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Veeco D-125 MOCVD system

In-situ MOCVD Etching of GaN using XeF2 for Selective-Area-Epitaxial-Regrowth of p-type GaN for High Voltage PN Diodes

Andrew Allerman, A.T. Binder, A.M. Armstrong, J. Steinfeldt, L. Yates, H. M. Vuong, M.L. Smith & R.J. Kaplar

Sandia National Laboratories, Albuquerque, NM

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NNSA National Nuclear Security Administration

U.S. DEPARTMENT OF ENERGY

Practical high-voltage diodes and transistor require selective area p-type doping

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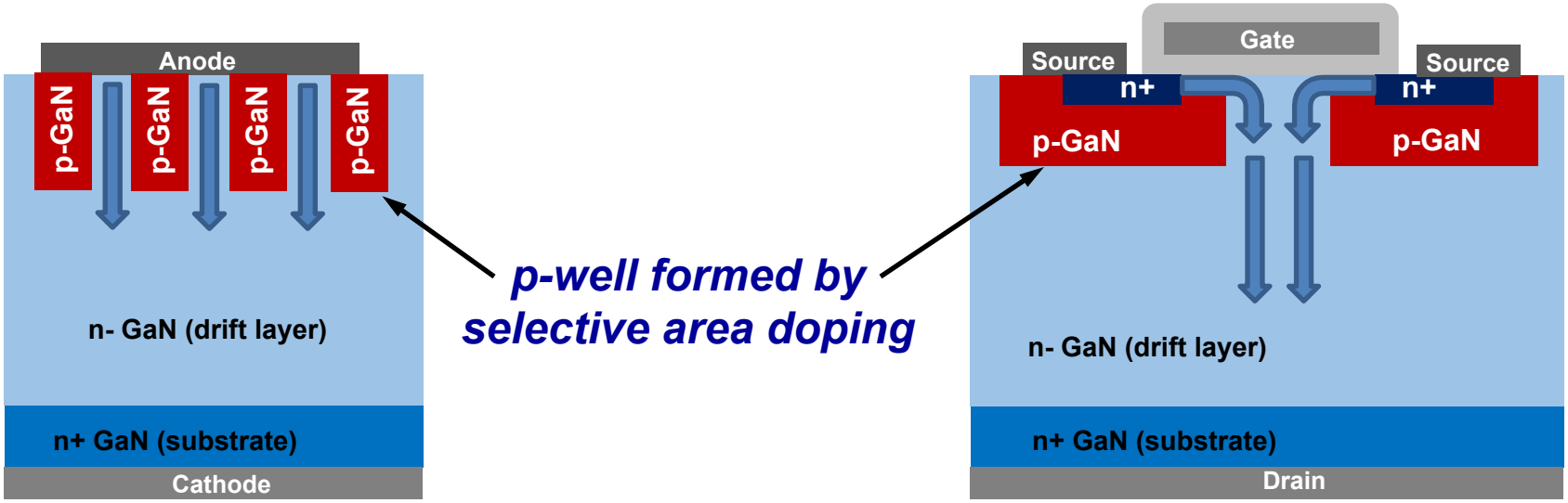
Merged PIN Schottky (MPS) diode

Double-well Metal-Insulator-Semiconductor Field-Effect-Transistor (D-MISFET)



- Reverse-bias PN junction key to multi-kilovolt blocking voltage (V_{br})
  - ➡ Must have low reverse leakage current
- P-layers formed by ion implantation and annealing for Si and SiC device
  - ➡ GaN JBS diodes by p-implant and HTA have been demonstrated

