Time Evolution of Electrical Degradation under High-Voltage Stress in GaN HEMTs

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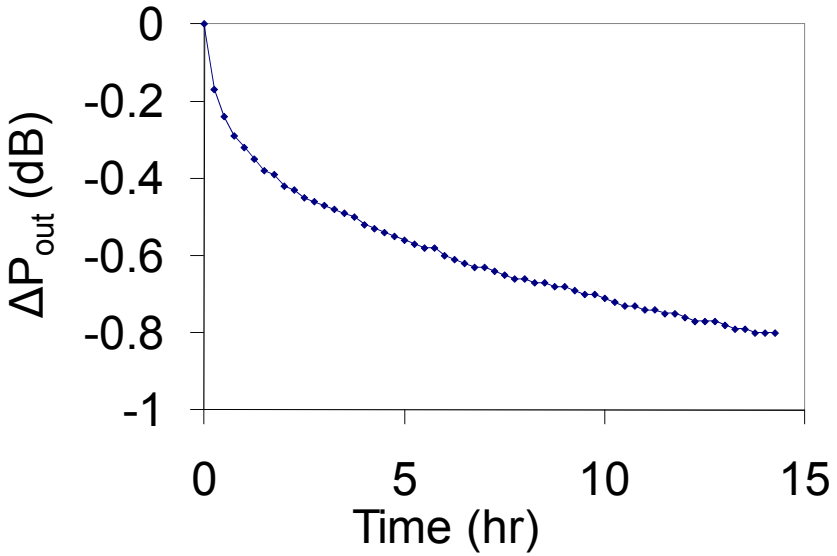
Acknowledgements: ARL (DARPA WBGS program)
ONR (DRIFT-MURI)
TriQuint Semiconductor

Purpose

- GaN HEMT Reliability: big concern
  - RF power degradation
  - $I_D\downarrow$, $R_D\uparrow$, $I_G\uparrow$, ΔV_T…
- Goal: understand degradation mechanism

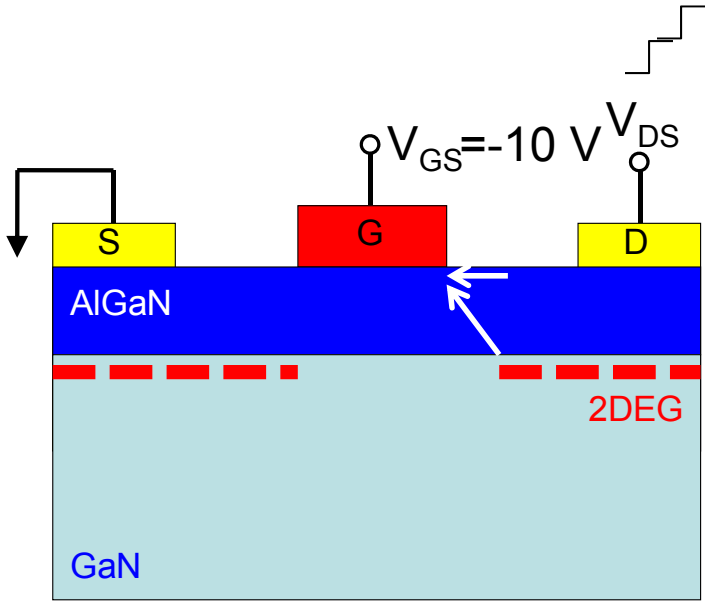
RF stress
10 GHz, V_D=28 V
I_{DQ}=150 mA/mm
P_{in}=23 dBm
P_{out}=33.7 dBm



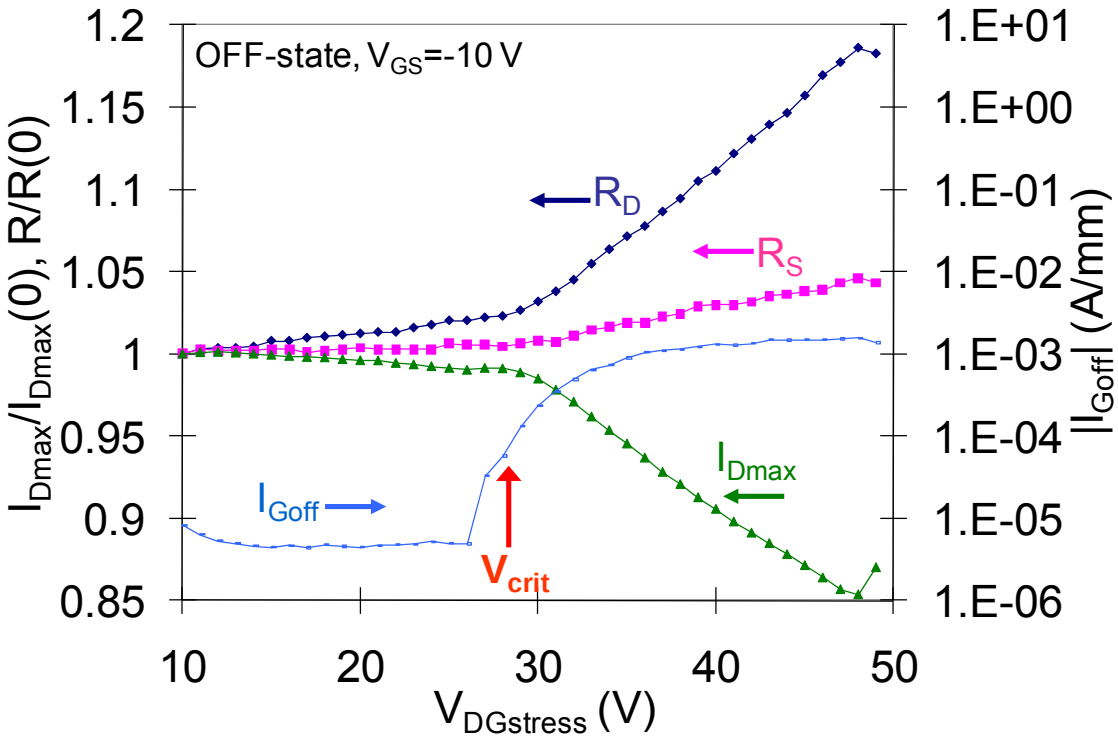
Outline

- Background
- Project goal
- Experimental
  - Procedure
  - Results
- Discussion
- Conclusions

High Voltage Degradation in GaN HEMTs



Joh, EDL 2008

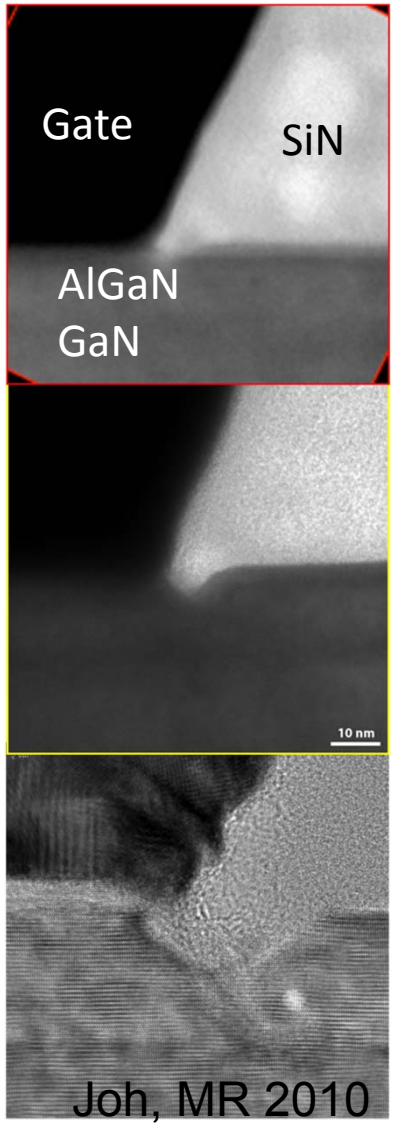


I_{Dmax}: V_{DS}=5 V, V_{GS}=2 V I_{Goff}: V_{DS}=0.1 V, V_{GS}=-5 V

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

Structural Degradation

Cross-section



1. $V_{stress} \sim V_{crit}$:

Groove formation in GaN cap

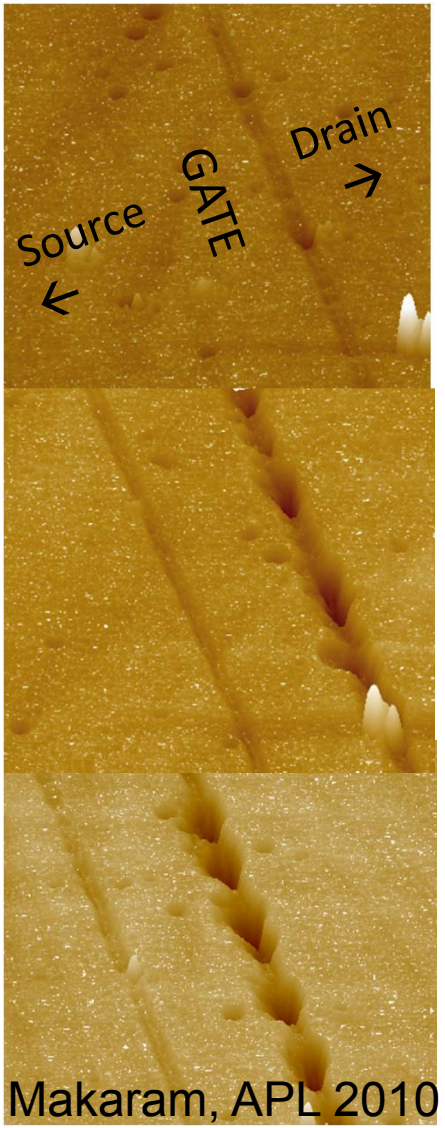
2. $V_{stress} > V_{crit}$:

Pit formation in AlGaN barrier

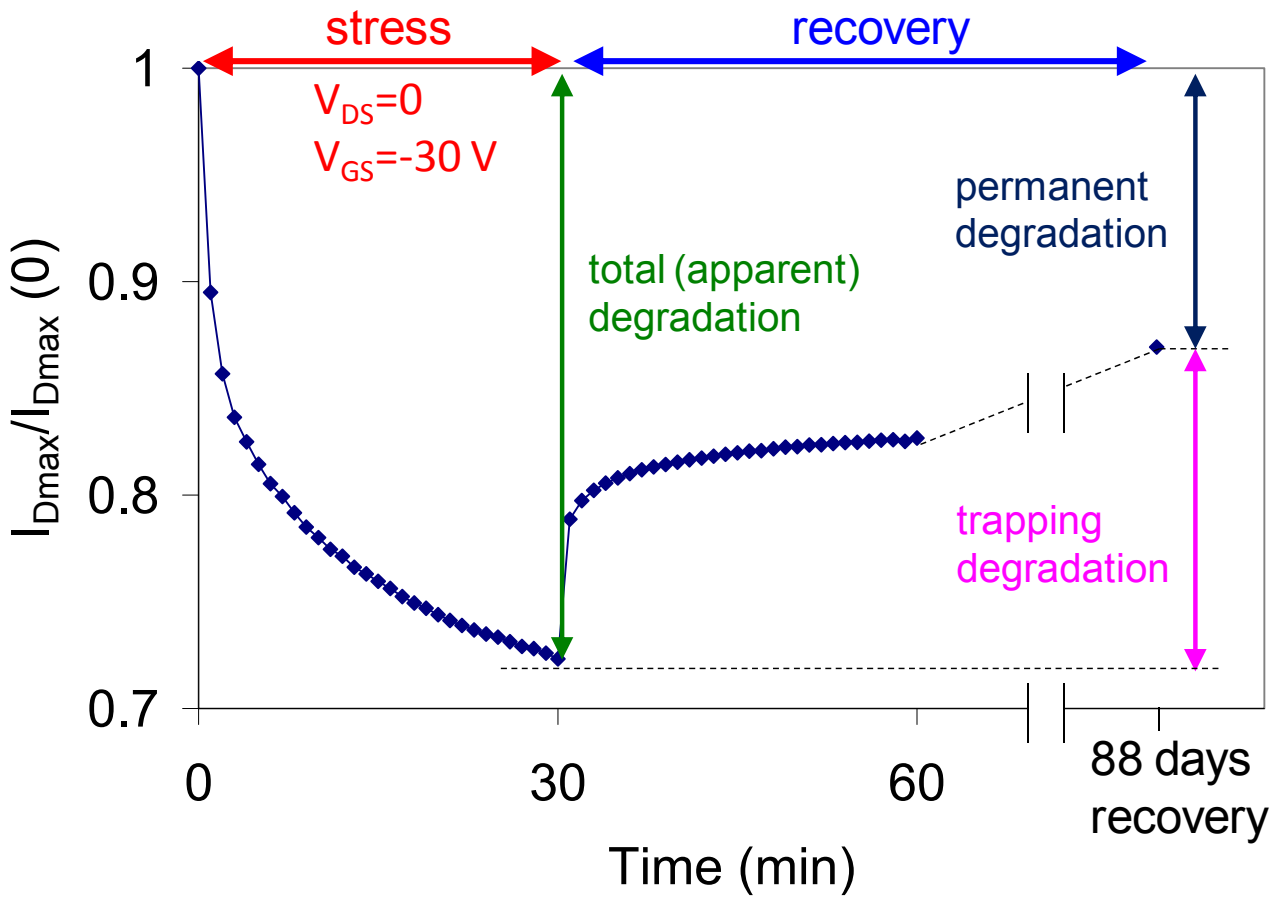
3. $V_{stress} >> V_{crit}$:

Pit growth (to AlGaN/GaN interface) and merge + crack formation

Plan-view



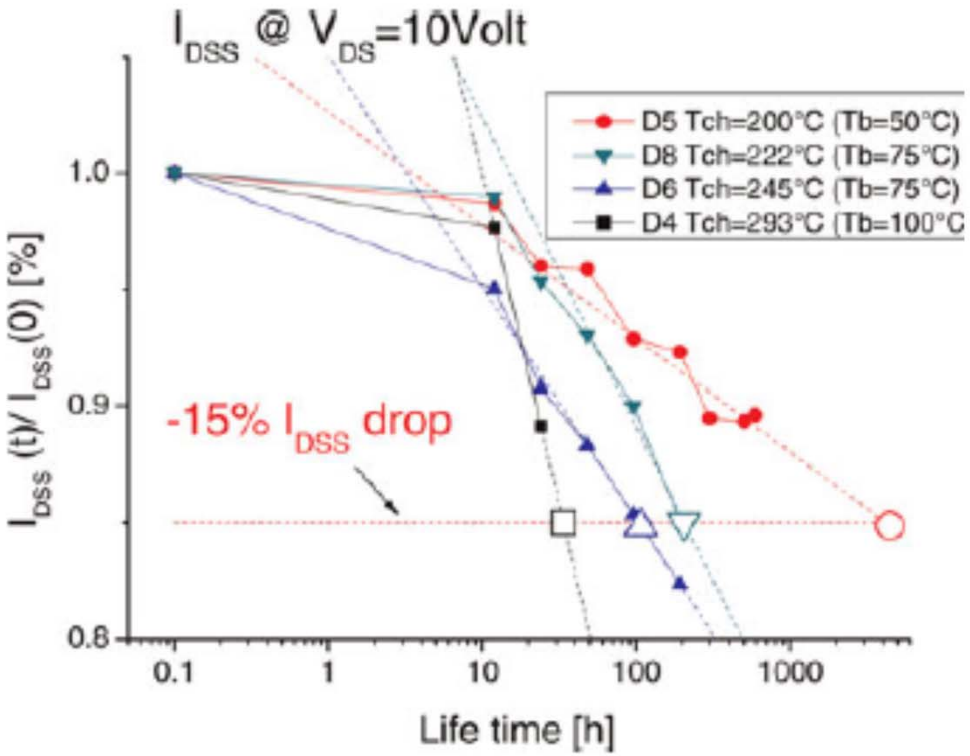
Trapping vs. Permanent



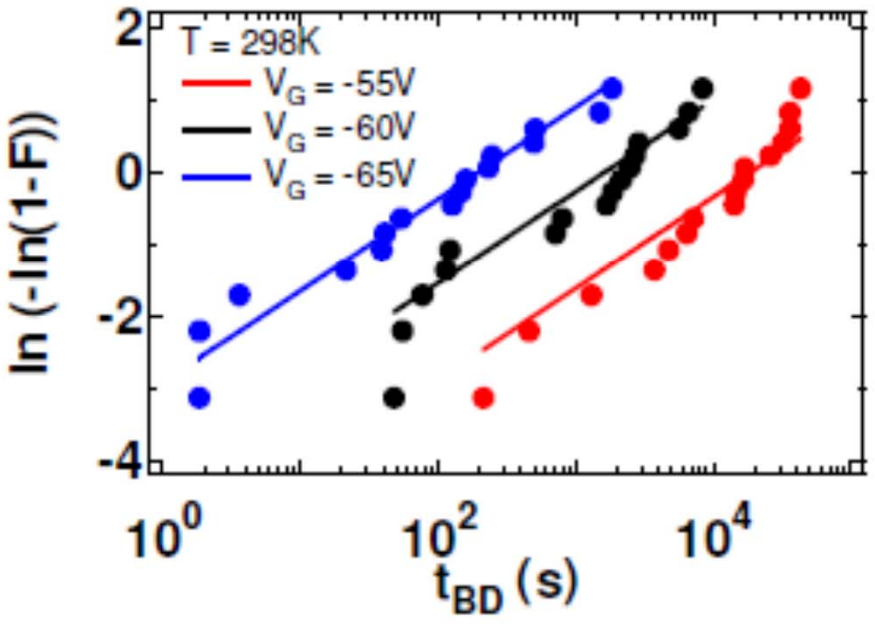
13 % permanent degradation + 15 % trapping degradation

Project Goal

- Investigate time evolution of degradation and correlate with structural degradation

