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Design and Fabrication of AlGa_N/Ga_N normally-off HEMTs

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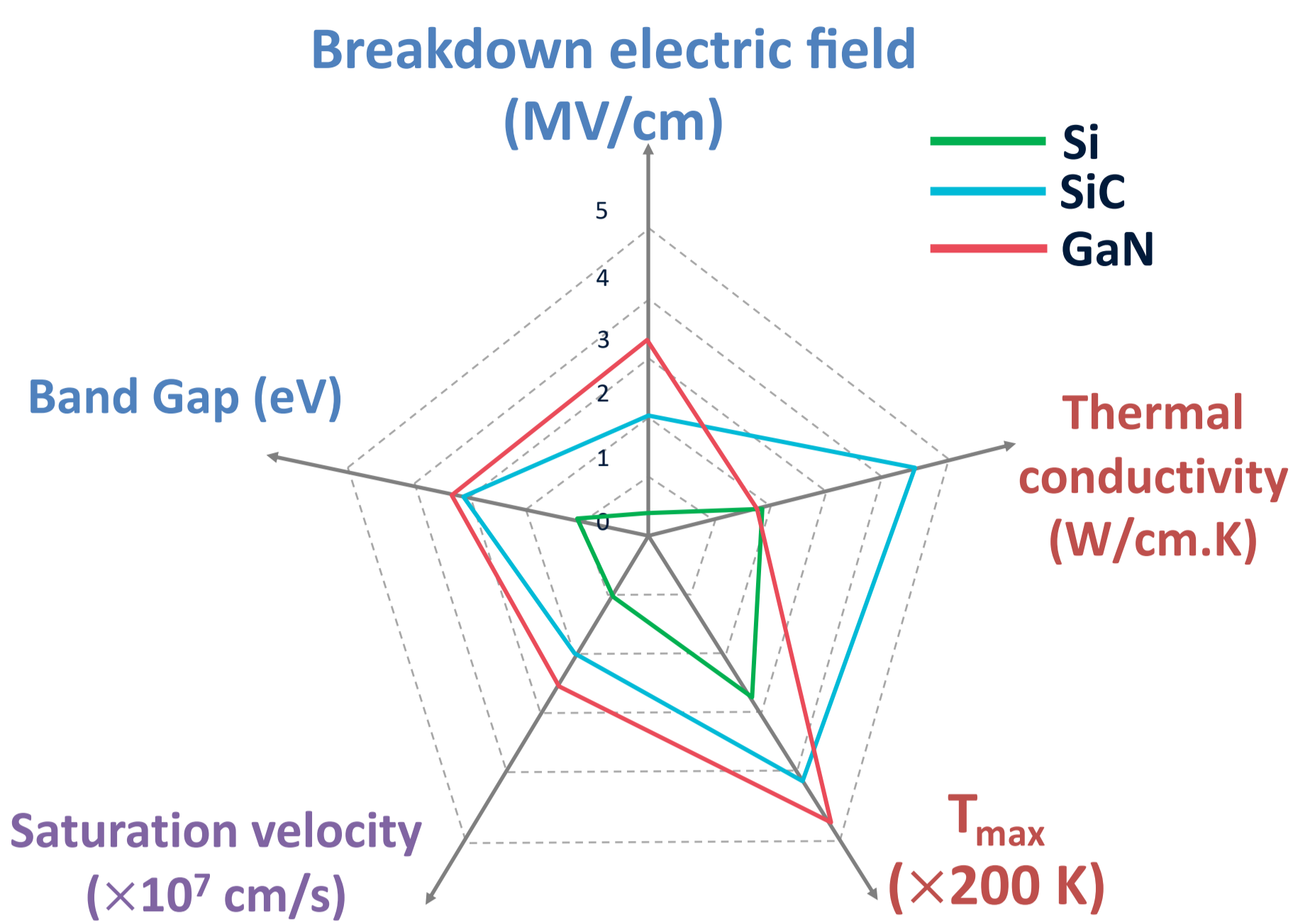
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Wide Band Gap materials for power applications



High voltage capability

High operating temperature

High operating frequency

Higher drift velocity at same electric field than silicon

High power density

Energy loss reduction
Better efficiency and space occupation
High power converters for electrical vehicles

GaN material for low (< 200 V) and medium (600 – 900 V) voltage range

Personal electronics

- chargers, adapters, USB PD, ...

