Planar View of Structural Degradation in GaN HEMT:

Voltage, Time and Temperature Dependence

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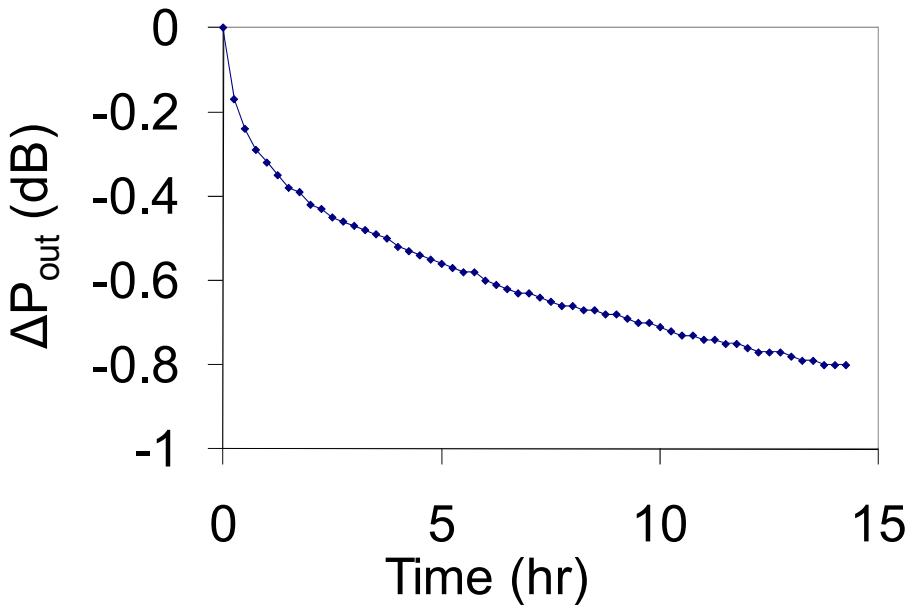
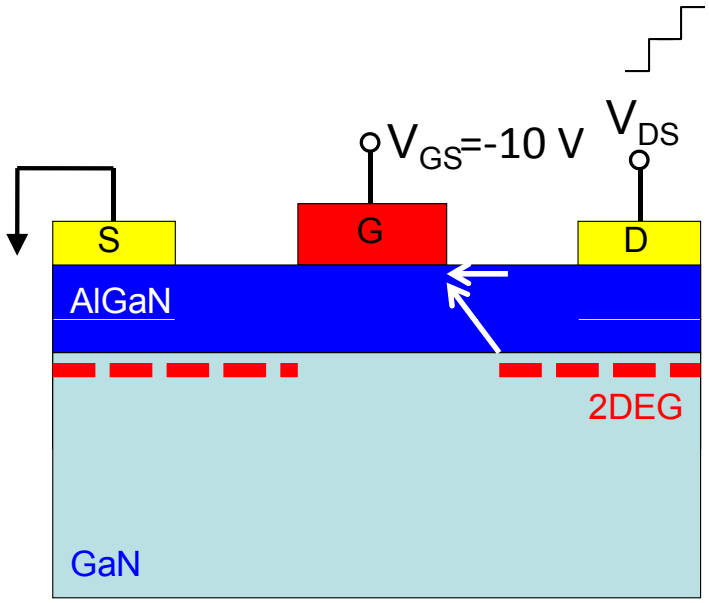
Introduction

- GaN HEMT Reliability: big concern
  - RF power degradation
  - I_D decrease, R_D increase, I_G increase, V_T change…
- Goal: understand degradation mechanism

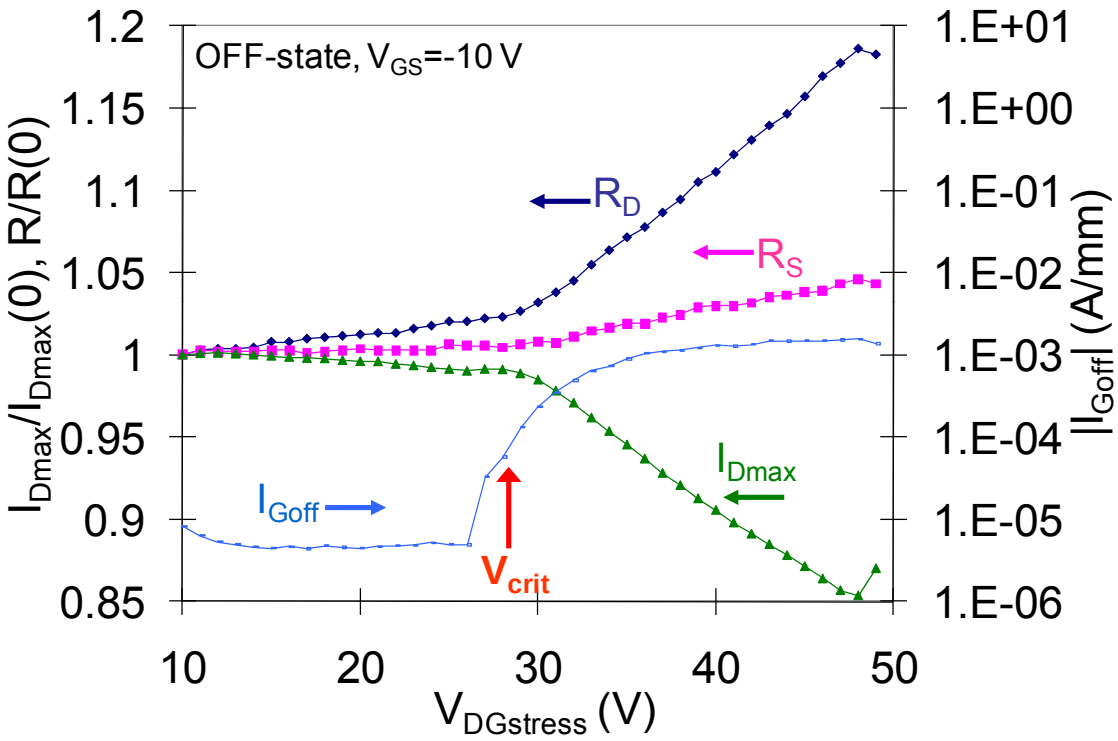
RF stress
10 GHz,V_D=28 V
I_{DQ}=150 mA/mm
P_{in}=23 dBm
P_{out}=33.7 dBm



