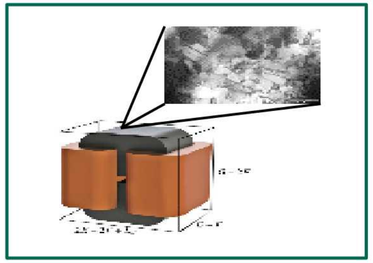
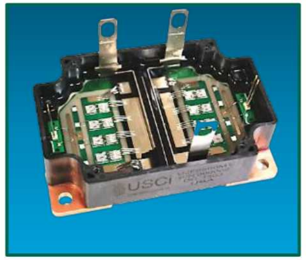
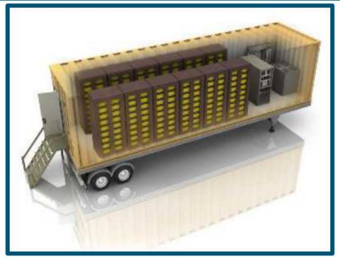
Sandia National Laboratories

SAND2020-2790C

ENERGY STORAGE POWER ELECTRONICS PROGRAM







PRESENTED BY

Stan Atcitty, Ph.D.

U.S. DEPARTMENT OF ENERGY NNSA

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

SAND2019 -XXXXXX

ENERGY STORAGE R&D AT SANDIA

BATTERY MATERIALS
Large portfolio of R&D projects related to advanced materials, new battery chemistries, electrolyte materials, and membranes.

CELL & MODEULE LEVEL SAFETY
Evaluate safety and performance of electrical energy storage systems down to the module and cell level.

POWER CONVERSION SYSTEMS
Research and development regarding reliability and performance of power electronics and power conversion systems.

SYSTEMS ANALYSIS
Test laboratories evaluate and optimize performance of megawatt-hour class energy storage systems in grid-tied applications.

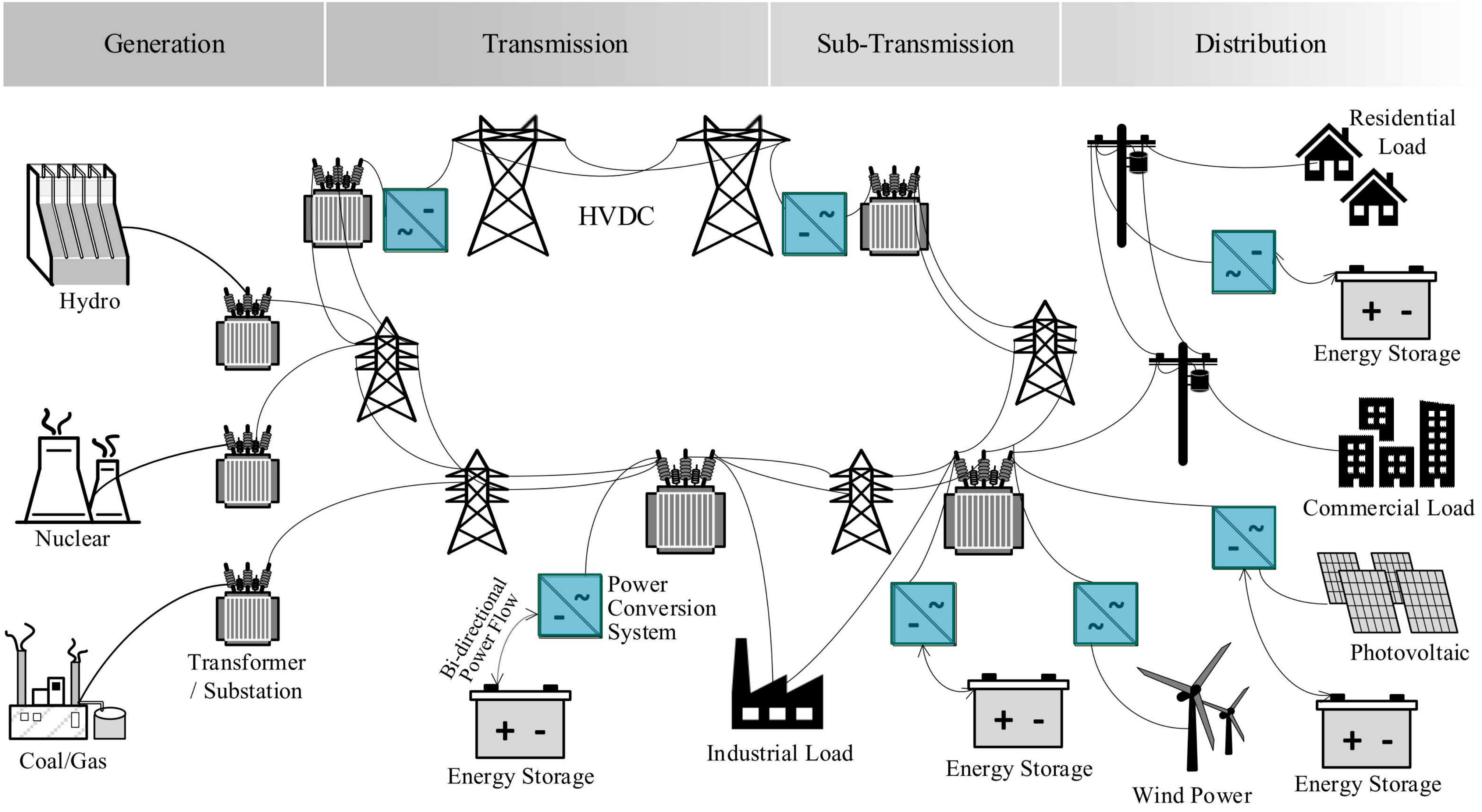
DEMONSTRATION PROJECTS
Work with industry to develop, install, commission, and operate electrical energy storage systems.

