Reliability challenges in GaN

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slides to post

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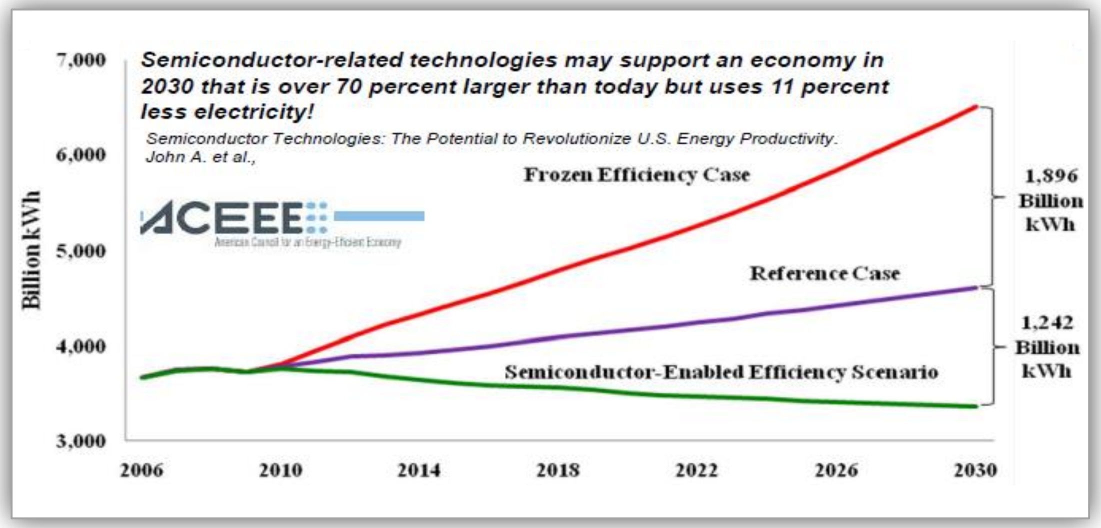
Texas Instruments

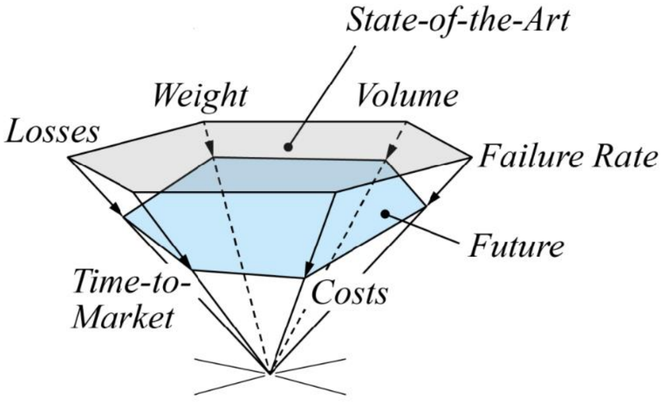
An increasing appetite for data and electrification

- *As electrification and data connectivity needs continue to grow across the globe, semiconductors will play a key role in creating a better world by making electronics more efficient and more affordable.*
- *However, the expectations of consumers will also continue to grow in that electronics and the resulting semiconductors must also become more robust.*

Semiconductor impact on power conversion



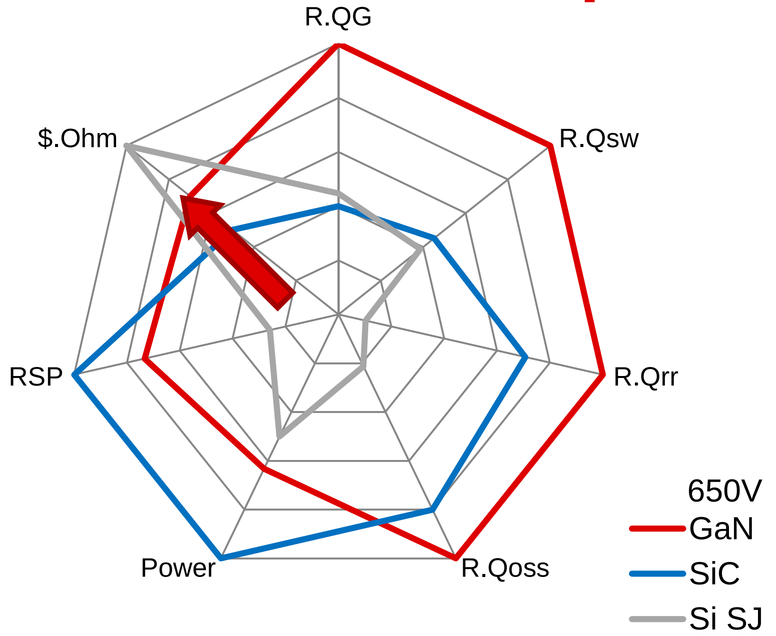
“Semiconductor Technologies: The Potential to Revolutionize U.S. Energy Productivity”, Report E094 of the American Council for an energy-efficient economy