High Voltage Degradation in GaN HEMTs



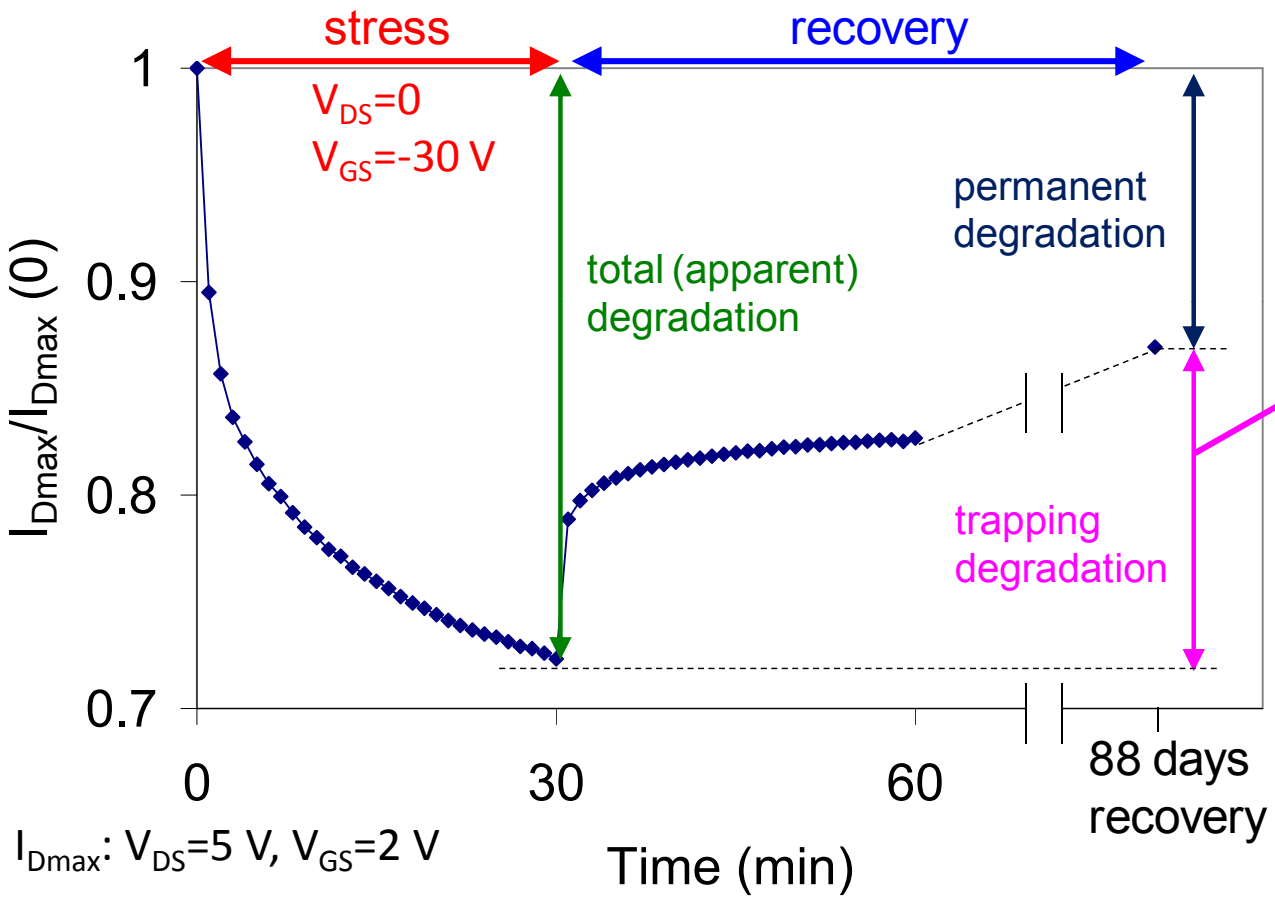
Joh, EDL 2008



I_{Dmax}: V_{DS}=5 V, V_{GS}=2 V I_{Goff}: V_{DS}=0.1 V, V_{GS}=-5 V

I_D, R_D, and I_G *start to degrade beyond critical voltage (V_{crit})*
(+ trapping behavior – current collapse)
Common physical origin in I_D and I_G degradation

Permanent vs. Trapping Degradation



Two components:

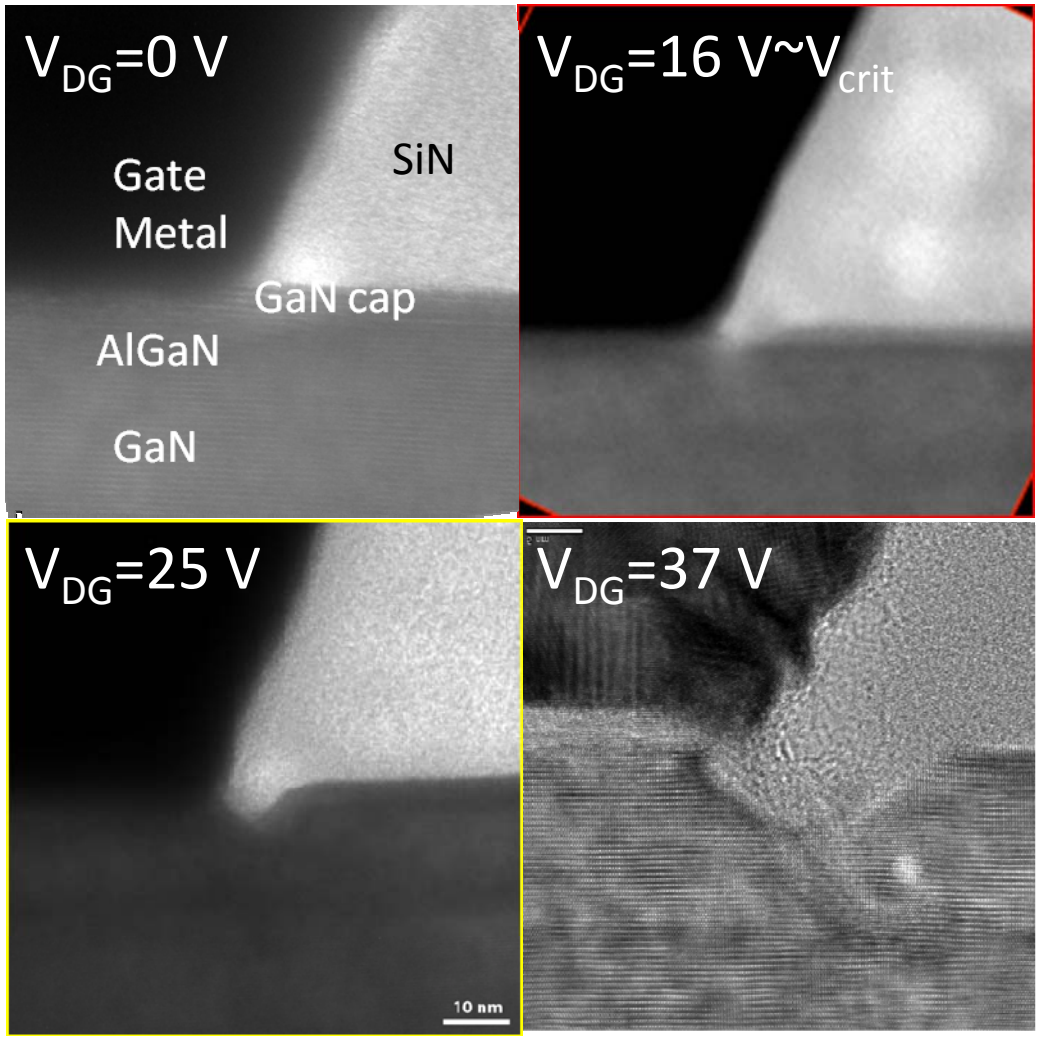
- **Native traps**
- **Stress-induced traps**

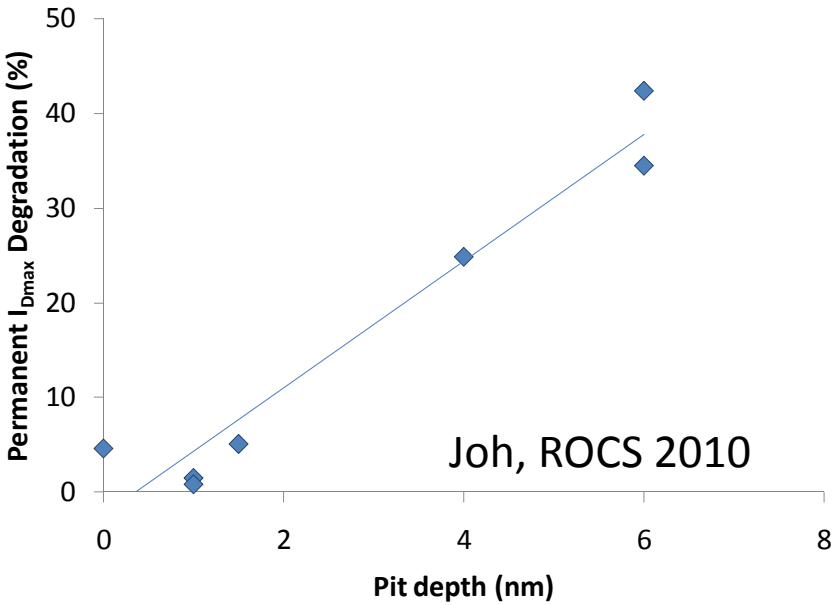
Separated by current collapse measurements:
1s V_{DS}=0, V_{GS}=-10V
diagnostic pulse