➡ *Form the p-well by ICP etch & maskless epitaxial regrowth of p-GaN*

Current-voltage characteristics of continuously grown and etched/regrown diode

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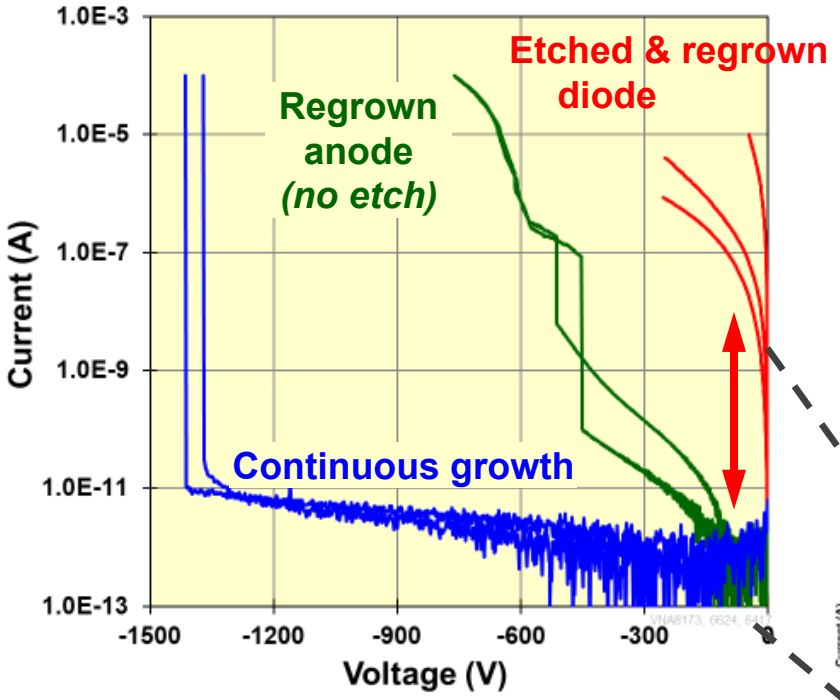
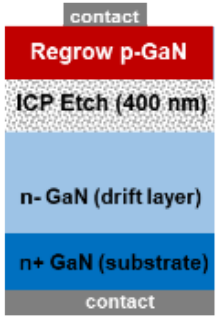
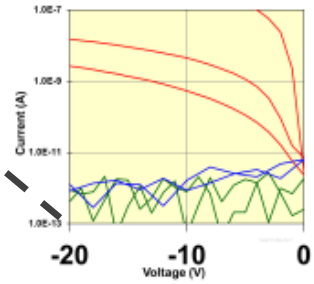
Reverse IV Characteristics

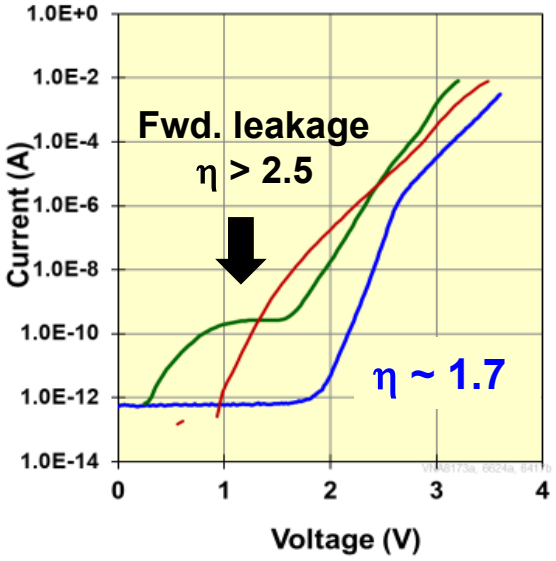




>10^2 x higher leakage current (-10 V)



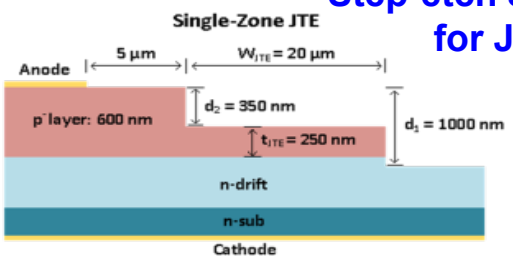
Forward IV Characteristics



Etched & Regrown diodes

- High reverse leakage @ -10V
- Forward leakage & η > 2.5

Step-etch structure for JTE



GOAL: ***Etched & regrown diodes electrically equal to continuously grown diodes***