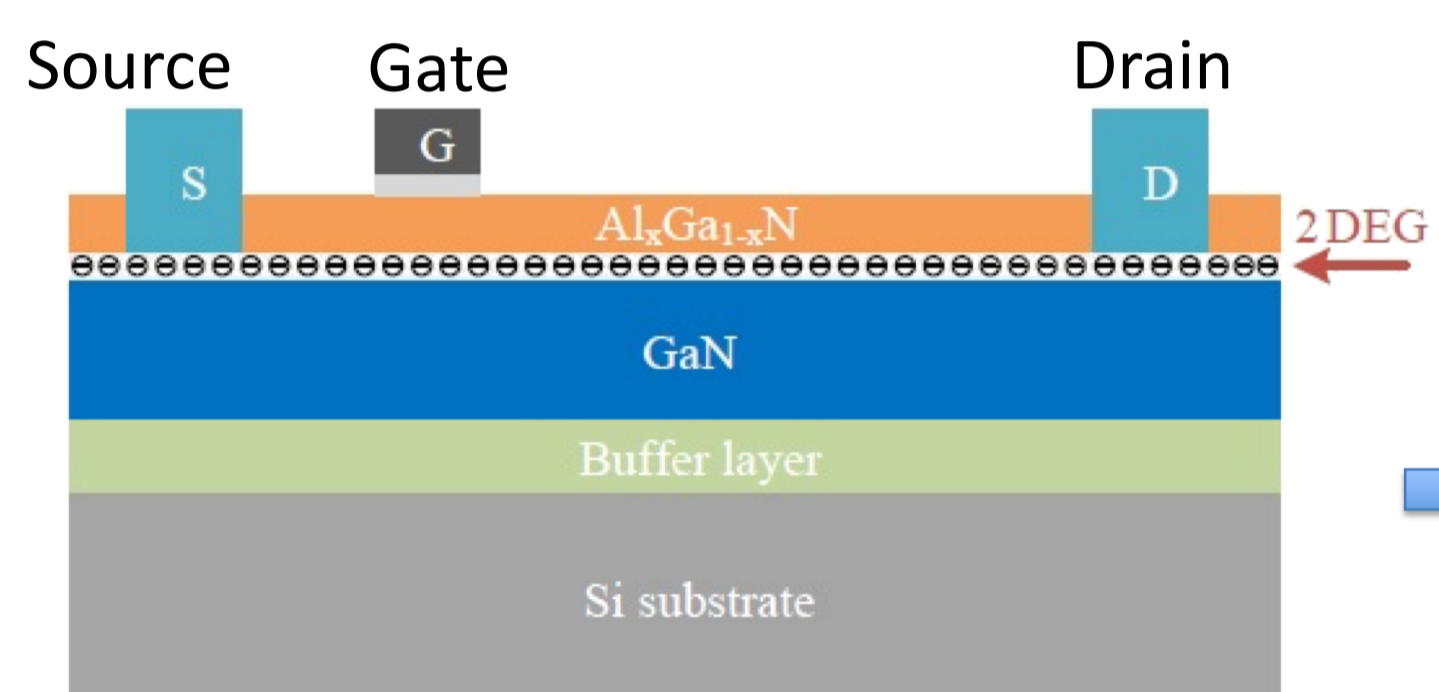
Smart Industry

- Telecom, Datacenters, Solar, ...

Car Electrification

- On-board chargers, 400V-12V DC/DC converter
- Traction inverter

The AlGa_{0.2}N/GaN HEMT (High Electron Mobility Transistor): a device of high interest



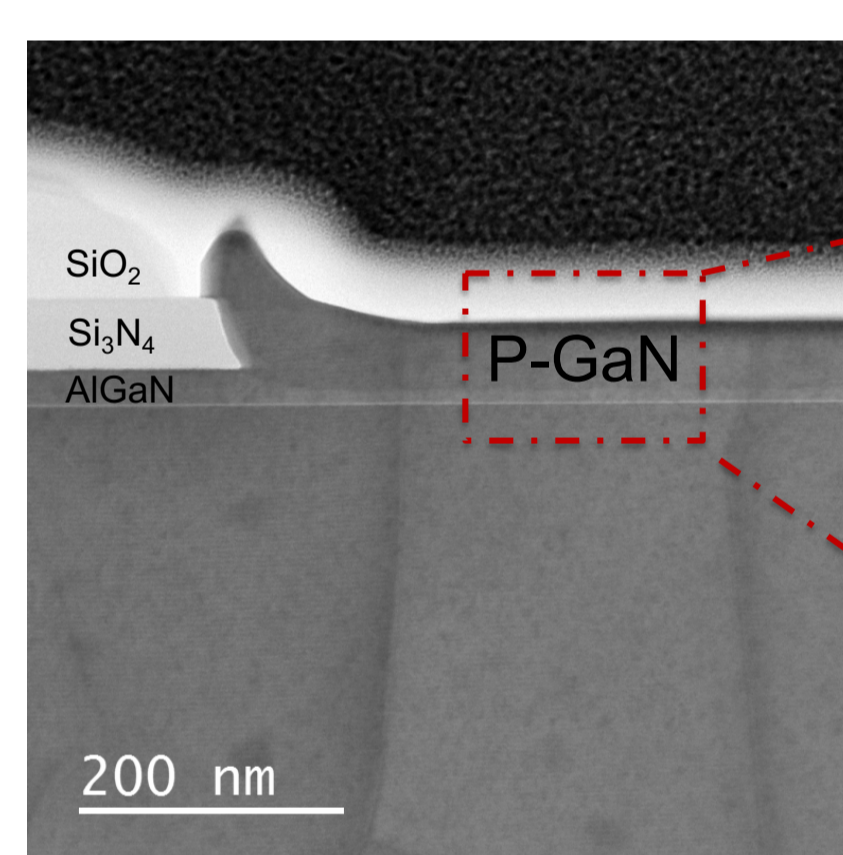
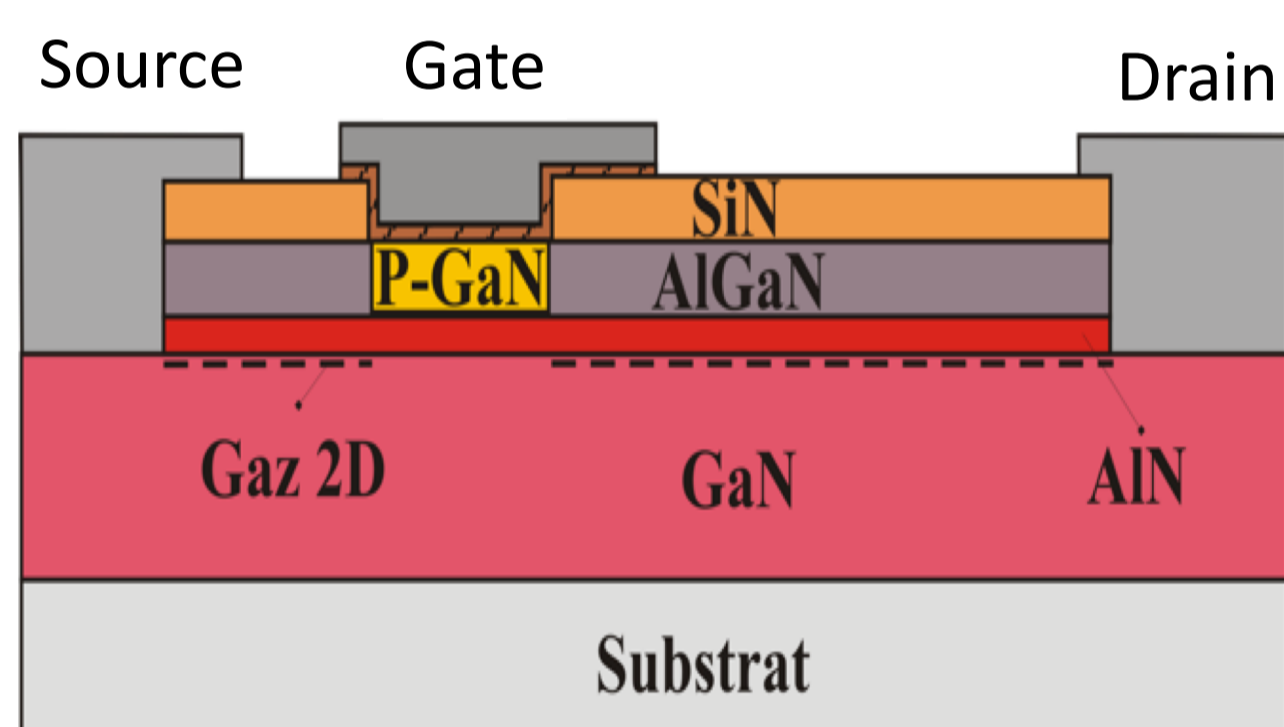
Schema of a conventional normally-on HEMT