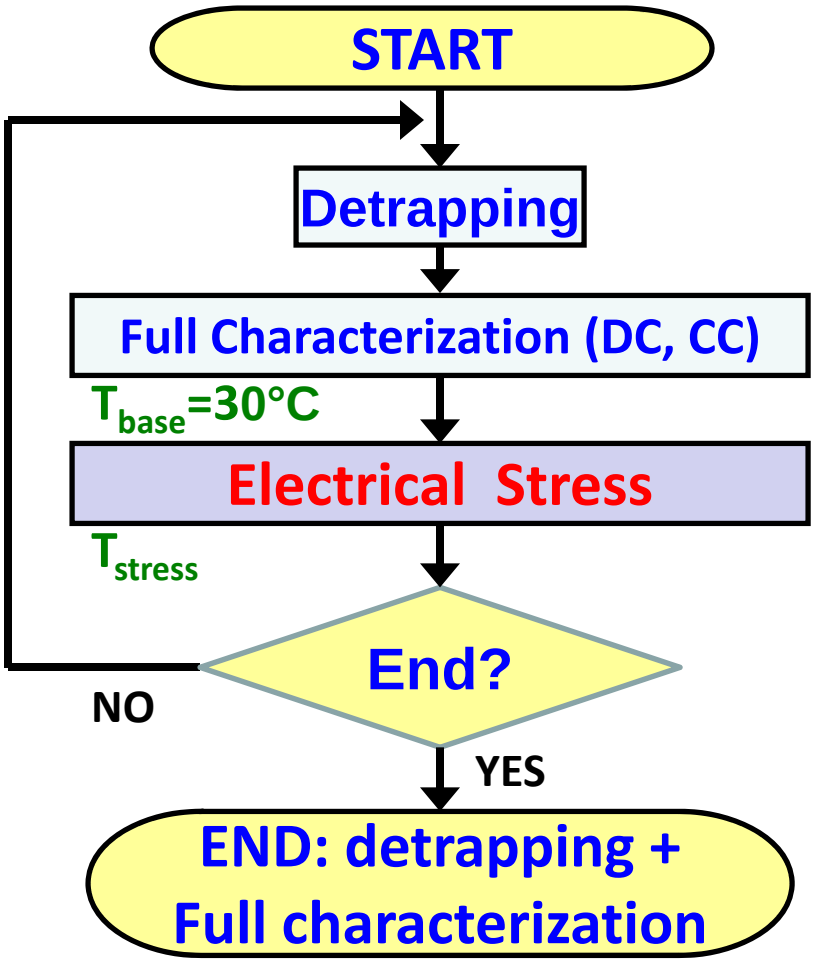


Meneghesso, IJMWT 2010



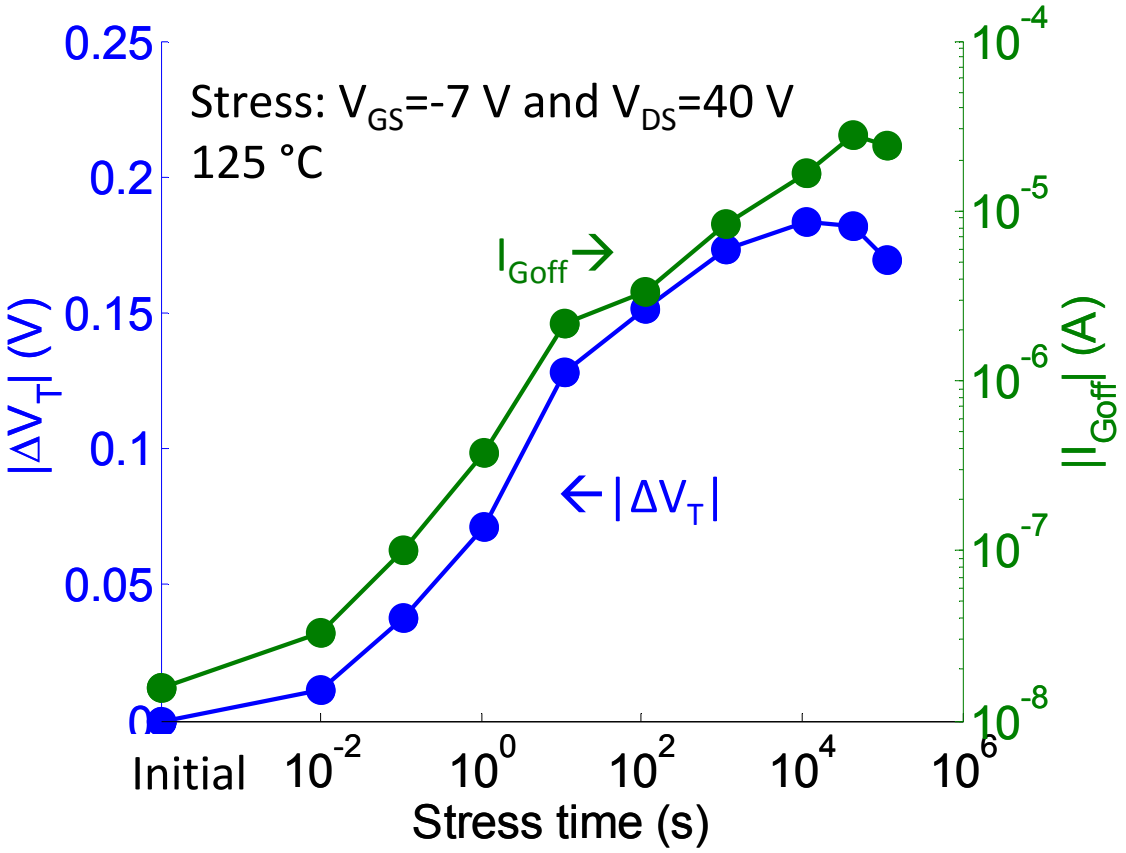
Marcon, IEDM 2010

Experimental Procedure



- Detrapping step to flush trapped electrons quickly
- Benign device characterization:
  - Full I_D-V_{DS}, I_D-V_{GS} curves
  - I_D transient measurement: current collapse, detrapping time constant
  - Performed at 30 °C
- Stress conditions:
  - OFF-state: V_{DS}=40 V, V_{GS}=-7 V
  - T_{stress}=75–200 °C

Gate Current and V_T

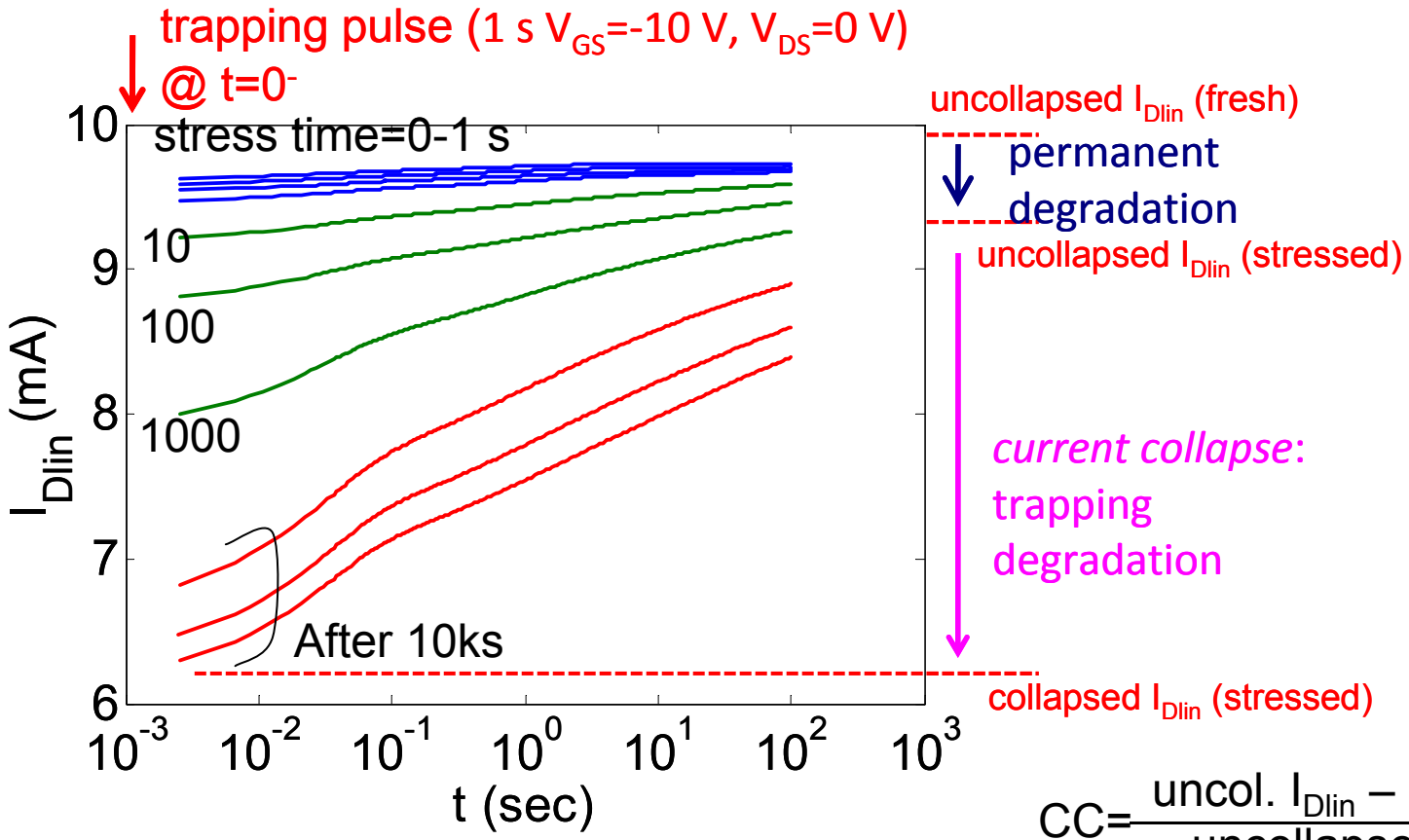


- Very fast I_{Goff} and V_T degradation (<10 ms)

→ E-field driven oxide punch-through? Electrochemical etching?

- Degradation saturates after 10^4 s.