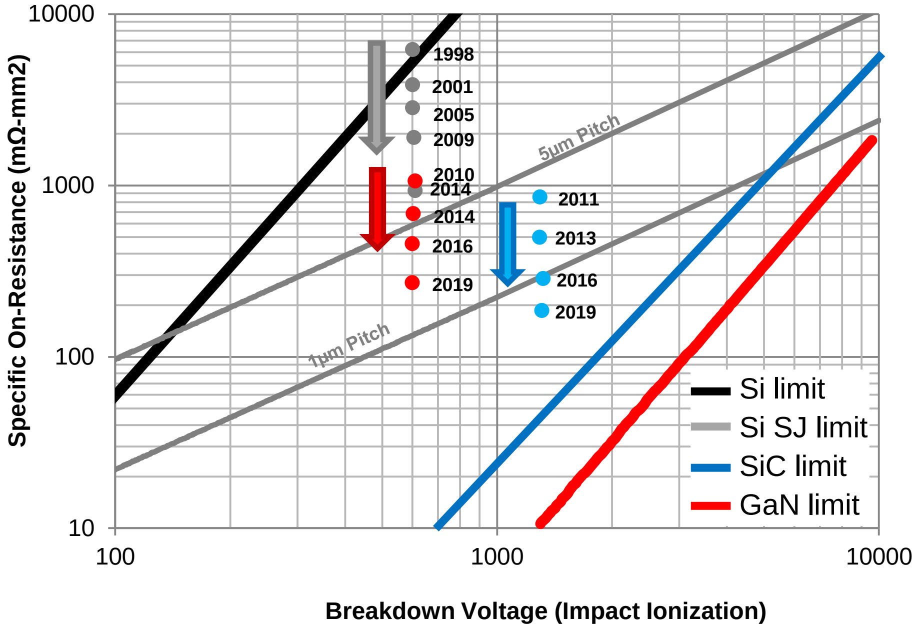


Multi-dimensional optimization needed

Power (weight) density; Efficiency, Cost, Failure rate

Performance improvement needs new technologies





- Improvement in device requires a (new) more expensive technology
- Critical needs to achieve technology potential
  - Equipment and material advances
  - **Understanding/modeling/improving different failure mechanisms**

Steps to achieving reliable GaN

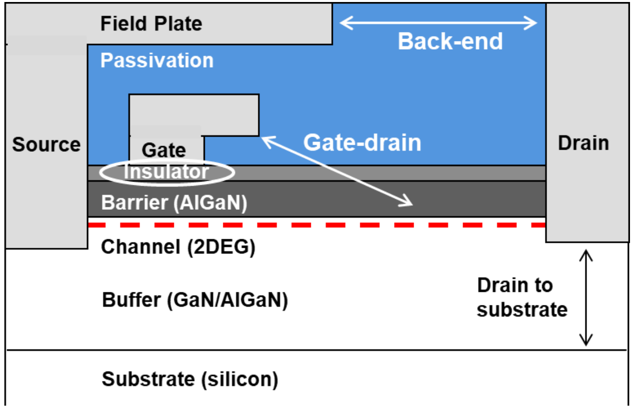
Component level	Use the established framework for Si qualification and reliability
	Address GaN Failure mechanisms and calculate lifetimes
	Measuring GaN specific degradation parameters and selecting a stress test circuit
Application level	Show that GaN is reliable for the actual switching application
	Assure robustness for extreme operating conditions like lightning surge and short circuit