- 😊 Formation of a 2D electron gas (2DEG) at the AlGa_{0.2}N / GaN interface:
- No junction
 - High electron mobility (2000 cm²/V.s)
 - High breakdown electric field (3 MV/cm)

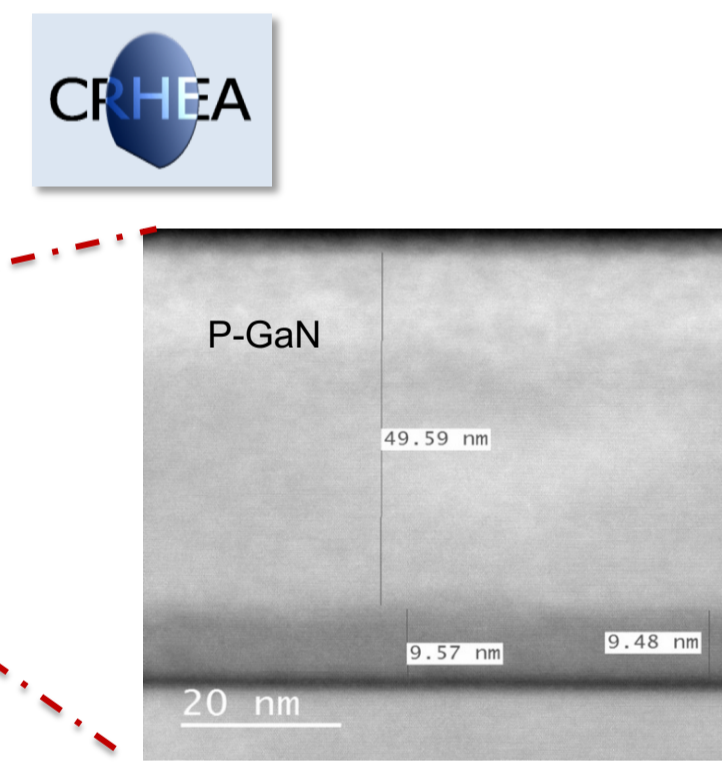
- 😞 **Naturally normally-on** (negative threshold voltage V_{th})
- No compatibility with power architectures
 - Only lateral GaN HEMT devices on Si

Technological challenge : Fabrication of Normally-off HEMTs (positive V_{th})

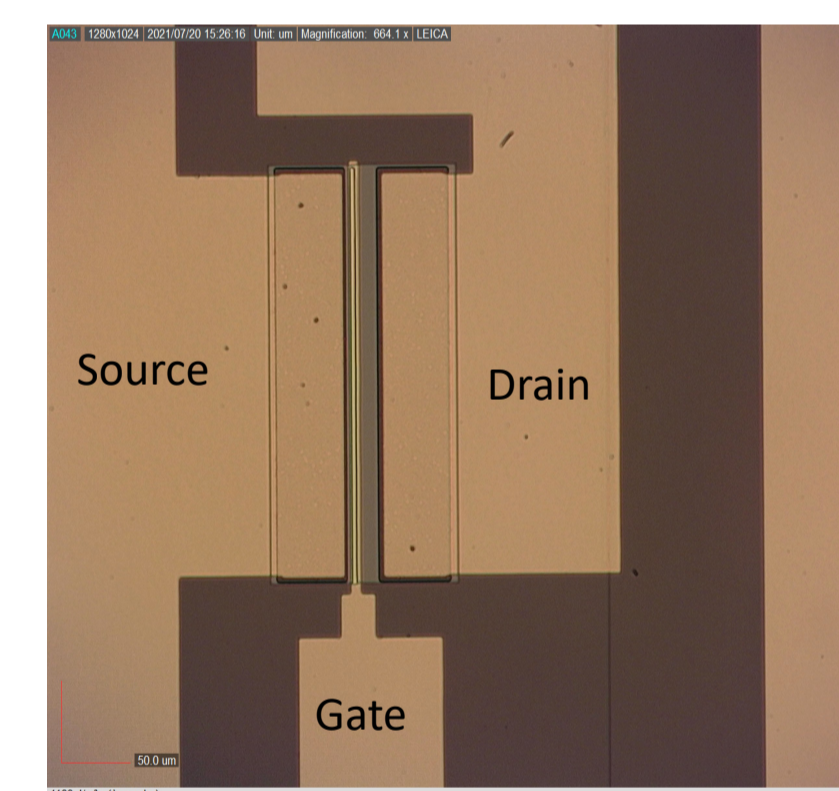
One solution : The recessed P-GaN gate HEMT