STRATEGIC OUTREACH
Maintain the ESS website and DOE Global Energy Storage Database, organize the annual Peer Review meeting, and host webinars and conferences.

GRID ANALYTICS
Analytical tools model electric grids and microgrids, perform system optimization, plan efficient utilization and optimization of DER on the grid, and understand ROI of energy storage.

Wide ranging R&D covering energy storage technologies with applications in the grid, transportation, and stationary storage

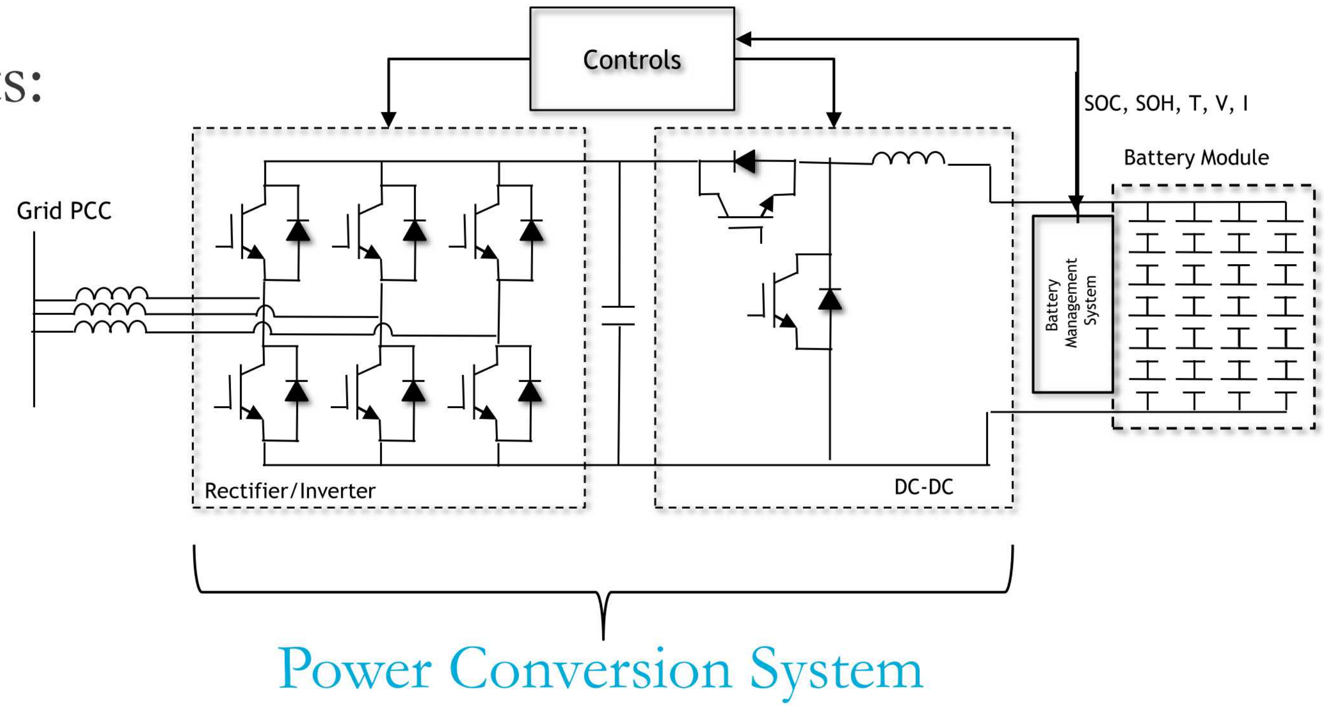
POWER CONVERSION SYSTEM – KEY ENABLING TECHNOLOGY



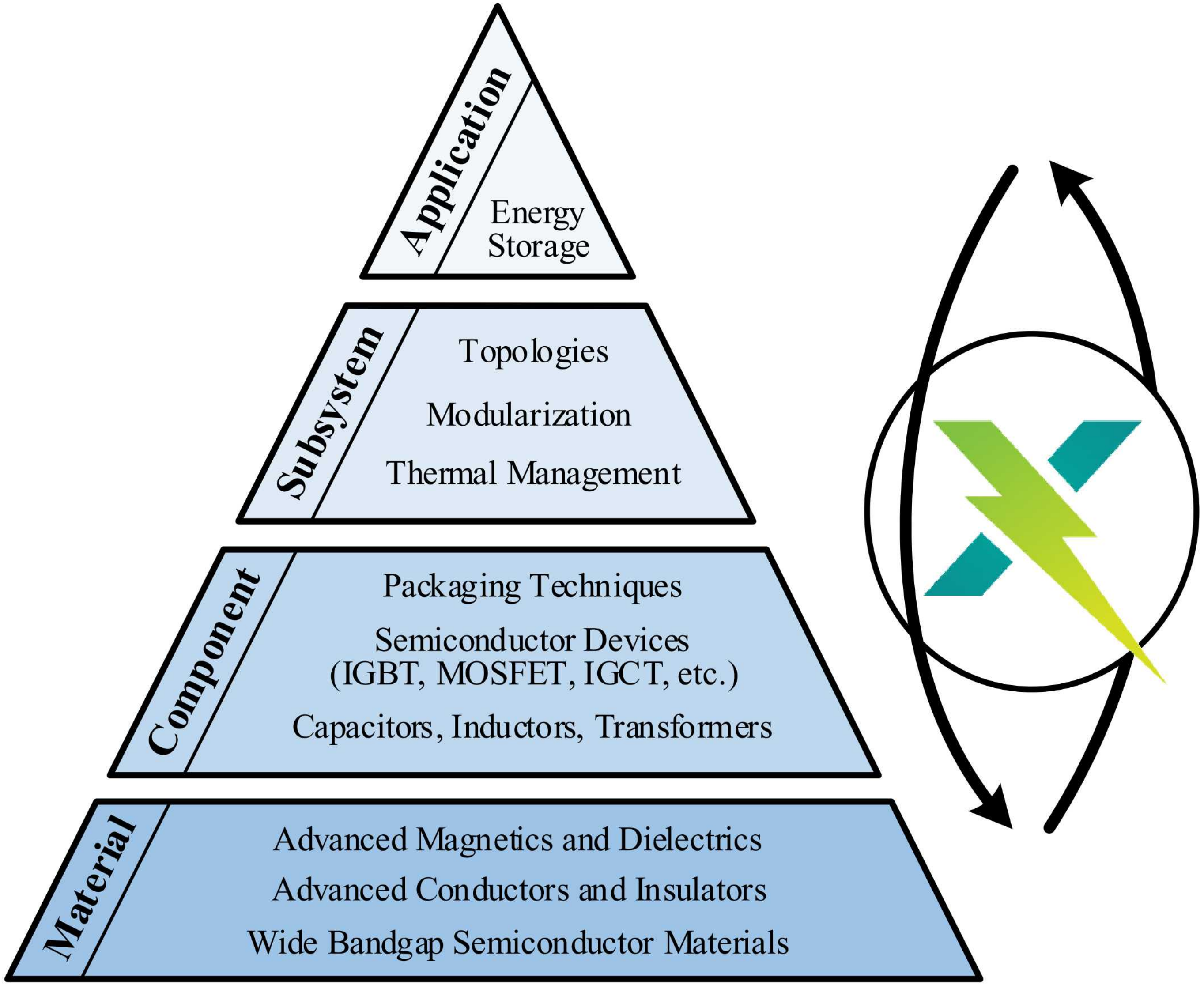
BATTERY ENERGY STORAGE SYSTEM

Battery Energy Storage System contain three major components:

- Battery Module
- Monitoring and Control System
- Power Conversion System



POWER ELECTRONICS R&D



Reliability is fundamentally a challenge in system integration

Reliable power electronics require R&D at all levels of

Strategic Principles:

- Optimally match advanced component and material capabilities to the needs of emerging applications