Sub-surface etch and atmospheric Si at regrowth interface results in "leaky" PN junctions in GaN

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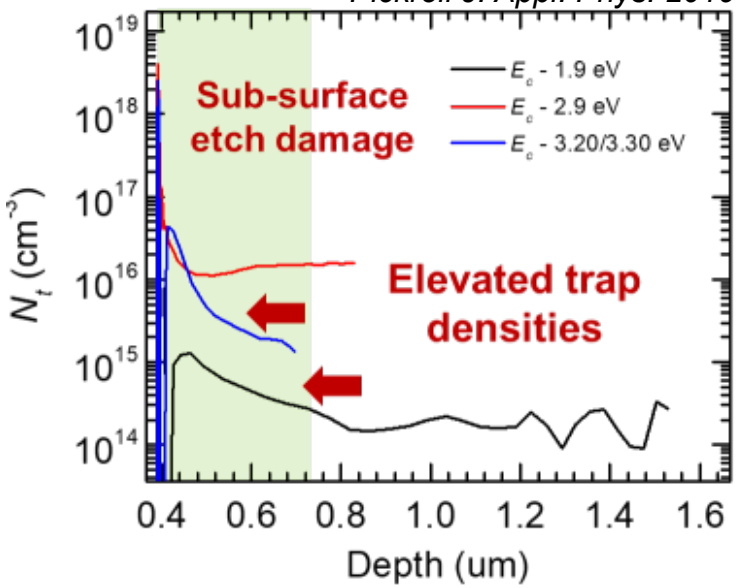
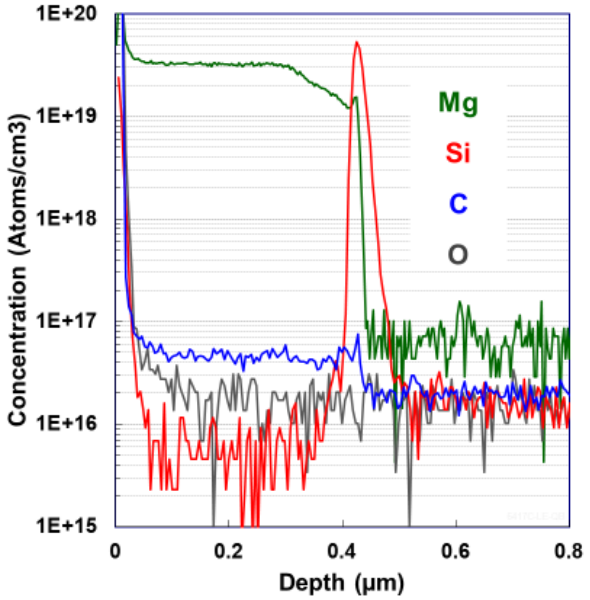
DLOS: Depth profiling of deep level traps in ICP etched n-drift layer

Pickrell J. Appl. Phys. 2019



- **Elevated trap density correlated with ICP etch damage & high diode leakage**

SIMS: Regrowth of p-GaN on ICP etched n-drift layer



- **Si spike found on surfaces exposed to air (etched or not)**

Challenges in p-GaN epitaxial regrowth for JBS diodes

- ***Sub-surface crystalline damage from plasma etching***
- ***High Si concentration at regrowth interface***