13 % permanent degradation + 15 % trapping degradation

Joh, ICNS 2009

Material Degradation around V_{crit}





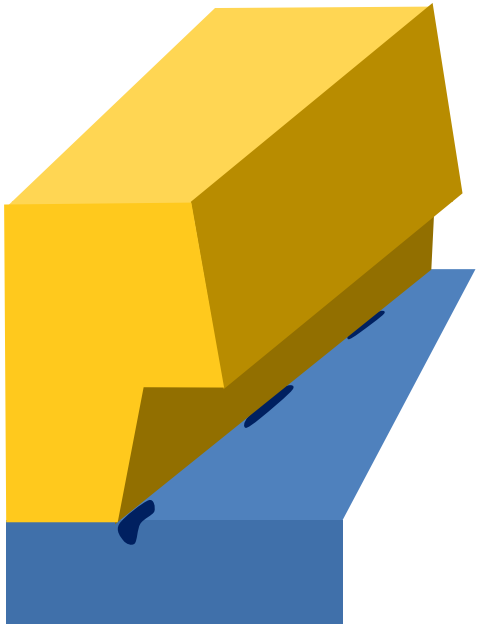
Initial dimple followed by deeper pit and crack.

Good correlation between pit depth and I_{Dmax} degradation

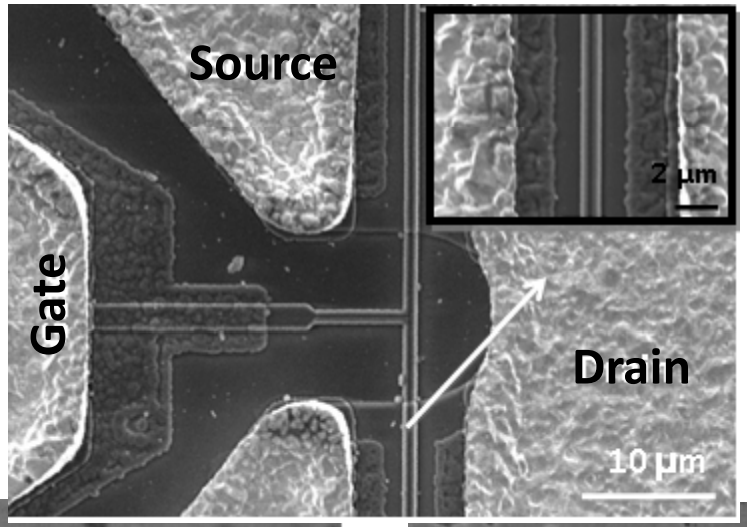
How do these defects extend along the device width?

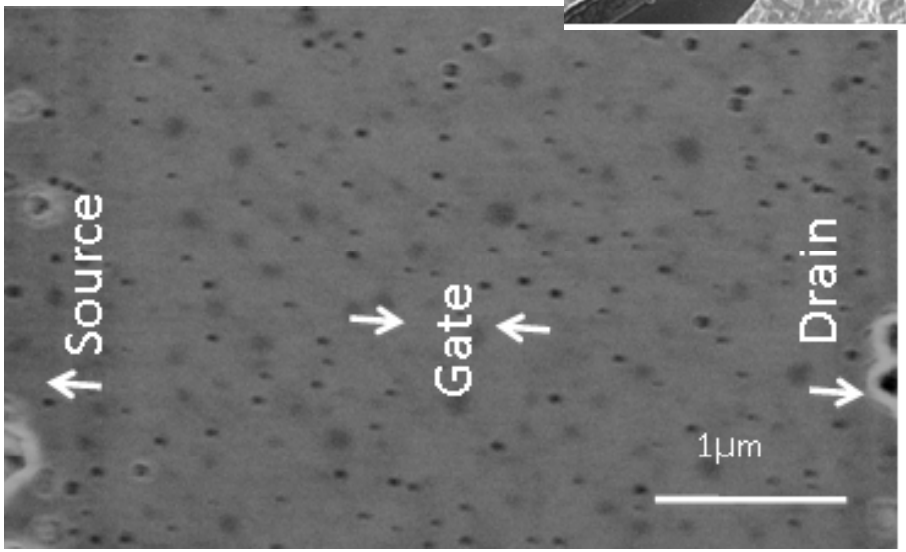
Plan View Approach

- Limitations of *TEM*:
  - Costly
  - Extremely local
- This work: (details in Makaram, APL 2010)
  - Removal of SiN passivation and gate
    - SiN passivation: HF etch
    - Contact and gate metals: aqua regia
    - Surface cleaning: piranha solution
  - Plan view imaging through *SEM* and *AFM*

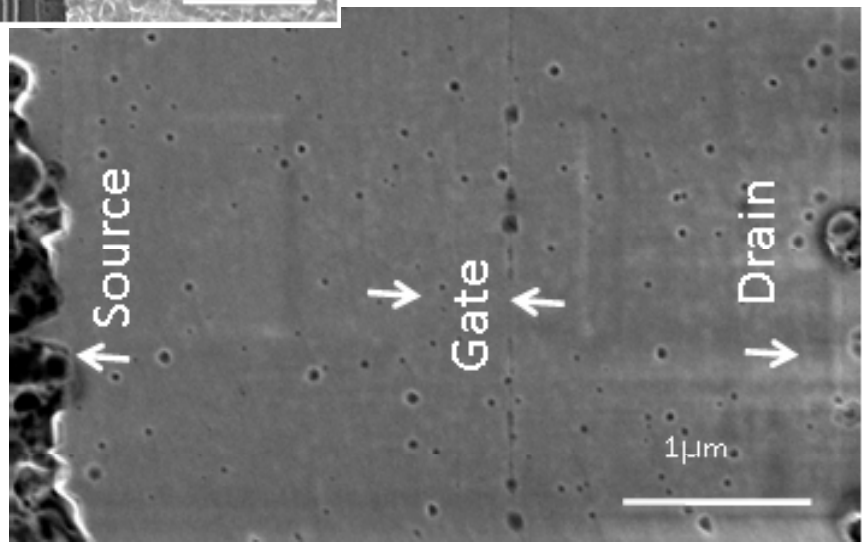


SiN and Gate Removal





Unstressed (high T storage)



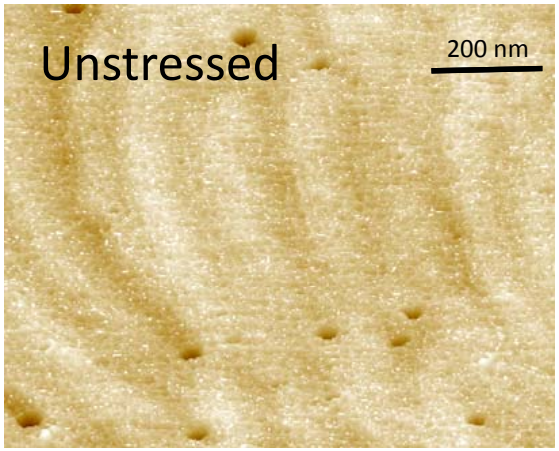
Stressed (> V_{crit})