- Facilitate a two-way information transfer between basic science research efforts and end-use applications
- In assessing new technologies, trust but verify through rigorous hardware experimentation

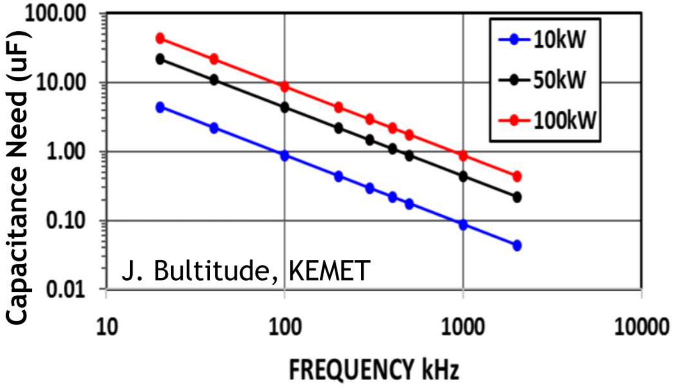
ADVANCED POWER ELECTRONICS CONVERSION (APEX) LAB

Contact:	Jake Mueller (jmuelle@sandia.gov), Stan Atcitty (satcitt@sandia.gov)
Problem:	New power conversion solutions are needed to support the expanding role of energy storage in the grid
SNL Approach:	Develop new power conversion topologies and intelligent control strategies; leverage the capabilities of advanced components and materials; verify performance through hardware experimentation
Key Outcomes:	Modular and fault-tolerant hardware architectures improve the reliability, scalability, efficiency, and flexibility of utility-scale storage
Key Capabilities:	Real-time simulation; rapid prototyping and electrical fabrication; energy storage emulation at cell, module, and system level; converter analysis in 30 kW bidirectional hardware-in-the-loop testbed, fault insertion and destructive testing