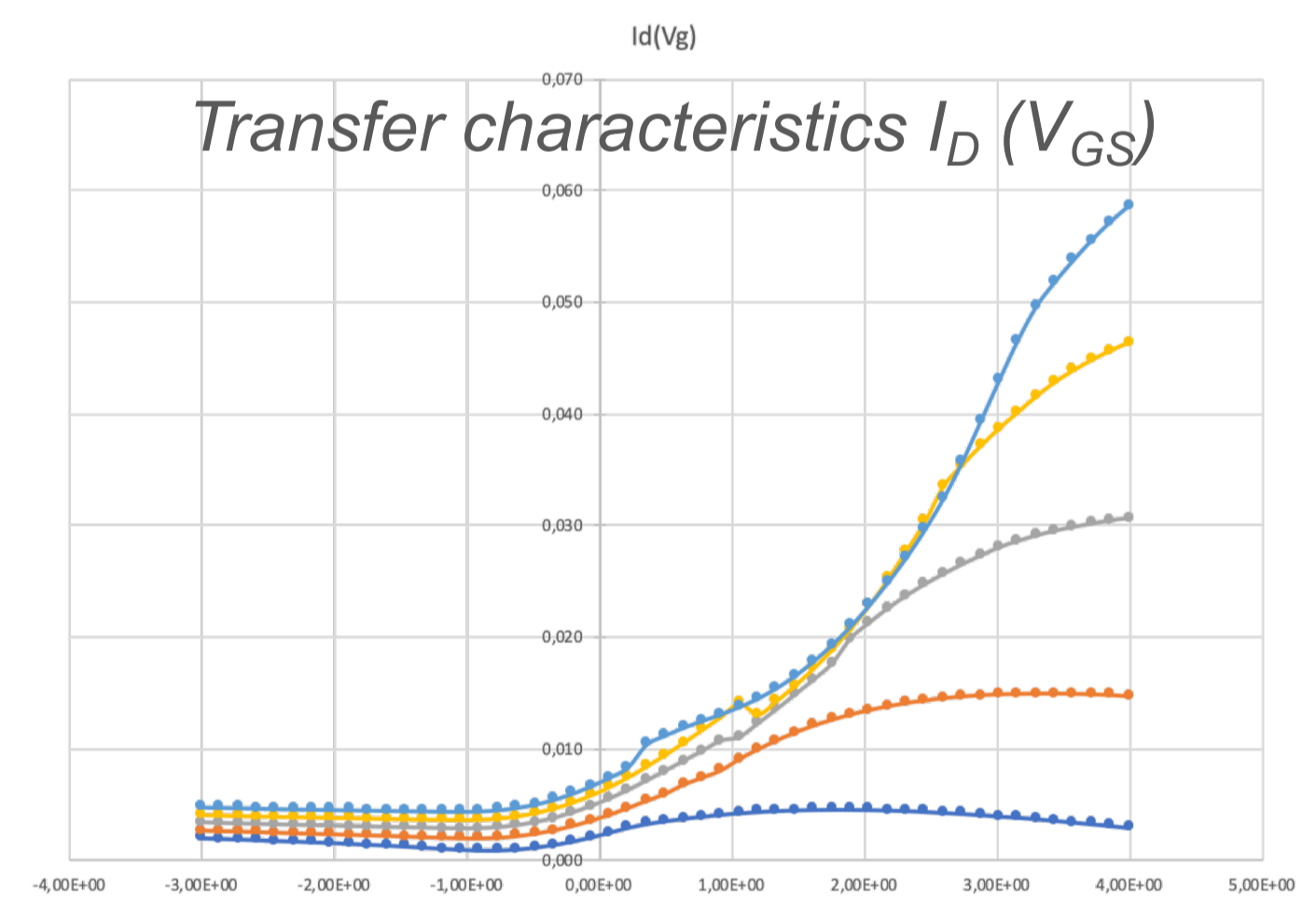
FIB cross-section on the gate after MBE P-GaN regrowth along the whole gate



