Time-Dependent Dielectric Breakdown in High-Voltage GaN MIS-HEMTs: The Role of Temperature

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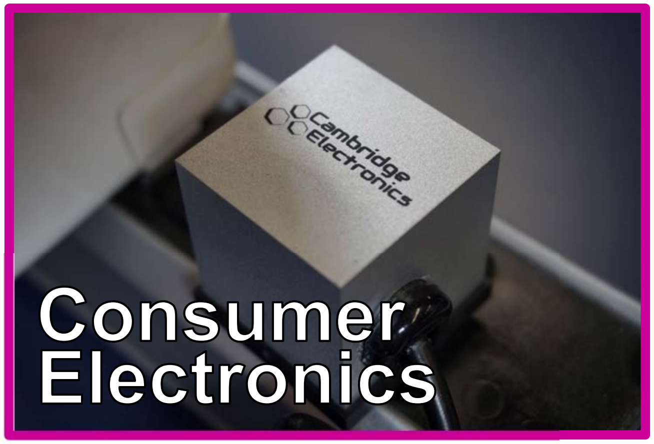
Purpose

- Understand time-dependent dielectric breakdown (TDDB) in GaN MIS-HEMTs
- Explore progressive breakdown (PBD) as a means of better understanding physics of gate dielectric degradation

Motivation

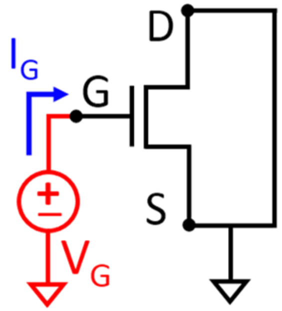
GaN Field-Effect Transistors (FETs) promising for high-voltage power applications → more efficient & smaller footprint

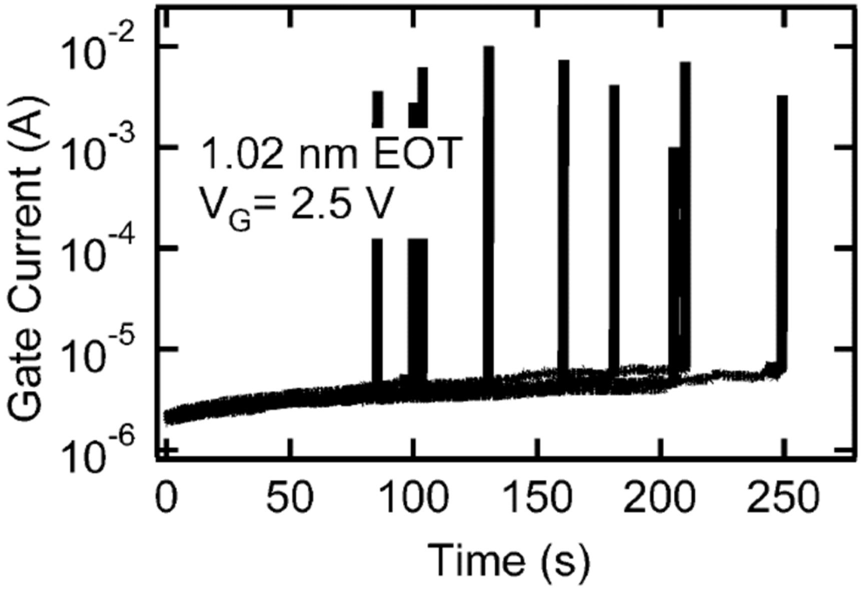


Time-Dependent Dielectric Breakdown

- High gate bias → defect generation → catastrophic oxide breakdown
- Often dictates lifetime of chip

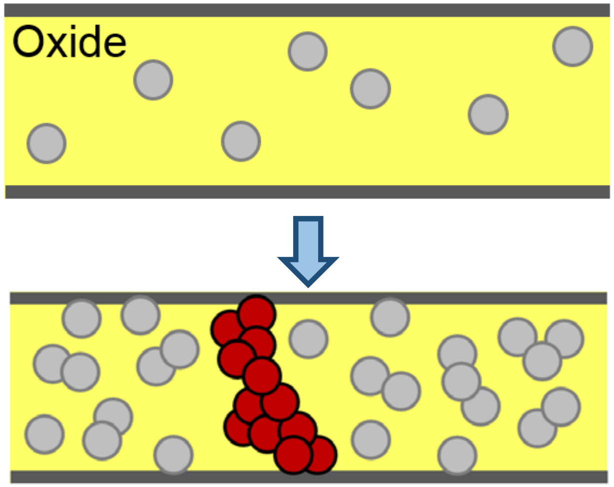
Typical TDDB experiments:
Si high-k MOSFETs





T. Kauerauf, EDL 2005

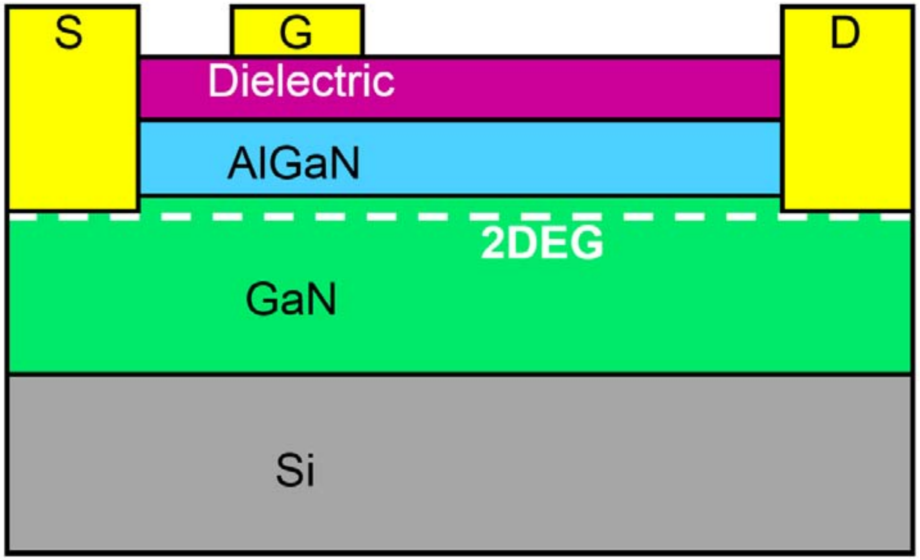
Modeling defect formation



R. Degraeve, MR 2009

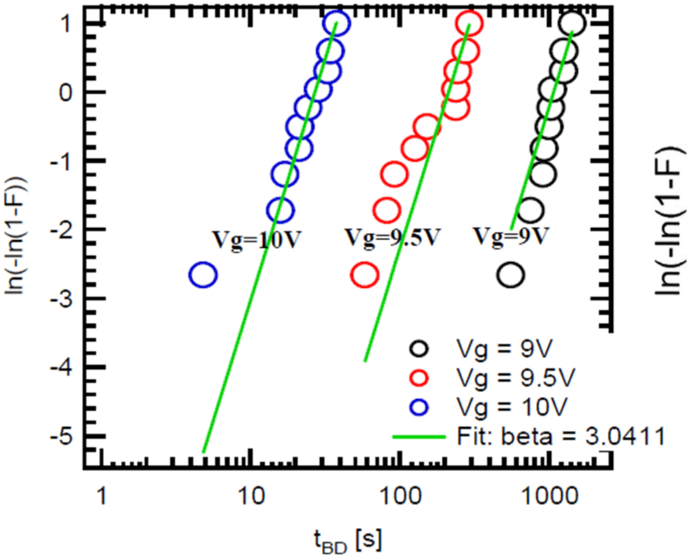
Dielectric Reliability in GaN FETs

AlGaN/GaN metal-insulator-semiconductor high electron mobility transistors (MIS-HEMTs)

