Power Electronics Thermal Management

Gilbert Moreno (PI), Kevin Bennion, Xuhui Feng, Ram Kotecha, Josh Major, and Jeff Tomerlin

National Renewable Energy Laboratory

Project ID: ELT211

FY19–FY24: Year 4 of 6

OVERVIEW

Timeline

- Project start date: FY 2019
- Project end date: FY 2024
- Percent completed: 65%

Budget

- Total project funding: 1,400,000
  - DOE share: $1,400,000
- Funding for FY 2021: $350,000
- Funding for FY 2022: $350,000

Barriers

- Size and weight
- Cost
- Performance and lifetime

RELEVANCE

- Thermal management is essential to increase power density and reliability.

Project Objectives:

- Develop thermal management techniques to enable achieving the (year 2025) DOE 100-kW/L power density target.
- Enable high-temperature (250˚C) and high-heat-flux wide-bandgap power electronics.

SUMMARY

Approach

- Develop single-phase heat transfer, dielectric-fluid cooling strategies to decrease junction-to-fluid thermal resistance and enable increased power density.

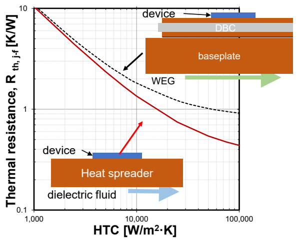
Technical Accomplishments

- Completed co-optimization of the thermal and thermomechanical performance for the double-side-cooled, dielectric fluid module and heat exchanger.
- Designed a prototype module that uses silicon-carbide devices and will be used to measure the junction-to-fluid thermal resistance of the single-side-cooled, dielectric fluid module and heat exchanger.
- Completed the design of a flow loop that will be used to evaluate the long-term reliability of the dielectric fluid and the heat exchanger.

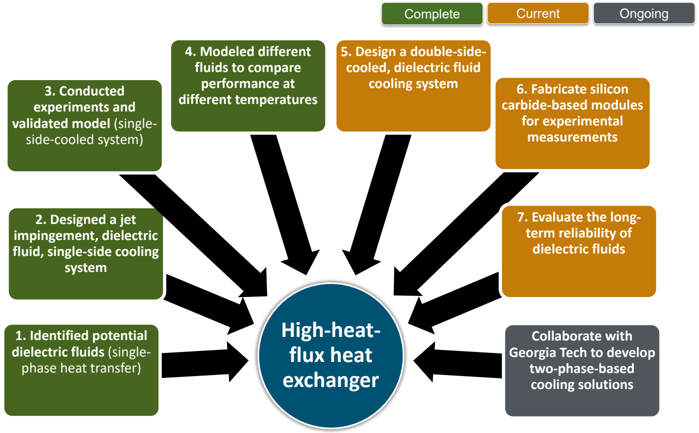
APPROACH

Motivation

- Package conduction resistance is the dominant resistance for existing power modules. Dielectric fluids enable a redesign of the package to minimize package resistance (i.e., eliminate the ceramic), allow for bus bar cooling, eliminate expensive ceramic substrates, and enable use of new automatic transmission fluid (ATF)-like fluids for direct cooling of power electronics modules.



DBC = direct bond copper, HTC = heat transfer coefficient, WEG = water-ethylene glycol



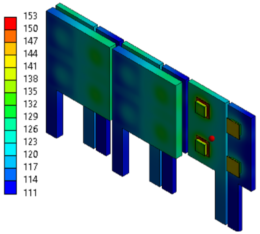
Enable reaching 100-kW/L power density

ACCOMPLISHMENTS AND PROGRESS

Co-optimized the thermal and thermomechanical performance of the double-side-cooled concept

Objectives: minimize thermal resistance, minimize device temperature variation, minimize stress

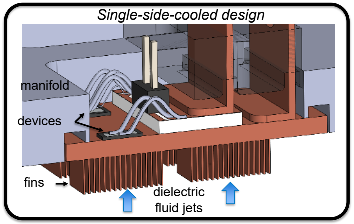
Temperature contours for co-optimized design



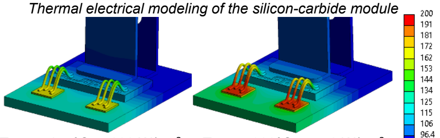
Achieved a junction-to-fluid thermal resistance of 11 mm²-K/W and reduced mechanical stress by ~6%

Designed silicon-carbide conceptual module cooled with dielectric fluids

Single-side-cooled design



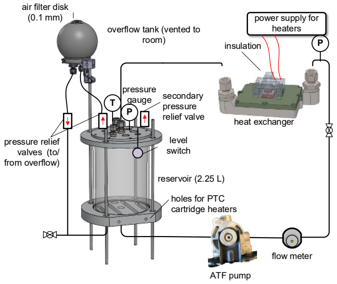
Thermal electrical modeling of the silicon-carbide module



$T_{j,\,max}$ = 175°C at 600 W/cm² $T_{j,\,max}$ = 200°C at 756 W/cm²

Performance to be measured using NREL's 2,400-amp PowerTester

Dielectric fluid long-term reliability



Completed the design of the fluid loop that will be used to assess the long-term reliability of the dielectric fluid and heat exchanger. The loop will expose the fluid to elevated temperatures, a voltage potential, and various materials (to evaluate for compatibility) for one year.

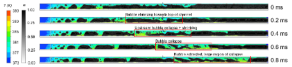
FUTURE WORK

- Measure the junction-to-fluid thermal resistance of the silicon-carbide metal–oxide–semiconductor field-effect transistor (MOSFET) modules from ROHM, cooled using the single-side-cooled concept.
- Fabricate prototype modules using SUNY Polytech silicon-carbide MOSFET devices for an experimental demonstration of the dielectric fluid, double-side-cooled concept.
- Characterize the performance of new Infineum electric-drive vehicle driveline fluids that are designed for direct cooling of power electronics applications.
- Complete the dielectric fluid reliability evaluation.
- Collaborate with Georgia Tech to develop the advanced cooling technologies.

Any proposed future work is subject to change based on funding levels

COLLABORATION AND COORDINATION

Georgia Tech: Providing an advisory role to graduate students working on developing advanced cooling technologies for power electronics.



Two-phase modeling conducted at Georgia Tech

SUNY Polytechnic Institute: Use SUNY Polytech devices to fabricate double-side-cooled power modules that will be cooled using dielectric fluids.

Infineum: Collaborating to develop new driveline fluids (e.g., automatic transmission fluids) that can be used for multiple electric-drive vehicle applications including direct cooling of power modules, cooling of the electric motor, and providing lubrication.

ROHM Semiconductors: Collaborating with ROHM to use their SiC devices to fabricate dielectric-fluid-cooled (single-side-cooled) modules.

Oak Ridge National Laboratory: Working to understand the effects of dielectric fluids cooling strategy on device electrical performance.

ACKNOWLEDGMENTS

Susan Rogers, U.S. Department of Energy

NREL EDT Task Leader

Sreekant Narumanchi

Sreekant.Narumanchi@nrel.gov

Phone: 303-275-4062

DOE Vehicle Technologies Program
2022 Annual Merit Review and Peer Evaluation Meeting
Washington, D.C.
June 21–23, 2022
NREL/PO-5400-82714