Heterogeneous Integration Technologies for High-Temperature, High-Density, Low-Profile Power Modules of Wide Bandgap Devices in Electric-Drive Applications

Project ID: elt242

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VIRGINIA TECH

Project Overview

Timeline

- Project start date: April 1st, 2019
- Project end date: March 31st, 2024
- Percent complete: 40%

Budget

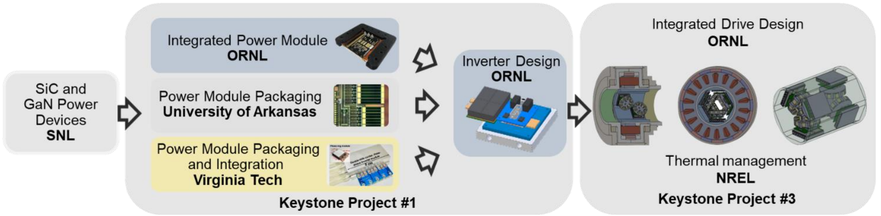
- Total project funding: $1.5 M
- Funding for FY 2020: $0.3 M
- Funding for FY 2021: $0.3 M

Barriers and Technical Targets

- **Materials:** high-performance bonding materials and assembly technologies (planar, double-side cooling) for making high-temperature (> 200 °C) power modules to enable high converter power density (> 100 kW/L);
- **Gate Driver:** high-temperature (> 200 °C) intelligent gate driver with integrated current sensor and EMI mitigation.

Relevance and Objectives

- **Goal:** Develop packaging materials, assembly processes, and circuit technologies for making WBG power modules with double-side cooling capability, intelligent gate driver, and integrated EMI mitigation solutions.
- **Impact:** Enable the EDT consortium to achieve its targets on performance, cost, power density, and reliability of a 100 kW traction drive system.
- **Project Objectives**
  - ✓ Develop a low-cost packaging technology for making double-side cooled WBG (SiC/GaN) power modules with parasitic inductances < 5 nH, heat flux density > 400 W/cm², and working junction temperature > 200 °C;
  - ✓ Design and prototype > 200 °C gate drivers with parasitic-inductance based current sensor and protection for module integration.

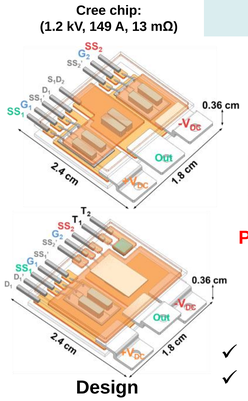


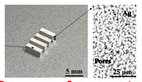
Approach

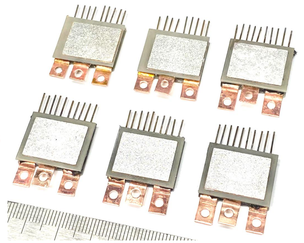
- **Proposed Research:** Design, fabrication, and testing of planar WBG power modules and their integration with gate drivers for electric drives.
- **Technology Summary:** Low parasitic & double-side cooled module fabrication; interconnection by silver-sintering; parasitic-inductance based current sensor integrated in gate driver; air-core transformer for driver power supply.
- **Challenges & Opportunities:** Prototyping yield for design verification; through materials and assembly engineering → low-cost manufacturing.