TEM analysis: Perfect nucleation of GaN on AlGa_{0.2}N etched by RIE



P-GaN gate AlGa_{0.2}N/GaN HEMT fabricated at LAAS

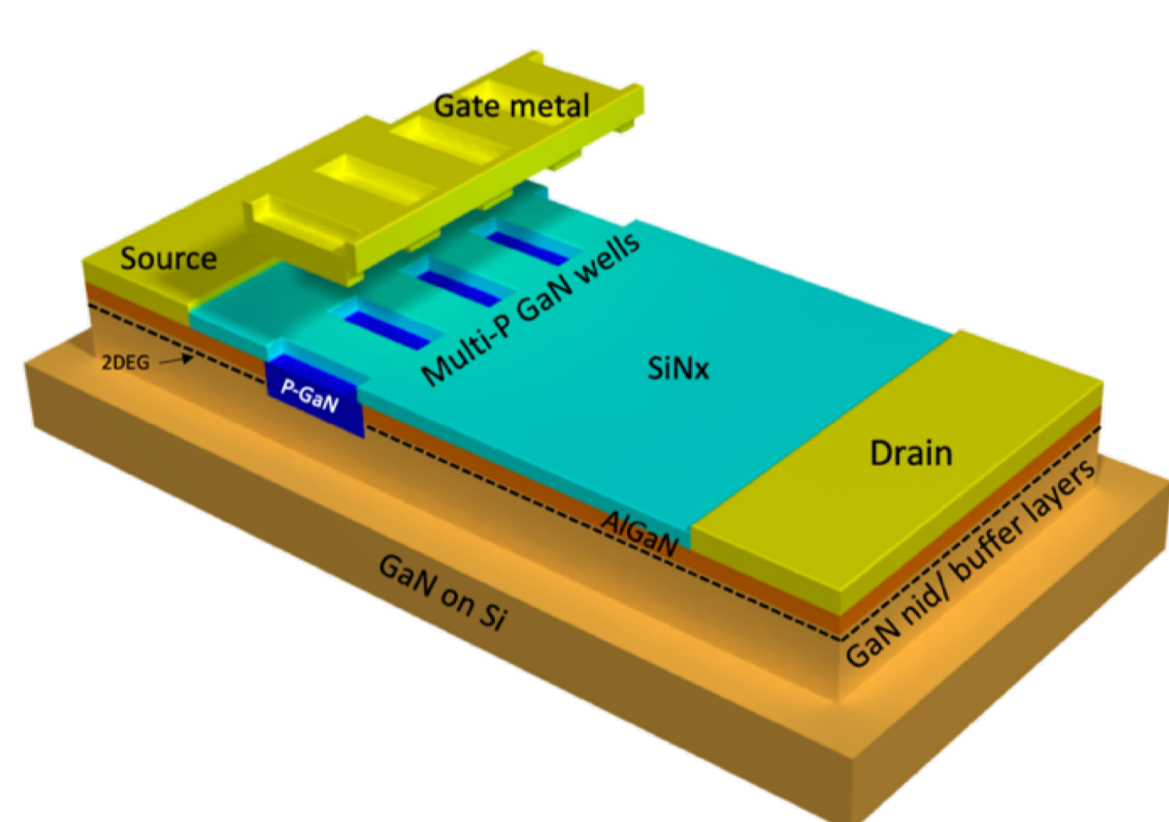


Positive $V_{th} > 1$ Volt → Validation of the P-GaN technology

(G. Toulon & C. Mattew - Patent FR 3 047 609A1)

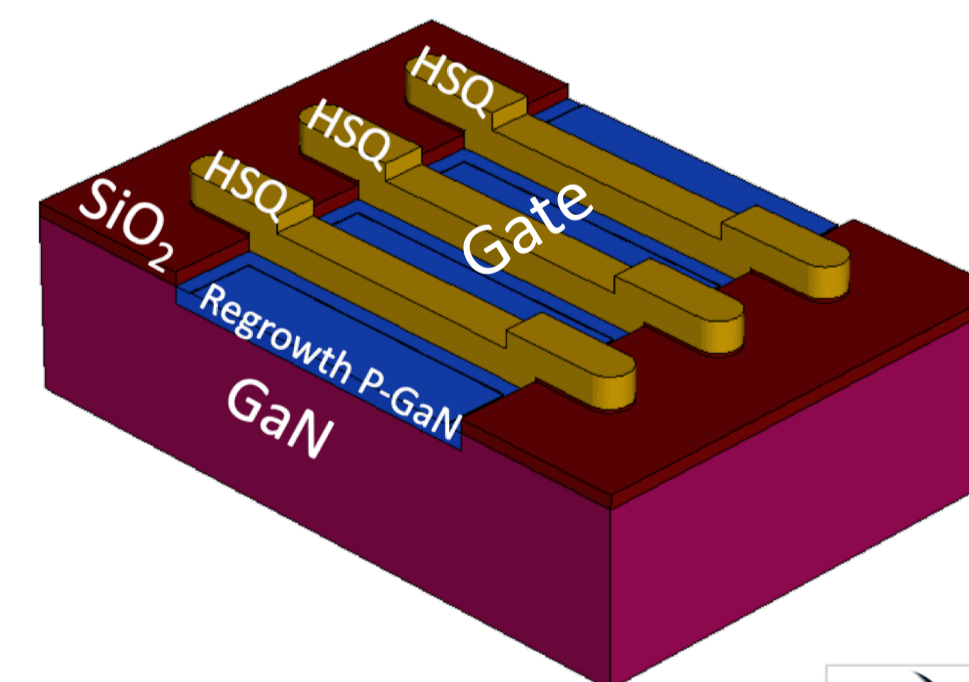
- ✓ Selective regrowth of Mg-doped GaN through the recessed gate using a SiO₂ mask by molecular beam epitaxy (MBE)
- ✓ Mg doping: 4×10^{18} cm⁻³

