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Wide-Bandgap Power Electronics Reliability: Device Physics to Converter Performance

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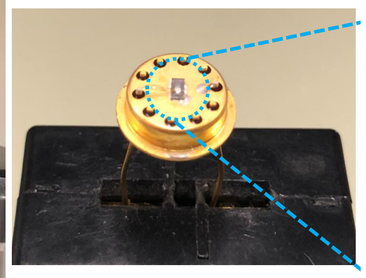
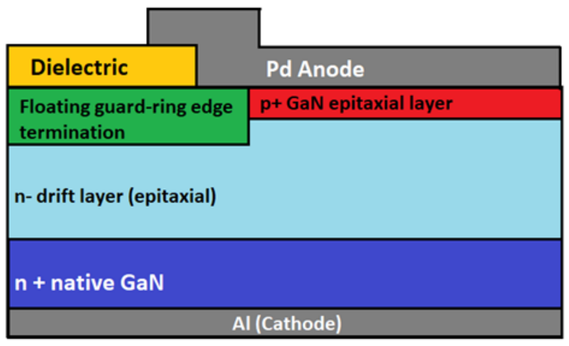
- **Wide-bandgap power switches benefit the integration of grid-scale energy storage by improving power converter efficiency, increasing power density, and adding functionality**
- **But the reliability physics of Silicon Carbide (SiC) and Gallium Nitride (GaN) devices must be tied to the performance of converters based on them, and realistic stress conditions must be understood**

Vertical Gallium Nitride Power Diodes

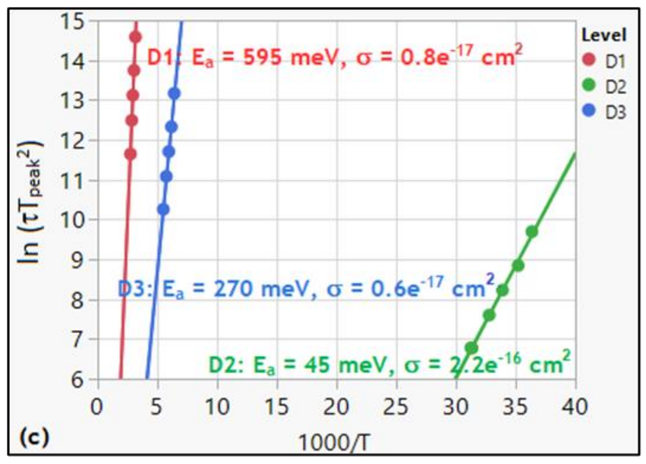
Deep Level Spectroscopy System



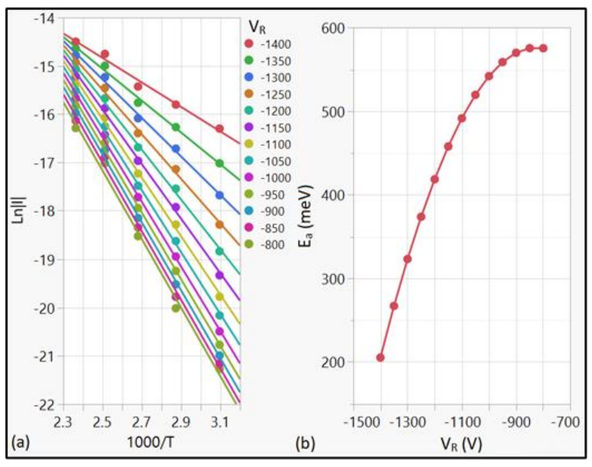


Possible Defect Locations
- Semiconductor-contact interface
- Epitaxial semiconductor interface
- Semiconductor bulk
- Edge termination