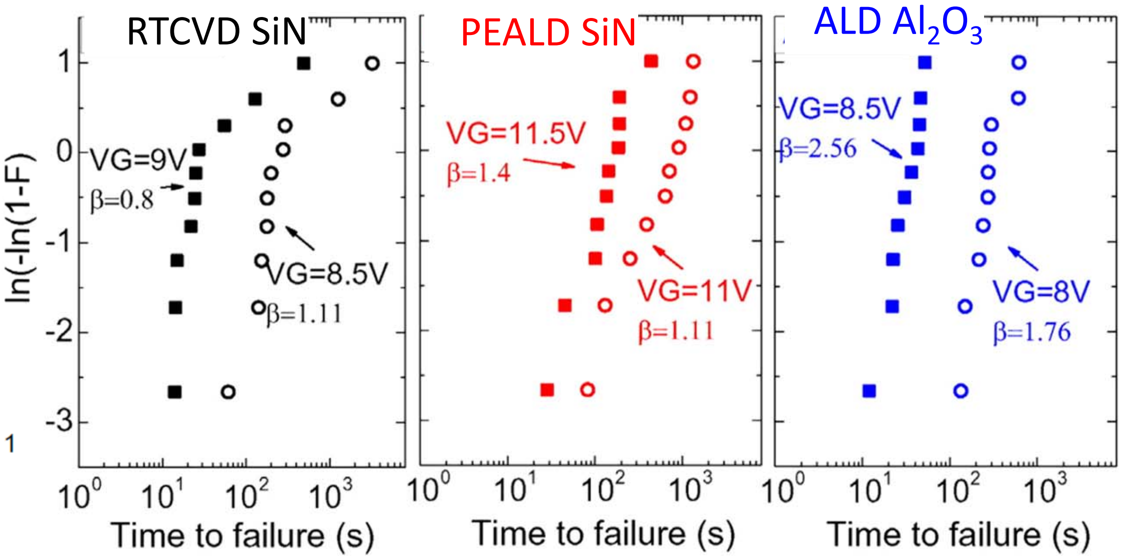


- Goals of this work:
  - What does TDDB look like in GaN MIS-HEMTs?
  - What is the temperature dependence of TDDB and what does it tell us about breakdown physics?

TDDB in GaN MIS-HEMTs



T.-L. Wu, IRPS 2013



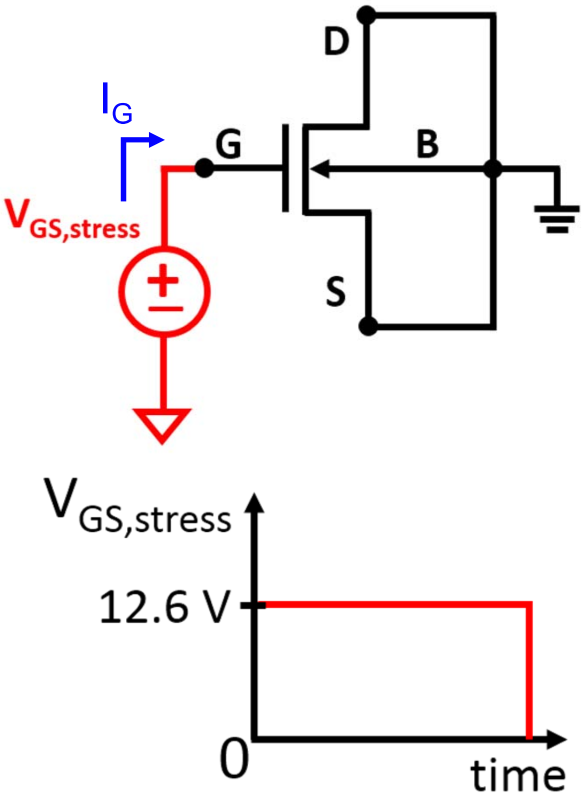
G. Meneghesso, MR 2015

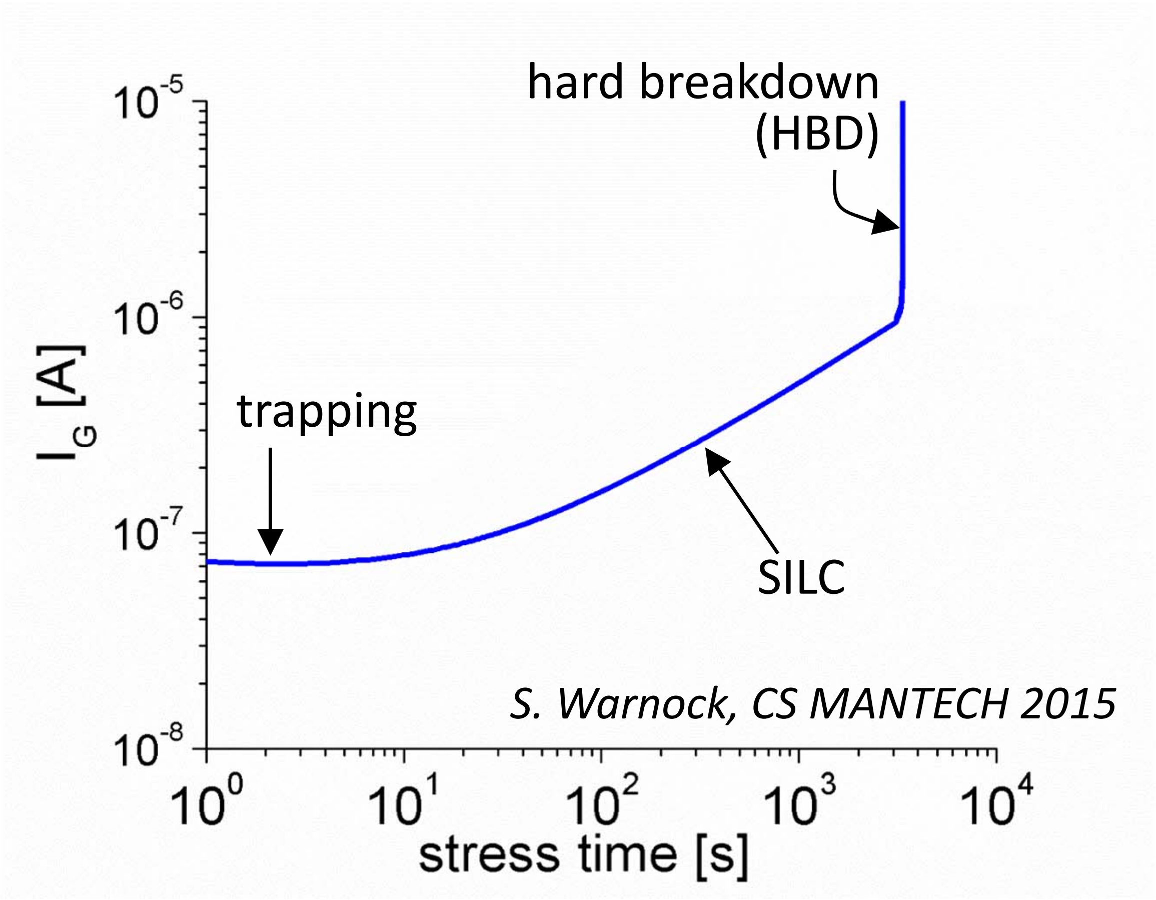
- Classic TDDB observed
- Studies to date focus largely on: breakdown statistics, lifetime extrapolation, evaluating different dielectrics
- Goal of this work: temperature dependence of TDDB