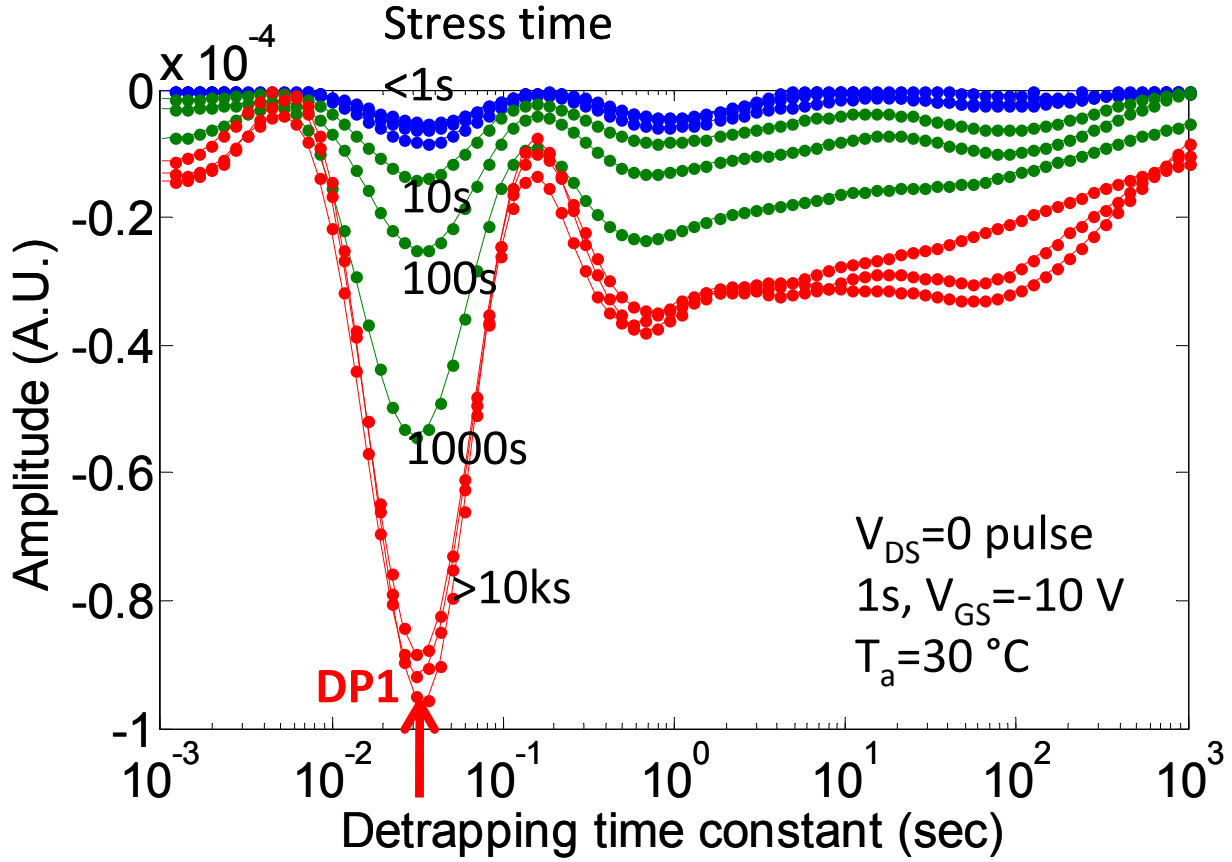
I_D Transient Measurement



$$CC=\frac{\text{uncol. } I_{Dlin} - \text{col. } I_{Dlin}}{\text{uncollapsed } I_{Dlin}}$$

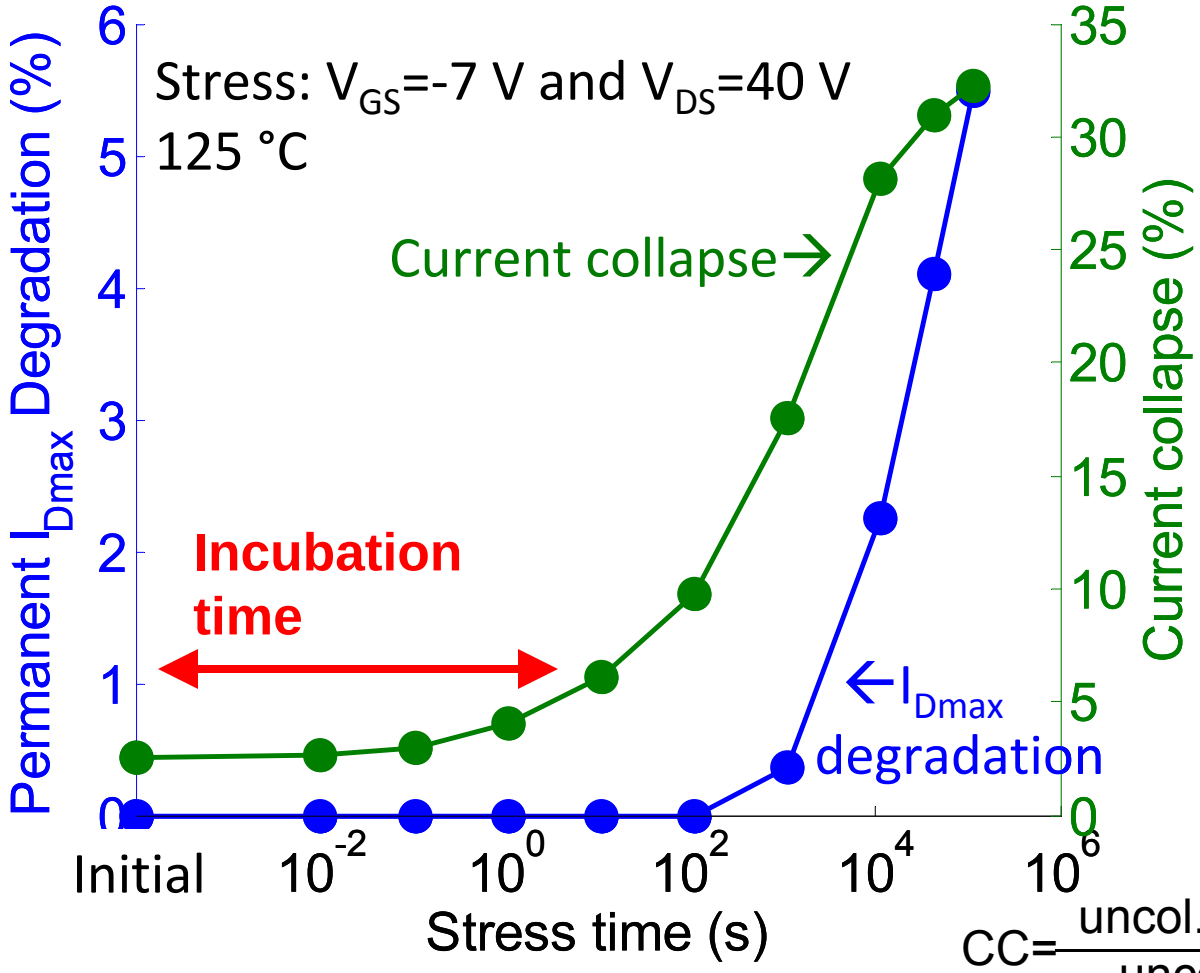
- After electrical stress:
  Permanent degradation + trapping related degradation

Detrapping Time-constant Spectrum



- Sharp increase in DP1 (E_a=0.56 eV) + long time constant slow traps beyond incubation time.