S. DasGupta et el., Appl. Phys. Lett. 120, 053502 (2022) - *Editor's Pick*



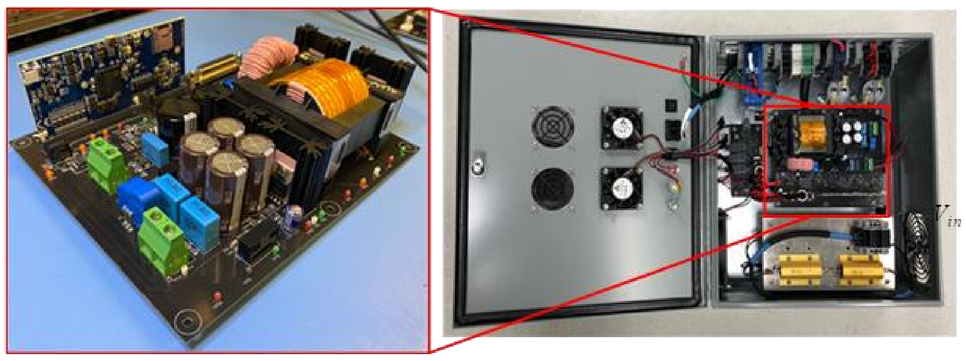
Arrhenius plots for DLTS peaks reveal three defect energies: 600 meV (highest density), 0.27 meV (lowest density), and ~45 meV (dopant)



Activation energy of reverse leakage current demonstrates field-dependent barrier lowering consistent with600 meV defect detected by DLTS

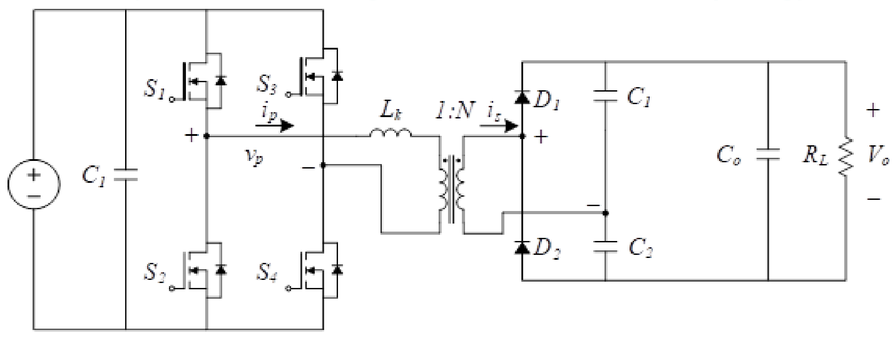
➤ **Objective: Understand defects in WBG devices and correlate them to device degradation & reliability**

Stressing of WBG Power Devices in Switch-Mode Converter

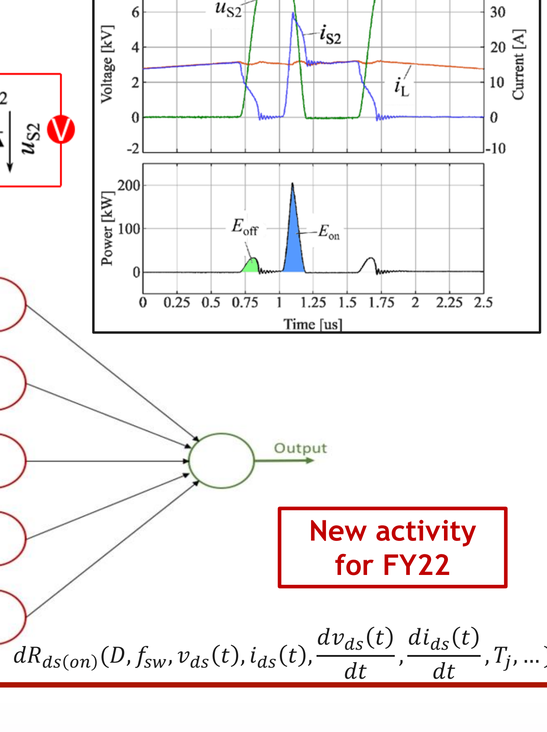


Custom-designed and built switch-mode power converter used to stress GaN and SiC WBG power devices

