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Reliability Characterization of Wide-Bandgap Semiconductor Switches

1. Motivation

- Wide-bandgap semiconductors such as Silicon Carbide (SiC) and GaN have material properties that make them theoretically superior to Silicon for power electronics for energy storage systems
  - *SiC and GaN promise to reduce the size, complexity, and cost of power conversion systems*
  - *However, questions about reliability have limited their implementation in systems*
- *Overall goal: Serve as an unbiased evaluator of the performance and reliability of wide-bandgap power semiconductor devices*
- Characterization is ongoing on several types of devices:
  - *SiC MOSFETs from various manufacturers (reported here)*
  - Non-MOS SiC power devices (e.g. BJTs, JFETs)
  - GaN High-Electron Mobility Transistors (HEMTs)

2. WBG Power Electronics Benefit Power Conversion Systems for Energy Storage

13.5 kV, 100 A Si IGBT module

M. K. Das et al., ICSCRM 2011

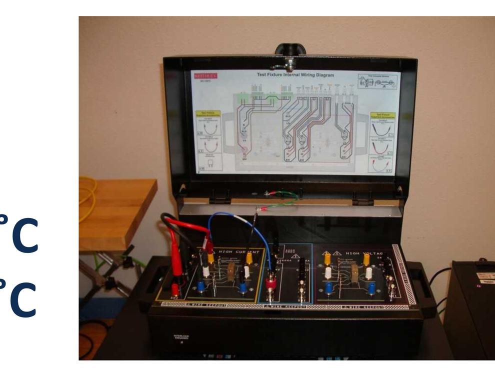
10 kV, 120 A SiC MOSFET module
10% weight and 12% volume of Si module

- All energy storage systems require power conversion
- Due to their higher switching frequency and higher temperature capability, WBG devices enable considerable size, weight, and complexity savings compared to Si
- *WBGs thus enable new functionality, reduce system cost, and increase system reliability*

3. Experimental facilities

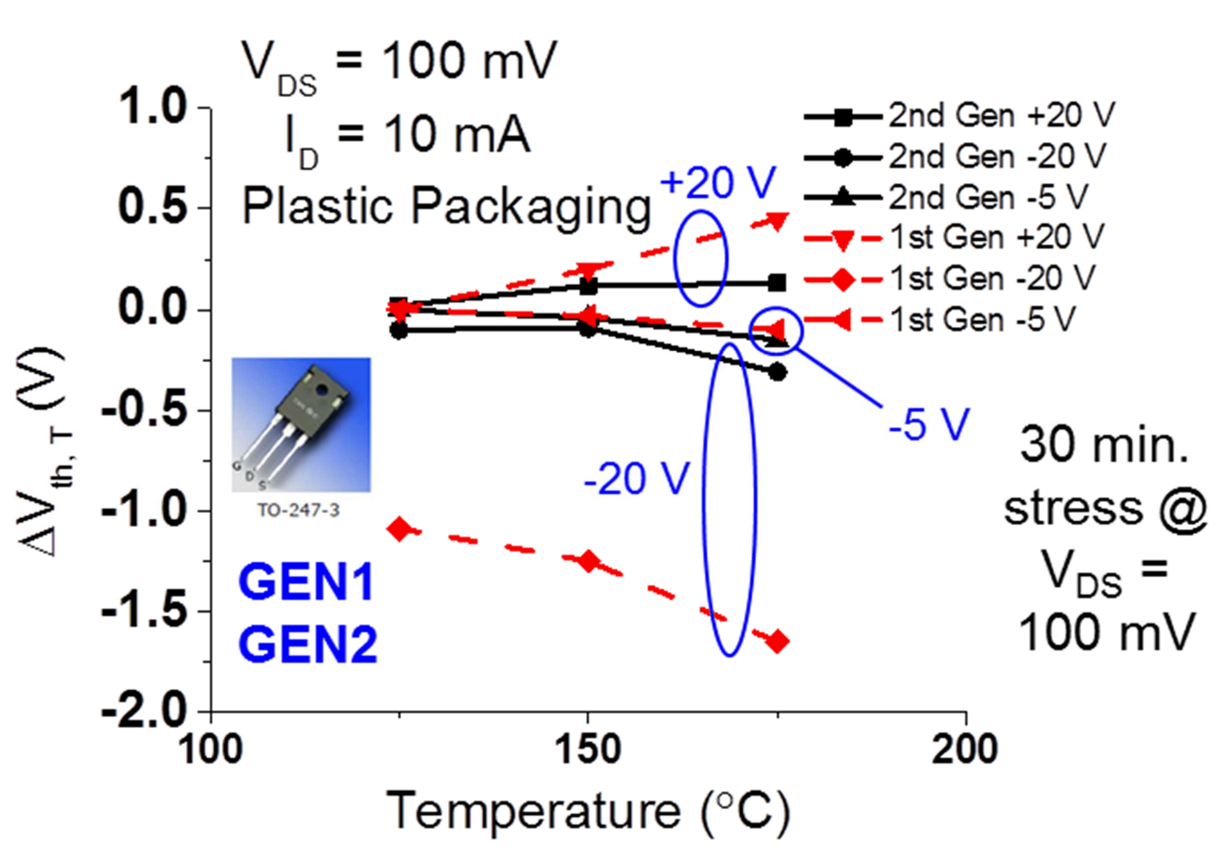
- Hot chuck capable of 600˚C operation (used for MOS capacitor measurements, including interfacial defect density characterization)