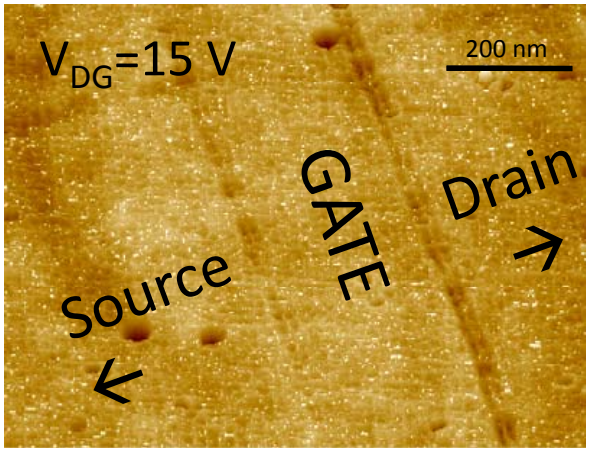
Voltage Acceleration

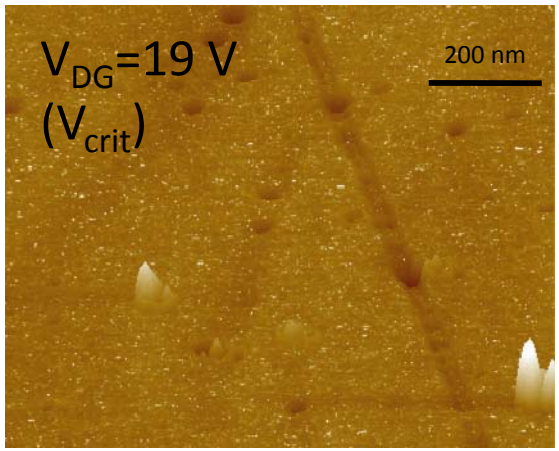
- OFF-state step stress:
  - V_{GS}=-7 V
  - V_{DS} stepped from 5 to 8, 12, 35, 50 V (1 min/1 V step)
  - T_{base}=150 °C
- Detailed device characterization:
  - DC device parameters: I_{Dmax}, R_S, R_D, V_T…
  - Trap characterization: current collapse
- Removal of passivation and gate metal
- SEM and AFM plan view imaging

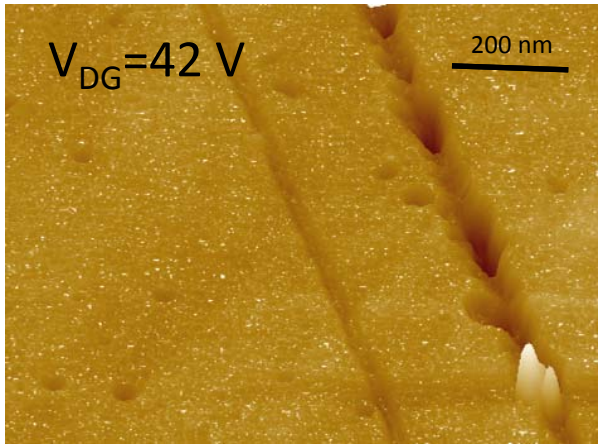
Voltage Acceleration

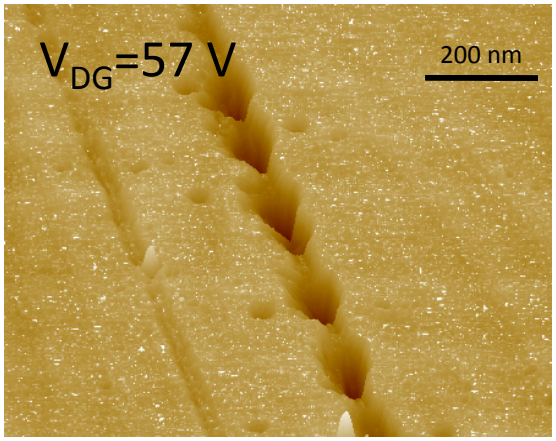
OFF-state step-stress, V_{GS}=-7 V, T_{base}=150 °C







