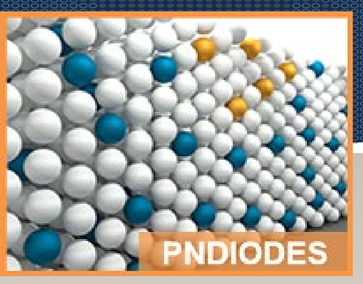
SAND2022-16876D

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Sandia National Laboratories

# High Voltage Regrown GaN P-N Diodes Enabled by Defect and Doping Control

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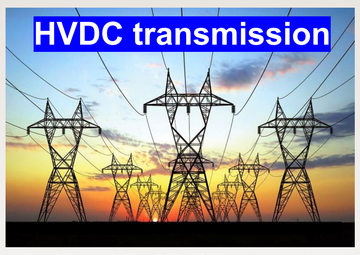
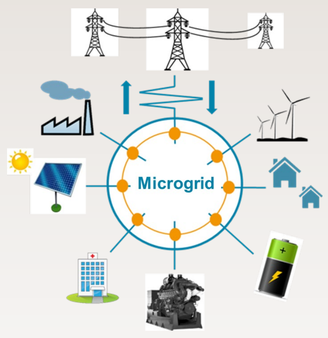
## GaN electronics for domestic energy security




https://www.electronicshub.org/high-voltage-dc-transmission-system/



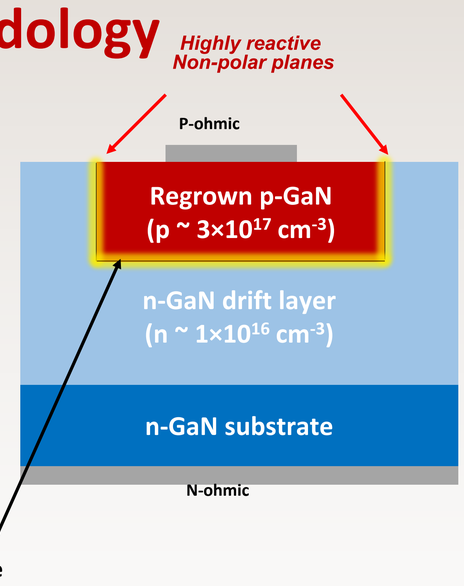

https://www.delta-ee.com/research-consulting/micro-grids.html


**Goal:** Demonstrate 1.2 kV GaN diodes using selective area regrowth

**Challenge:** Regrown GaN diodes exhibit current leakage and premature breakdown

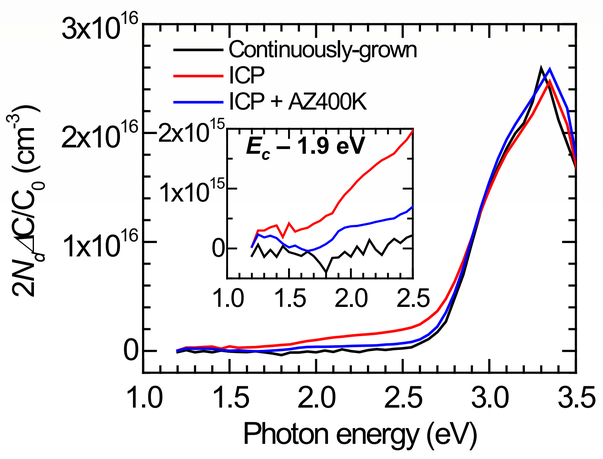
## Problem and Methodology

- Regrowth interfaces have elevated impurity concentrations that can lead to excess leakage
- Si is main concern for c-plane
- Si and O impurities are important for *m*-plane sidewalls
- Control impurities at regrowth interface of *c*-plane and *m*-plane regrown diodes
- Optimized regrowth so that Si contamination is not detrimental to diode operation

