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N-polar GaN on SiC and sapphire epitaxy for high performance RF and mm-wave electronics: from R&D to commercial production platforms

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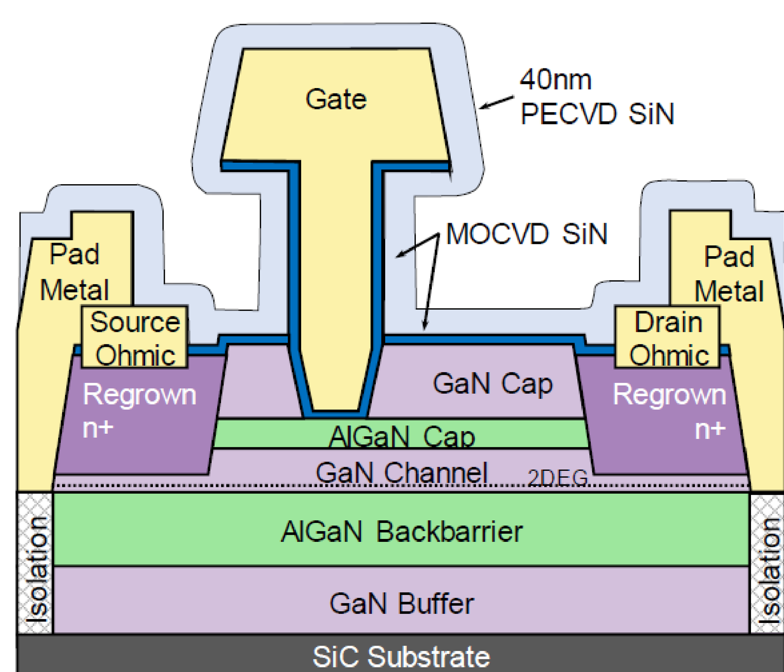
Establishing US based dedicated production source of GaN Epitaxy for high performance RF and millimeter wave Electronics

5G and Future RF

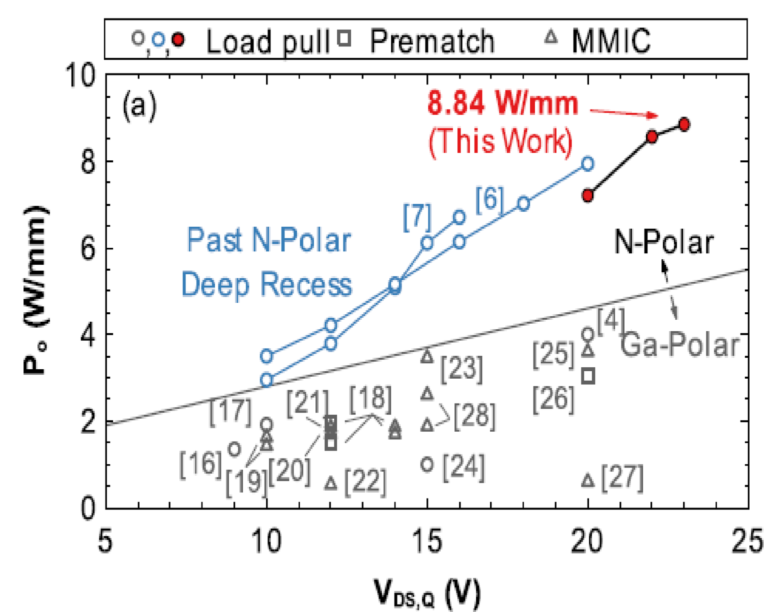
Background

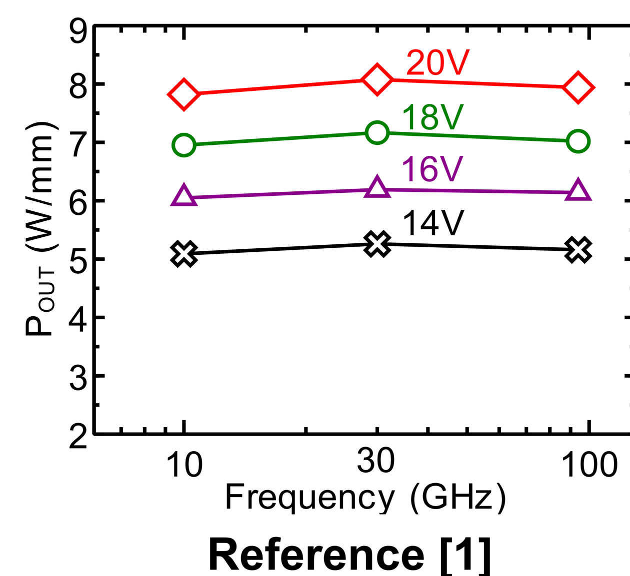
Nitrogen polar (N-polar) GaN is a key material for the next generation of radio frequency (**RF**) and millimeter-wave (**mm-wave**) applications [1]. Thanks to its advantageous materials properties [2], **lower sheet-resistance** and **better dispersion control**, the power density at 94 GHz of an N-polar GaN HEMTs is **more than 2x** that of any state-of-art Ga-polar alternative.