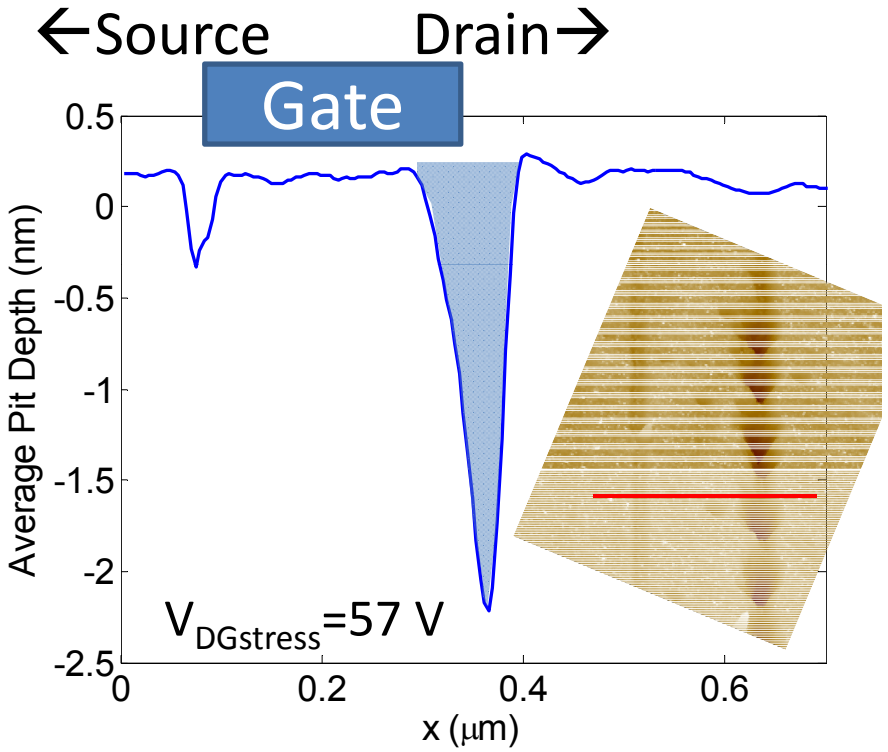




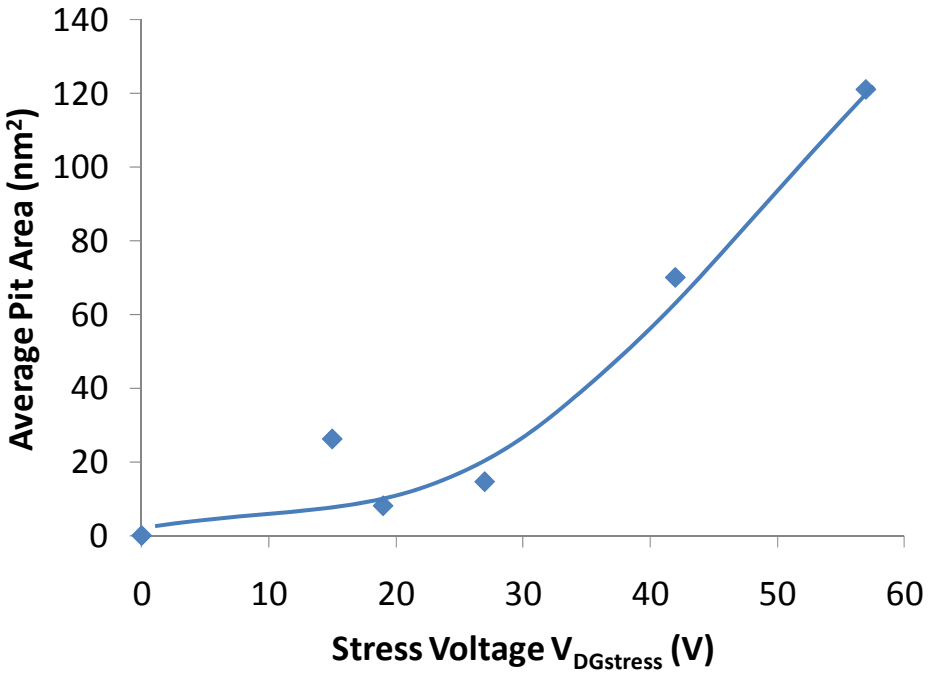
Initial continuous groove formation

Deeper pit formation along the groove

Pit Cross Section Area



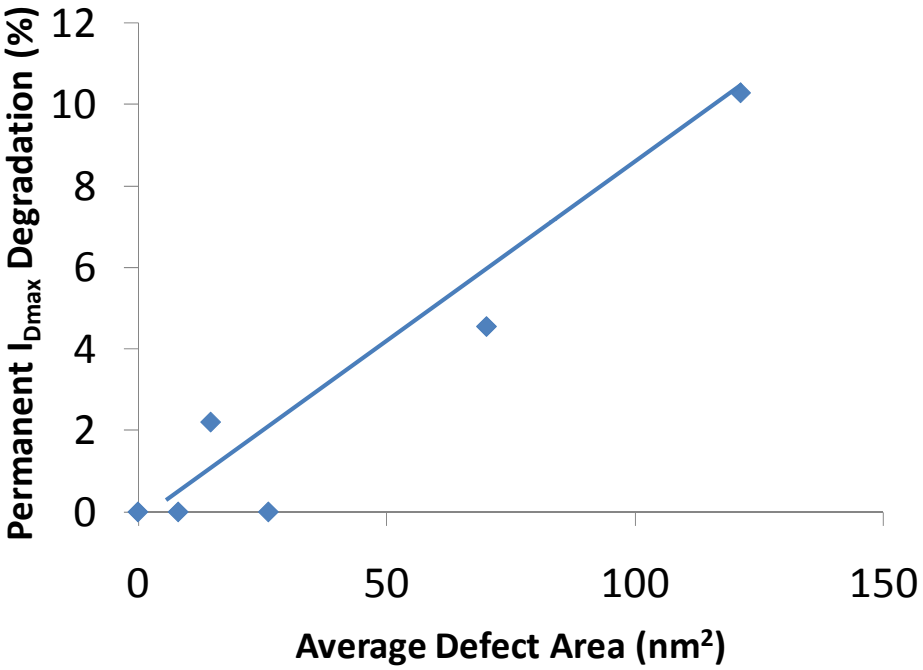
Cross section averaged over 1 μm.

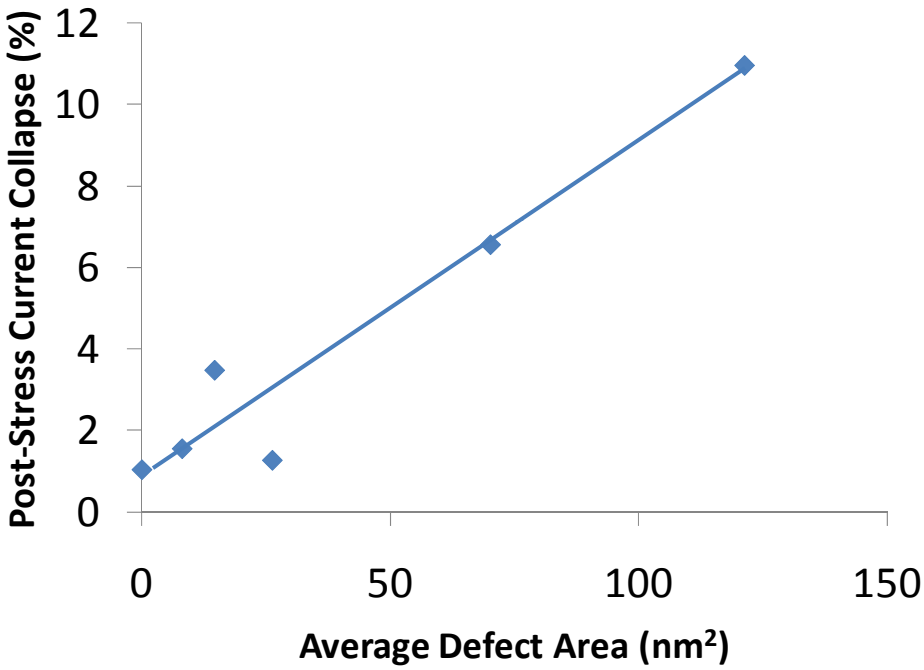


Pit formation is voltage accelerated.

Drain side pit area also shows critical behavior.

Correlation between Electrical and Structural Degradation

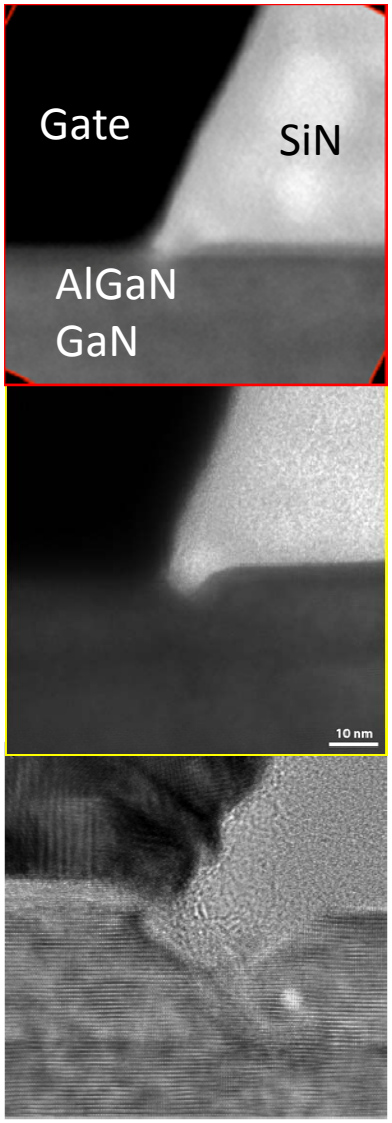




Good correlation between electrical degradation and pit area

Degradation Process

Cross-section



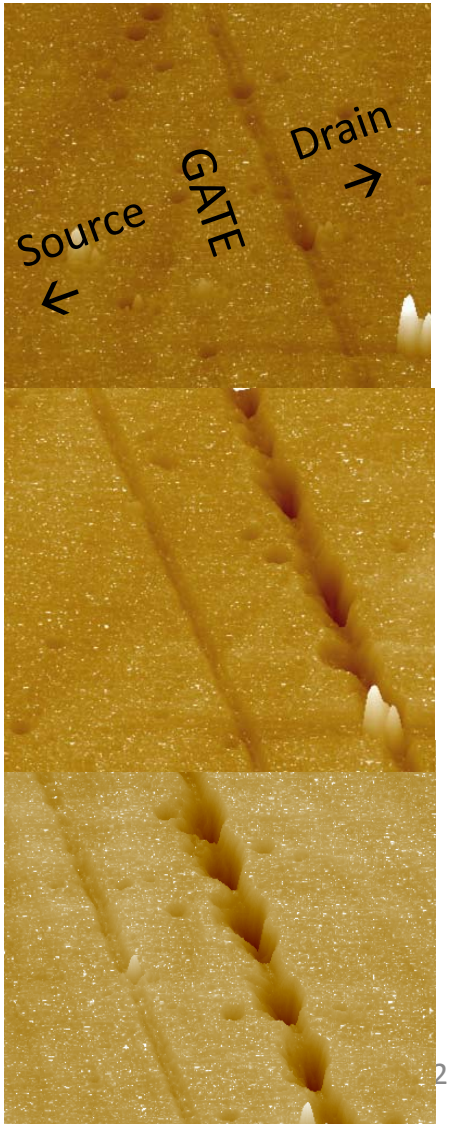
1. Below and around V_{crit}:
Groove formation in GaN cap