Failure modes and failure mechanisms

Level	Failure mode	Failure mechanism
Component level	Increase in leakage current	Time Dependent Breakdown (TDB)
	Lower efficiency and overheating due to increase in dynamic Rds-on	Charge trapping
	Hard-failure	Time Dependent Breakdown (TDB)
		Hot-carrier wear-out (switching)
Application level	Hard-commutation related	Reverse recovery
	Miller turn-on shoot-through	Device hold-off at high slew rate
	GaN device interaction with driver and system	Avalanching of Si FET during turn-off due to Coss mismatch in Cascode GaN

Component level reliability

Time dependent breakdown



- High fields cause defect generation over time, increasing the leakage currents and causing eventual hard-failure
- Well known and studied for dielectrics used in Si IC's

Failure mode
Gate TDDB (forward)
Gate TDDB (reverse)
OFF-state TDDB (gate-drain)
OFF-state TDDB (source-drain)
Epi TDDB
Electromigration

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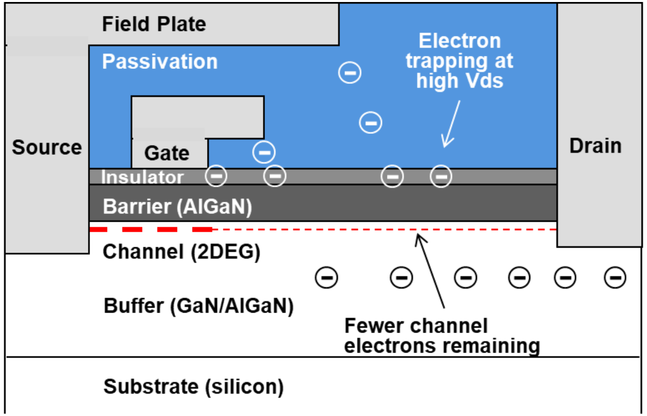
Component level reliability

Charge trapping



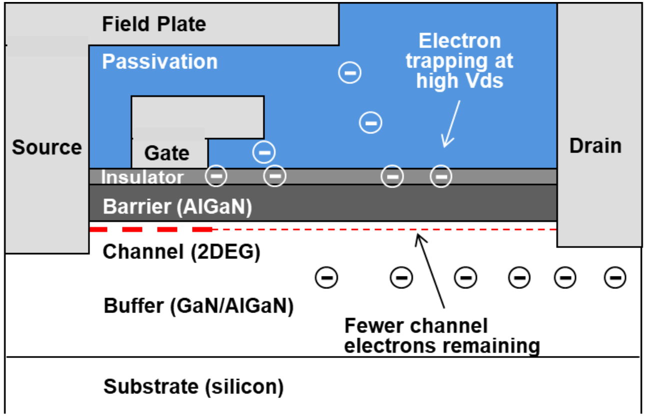
- Charge trapping – high voltage / hot e-
- Dynamic Rds-on is high on the timescales of switching. It is difficult to measure on a tester, since the traps discharge quickly.

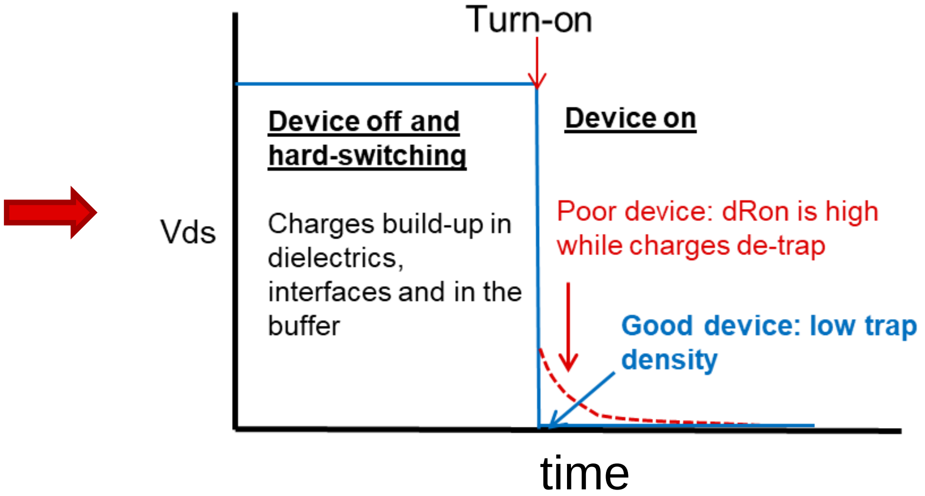
Classify switching stress type with switching locus