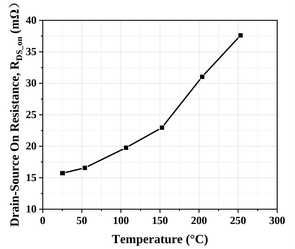
Technical Accomplishments

Power Module Packaging





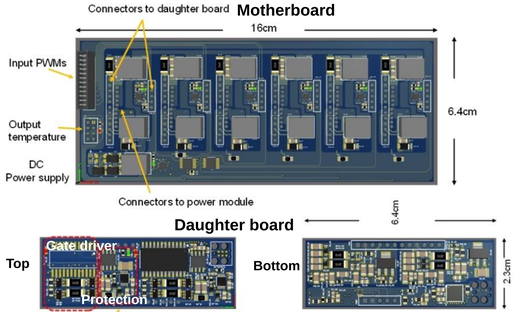




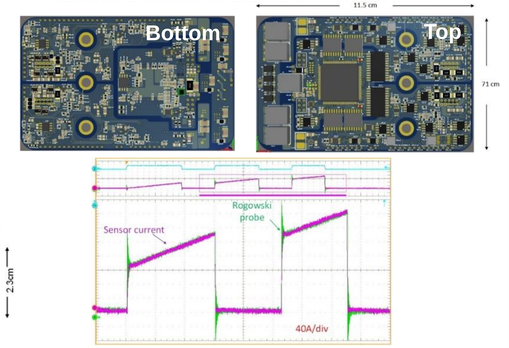
- ✓ Prototypes delivered to ORNL
- ✓ Static, dynamic, and thermal testing (passed)
- ✓ Potential for higher temperature

Gate Driver and Current Sensor

Gate driver for the segmented inverter at ORNL

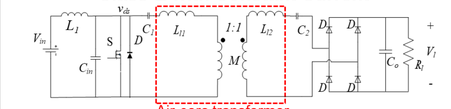


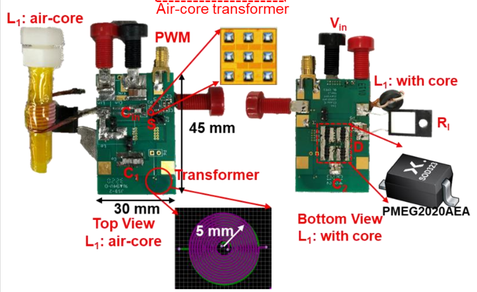
Parasitic Inductance-Based Current Sensor



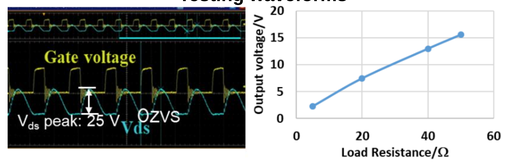
Power Supply with Air-Core Transformer

Class-E with Constant Current

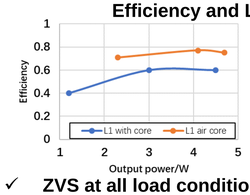


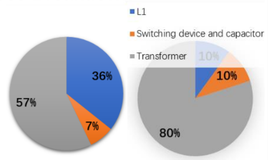


Testing waveforms



Efficiency and Loss Breakdown





- ✓ ZVS at all load conditions;
- ✓ Constant output current;
- ✓ Improved efficiency with air-core input inductor.

Collaboration

ORNL: G-J Su, E. Gurpinar, & B. Ozpineci, inverter
NREL: P. Paret & S. Narumanchi, reliability
Dowa: S. Yuki, substrate
UArk: A. Mantooth, HT gate driver chip
SUNY-Poly: W. Sung, SiC power device

Summary

- **Relevance:** enable the EDT consortium to achieve its targets on performance, cost, power density, and reliability of a 100 kW traction drive system.
- **Approach:** research, develop, and evaluate the integration and packaging technologies for making high-temperature, high-density, and low-profile wide-bandgap (WBG) power electronics modules with intelligent gate driver, current sensor, and EMI mitigation.
- **Deliverables:**
  - A minimum of six working prototypes of double-side cooled SiC (1.2 kV, 149 A, 13 mΩ) phase-leg modules and a minimum of six gate drivers to ORNL for the team's construction of a 100 kW, segmented inverter;
  - Module design and simulation results, materials processing conditions, assembly procedures, and testing data to DOE and potential module manufacturers;
  - Circuit design, simulation results, and bill of materials for making gate drivers with parasitic-inductance based current sensor to DOE;
  - Circuit design, simulation results, and bill of materials for making gate driver power supply with air-core transformer to DOE.

Next Steps

- **Reliability** evaluation of the double-side cooled modules;
- Selection and evaluation of high-temperature **encapsulation** materials;
- Fine-tuning of the current sensor for compensating the **temperature effect;**
- Selection and testing of **high-temp components** for constructing the gate-driver power supply.

** This presentation does not contain any proprietary, confidential, or otherwise restricted information.*
** Any proposed future work is subject to change based on funding levels.*