2. Beyond V_{crit}:
Pit formation in AlGaN barrier

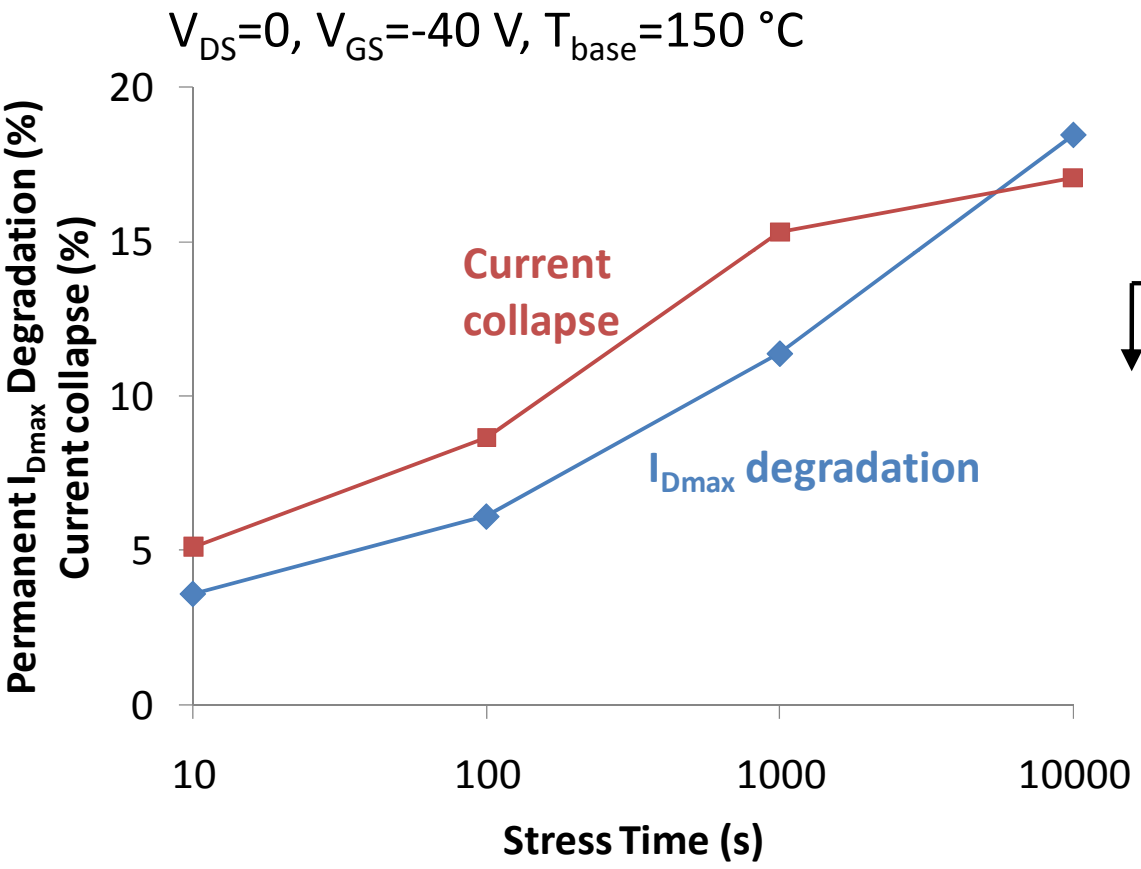
3. Pit growth (to AlGaN/GaN interface) and merge

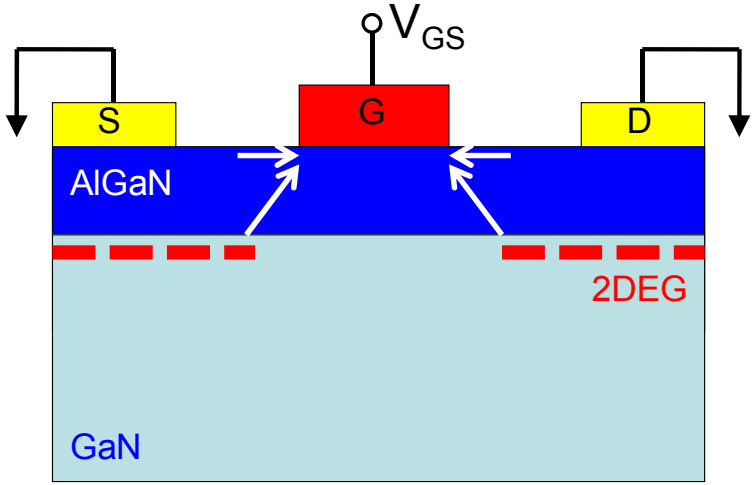
Consistent behavior
Complimentary techniques

Plan-view



Time Evolution – Electrical Degradation



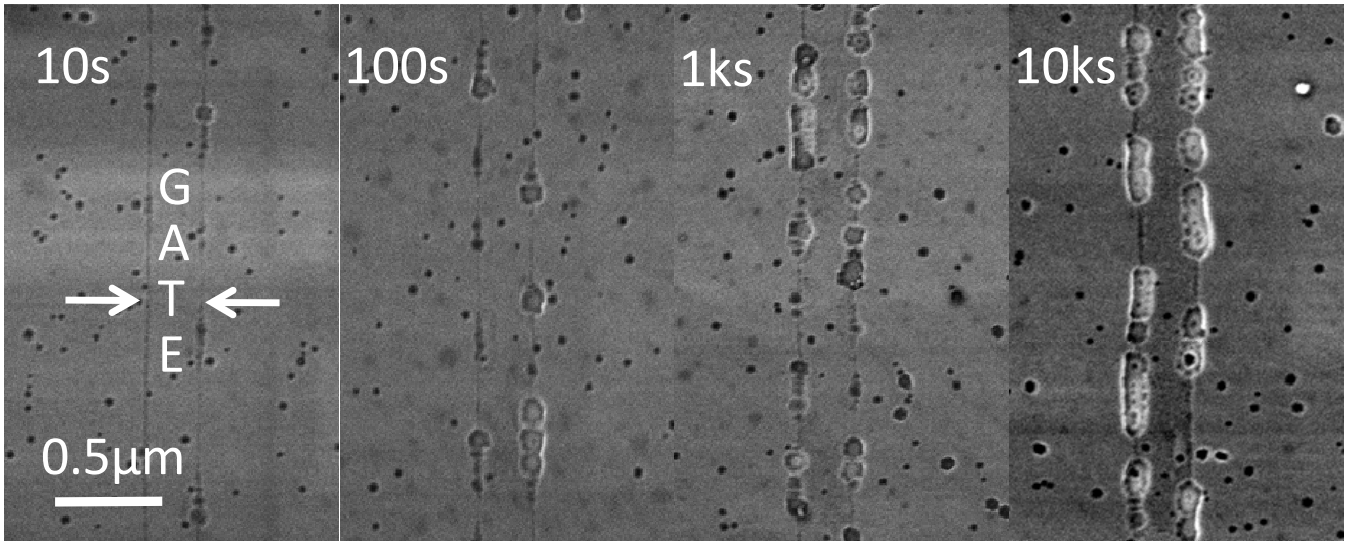


Current collapse tends to saturate.