Experimental Methodology & Breakdown Statistics

Classic TDDB Experiment

Constant gate-voltage stress:



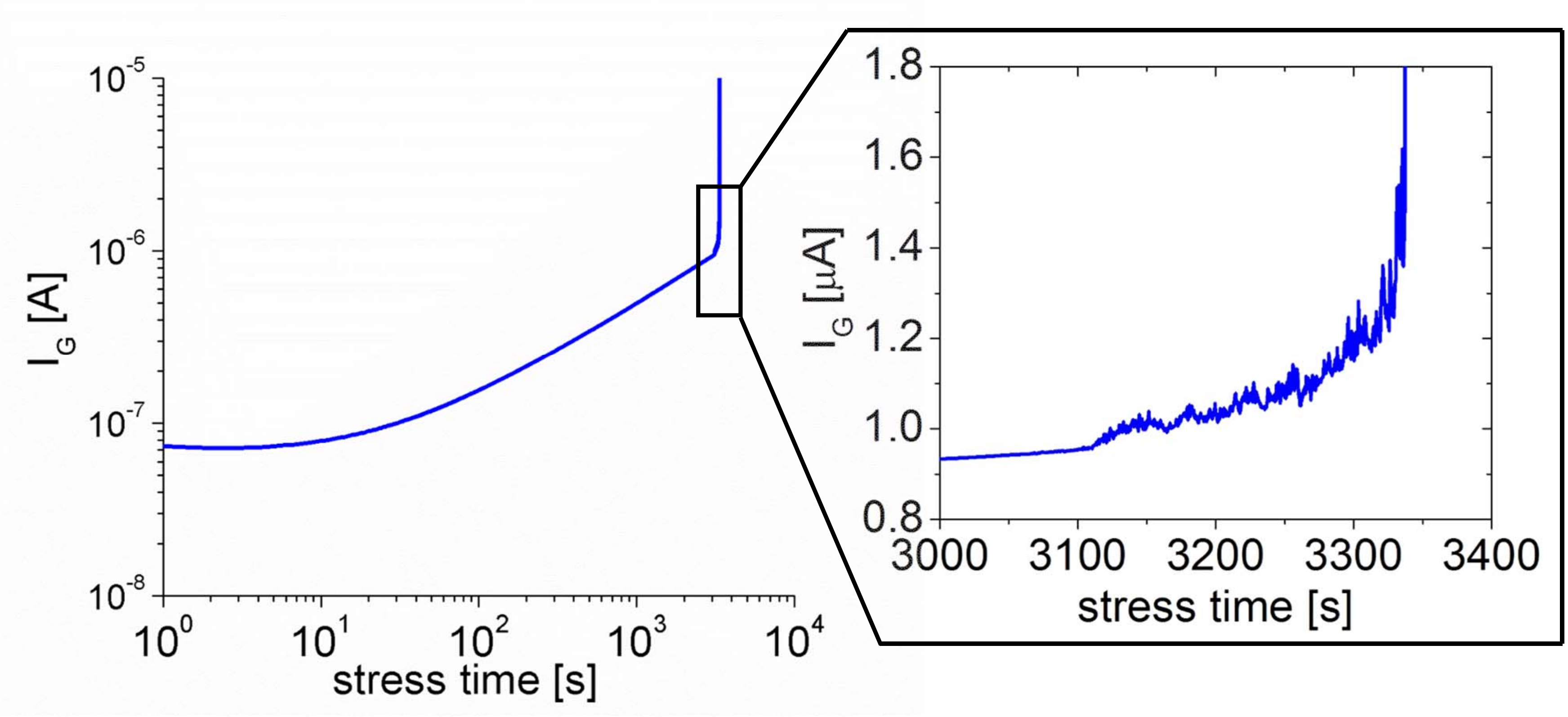


S. Warnock, CS MANTECH 2015

Experiment gives time to breakdown and shows generation of *stress-induced leakage current* (SILC)

