Advanced Packaging Designs

PI: Douglas DeVoto
Team: Joshua Major, Paul Paret, Bob Allen, Joel Miscall, Lincoln Xue (ORNL), Susan Herczeg (DuPont), Greg Smith (Flex Power Control)

June 12, 2023
Project ID: ELT218

OVERVIEW

Timeline

- Project start date: October 1, 2018
- Project end date: September 30, 2024
- Percent complete: 75%

Budget

- Total project funding: $850K
- U.S. Department of Energy (DOE) share: $850K
- Funding for FY 2022: $175K
- Funding for FY 2023: $150K

Barriers Addressed

- Cost, performance, reliability, and lifetime

Milestones

- Conduct the reliability evaluation of polymeric bonded materials and sintered copper under high-temperature thermal cycling (6/30/23).

RELEVANCE

- Wide bandgap (WBG) packaging designs must thermally allow for:
  - Higher operating temperatures
  - Higher heat fluxes/power densities
  - Hot spots.
- Coefficient of thermal expansion (CTE) mismatch between layers of the module will impose stresses that can initiate and propagate defects:
  - Attach layer fatigue
  - Interconnect fatigue.
- New package designs must address thermal and reliability concerns and be evaluated under accelerated conditions that approximate real-world conditions.

SUMMARY

Relevance

- New package designs must address thermal and reliability concerns and be evaluated under accelerated conditions that approximate real-world conditions.

Approach

- Collaborate with ORNL and industry partners to evaluate new packaging materials and manufacturing techniques for WBG-based traction inverters.

Technical Accomplishments

- Evaluated limits of Temprion material for laser patterning and processing.
- Bonded ODBC samples using a high-temperature press installed in a vacuum chamber.
- Shear strength evaluation has ensured adequate bond strength for Cu/Temprion bonds.

Acknowledgments

Susan Rogers, U.S. Department of Energy

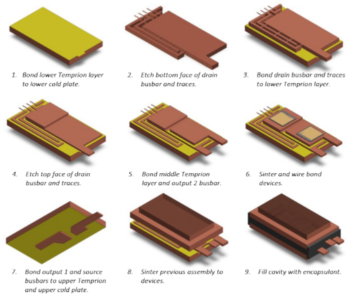
APPROACH

Alternative Substrate Development

- Alternative electrically insulated substrate designs are required to enable reliable packages that operate with higher power densities and higher temperatures.
- Simplified packaging process has been envisioned with ODBC substrates in a double-side-cooled module.

Substrate Technology Comparison

- *Direct-bond copper (DBC)*
  - Oxidation of copper (Cu) foils during bonding lowers melt temperature from 1,083˚C to 1,065˚C.
  - Requires symmetrical metallization layers (up to ~1 mm thickness) on both sides of the ceramic.
  - Examples include aluminum oxide (Al_2O_3), aluminum nitride (AlN), and zirconia (ZrO_2)-doped high-performance substrates (HPS).
- *Active metal bonding (AMB)*
  - Brazing process with silver-copper (Ag-Cu) alloy between Cu and ceramic at 850˚C in vacuum requires more processing steps and is more expensive than DBC.
  - Silicon nitride (Si_3N_4) substrate is an example.
- *Organic direct-bond copper (ODBC)*
  - A polyimide dielectric is bonded with metal through elevated temperature and pressure.
  - No limitations in metal material or metallization thickness.
  - Maintains electrical and thermal performance after 5,000 thermal shock cycles (−40˚C to 200˚C, 5-minute dwells).



Proposed ODBC packaging steps

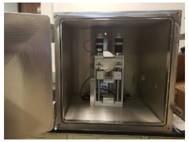
ACCOMPLISHMENTS AND PROGRESS

Polyimide (DuPont Temprion) Evaluation

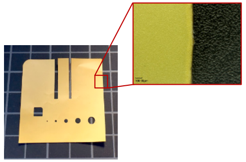
- Evaluated limits of Temprion material for laser patterning and processing.
  - FTIR spectroscopy indicates that Temprion has higher absorption values at 9.3 µm than 10.6 µm, common CO_2 laser wavelengths. Initial test cut shows a clean edge with optimized laser parameters and cleaning.
  - Thermogravimetric analysis (TGA) and dynamic mechanical analysis (DMA) indicate very high thermal stability (>500˚C) and wide processing window.

ODBC Bonding Process and Evaluation

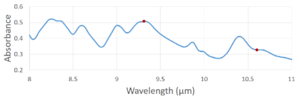
- High-temperature press installed in a vacuum chamber has been used for ODBC substrate fabrication.
  - Temperature and pressure conditions have been optimized in an inert, oxygen-free atmosphere.
- ODBC substrates are sectioned into 10 × 10-mm coupons for shear strength evaluation.



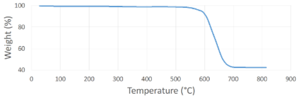
Vacuum chamber with high-temperature press



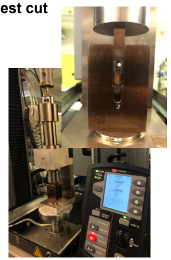
Temprion test cut



Temprion absorption analysis



TGA indicating high thermal stability



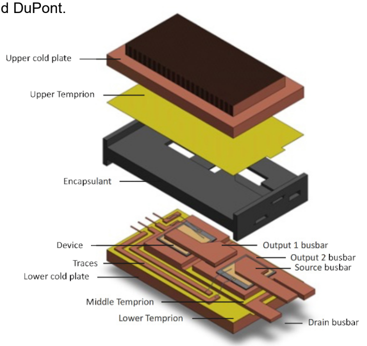
Shear apparatus

CHALLENGES AND BARRIERS

- Thermal and reliability concerns of new packaging technology must be experimentally evaluated.
  - Experimental characterization will be performed to evaluate reliability under power, thermal, and vibration conditions.
- New technologies may be susceptible to unforeseen failure mechanisms.
  - Past reliability evaluation of ODBC substrates has been promising, but full module assembly and evaluation in collaboration with ORNL is needed.

FUTURE WORK

- Bond and test additional double-lap shear samples between Temprion and Cu/Al/AlSiC metallization layers under optimized bonding conditions (temperature, pressure, inert atmosphere).
- Evaluate electrical, thermal, and reliability performance of assembled half-bridge module in collaboration with ORNL and DuPont.



Example ODBC half-bridge module

COLLABORATION AND COORDINATION

- ORNL: Laboratory partner for ODBC electrical performance.
- DuPont: Industry partner of ODBC technology.
- Flex Power Control: Industry partner for manufacturability.

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy's Vehicle Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

DOE Vehicle Technologies Office
2023 Annual Merit Review (virtual)
June 12-15, 2023
NREL/PO-5400-85897