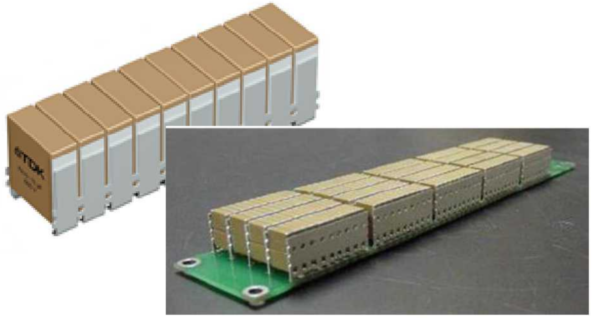
ADVANCED COMPONENTS: CAPACITORS

- **Contact:** Jon Bock, jabock@sandia.gov
- **Why do they fail?**
  - **Excessive heating** from electrical losses (Tan δ, ESL, ESR)
  - **Current spikes** leading to electrode arcing/evaporation (polymer film caps)
- **How do they fail?**
  - Heating causes melting, defect electromigration, or other problems
  - Capacitance loss, shorting, open-circuit failure, depending on cap type and failure mode
- **How are we increasing reliability?**
  - Evaluation of ceramic capacitor replacements for polymer capacitors in high dV/dT situations
  - Evaluation of lifetime and identification of degradation in ceramic capacitors designed for DC-Link applications (e.g. Ceralink)
  - Investigation of Next-Generation dielectric materials
    - (Bi,Zn):$BaTiO_3$
      - 3 orders of magnitude higher resistivity than $BaTiO_3$, high permittivity up to 200°C+, low loss.
      - Processability concerns being addressed.
      - Degradation behavior unknown – investigating.

