 36 (2015)

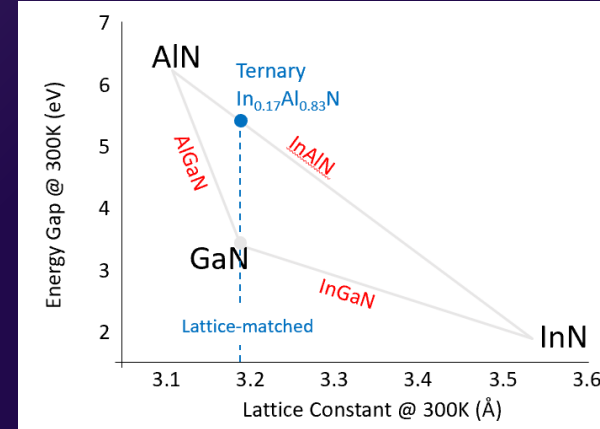


Demo of 0.25 μ m GaN/Si
in 200 mm silicon foundry
LaRoche et al, CS MANTECH 2014

Next gen HEMTs: InAlN

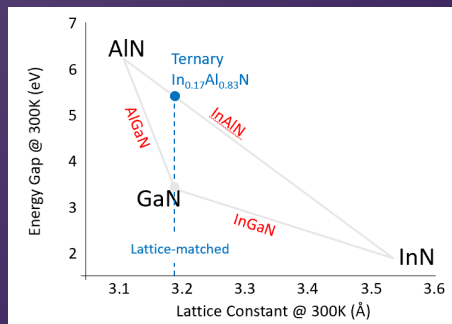


Adapted from Herfurth 2015 Ulm. Univ. Diss. (InAlN);
Heikman et al. JAP 94(8), 5321 (2003) (AlGaIn)

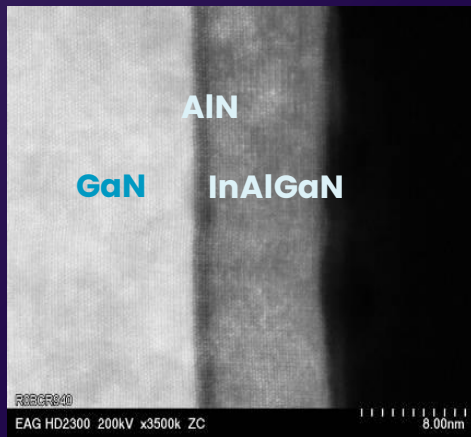


J. Kuzmik, *Electron Device Letters* 22, 11 (2001)

Next gen HEMTs: InAlN



InAl(Ga)N for thin barriers and low R_{sh}



Gao et al, Phys. Stat. Sol. C, 2014

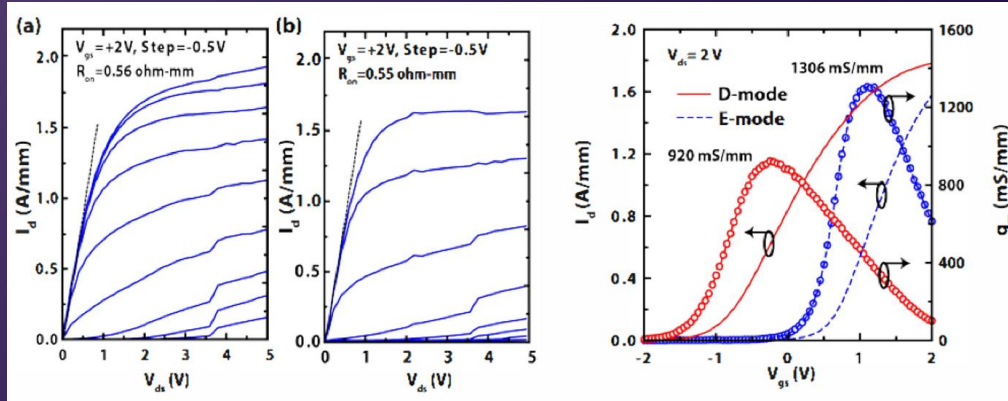
Cation Sublattice Mole Fraction			TriQuint  Reach Further • Reach Faster™			
In	Al	Ga	Barrier Thickness [nm]	R_{sh} [W/sq]	Mobility [cm ² /Vs]	N_s [E13 cm ⁻²]
17%	83%	0%	5.1	253	1,434	1.7
14%	72%	14%	5.6	319	1,761	1.1
11%	73%	16%	5.3	274	1,699	1.4
11%	73%	16%	15	249	1,258	2.1
7%	75%	18%	4.4	228	1,606	1.4
7%	75%	18%	4.8	218	1,480	2.0
7%	75%	18%	6.8	210	1,302	2.4
3%	77%	20%	6.4	274	1,661	1.4