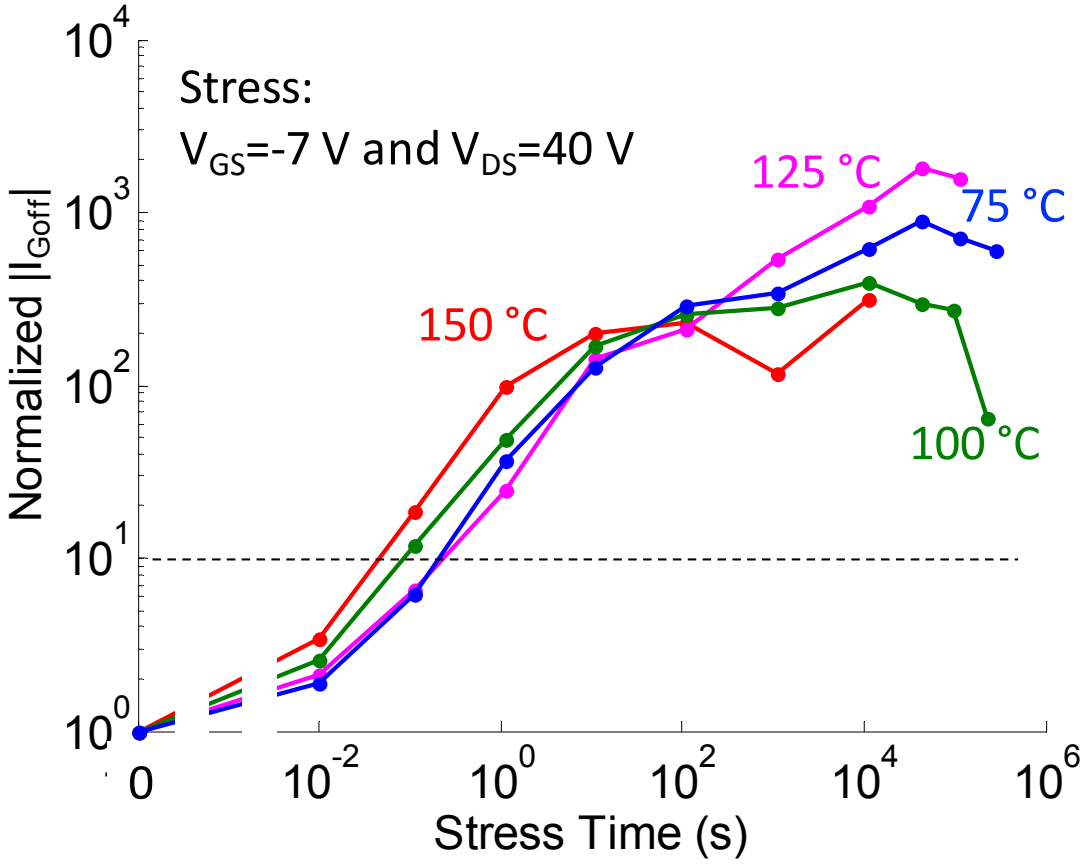
Drain Current Degradation



$$CC=\frac{\text{uncol. } I_{Dlin} - \text{col. } I_{Dlin}}{\text{uncollapsed } I_{Dlin}}$$

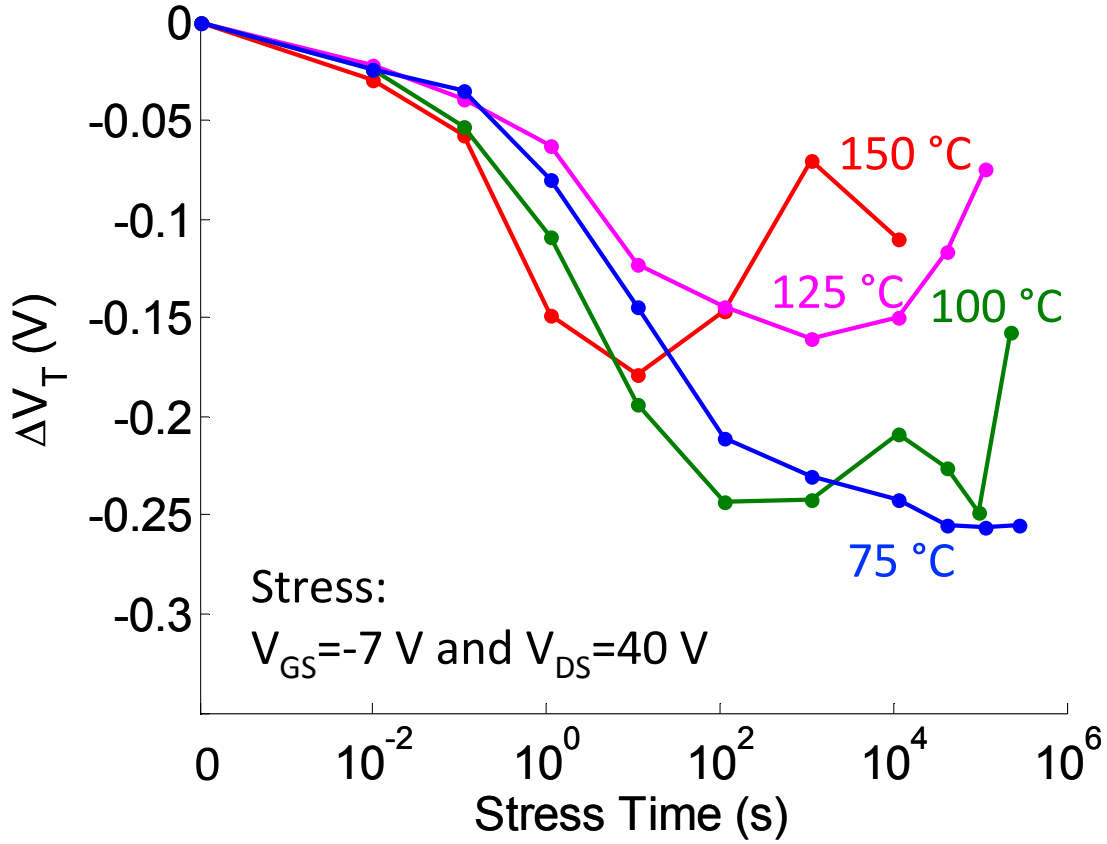
- For current collapse and permanent I_{Dmax} degradation, incubation time is observed.