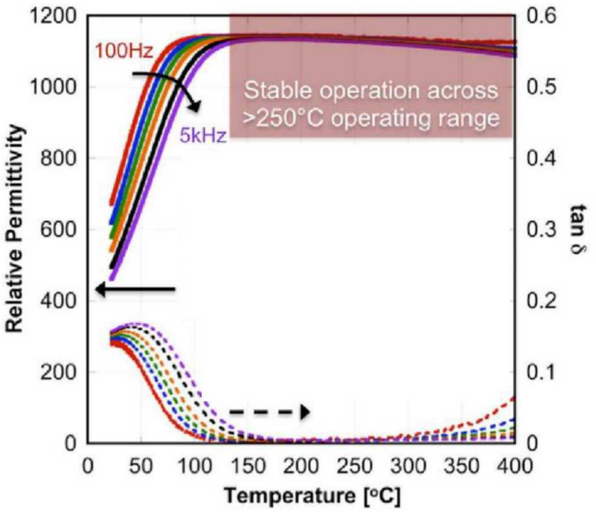
Increased Frequency and Voltage
Lowers Capacitance Needs



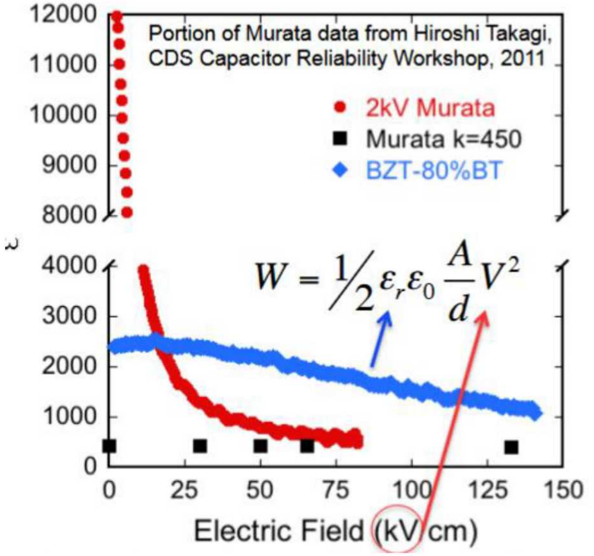
In-Depth Lifetime Evaluation of
Current-Gen Technologies
KC-Link and Ceralink



High Permittivity Dielectrics >150°C



High Permittivity *at high field*

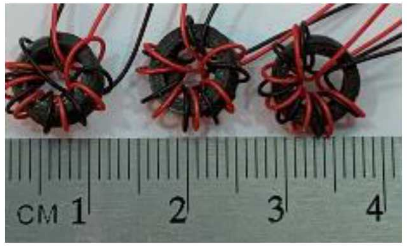


ADVANCED COMPONENTS: MAGNETICS

- **Contact:** Todd Monson, tmonson@sandia.gov
- **Why do they fail?**
  - Excessive heating from electrical losses
  - Saturation from current/voltage excursions, GMP, EMD
- **How do they fail?**
  - Heating causes deterioration in conductor insulation
  - Radiative heat from magnetics can cause neighboring components to fail
  - A saturating inductor or transformer becomes a short and can damage other components
- **How are we increasing reliability?**
  - New high magnetization core materials robust against saturation in the face of EMP, GMP, and other current/voltage excursions
  - Low loss magnetic core materials generate less waste heat
    - Less risk to conductor insulation
    - Less aging effects to other power electronics elements from elevated temperature
    - Only passive cooling required