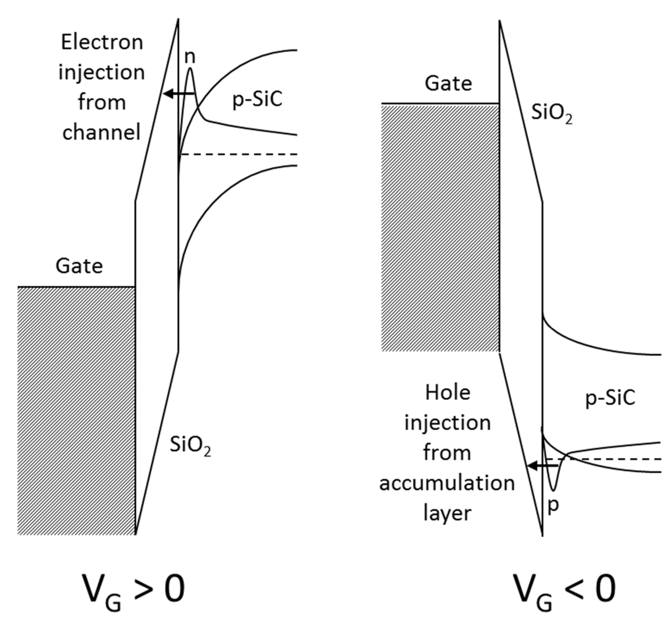
- High-power test system for evaluation of power semiconductor switches
  - 3 kV, 50 A
  - Packaged parts up to 400˚C
  - Wafers and die up to 300˚C



- *Leverages Sandia's role as the lead DOE lab for electronics, including significant investments in silicon (e.g. ASICs) and compound semiconductors (e.g. solid-state lighting EFRC)*