Choose an appropriate test-vehicle to accelerate the desired switching type

Generate a model and calculate lifetime

Dynamic Rdson reliability with aging

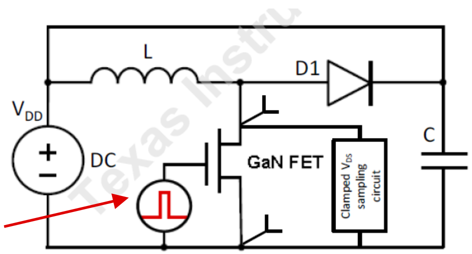




- Charge trapping causes higher dynamic Rds-on, which results in more self-heating and lower efficiency
- Device aging can increase trap density and result in higher dynamic Rds-on
- **Need to validate that new traps are not being generated with aging**

Validating dynamic Rds-on reliability

Test circuit to measure dRon

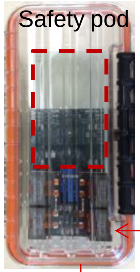


Turn on to measure dRon within 1-usec

FET card

DUT and heater

Safety pod



Inductors

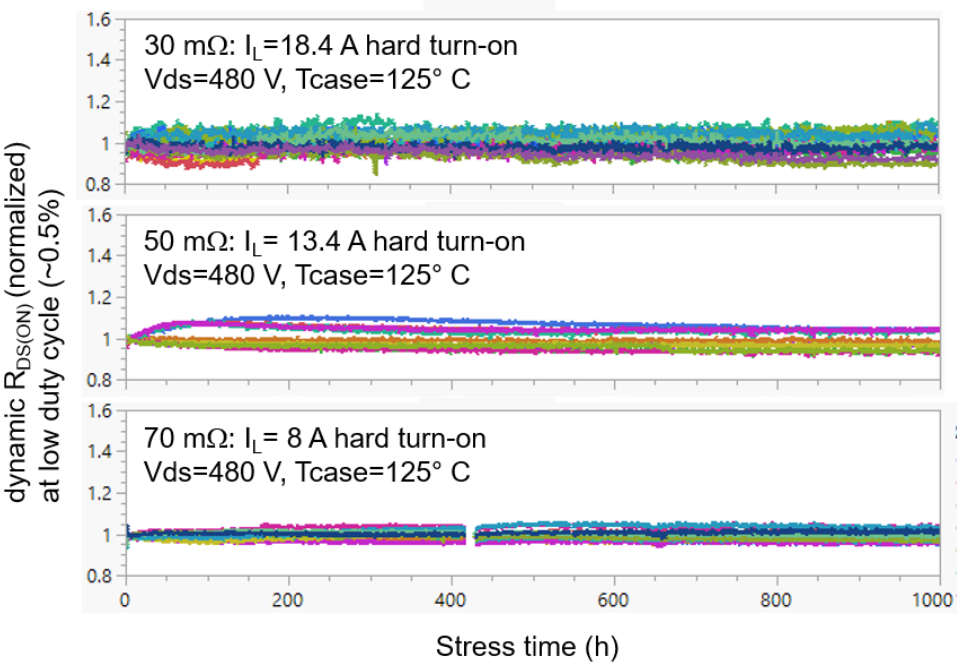
Shutoff circuit to save device for FA

Motherboard

Hard-switching test system, for dynamic Rds-on (and hot-carrier wearout) reliability

Dynamic Rds-on does not increase with aging

- Stable dRon at low duty cycle demonstrates lack of new trap creation and excellent material quality with aging



Stable dynamic Rds-on with aging at high-voltage, high-current, high-temperature, hard-switching