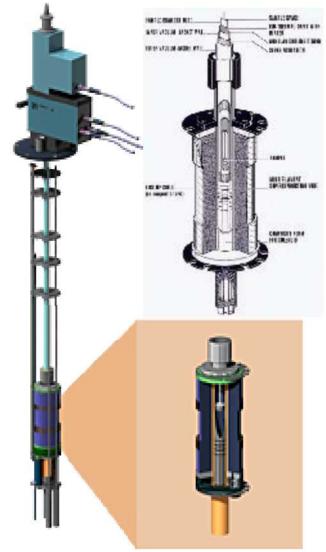
γ'-Fe_4N toroidal inductive cores

Composite magnetic cores wound for B-H analysis

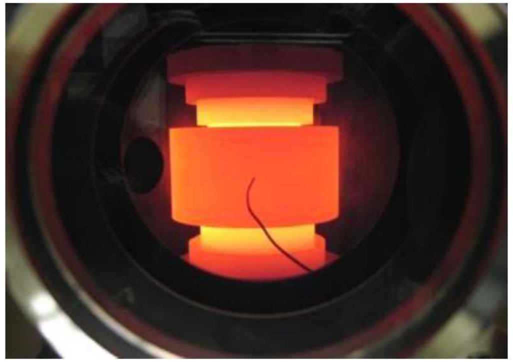


Iwatsu B-H analyzer

Quantum Design Magnetic Property Measurement System (MPMS)



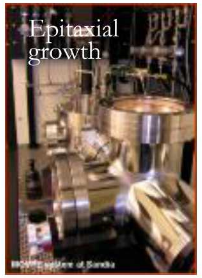
Spark Plasma Sintering (in collaboration with UC Irvine)



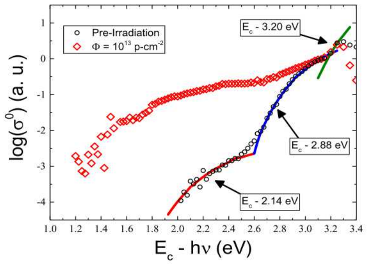
ADVANCED COMPONENTS: SEMICONDUCTORS

- **Contact:** Bob Kaplar, rjkapla@sandia.gov
- **Why do they fail?**
  - Failure can occur at package or die level
  - Defects of various types can form in the materials or interfaces between these materials (i.e. semiconductors, gate dielectrics, metals contacts, etc.)
  - Such defects can impact electrical properties of the device
- **How do they fail?**
  - Variety of types of failures can occur
    - Gradual – e.g. charges may be trapped in a defect in the material, producing a shift in the threshold voltage of a transistor or in the leakage current of a diode
    - Catastrophic – e.g. if a sufficient number of defects builds up in a gate dielectric, it may completely break down, resulting in a short
- **How are we increasing reliability?**
  - Sandia is studying how defects form in WBG power devices, and what their impact on performance is, by studying:
    - The operation of the devices in realistic circuits
    - The fundamental properties of defects
    - How defects impact device performance
    - How changes in device properties impact circuit and system performance