Permanent degradation keeps increasing.

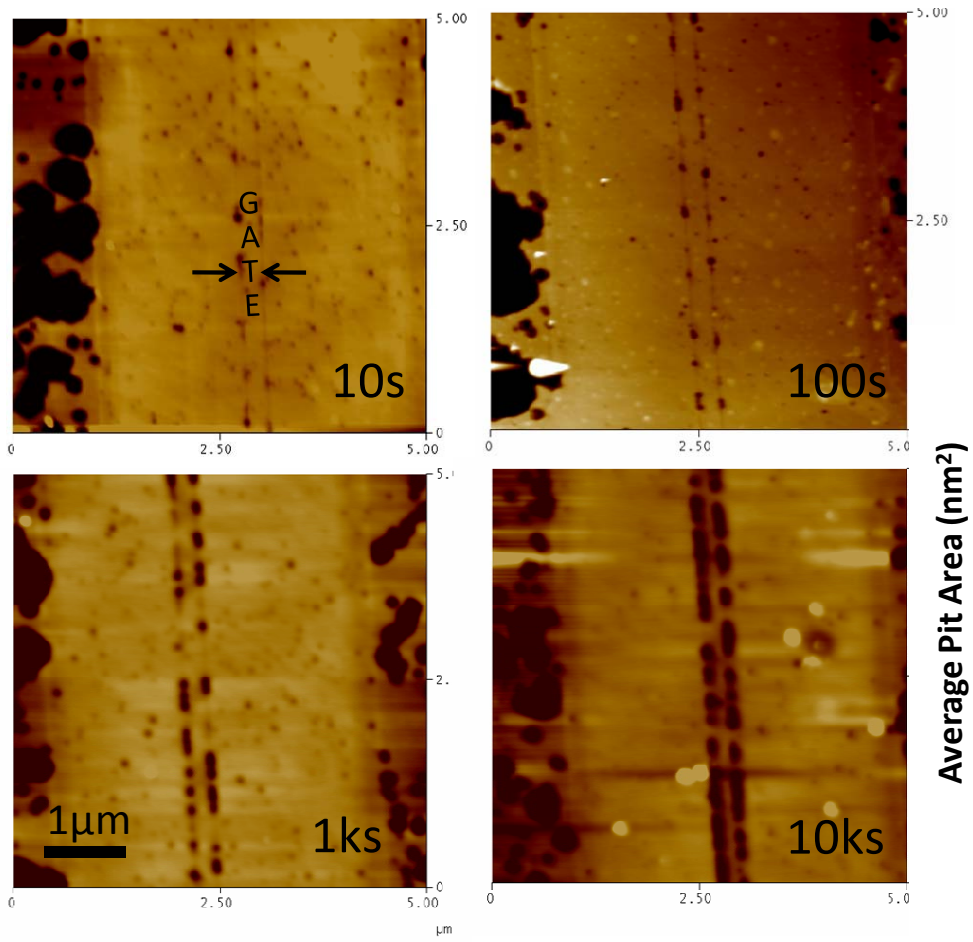
Time Evolution – SEM

V_{DS}=0, V_{GS}=-40 V, T_{base}=150 °C

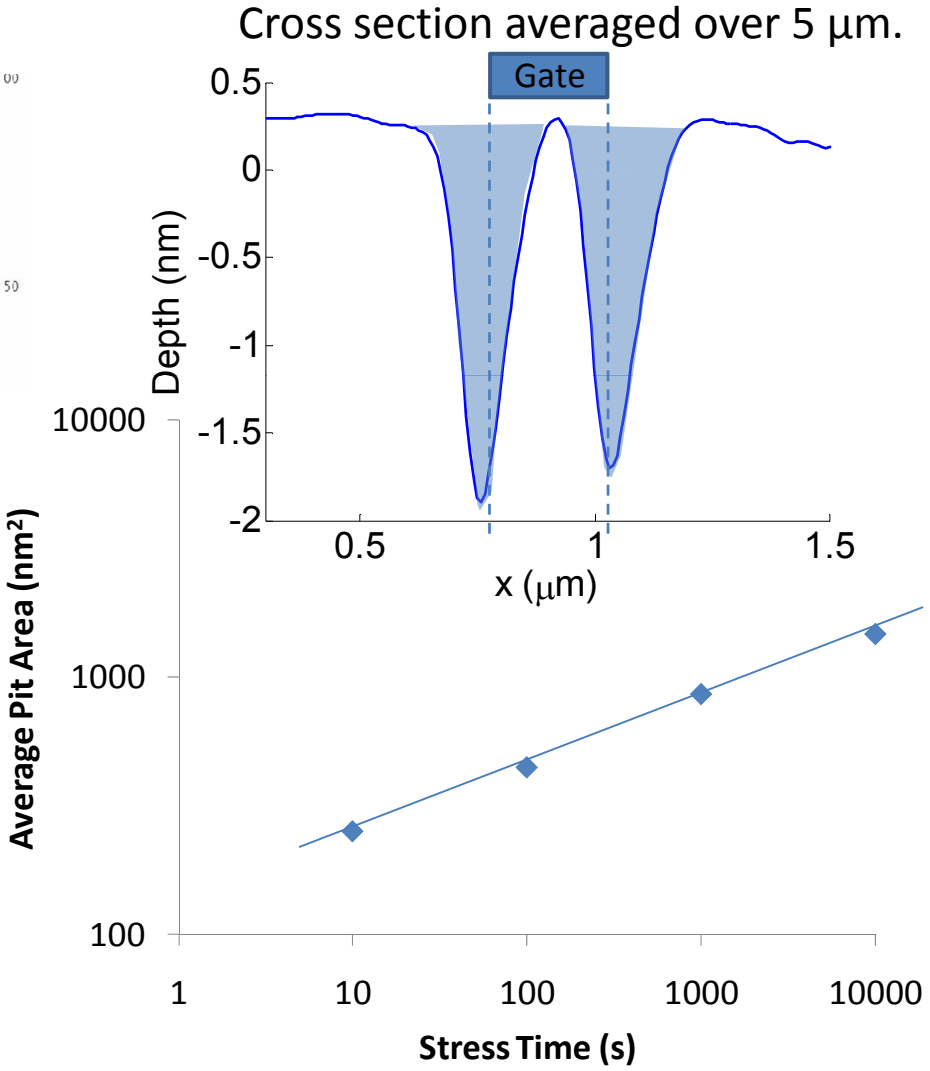


Very fast groove formation (10 s) on both sides.
Pit density/size increase with time.