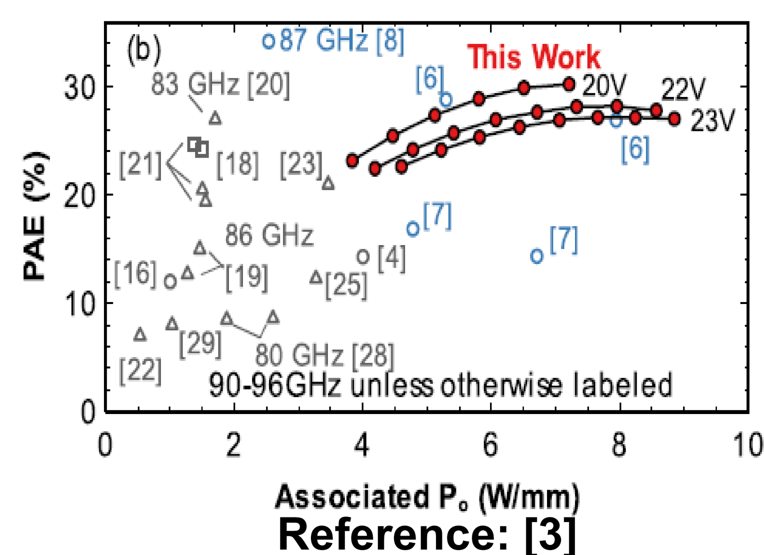
	Ga-Polar	N-Polar
Status	Established	Emerging
Pout @ 94 GHz (W/mm)	< 4 W/mm	> 8 W/mm
2DEG Rsh (Ω/sq)	> 280	< 200
ID,max (A/mm)	< 1.3	> 2.0
RF Current Swing	Baseline	Expanded
DC-RF Dispersion Control	Capacitance penalty	No penalty
Surface Traps	Close	Far
Backbarrier	Depletes channel	No penalty
Minimum Buffer thickness (μm)	> 1.5	< 0.5

Reference: [3] B. Romanczyk *et al.*, *IEEE EDL* **41**, 349 (2020)





Reference [1]



Reference: [3]

N-polar GaN deep-recess MIS-HEMTs developed at the **University of California, Santa Barbara (UCSB)** exhibit a power density of **8 W/mm** at 10, 30, and 94 GHz with record efficiencies [1,3].

References

[1] B. Romanczyk *et al.*, *IEEE TED* **65**, 45, (2018)
[2] S. Keller *et al.*, Semicond. Sci. Technol. **29**, 113001 (2014)
[3] B. Romanczyk *et al.*, *IEEE EDL* 41, 349 (2020)

Approach

Transphorm produces **epiwafers for commercial GaN companies and the U.S. Department of Defense,** initially focused on gallium polar (Ga-polar) GaN. Under ONR contract, Transphorm expanded in 2019 to became the first and only domestic **manufacturer and supplier of commercialized N-polar GaN**. Transphorm is transferring the UCSB N-polar GaN on SiC process to a large-scale production platform and selling engineering wafers to select customers.

Skilled U.S.-based Supplier
Pure-play supplier with 12+ years of epi manufacturing experience.

Exclusive, Flexible Product Portfolio
N-polar (exclusive) and Ga-polar GaN epi with choice of substrates.

High Volume Scalability & Reproducibility
Proven control process in multi-wafer MOCVD reactors.

Extensive IP Portfolio
Access to 1,000+ patents for end-to-end GaN product development.

Validated Epi Performance
Used in high reliability GaN power devices with 5B+ hours of field reliability data.