WBG Material and Device Fabrication and Characterization

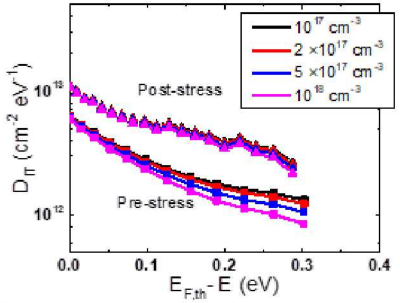


Defect Spectroscopy



Reliability Physics

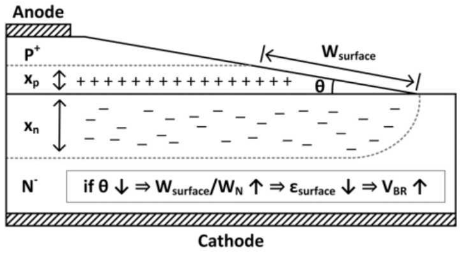
Switching Reliability Testing

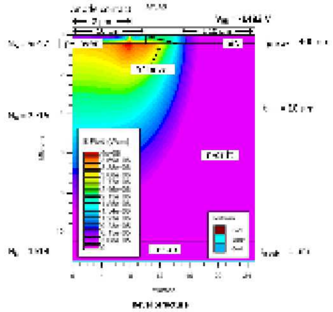


SiC MOSFET Reliability

Device Simulation

Novel Edge Terminations





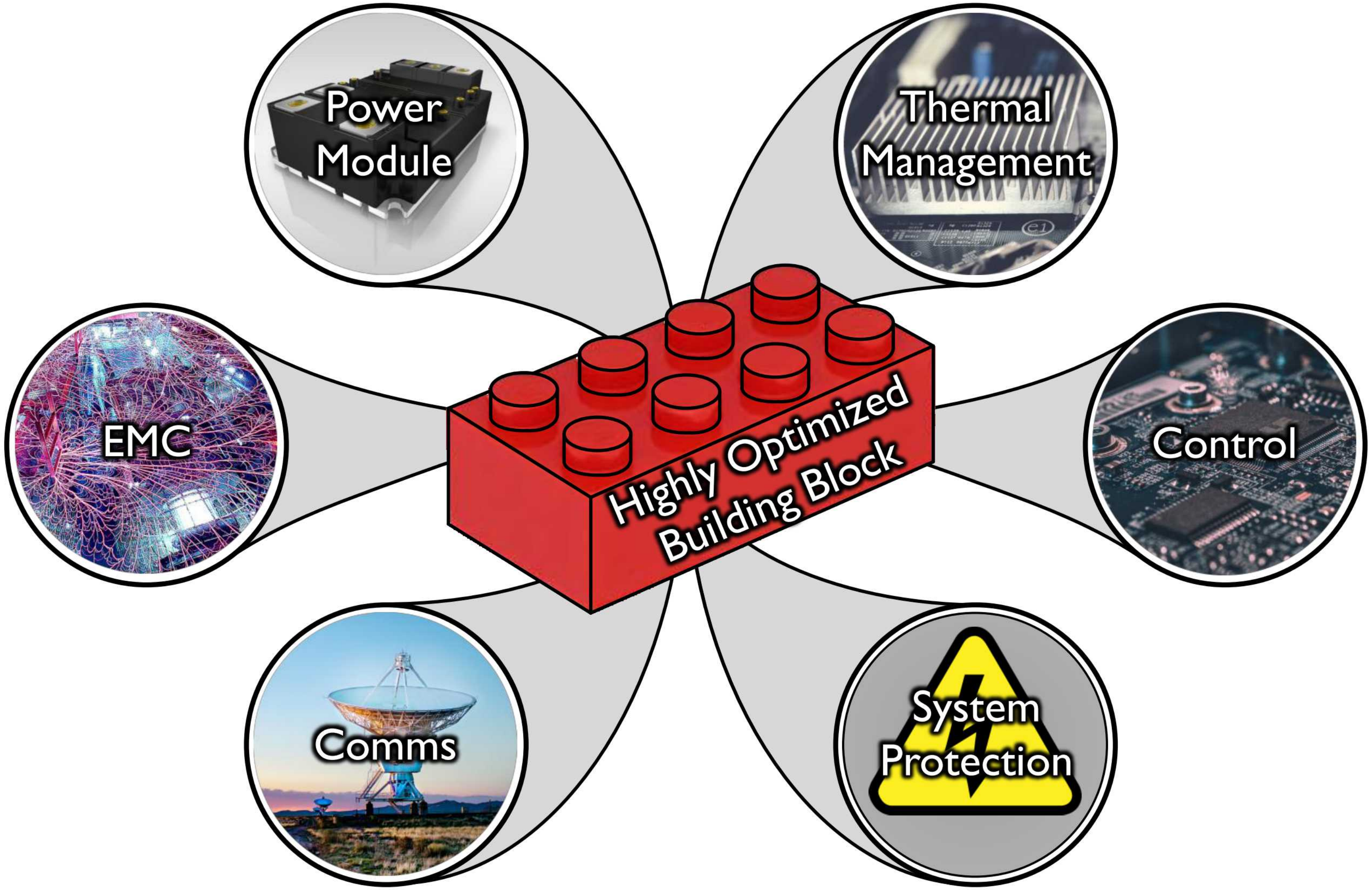
SYSTEM INTEGRATION

New components are important, but not the whole story

Advanced Topologies: Modular, fault-tolerant hardware architectures

Advanced Control Systems: Methods for detecting and reacting to internal failures in real time

Design-For-Reliability: Computational tools for assessing reliability and remaining time-to-failure based on application-specific operating conditions



The Energy Storage Power Electronics Program is supported by Dr. Imre Gyuk and the Energy Storage Program in the DOE Office of Electricity.

Questions?

Thank You!