Observations and sources of surface Si contamination

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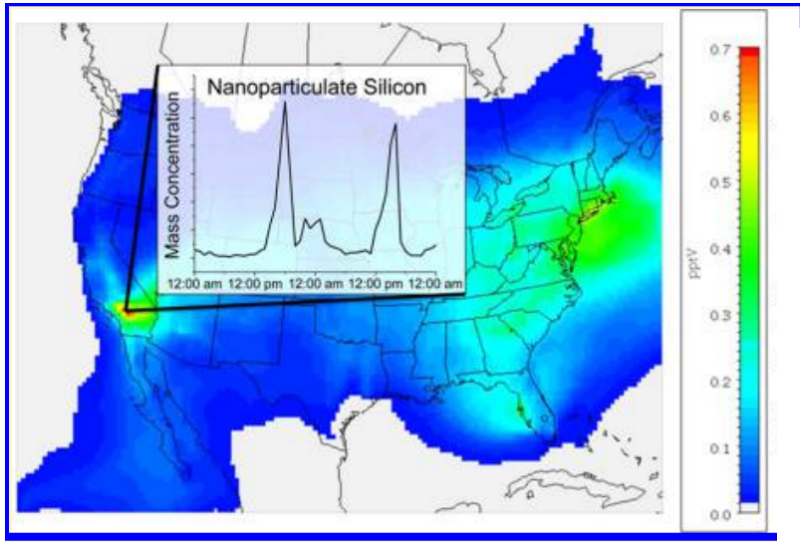
- ***Observations***
  - **Found on any surface exposed to air (SIMS: $[Si]_{peak}$ 1e17 to 2-3e19 cm-3)**
  - **Concentration is variable in time**
  - **Present in HEPA filter, Class 100 clean room**
  - **HF does not remove, (but Ozone + HF will)**

- ***Sources of Si contamination***
  - **Equipment (reactor chamber, ICP tool, etc.)**
  - **Environment (surface exposed to air)**



Oxidized Siloxane

Silicon is a Frequent Component of Atmospheric Nanoparticles

Bryan R. Bzdek,[†] Andrew J. Horan,[†] M. Ross Pennington,[†] Nathan J. Janechek,[‡] Jaemeen Baek,[§] Charles O. Stanier,[‡,§] and Murray V. Johnston*,[†]

dx.doi.org/10.1021/es5026933 | *Environ. Sci. Technol.* 2014, 48, 11137−11145

http://rem-main.rem.sfu.ca/papers/kohfeld/TegenKohfeld_Scope_ch_7pp81_92.pdf (sfu.ca)

Atmospheric Transport of Silicon

Ina Tegen and Karen E. Kohfeld

➡ ***Pursue in-situ Si removal prior to MOCVD growth***

In-situ XeF_2 etching of ICP etched GaN drift layers (Air Exposed surface)

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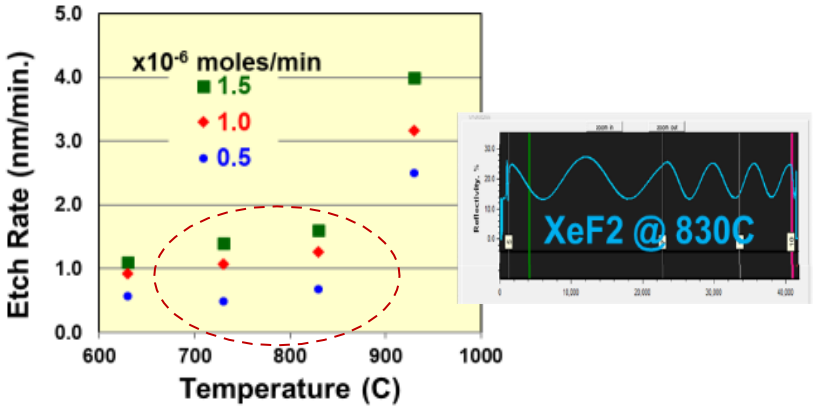
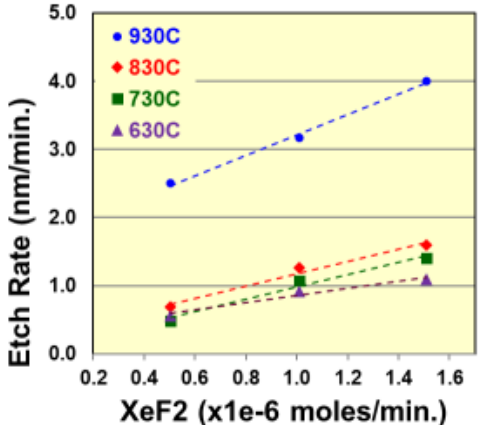
Etch Rate vs. Temperature