Thin barriers

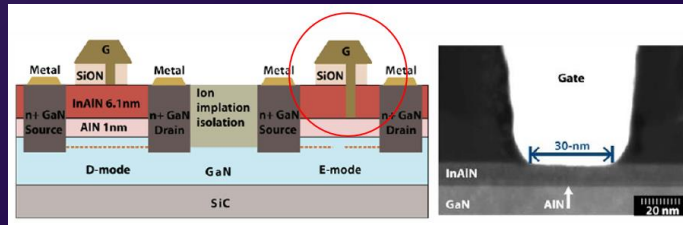
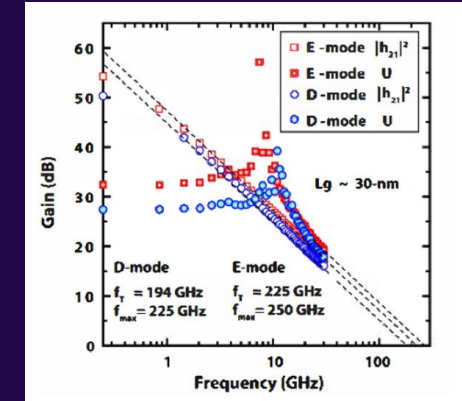
Low R_{sh}

InAlN – E-mode/D-mode integration

E-mode/D-mode Integration



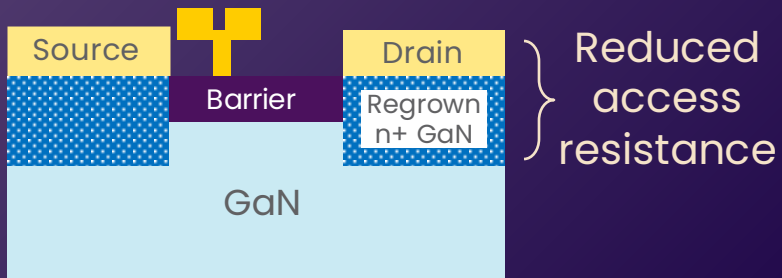
State-of-the-art results



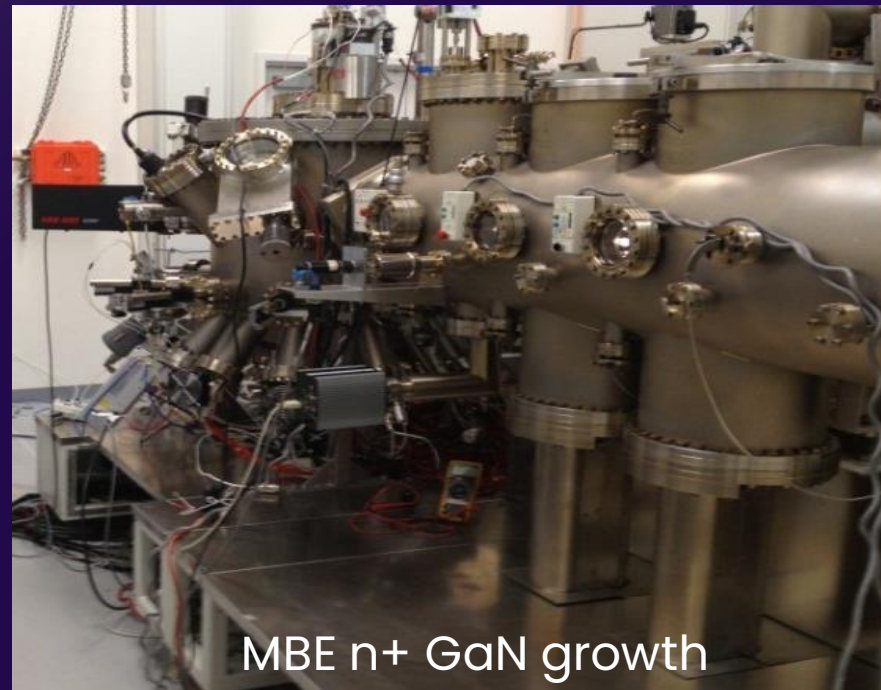
- E/D mode by controlling gate recess
- $\text{In}_{0.17}\text{Al}_{0.83}\text{N} / \text{AlN} / \text{GaN}$, 30 nm gate length

Song et al, DRC 2012
Lee et al. EDL 32(6) (2011)

GaN for mobile devices



R_c reduction of $\sim 3x$



Summary

**Next-gen
connectivity requires
innovation at the
fundamental
materials level**

**Epitaxy unlocks
the full potential
of compound
semiconductors**

**GaN is a
promising
platform for
next-gen
handsets**

Compound Semiconductor Epitaxy at the Core of Next-gen Connectivity

Thank you



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of tomorrow