Time Evolution – AFM

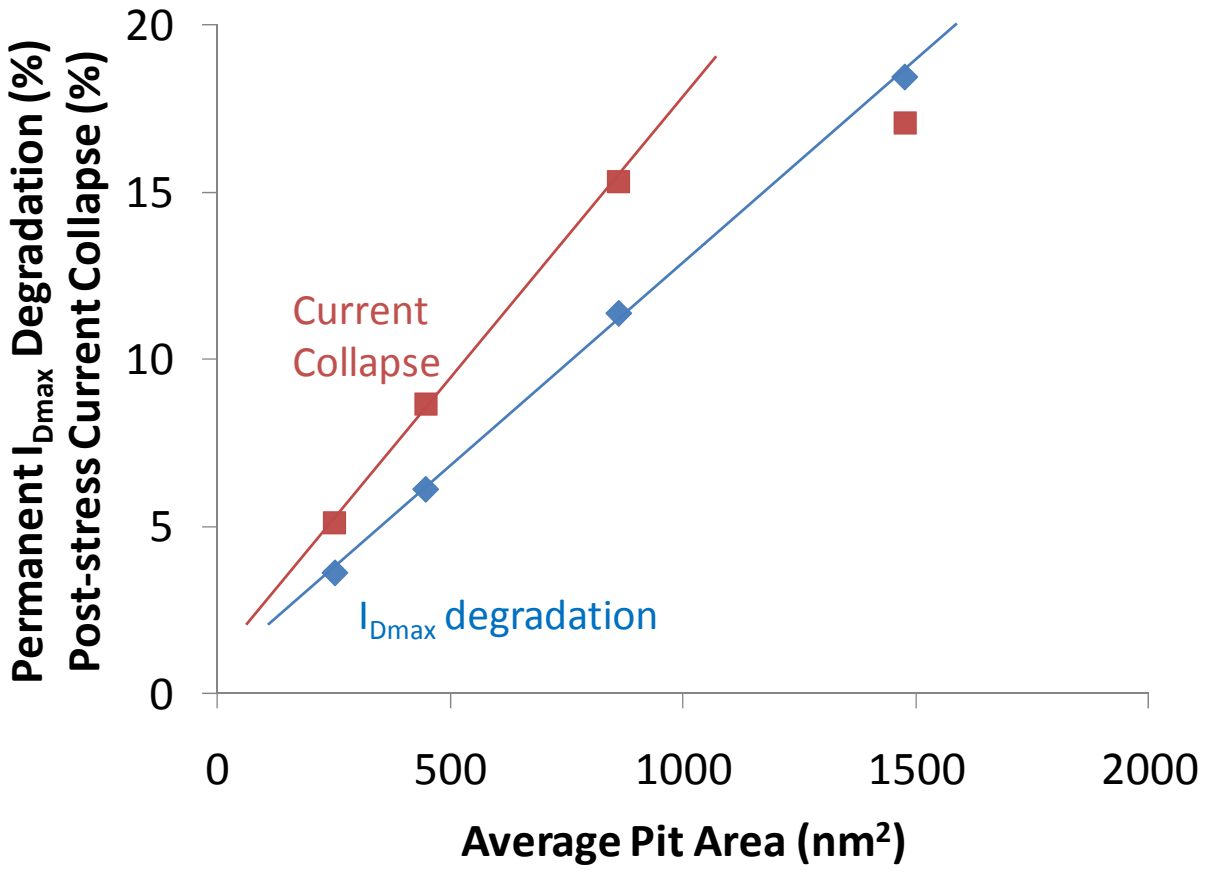


Cross section averaged over 5 µm.



Average pit area (~pit volume) ~ $t^{1/4}$

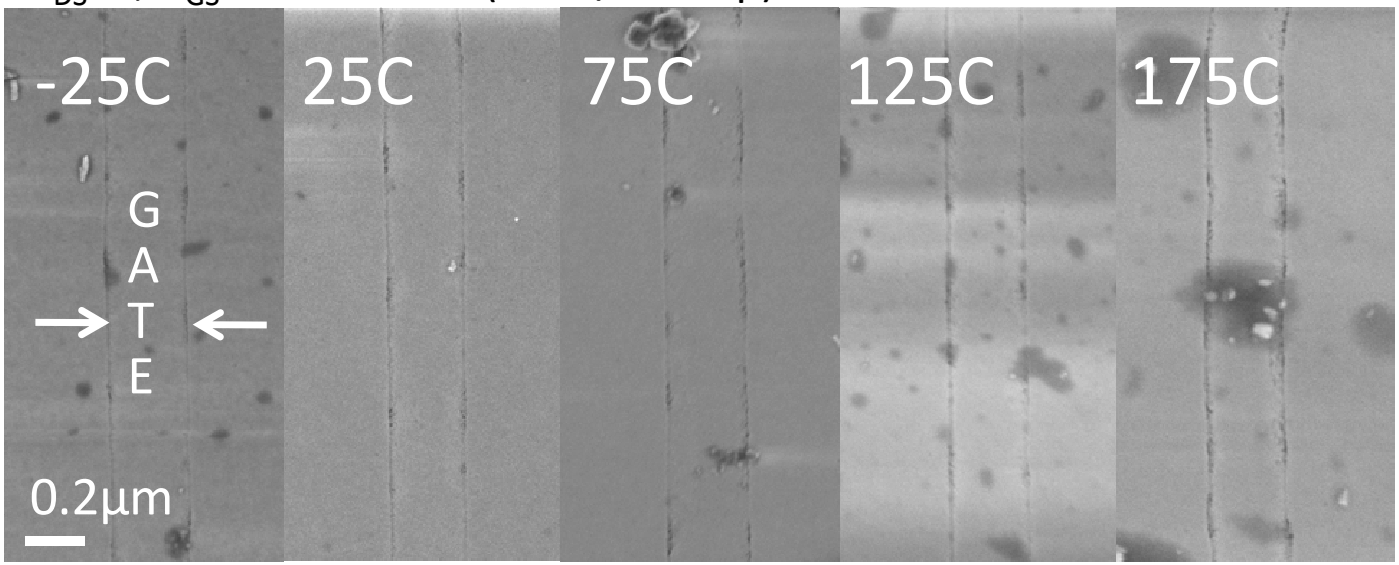
Electrical vs. Structural Degradation



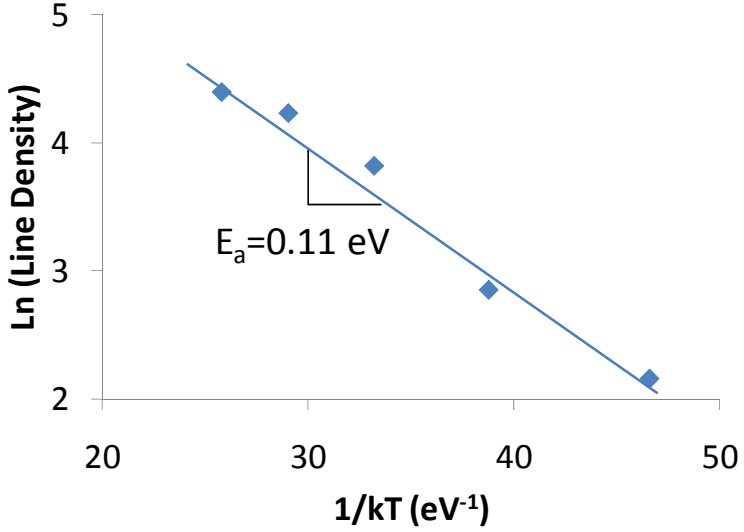
Good correlation between electrical and structural degradation.

Temperature Dependence

V_{DS}=0, V_{GS}=-10 to -50 V (1min/1V step)



Linear defect density (~1/degradation rate) is thermally activated with E_a~0.11 eV



Degradation Mechanisms

- Groove formation: fast process
  - Field induced oxidation?
  - Electrochemical etching?
- Pit formation: slow process
  - E-field driven (Little current is needed)
  - Thermally activated
  - Field/stress induced diffusion of material away from gate?
- In any event, mass transport is involved.

Summary

- Developed a simple process for plan-view assessment of structural degradation
- Evolution of structural damage:
  - Below V_{crit}: shallow continuous groove formation at gate edge
  - Above V_{crit}: local pit formation along the groove
  - Pits grow with V_{stress} and time and merge
  - Pit formation is thermally activated.
- Field/stress induced mass transport is involved in GaN HEMT degradation