ISO 9001 Certified
AEC/Q101 Qualified for Power electronics

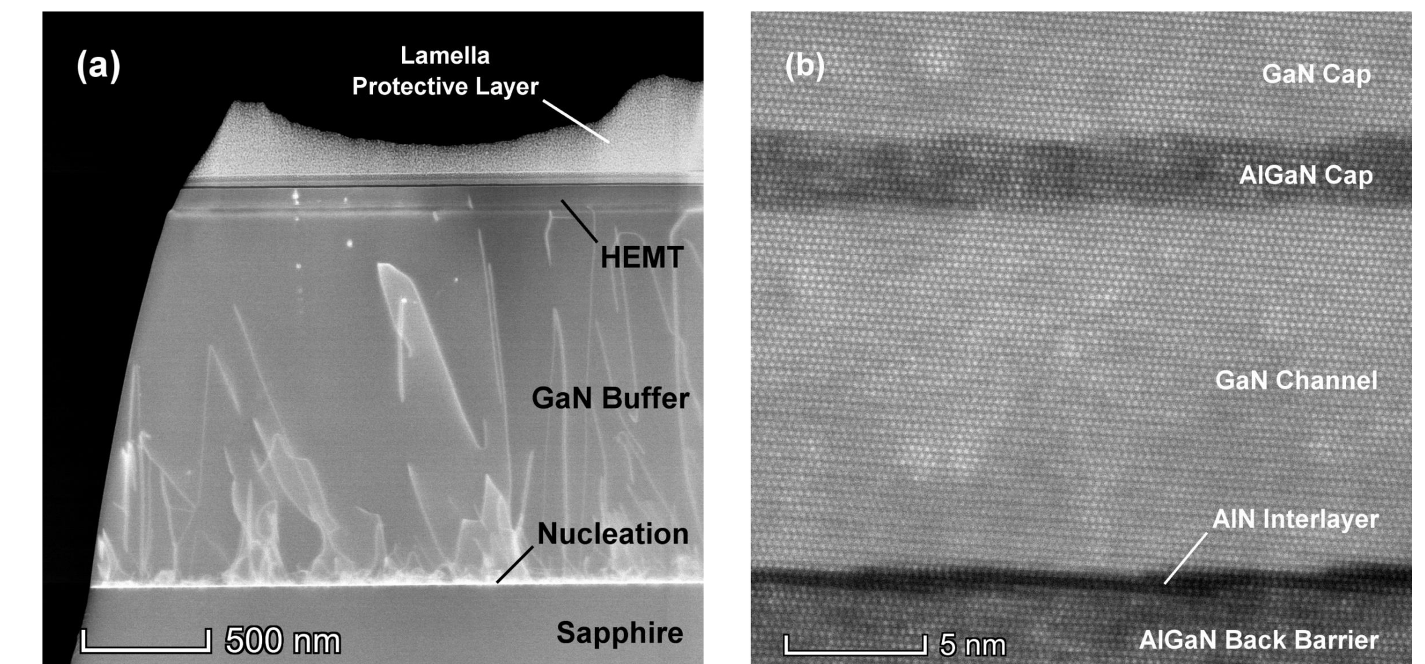
- Full epi material characterization verified to NIST standards
- Automated SPC with documented manufacturing systems (CA, OCAP, FMEA)
- Short-loop fab feedback available for fast verification

Layer	
5 nm: SiN	
50 nm: GaN Cap	
3 nm: AlGaN Top Barrier	
12 nm: GaN channel	2DEG
10 nm: AlGaN Back Barrier	
20 nm: Graded AlGaN Back Barrier	
150 nm: GaN:UID	N-pol
1.5 μm: GaN insulating Buffer	↑
Substrate	