Observing Progressive Breakdown

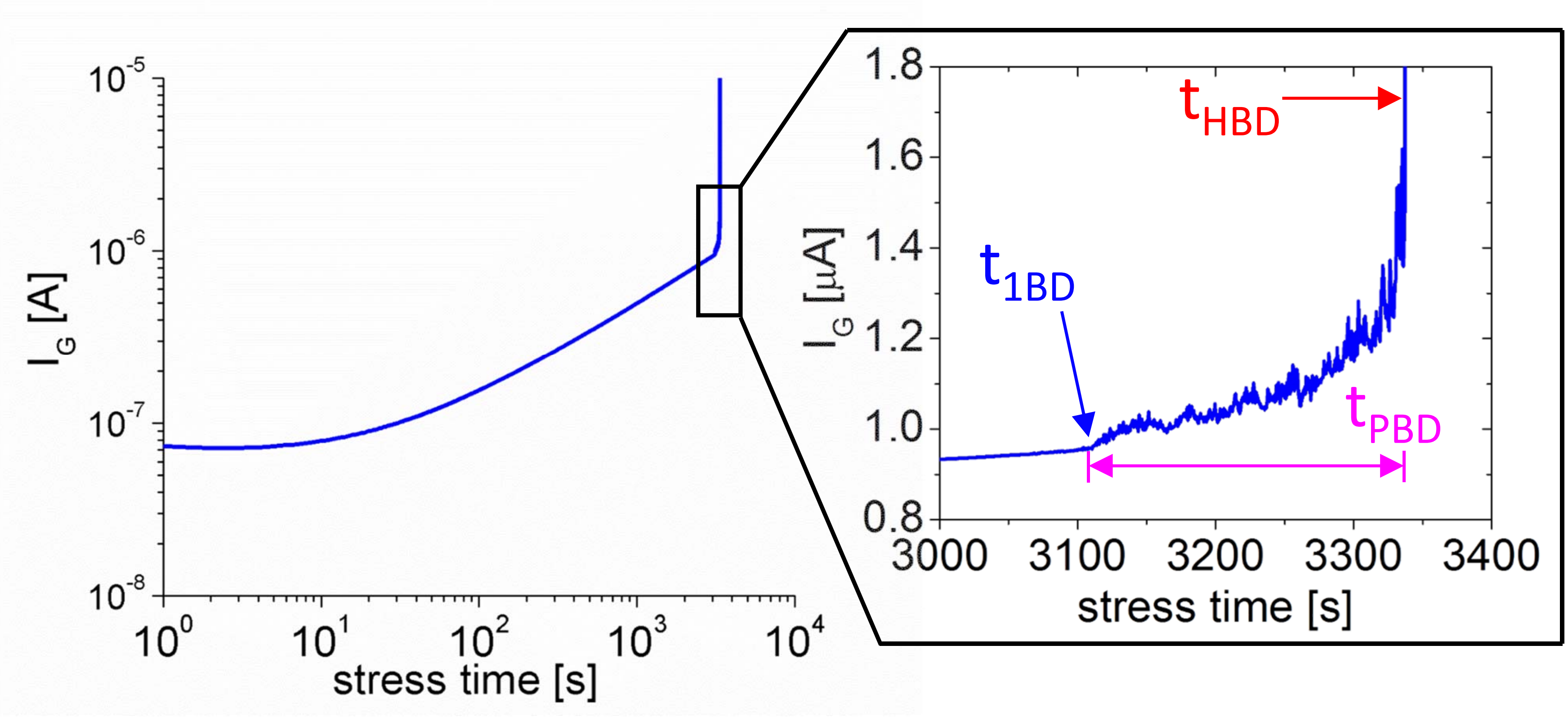
Classic TDDB experiment: $V_{Gstress}$=12.6 V, V_{DS}=0 V



Near breakdown, I_G becomes noisy → *progressive breakdown* (PBD)

Observing Progressive Breakdown

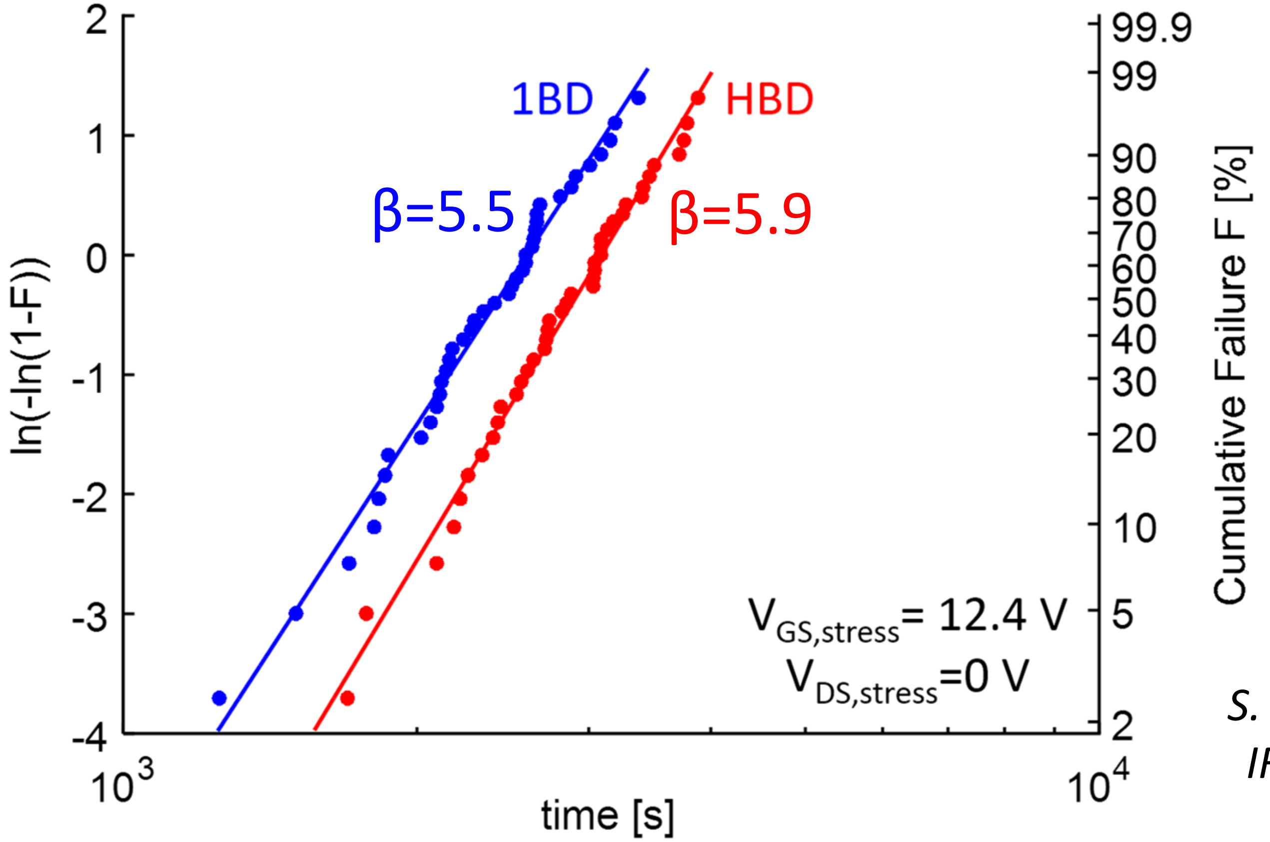
Classic TDDB experiment: $V_{Gstress}$=12.6 V, V_{DS}=0 V



- Time-to-first-breakdown t_{1BD}: I_G noise appears
- Hard breakdown (HBD) time t_{HBD}: Jump in I_G, device no longer operational
- t_{PBD}: duration of progressive breakdown (PBD)