A new structure: The nanostructured P-GaN gate HEMT



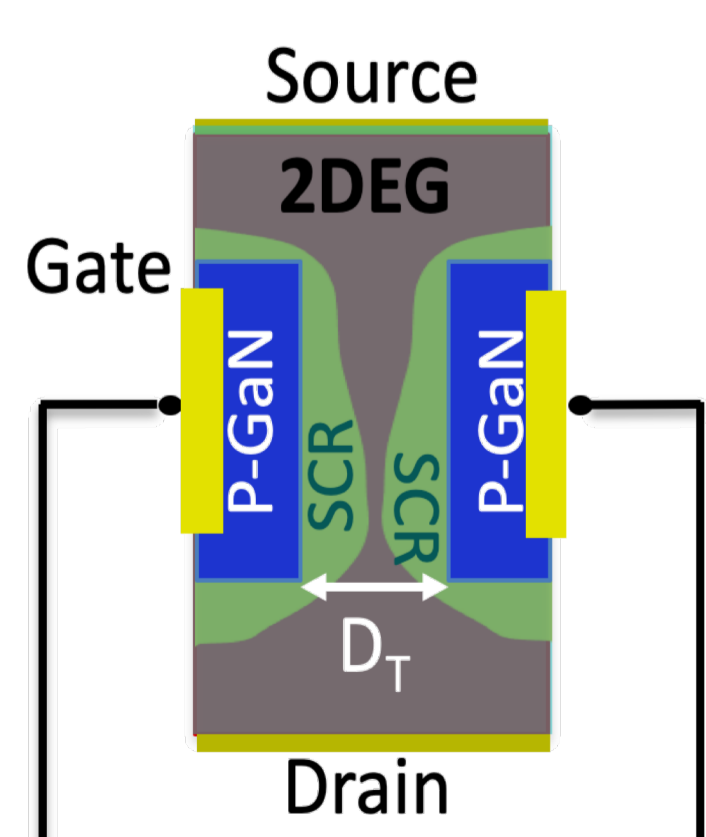
Schematic 3D view of the nanostructured P-GaN wells on the gate

- No degradation of the channel mobility
- Better ionization of Mg doping
- V_{th} control by acting on P-GaN wells parameters (depth, width, spacing, P-doping)
- Technology suitable for power functions integration

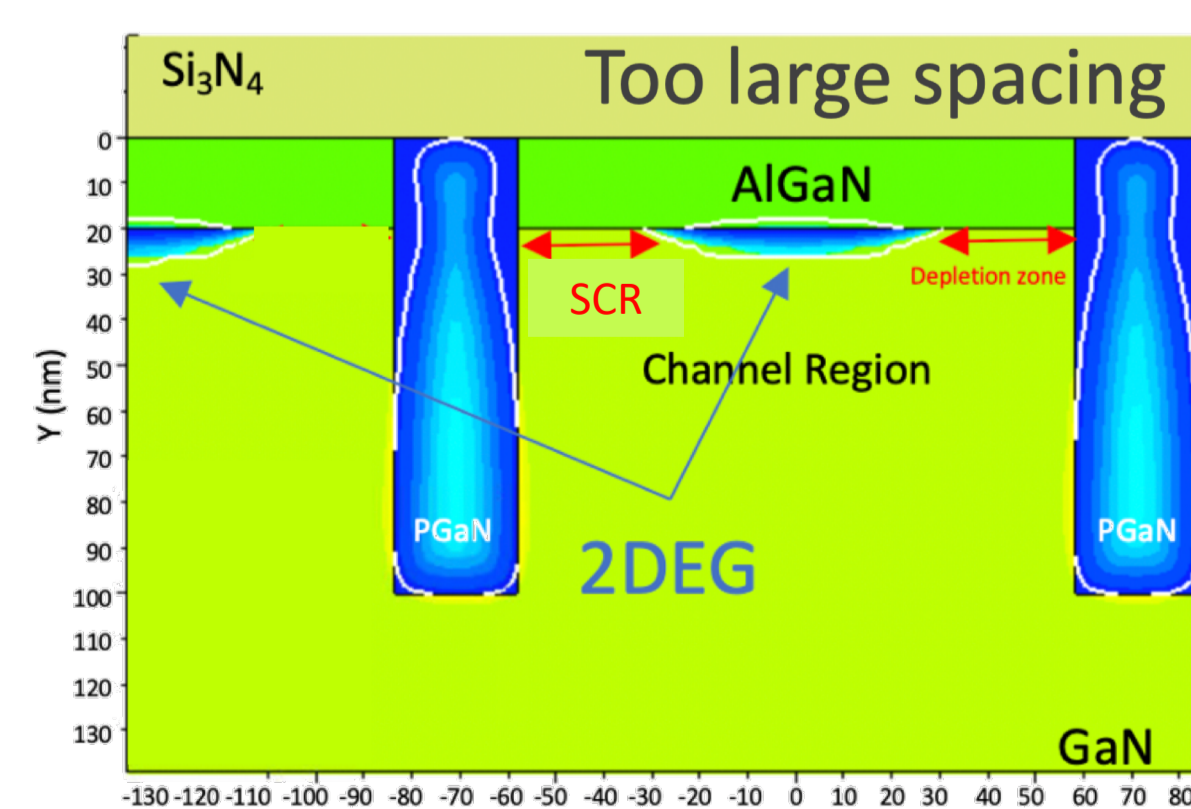


Critical technological steps:

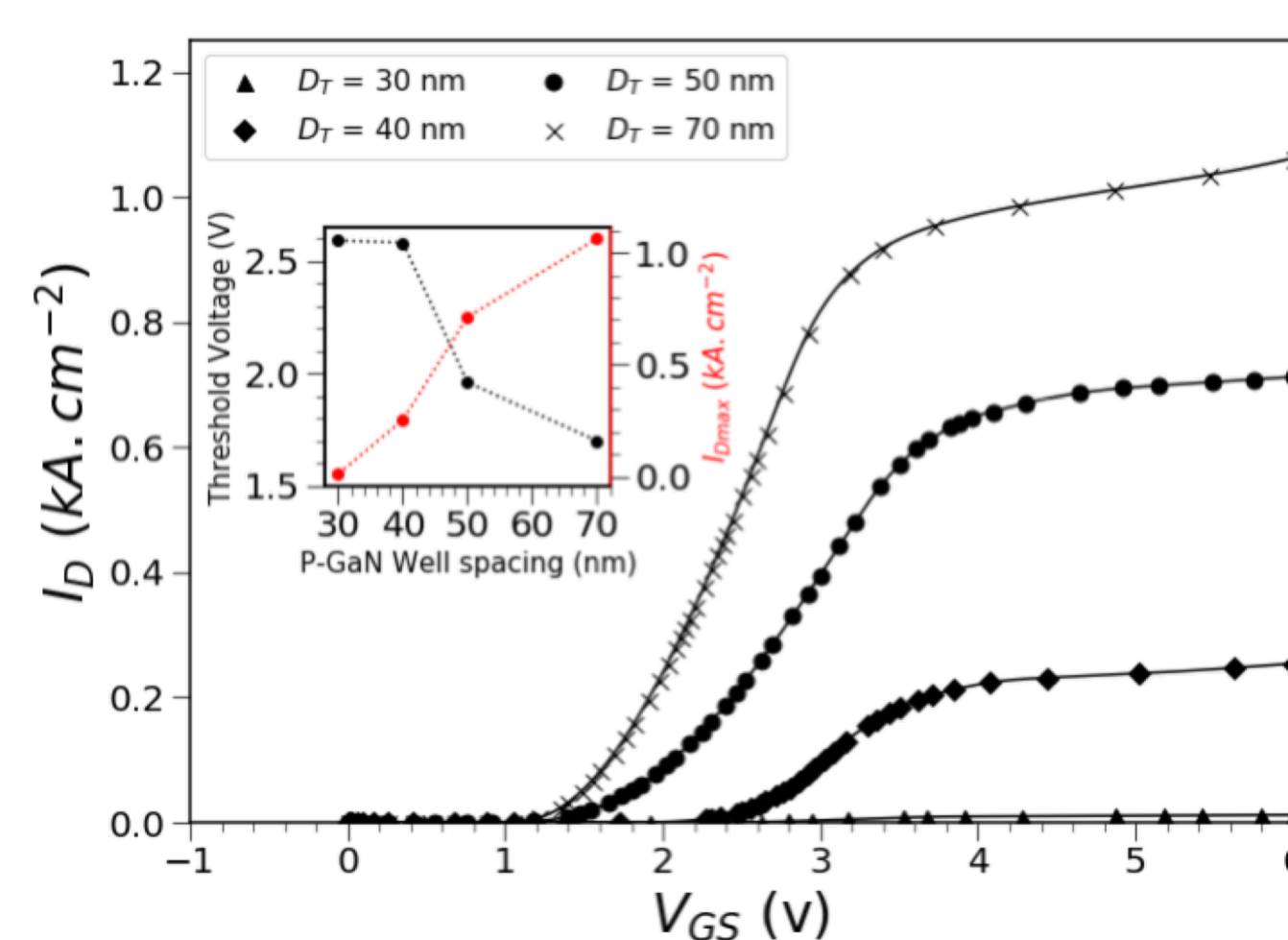
- E-beam lithography of HSQ for the delimitation of P-wells at a nanometric scale (50 - 100 nm)
- Well etching by BCl₃ RIE (150 nm deep)
- MBE Selective area P-GaN regrowth with HSQ mask



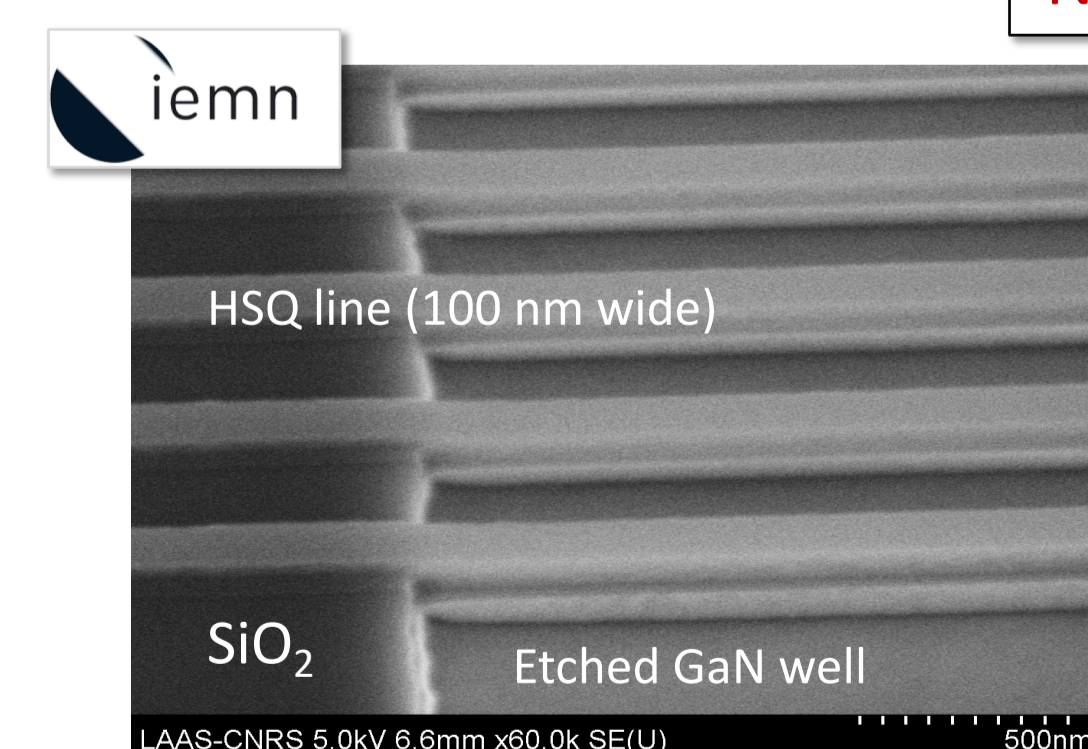
Formation of space charge regions (SCR) between two wells (schematic top view)