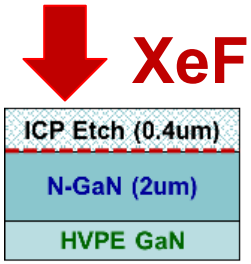


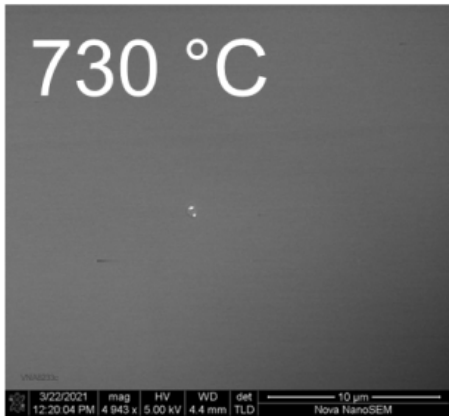
Etch Rate of GaN vs. XeF2 Flux

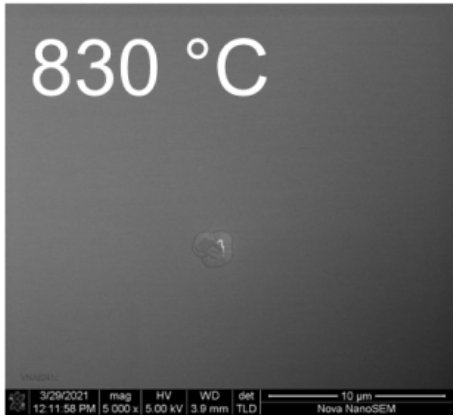


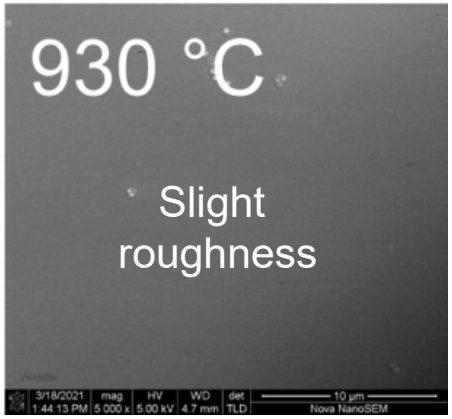
- *Etch rate is linear with XeF2 flow*
- *Stable reflectance @ 730C, 830C*

SEM of XeF2 etched - ICP etched GaN (air exposed)









