Reliability of GaN HEMTs in power electronics

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Personal introduction

- PhD candidate in TU/e's Electromechanics and Power Electronics group
- Specialization: hard-switched degradation of GaN HEMTs
- Graduation topic: high speed high voltage switching using GaN (2024)

Agenda

Introduction & motivation

What makes GaN different

Failure modes

Qualification

Design guidelines

Summary & key takeaways

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Introduction & motivation

- Growing adoption of GaN in power systems [1]
  - Market projected to reach $3 billion by 2030
  - Driven by increased efficiency and power density
  - Adoption in consumer fast chargers, data centers, automotive power electronics
- *Reliability and qualification are key industrial concerns for adoption of GaN [2]*
- Focus of this presentation: practical implications for converters

[1] Yole Group – Power GaN 2025: Market and Technology Trends
[2] Texas Instruments – Is GaN Reliable, or Is That the Right Question?

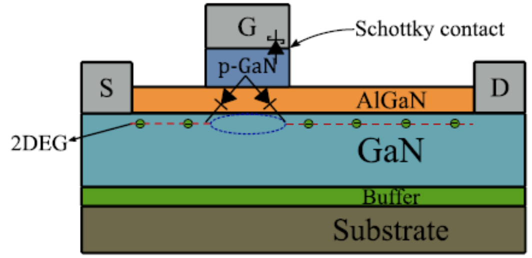
GaN vs Si vs SiC

	Si	SiC	GaN
Maturity	High	Medium	Developing
Switching speed	Low	Medium	High
Reliability prediction	High	Medium	Low
Sensitivity to design	Medium	Medium	High

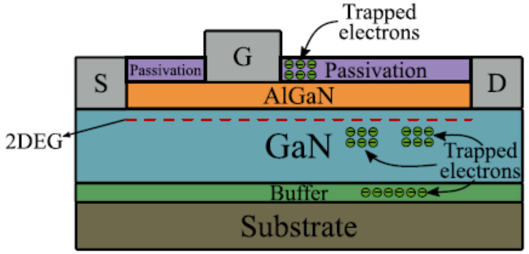
- GaN is not worse — but more sensitive

What makes GaN different?

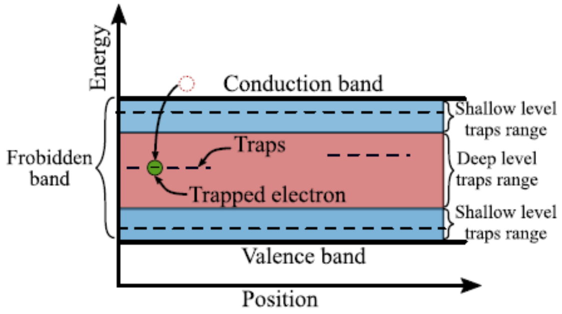
- Lateral device structure
  - Conductive 2-dimensional electron gas (2DEG)
  - Structure is normally on → gate needs doping for enhancement mode
- Traps in lattice can trap electrons
- Number of trapped electrons depends on operating conditions (voltage, temperature, switching)



p-GaN gate transistor structure



Different trap locations in a GaN HEMT



↑ *Different traps in the semiconductor energy band diagram*

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What this means in practice

- Trapping → Threshold voltage instability
- Trapping → Dynamic $R_{ds,on}$ increase
- Stress → Gate oxide degradation
- Why this matters:
  - Performance drift over time
  - Application-to-application variation
  - Difficult to predict degradation

→ Performance depends on operating conditions

Failure modes – depend on device stress

Overheating due to reduced efficiency	←	Increase in dynamic R_{ds} and C_{OSS} losses	←	Current-voltage overlap (HS) induced defects
Hard failure / short circuit	←	Drain to substrate or gate to drain breakdown	←	Overvoltage, SEB, high gate stress
Overheating due to high contact resistance	←	Fatigue in solder connections due to CTE mismatch	←	High ΔT temperature swing

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Qualification

- Standard tests:
  - HTRB
  - HTGB
  - HTOL
- Still relevant!

- Real GaN application:
  - Switching stress
  - Dynamic effects
  - Parasitics

- JEDEC JC-70 is developing GaN-specific guidelines
  - Check JEDEC JEP180 and JEP182
- **Standards are evolving, but not complete**

Guideline for Switching Reliability Evaluation Procedures for Gallium Nitride Power Conversion Devices

Version 1.0

JEP180.01
(Editorial revision of JEP180, February 2020)

JEDEC JEP180 (source: JEDEC)

Testing in practice

- Standard static tests
  - HTOL, HTRB, etc.
- Double pulse test
  - Measures switching behavior
- Switching stress tests
  - Continuous switching captures dynamic $R_{ds,on}$
- Accelerated lifetime testing
  - Combine earlier points into lifetime prediction. See JEP180.

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Design guidelines

- Gate-driver voltage margins (especially in pGaN)
  - Gate structure is sensitive to voltage stress

  → be aware of gate voltage recommendations
- Layout and parasitic inductance
  - Poor layout leads to voltage overshoots
- Thermal management
  - GaN is small and hard to cool but $R_{ds,on}$ and T_j are strongly correlated

  →Thermal runaway is more likely

Reliability is largely driven by design!

Summary

- GaN is not inherently unreliable, but it is sensitive
- Reliability is dependent on use-case and design (as with every device!)
- Qualification ≠ lifetime prediction
- Design expertise is essential – GaN is not forgiving of poor design

End of the presentation

Thank you for listening