GaN Gate Breakdown Statistics

Statistics for time-to-first-breakdown t_{1BD} and hard breakdown t_{HBD}`



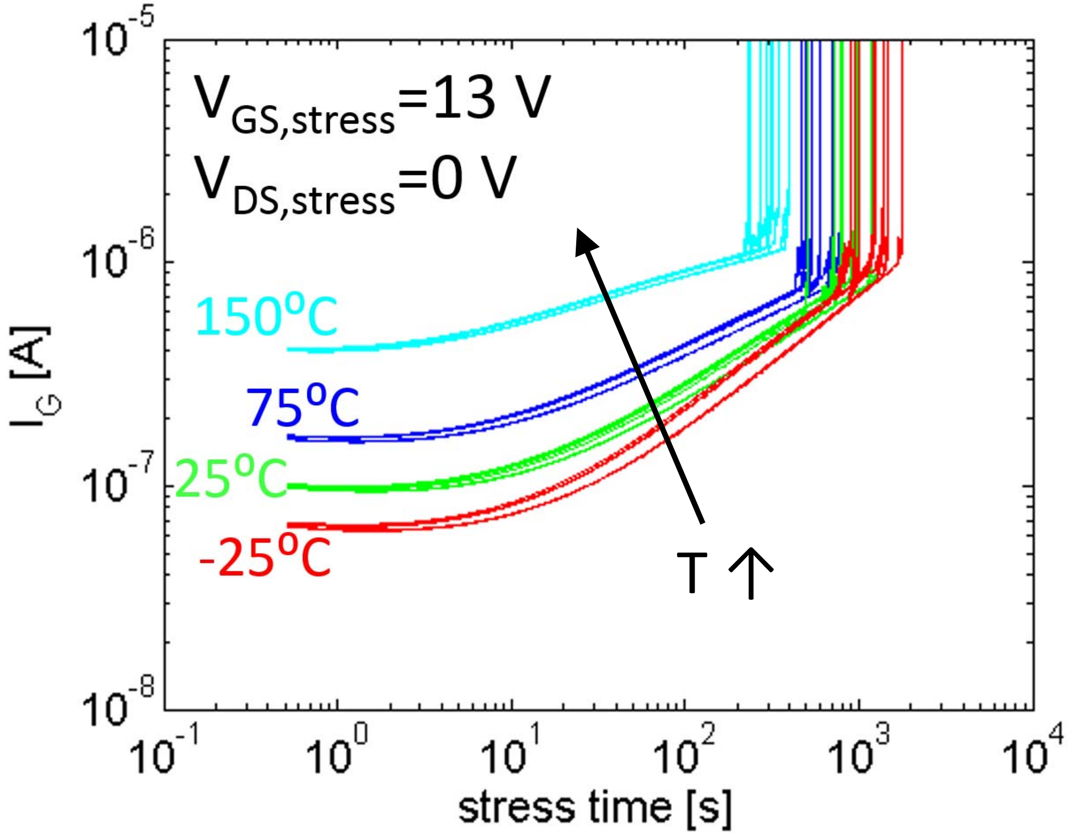
S. Warnock, IRPS 2016

- *Weibull distribution*: ln[-ln(1-F)] = βln(t) - βln(η)
- Nearly parallel statistics → common origin for t_{1BD} and t_{HBD}

Understanding the Role of Temperature

TDDB Across Temperature

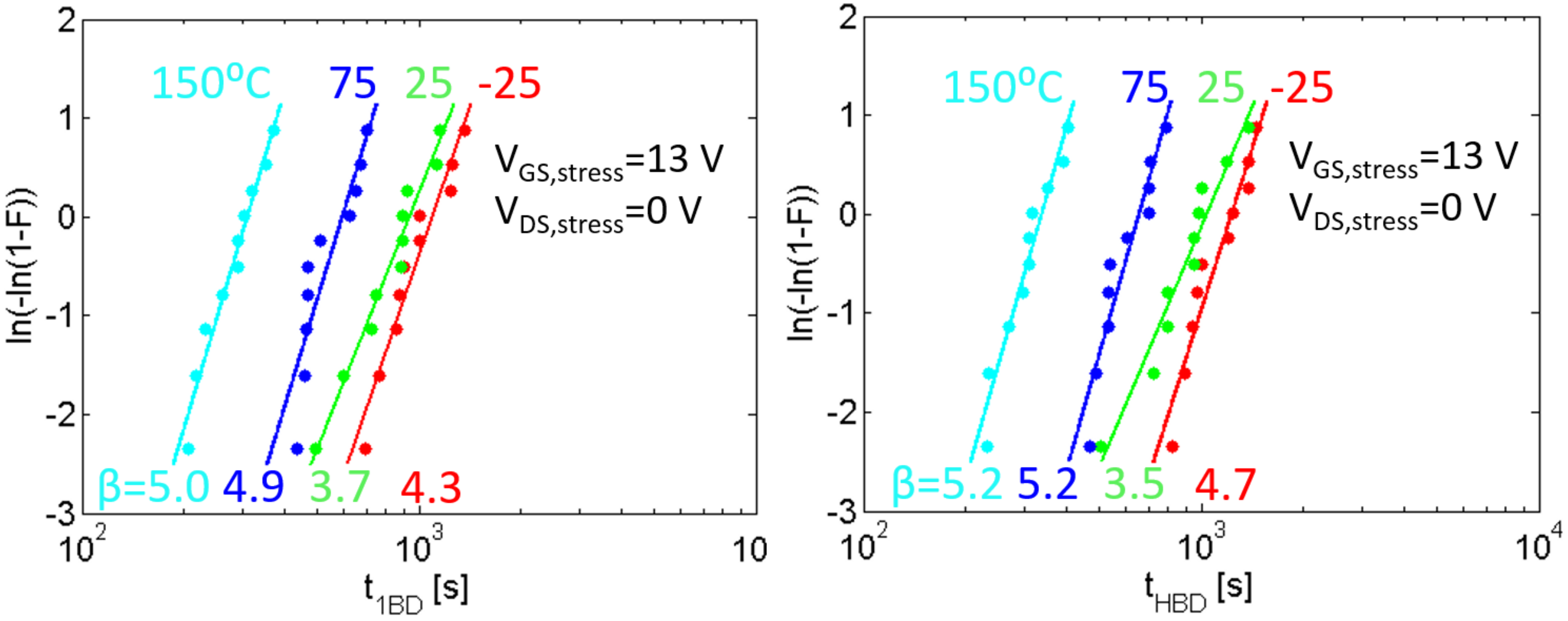
Constant gate-voltage TDDB stress:



- As T ↑, I_G ↑
- I_G evolution at each T nearly identical across 10 devices → uniform device fabrication