Test system full-bridge DC-DC converter topology



Tie device physics to circuit behavior

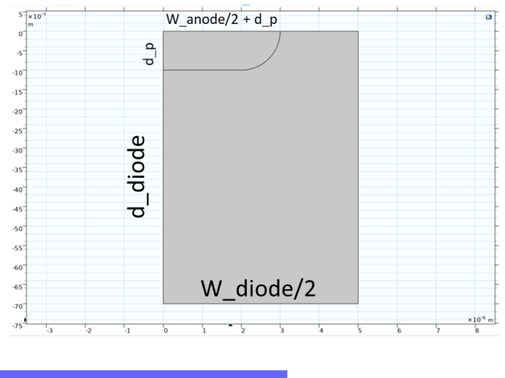


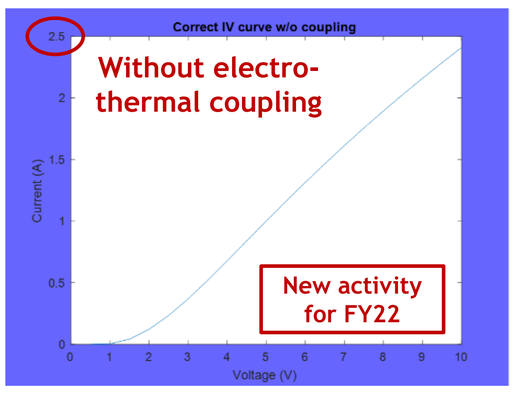
Full-bridge DC-DC converter experimental waveforms

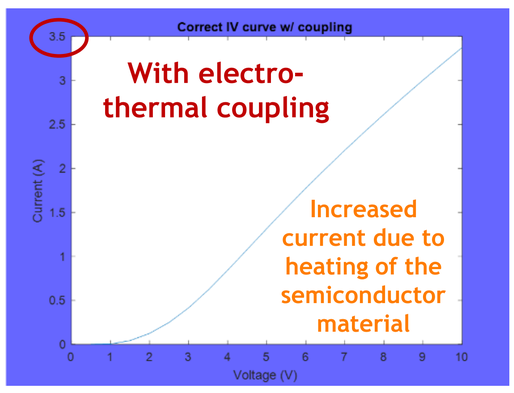
WBG Device Degradation Modeling

Multi-Physics Modeling
- Coupled electro-thermal modeling of WBG devices performed to ascertain reliability
- Especially important for excursions from normal operation, e.g. short-circuit

Geometry used for COMSOL modeling of GaN diode to examine coupled electro-thermal analysis



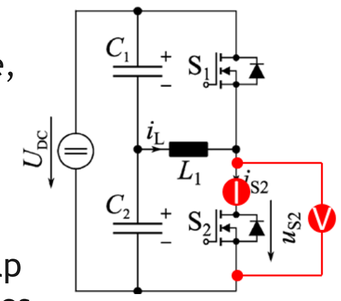


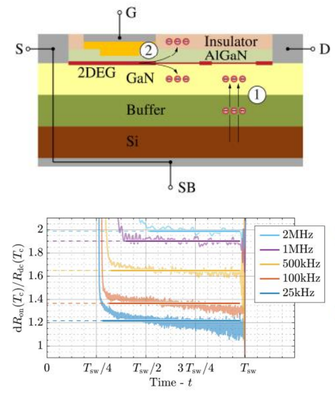


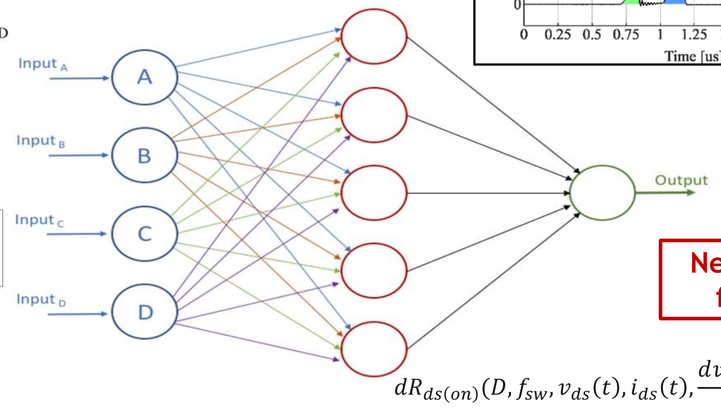
Simulated forward diode IV curves (note the difference in scale between the two plots)

Implementing Machine Learning Analysis

- Interaction of defect physics, device structure, and switching dynamics results in a complex, multi-dimensional experimental space
- Machine learning can help to recognize dependencies







New activity for FY22

$$dR_{ds(on)}(D, f_{sw}, v_{ds}(t), i_{ds}(t), \frac{dv_{ds}(t)}{dt}, \frac{di_{ds}(t)}{dt}, T_j, \dots)$$

Conclusions & Future Work:

- DLTS analysis used to identify defect responsible for diode leakage current resulting from switching stress
- Full-bridge switch-mode power converter upgraded to stress multiple device types (diodes, transistors, SiC, GaN)
- New approaches including multi-physics modeling and machine learning added this FY to interpret data

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