➡ **In-situ XeF2 is effective for etching GaN**

Schottky Barrier Diodes on ICP-etched GaN drift layers

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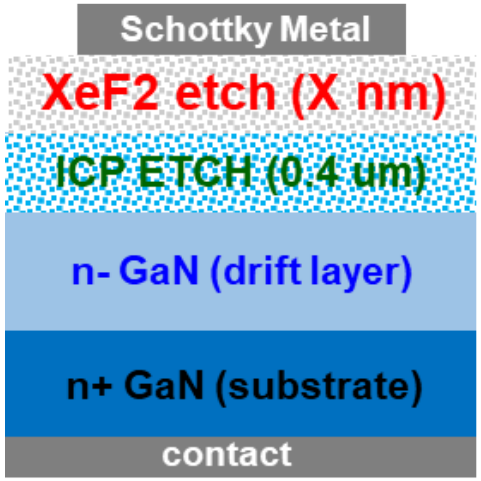
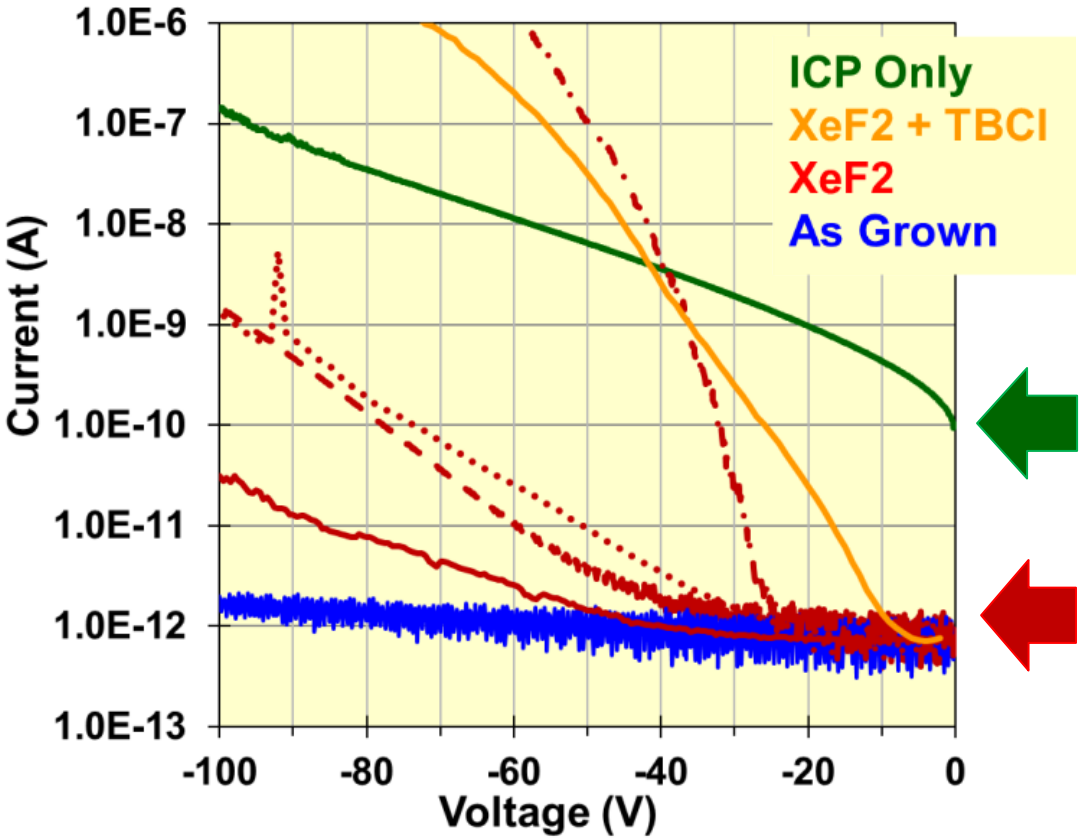
Schottky Barrier Diode



- GaN drift layer (3um, 1e16)
- ICP (0.4 μm)
- XeF2 etch (730C, 830C)
- Shadow mask SBD (Pd/Au)

Reverse IV's - Schottky Barrier Diode



➡ XeF2 is removing residual ICP etch damage

Elimination of all surface Si from GaN template with "known" surface Si concentration