GaN Breakdown Statistics

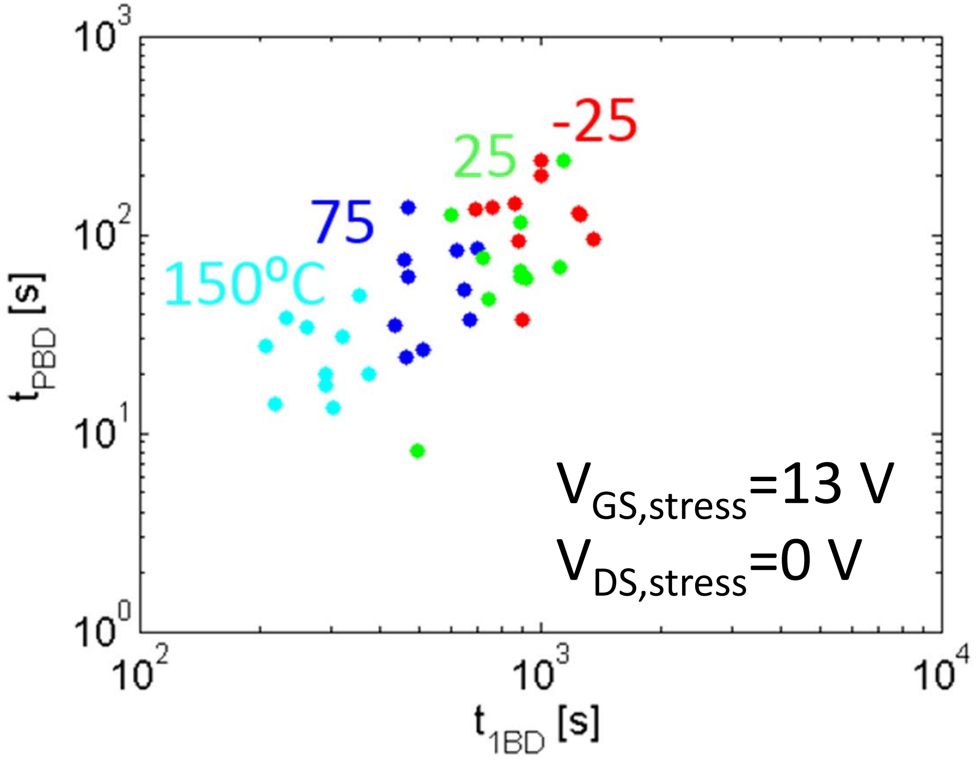
Weibull plots of time-to-first breakdown t_{1BD} (left) and hard breakdown time t_{HBD} (right)



- As T ↑, t_{HBD} and t_{1BD} ↓
- Variation in Weibull slopes due to small sample size

GaN Breakdown Statistics

Correlation between time-to-first-breakdown t_{1BD} and PBD duration t_{PBD}



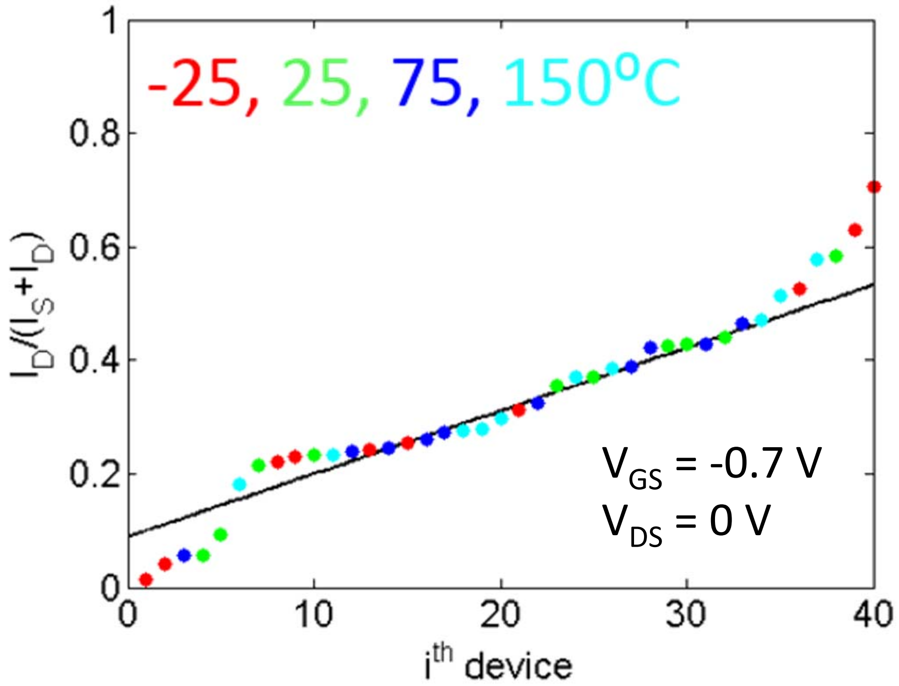
$V_{GS,stress}$=13 V
$V_{DS,stress}$=0 V

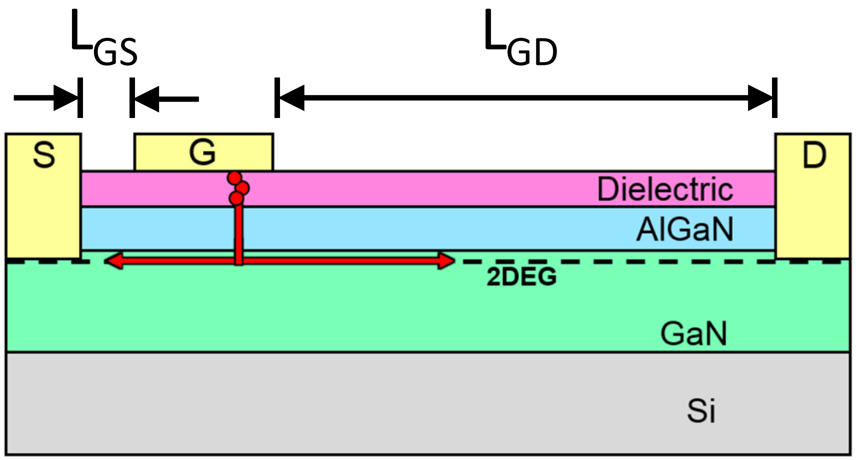
(following E. Wu, IEDM 2007)

- As T↓, t_{PBD} and t_{1BD} ↑
- t_{1BD} and t_{PBD} independent of one another → after first breakdown, defects generated at random until HBD occurs