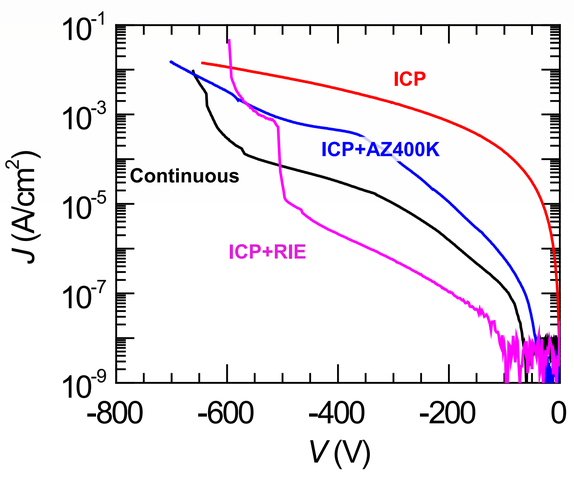



## Quantitative correlation of ICP etching, deep level defects and reverse leakage

### Steady-State Photocapacitance




### Reverse leakage

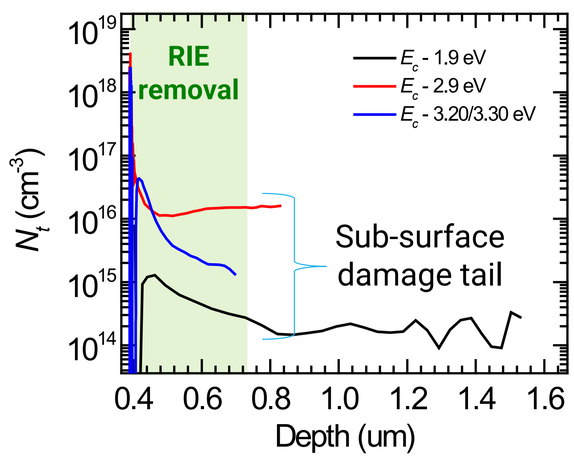



### ICP etch and regrowth

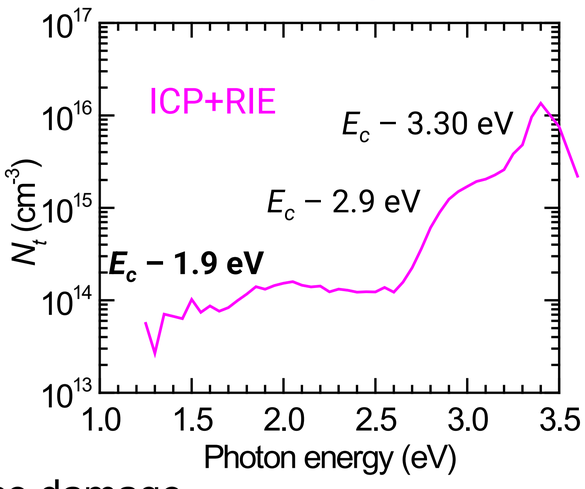
- Etch-enhanced $E_c$ – 1.9 eV deep level correlated with increased reverse leakage
- ICP+AZ400K reduces $E_c$ – 1.9 eV deep level relative to ICP only
- Correlated with large reduction in reverse leakage

## Remove ICP etch damage using slow RIE etch

### Deep level depth profile for AZ400K treatment




### SSPC of ICP+RIE pn-diode

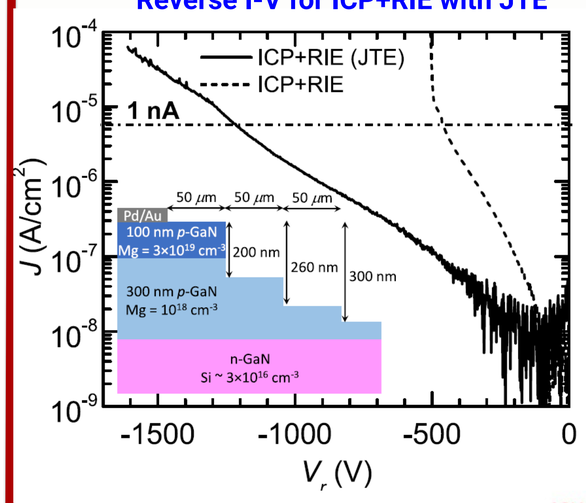



### RIE after ICP removes sub-surface damage

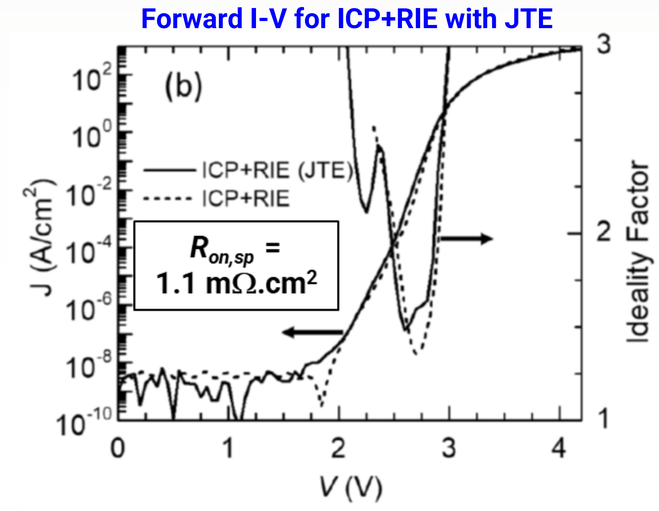
- Depth profiling of deep levels reveals sub-surface damage not removed by AZ400K
- Removed 270 nm of material below ICP-etched surface using slow RIE etch
- RIE etch reduces $E_c$ – 1.9 eV defect state and reverse leakage to as-grown levels

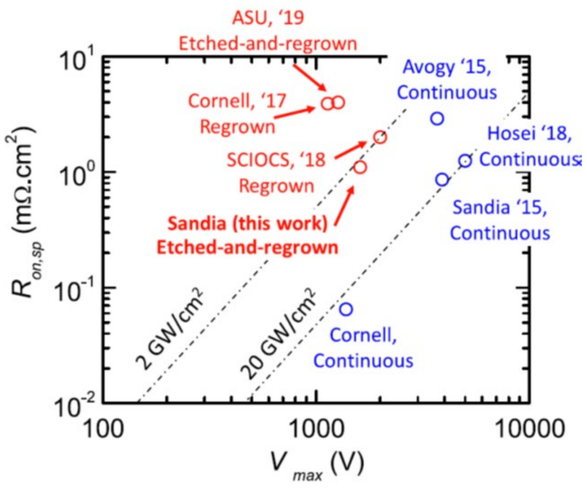
## 1500 V etched-and-regrown diode using ICP+RIE and Junction Termination Extension (JTE)

### Reverse I-V for ICP+RIE with JTE




### Forward I-V for ICP+RIE with JTE




### kV-class etched-and-regrown diodes with JTE

- 1.5 kV diode with lower leakage (< 1.2 kV) than best reported regrown diode (no etch)*
- Figure-of-merit still lags continuously-grown diodes
- Suggests other leakage paths exist beyond defectivity in drift region

* **H. Fujikura, et al., APEx 11, 045502 (2018).**

## Summary and Conclusions

- ICP etch strongly increases $E_c$ – 1.9 eV deep level concentration and reverse leakage
- Slow RIE etch after ICP reduces $E_c$ – 1.9 eV concentration and reverse leakage to as-grown levels
- Achieved 1.5 kV etched-and-regrown diode by combining ICP+RIE with JTE
- Additional leakage path must exist beyond deep levels because ICP+RIE w/ JTE diode FOM lags that of continuously-grown diode

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