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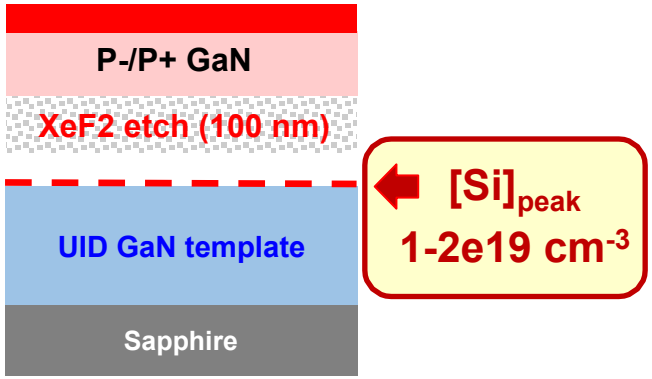
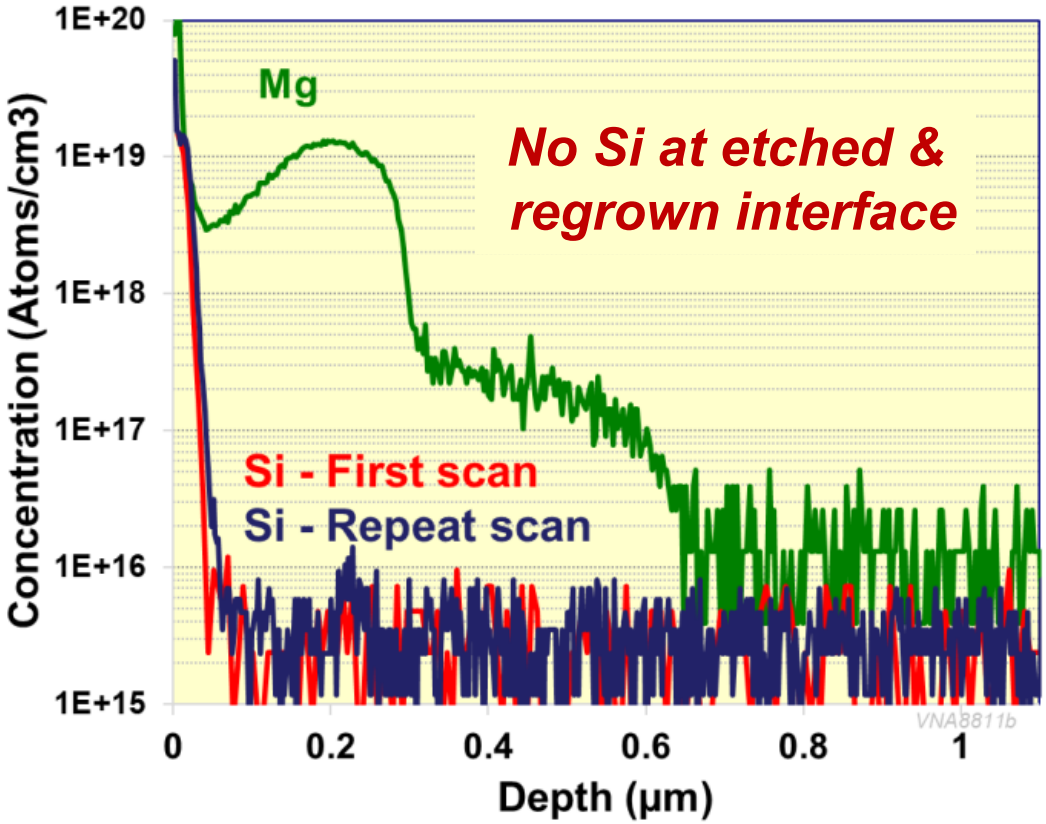
Surface Si Test Structure



- Uid-GaN on sapphire template
- [Surface Si] ~ 1-2e19 cm^{-3} (expected)
- XeF2 etch (830C, 150nm) & regrow p-GaN anode

SIMS



➡ *XeF2 removes surface Si from regrowth interface*

Regrown PN diode with ICP + XeF2 etched drift layer with sub nA reverse leakage and Vbr > 1kV