After Hard Breakdown

Lateral location of BD path: measure $I_D/(I_S+I_D)$ at V_{DS}=0 V



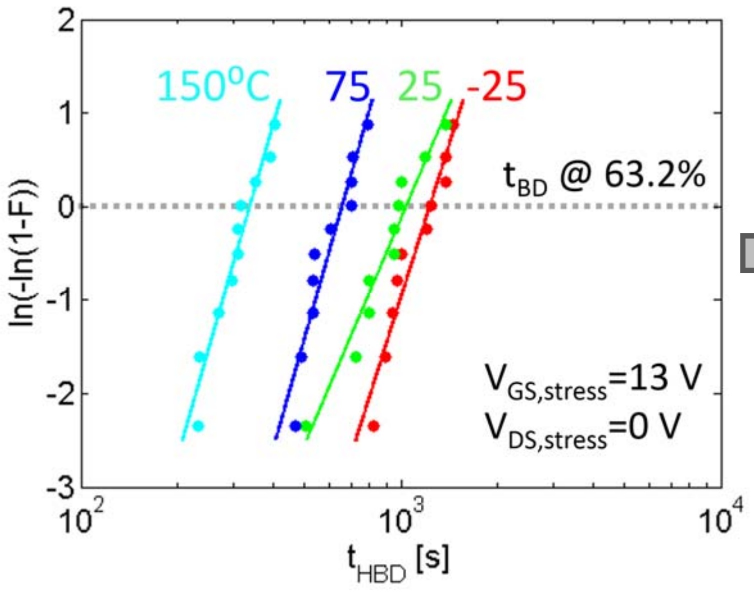


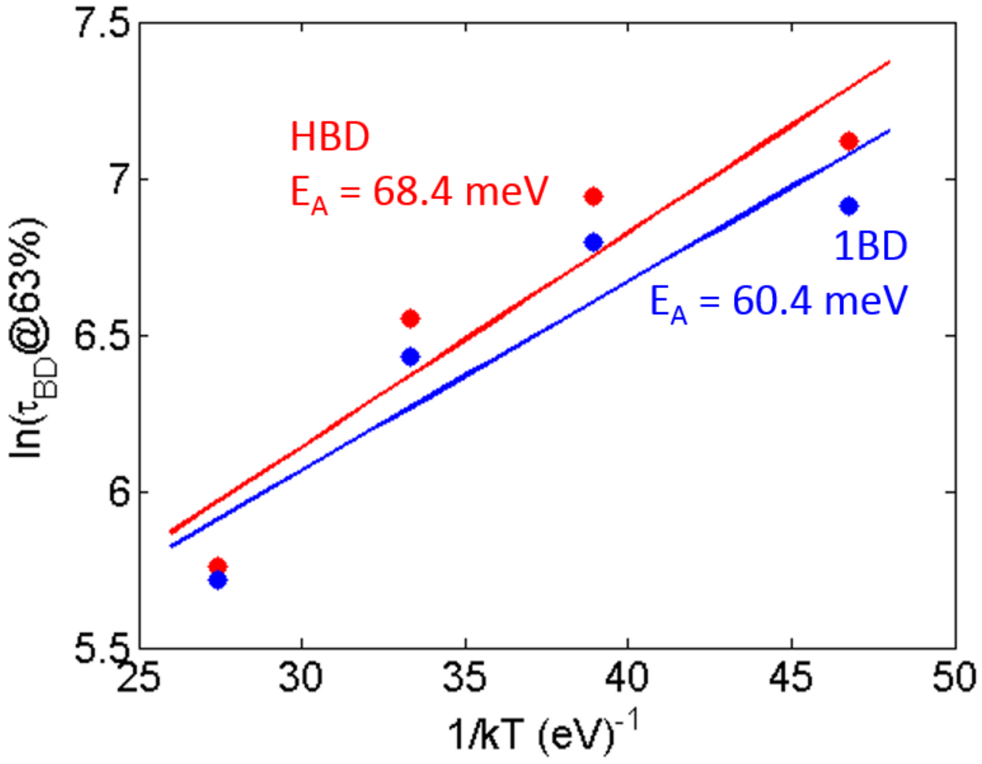
(following R. Degraeve, IRPS 2001)

- Spread of BD locations across channel, no particular trend with T
- $L_{GD} > L_{GS}$ → current preferentially flows through source terminal
- Fit line gives $R_{Daccess}=5*R_{Saccess}$

TDDB Activation Energy

Take the time t_{BD} where Weibull function = 0
(cumulative failure F=63.2%)

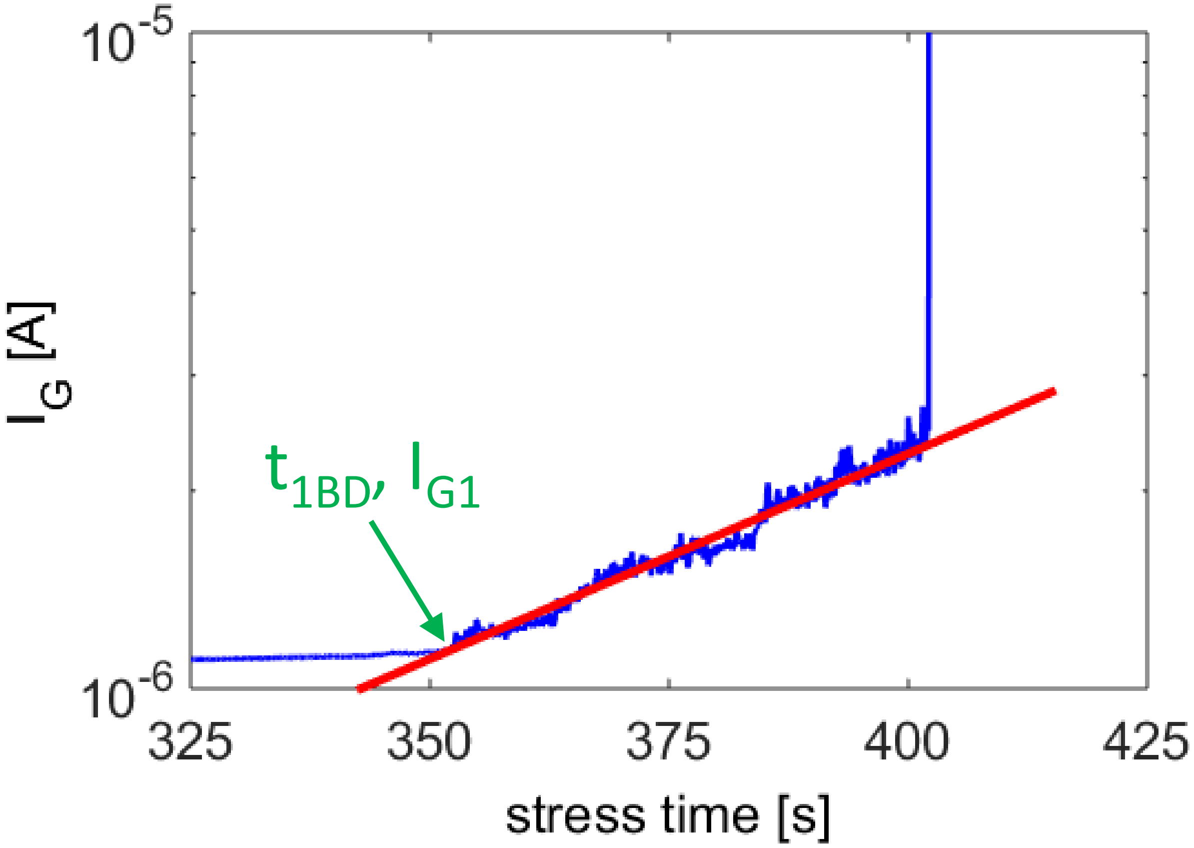




- E_A for first breakdown, hard breakdown nearly identical
  → likely common physical origin
- Very small E_A, unlike reports in Si CMOS or other GaN MIS-HEMTs