Reference: Author's Own

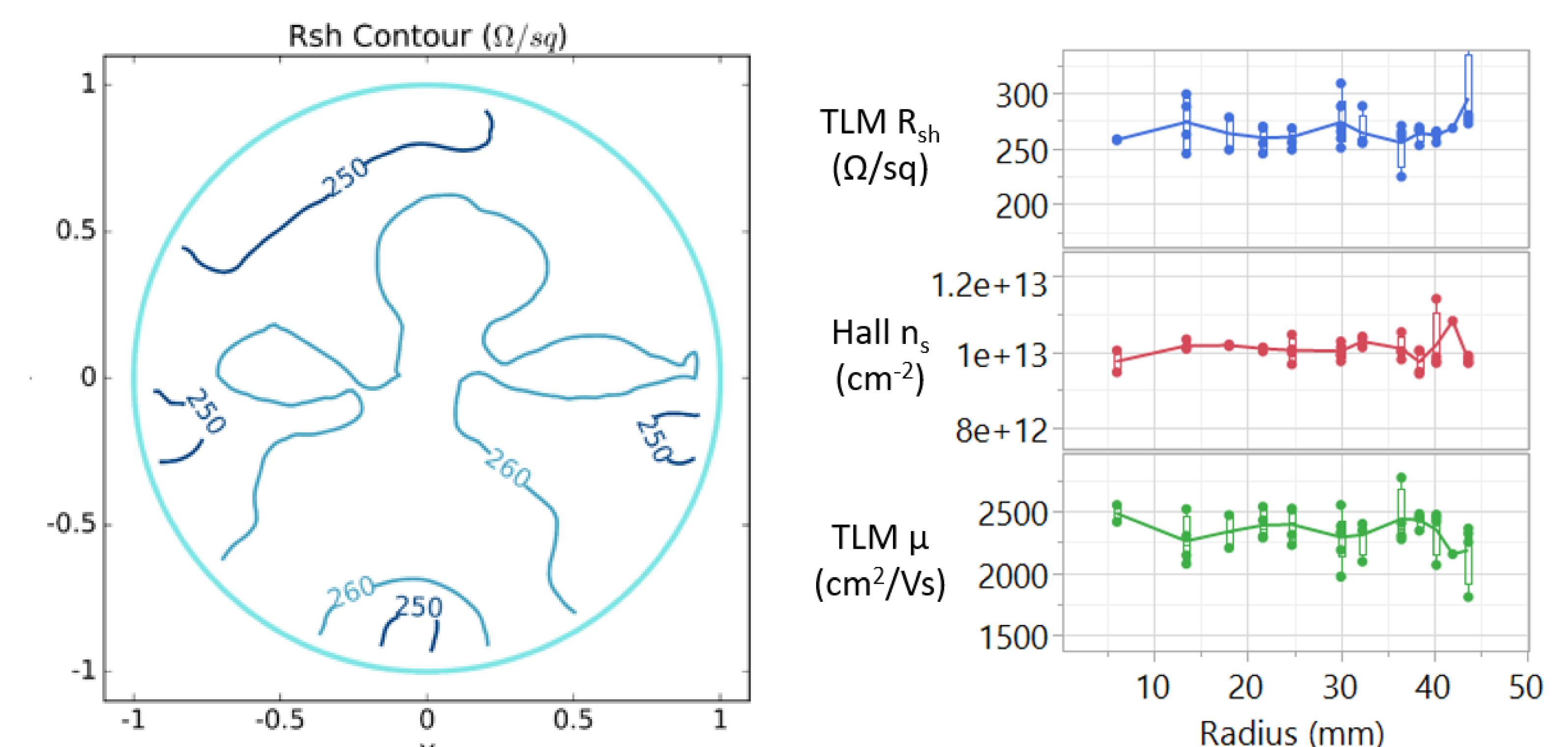
Transphorm validated the N-polar GaN epi manufacturing process with an **N-polar GaN deep-recess MIS-HEMT** epi structure [1,3] on 100-mm off-cut sapphire substrates. Work continues with the same structure on 6-H SI SiC substrates. Transphorm has sold engineering grade N-polar on SiC wafers to multiple US companies in the DoD community. Transphorm is ready to expand this capability to include 150 mm sapphire and SI SiC substrates (upon availability). Future plans include 200 mm.

Results and Impact



Reference: X. Liu *et al.*, CS MANTEC 2020

Scanning transmission electron microscopy (STEM) of the N-polar GaN deep-recess MIS-HEMT epitaxy grown at Transphorm on 100-mm off-cut sapphire. Note the GaN buffer layer (**left**) and the aluminum compositional contrast of the HEMT layers (**right**). The **expected off-cut steps** transferred from the off-cut substrate along the GaN [11$\bar{2}$0] direction are also visible. Devices are designed with 2DEG current flowing parallel to the off-cut steps, where **electron mobility** is ~15% higher than the electron mobility in a perpendicular direction to the steps.



Reference: X. Liu *et al.*, CS MANTEC 2020 **Reference:** Author's Own

Typical R_{sh} contour map by contactless measurement on a 100-mm N-polar deep-recess HEMT on sapphire with low buffer impurities (**left**). The mean R_{sh} is **257 Ω/sq** with a **uniformity of 2%.** The mean Hall 2DEG density and mobility extracted from TLM structures are **1.0x10^{13} cm^{-2}** and **2351 cm^2/V·s**, respectively (**right**). The full fabrication of transistor devices to evaluate static (DC) and dynamic (pulsed I-V) device performance is ongoing.

Impact: Transphorm has delivered high quality Ga-polar and N-polar GaN epiwafers on Sapphire and SiC to the U.S. Department of Defense and U.S. Customers for the implementation of next generation RF & mm-wave devices. Transphorm's Navy program execution including infrastructure for a dedicated US Epi supply is on track.

Office of Naval Research ONR Science & Technology
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