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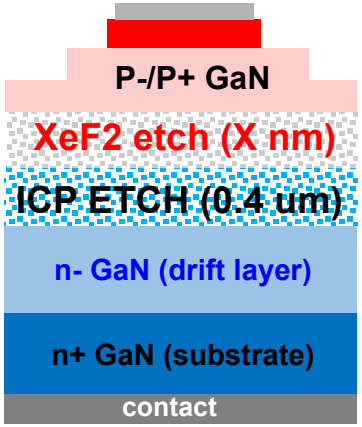
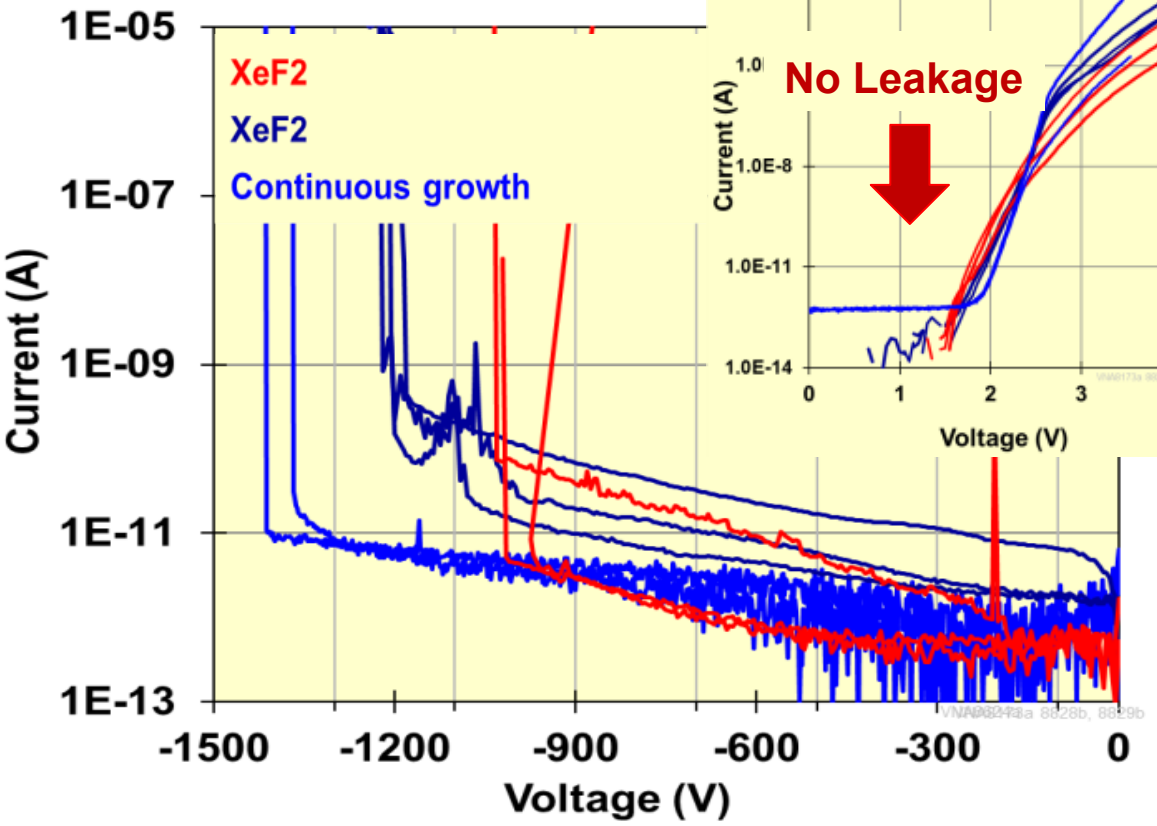
Diode Structure



- GaN drift layer (10um, 1-2e16)
- ICP (0.4 μm)
- XeF2 etch (830C)
- Regrow p-GaN anode
- Step-etch JTE

Reverse IV Characteristics



Forward IV

➡ *XeF2 enables sub-nA leakage in etched & regrown, kilovolt-class PN diodes similar to continuously grown diodes*