4. DC Gate Bias-Temperature Stress Testing

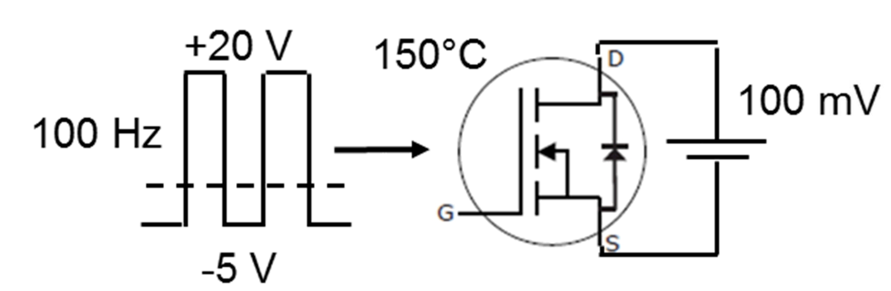




Hole injection dominates electron injection for 1st generation device

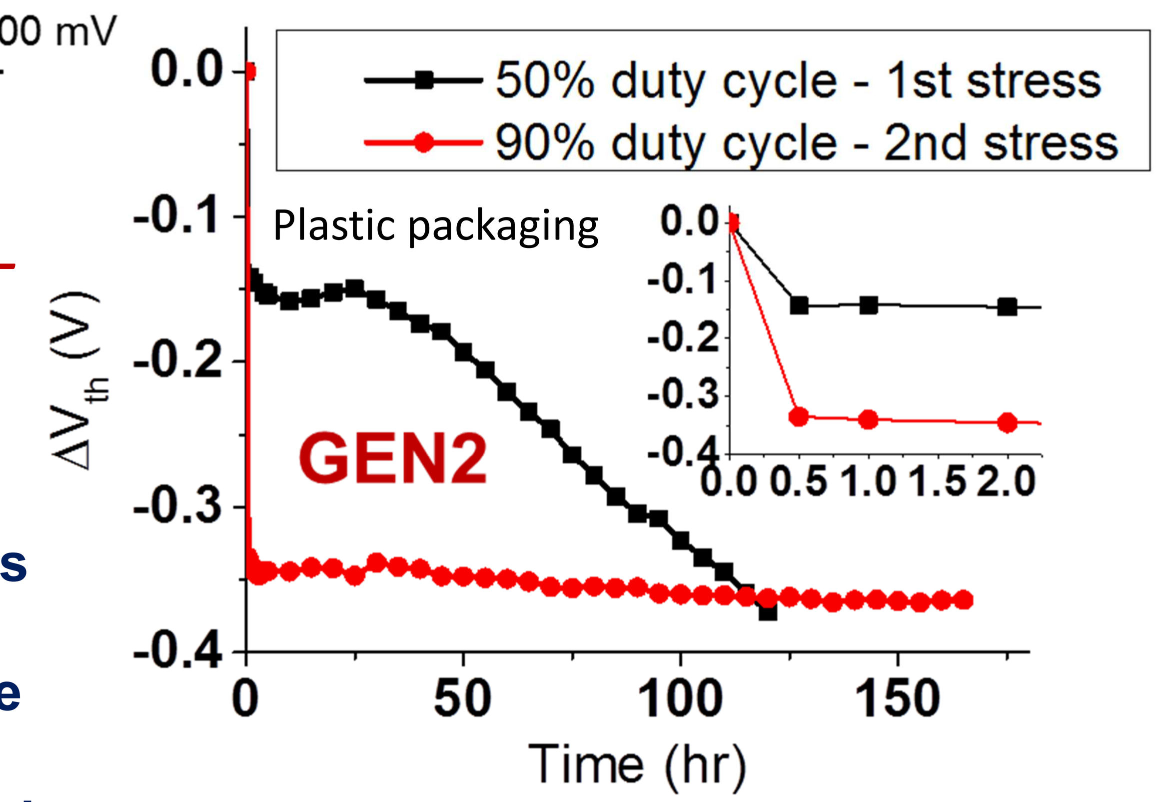
- *A huge improvement is seen in V_T stability for the 2nd generation parts, especially for the -20 V gate stress condition*
- *Likely due to design and/or processing improvements in the 2nd gen. device compared to the 1st gen. device*

5. AC Gate Bias Stress Testing



More realistic stress condition – better approximation to the environment in a real system

- ΔV_T is negative, suggesting that hole injection dominates electron injection
- True even for 90% duty cycle
- A very fast negative shift is observed, followed by a much slower negative shift
- *Complex and surprising behavior that can adversely affect the operation of power converters*



Much more study is needed to understand the complex injection, capture, and emission properties of electrons and holes into bulk and interface states needed to ascertain SiC MOS reliability under AC stress

6. FY13 Publications and Impact

- S. DasGupta et al., IEEE Trans. Electron Devices 60 (8), 2619 (2013).
- R. Kaplar et al., High Temp. Elect. Network (Oxford, UK, July 2013).
- D. R. Hughart et al., 8th Annual SiC MOS Workshop (August 2013).
- Work presented in seminars at Oak Ridge, United Technologies, Auburn University, and KLA-Tencor
- Work cited in recent DOE SBIR call

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U.S. DEPARTMENT OF ENERGY

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