Temperature Dependence: I_G



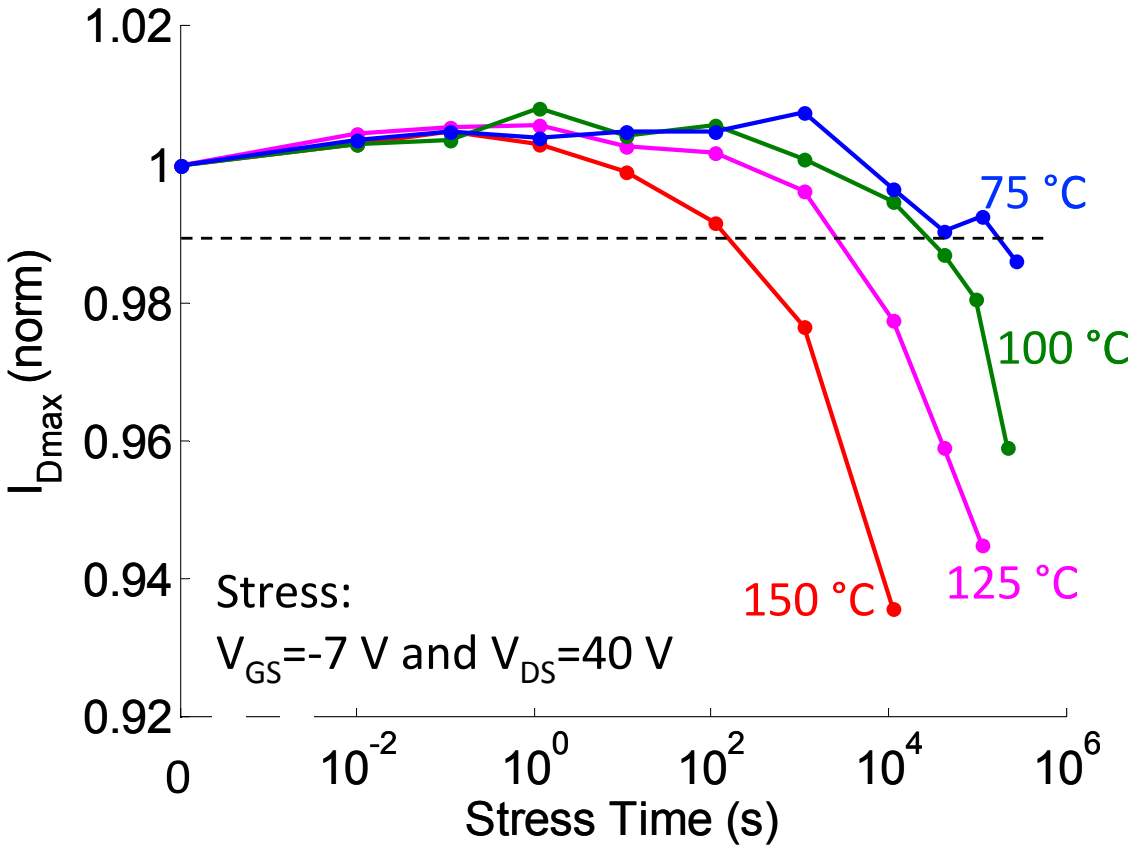
- Weak temperature dependence

Temperature Dependence: V_T



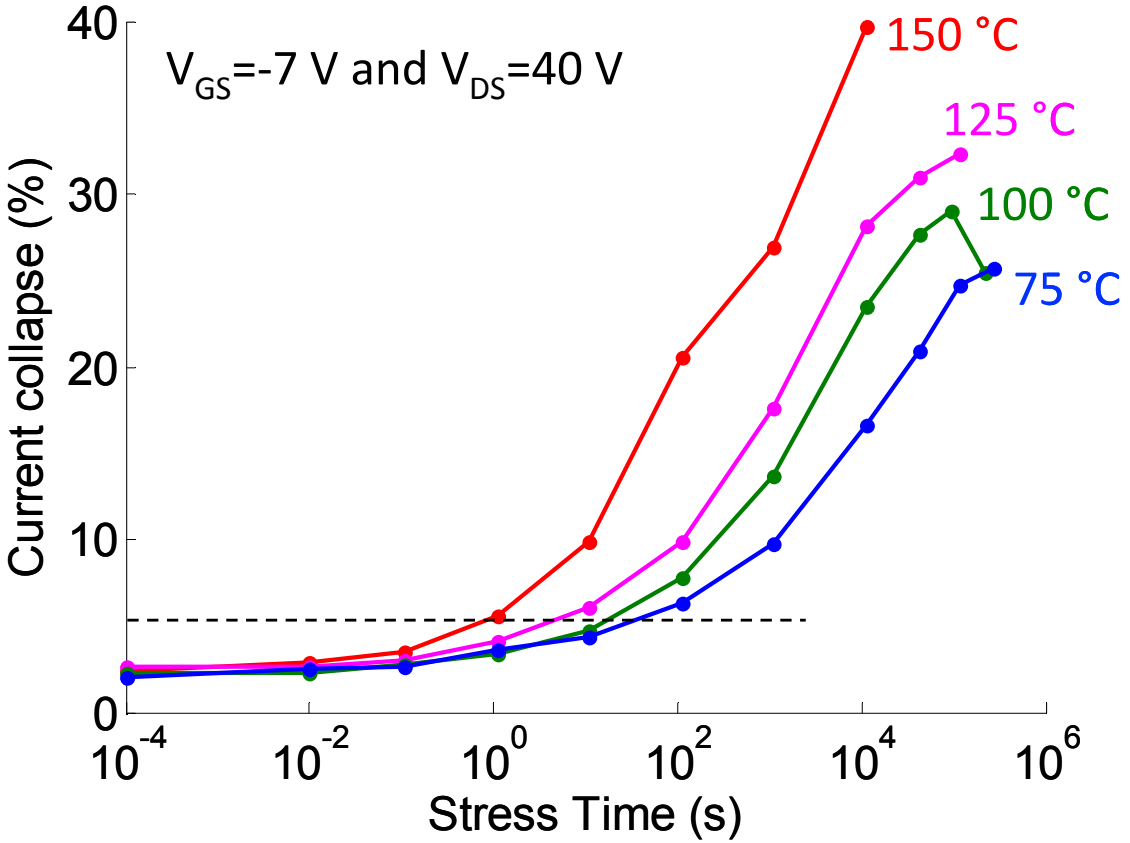
- No dependence during initial negative V_T shift
- Positive turn-around seems to occur earlier at high T

Permanent I_{Dmax} Degradation



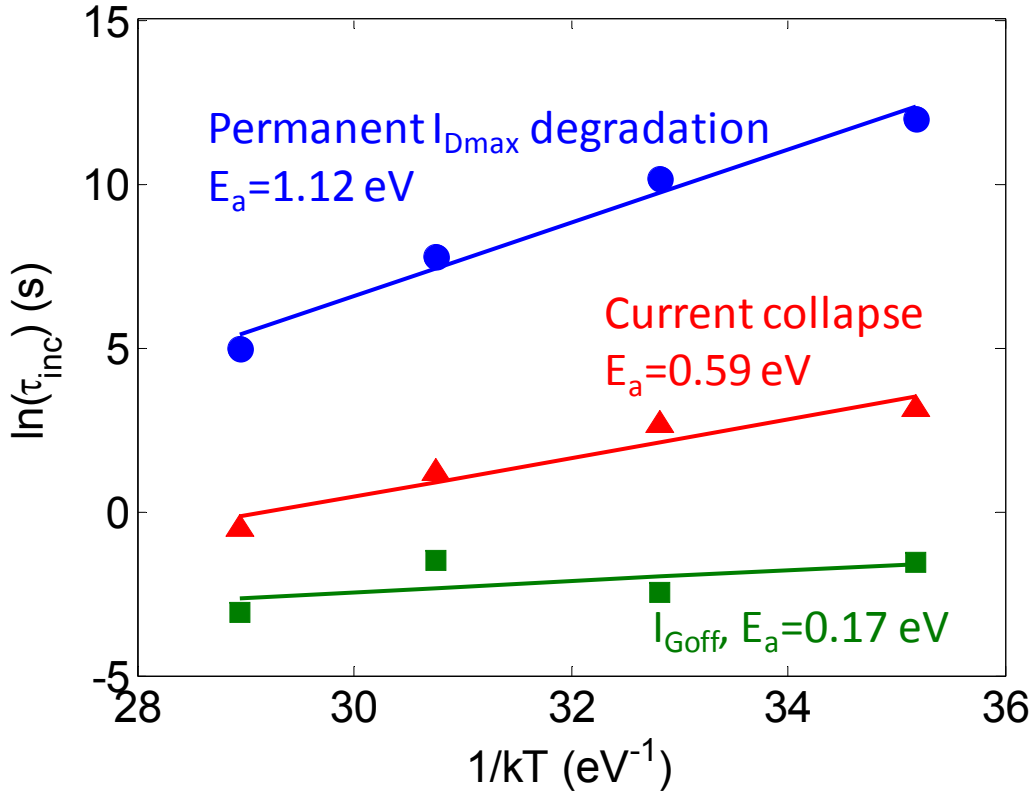
- Shorter incubation time at high T
- No saturation behavior up to >10^5 s