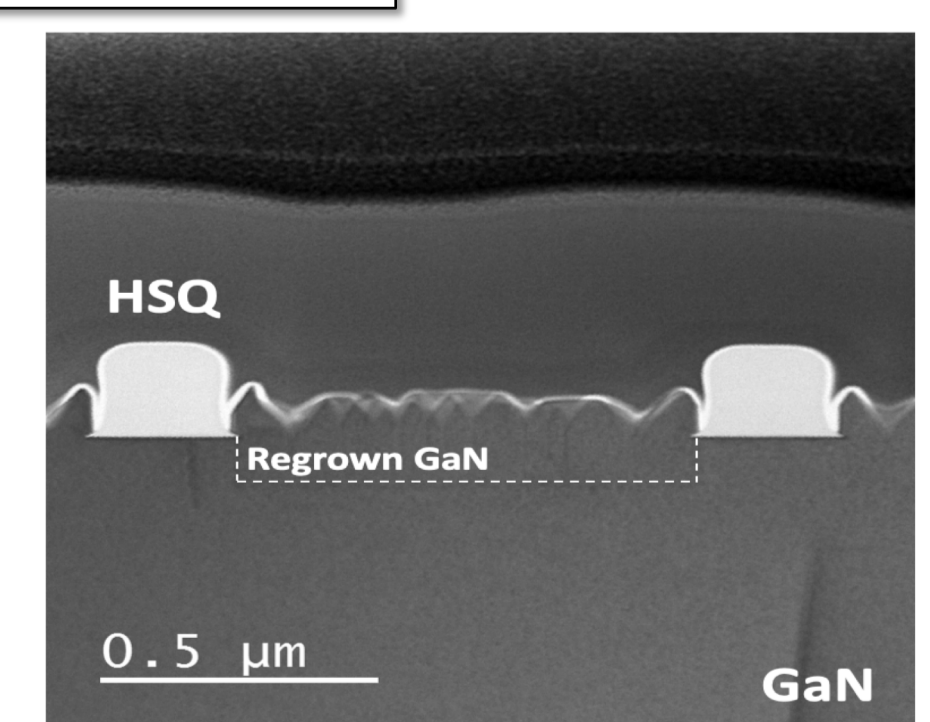
SENTAURUS TCAD simulations: Evaluation of SCR extension between two wells as a function of their spacing



3D simulated transfer characteristics for P-GaN doping of 1.10^{19} cm⁻³:
➢ When spacing increases, threshold voltage decreases
➢ $V_{th} > 1$ V

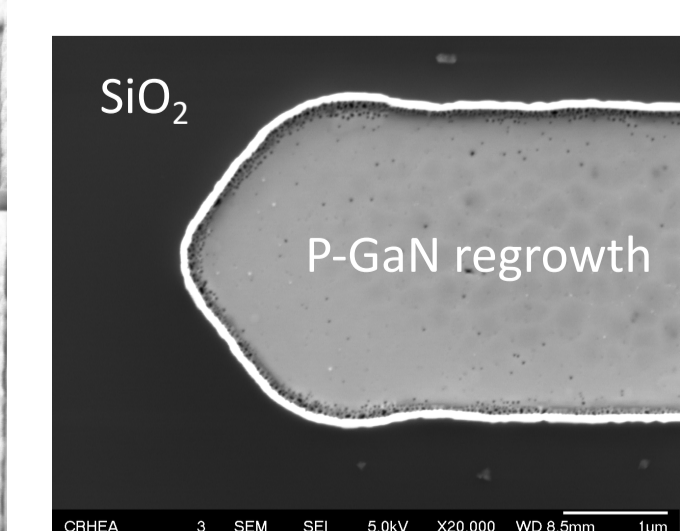
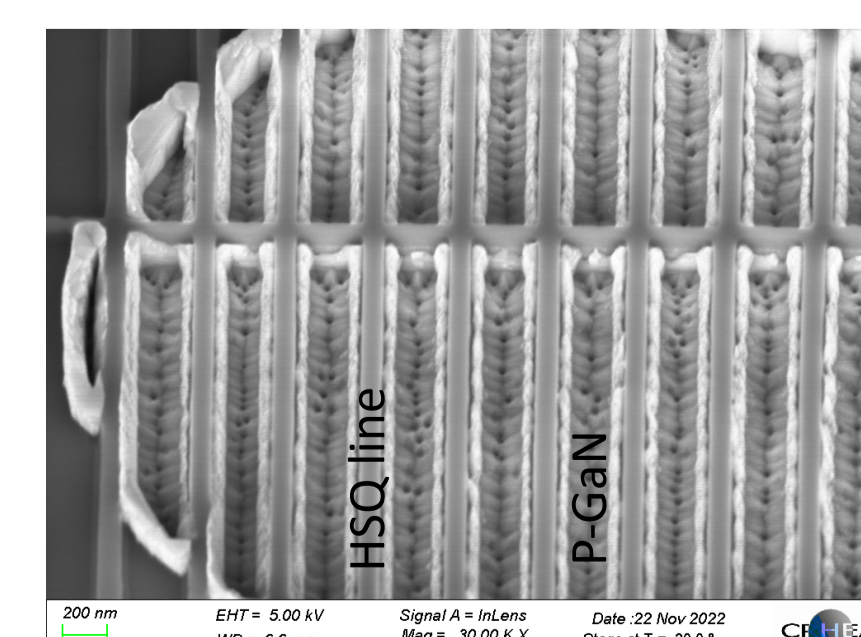


MEB view after HSQ lithography and GaN wells etching



TEM analysis after Nid-GaN regrowth Good crystal quality

Mg doped-GaN regrowth



Study under progress for optimizing MBE regrowth parameters in order to fulfill the wells