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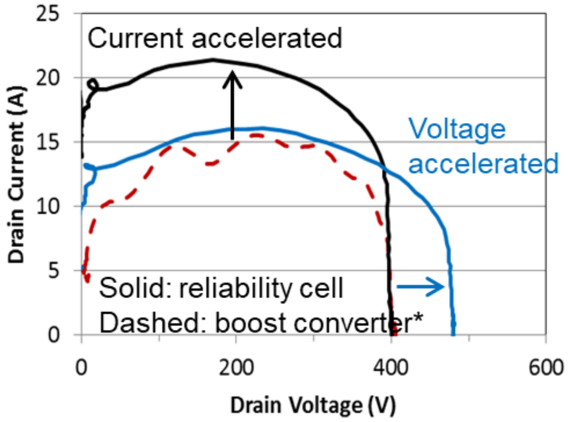
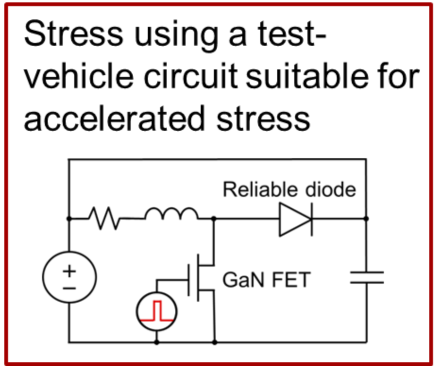
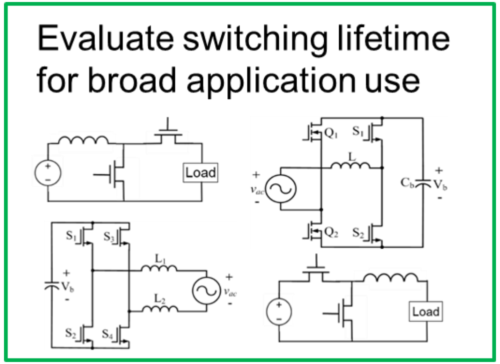
Hot carrier wear out: Switching lifetime model







Construct switching stress model

Voltage acceleration

- **Exponential model (TDDB):** $TTF \propto e^{-\beta_V(V_{DS})}$

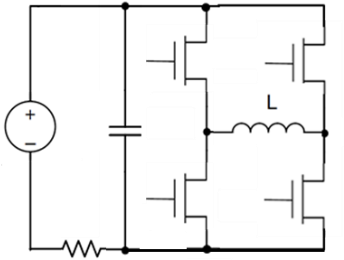
Current acceleration

- **Exponential model:** $TTF \propto e^{-\beta_C(I_{Ch})}$
- **Power-law model:** $TTF \propto (I_{Ch})^{-n}$
  (electromigration, hot-carrier)

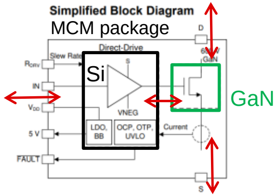
Temperature acceleration

- **Arrhenius model:** $TTF \propto e^{\frac{Ea}{k}\left[\frac{1}{T}-\frac{1}{To}\right]}$

Reliable actual application operation: dHTOL testing



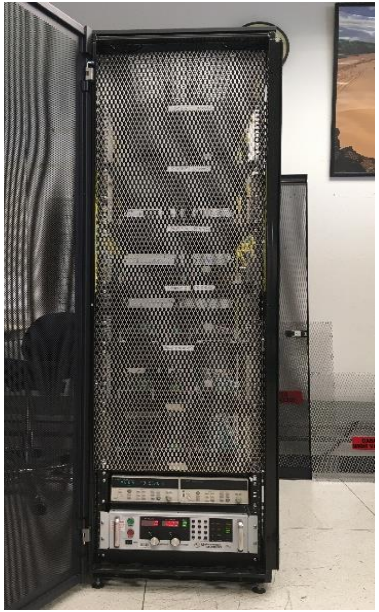
Loss current sensing



GaN device interaction with driver (and other system components)

<u>H-bridge circuit</u>

- Recycle power
- Both hard and soft-switching stress at high power
- In-system stress modes



Stress rack: 200 kW of stress power

Application half-bridge boards under stress

Summary

- GaN is a key enabler for power electronics. To gain widespread acceptance, reliability needs to be understood and demonstrated

- Detailed understanding of failure & degradation mechanisms allows predicting lifetime & engineering reliability problems.

- Traditional qualification does not imply desired lifetime in real applications. Use of switching test circuits is critical for application-level reliability validation.

- System-level design can ensure application reliability.

Thank you!