Current Collapse



- Shorter incubation time at high T
- More degradation at high T

Temperature Acceleration of Incubation Time

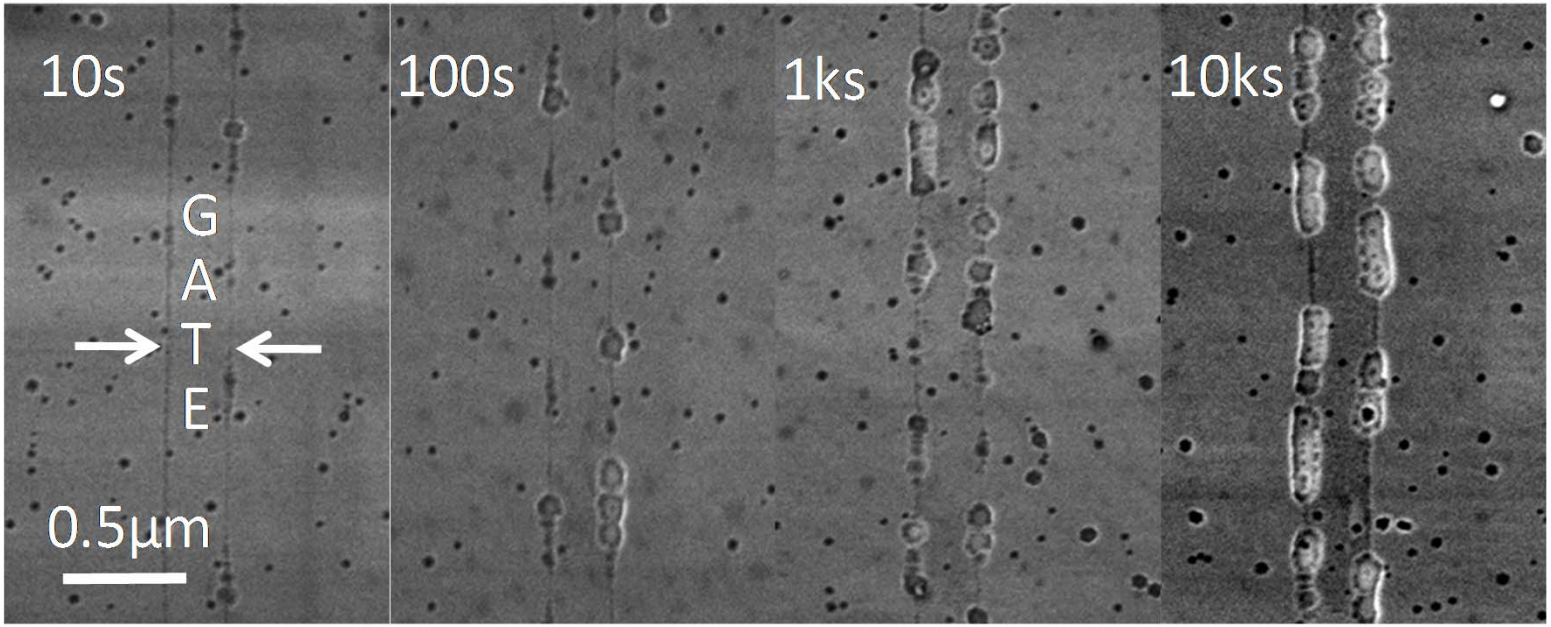


- Different level of temperature acceleration for incubation time.
- E_a for permanent I_{Dmax} degradation is similar to life test data*.

* Saunier, DRC 2007; Meneghesso, IJMWT 2010

Discussion: Time Evolution of Structural Degradation

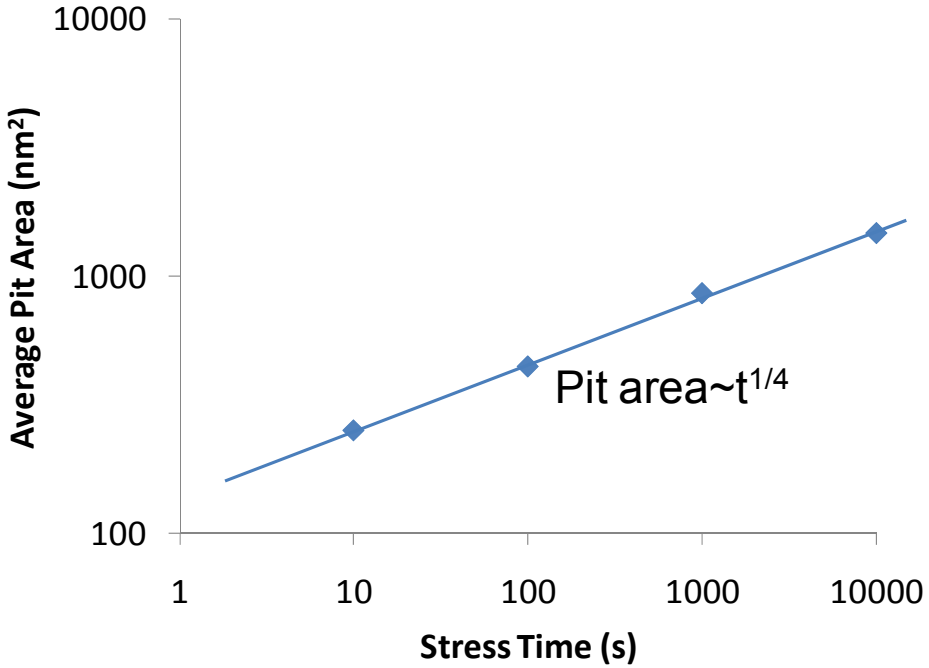
V_{DS}=0, V_{GS}=-40 V, T_{base}=150 °C

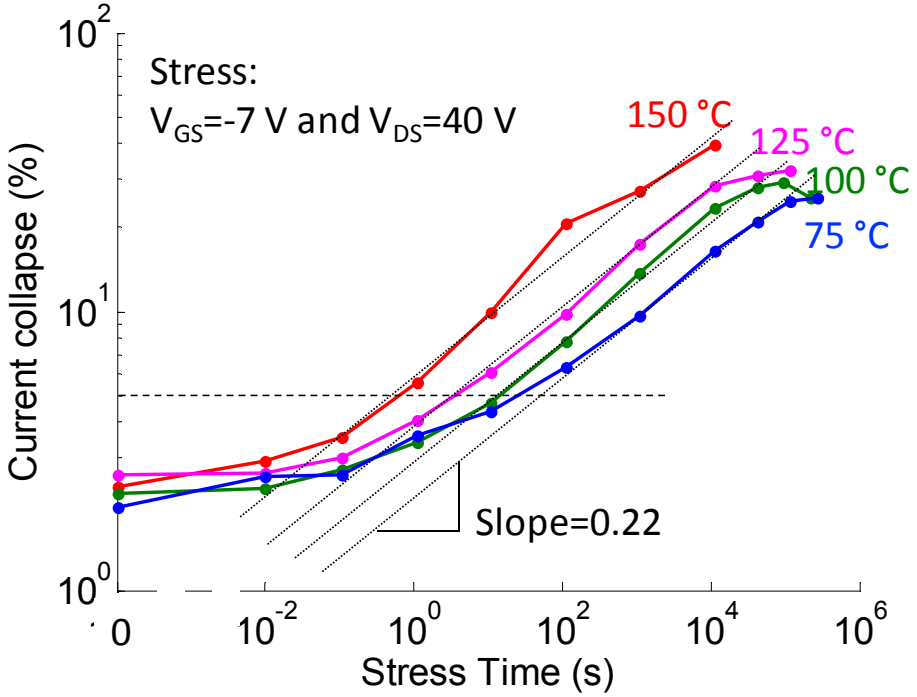


Joh, IWN 2010

- Very fast groove formation (10 s) on gate edge.
  → Related to gate current degradation
- Pit density/size gradually increase with time.

Electrical vs. Structural Degradation





Joh, IWN 2010

Similar time dependence in current collapse and pit formation.

Conclusion

- Investigated time evolution of electrical degradation in GaN HEMTs
- Fast I_G degradation ~ 10-100 ms
  - Weak temperature dependence
  - Oxide punch through / groove formation?
- Current collapse degradation ~ 10-100 s
  - Related to pit formation
- Permanent I_D degradation >100 s
  - Strong thermal activation (E_a=1.1 eV)