I_G Evolution During PBD

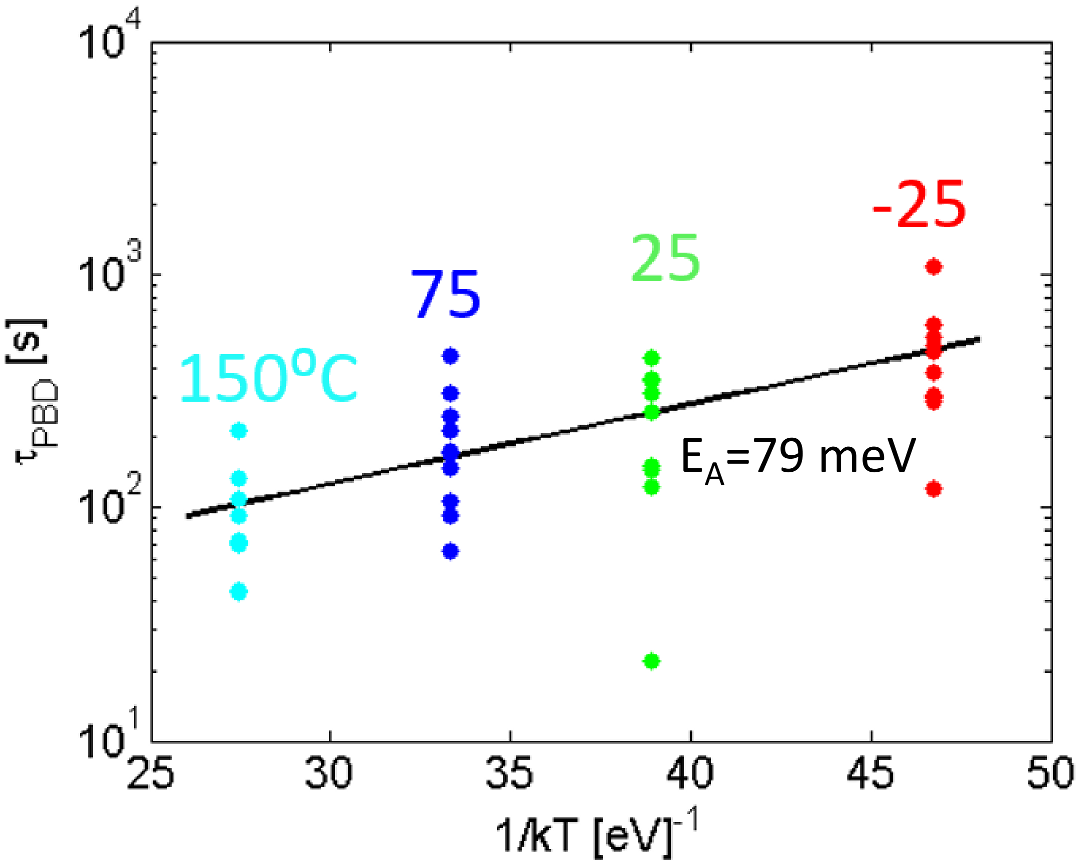
I_G during PBD follows exponential trend, consistent with PBD in Si



Fit with equation of the form $I_{G1}*\exp([t-t_{1BD}]/\tau_{PBD})$

I_G Evolution During PBD

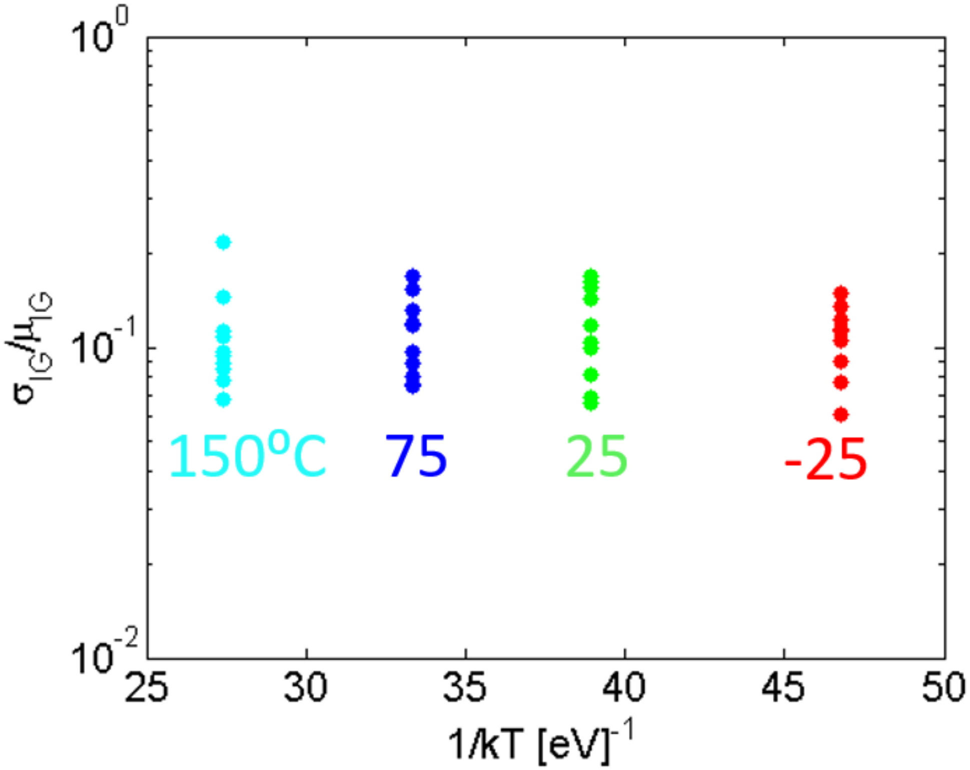
Fit PBD regime with exponential for every measured temperature



- E_A for avg(τ_{PBD}) ~ 79 meV
- Close to E_A for 1BD, HBD → suggests similar underlying mechanism

I_G Noise During PBD

- Does I_G noise increase or decrease with temperature?
- Find standard deviation of I_G and normalize by average I_G (because I_G ↑ as T ↑)



No trend over temperature → origins of noise likely to be tunneling phenomenon

Conclusions

- Developed methodology to study TDDB and explore PBD in GaN MIS-HEMTs
- Classic t_{1BD} and t_{HBD} statistics
  - Common physical origin for first breakdown and hard breakdown: parallel statistics, similar activation energies
  - However, t_{1BD} not predictive of t_{HBD}
- PBD characteristic time constant, τ_{PBD}, has E_A near that of 1BD, HBD (≈60-80 meV)
- I_G noise shows no temperature trend, suggests tunneling

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Questions?