Future of Semiconductor Technology Development

Madhu Chinthavali

Oak Ridge National Laboratory

Industry Engagement Meeting

VTO EDT Program

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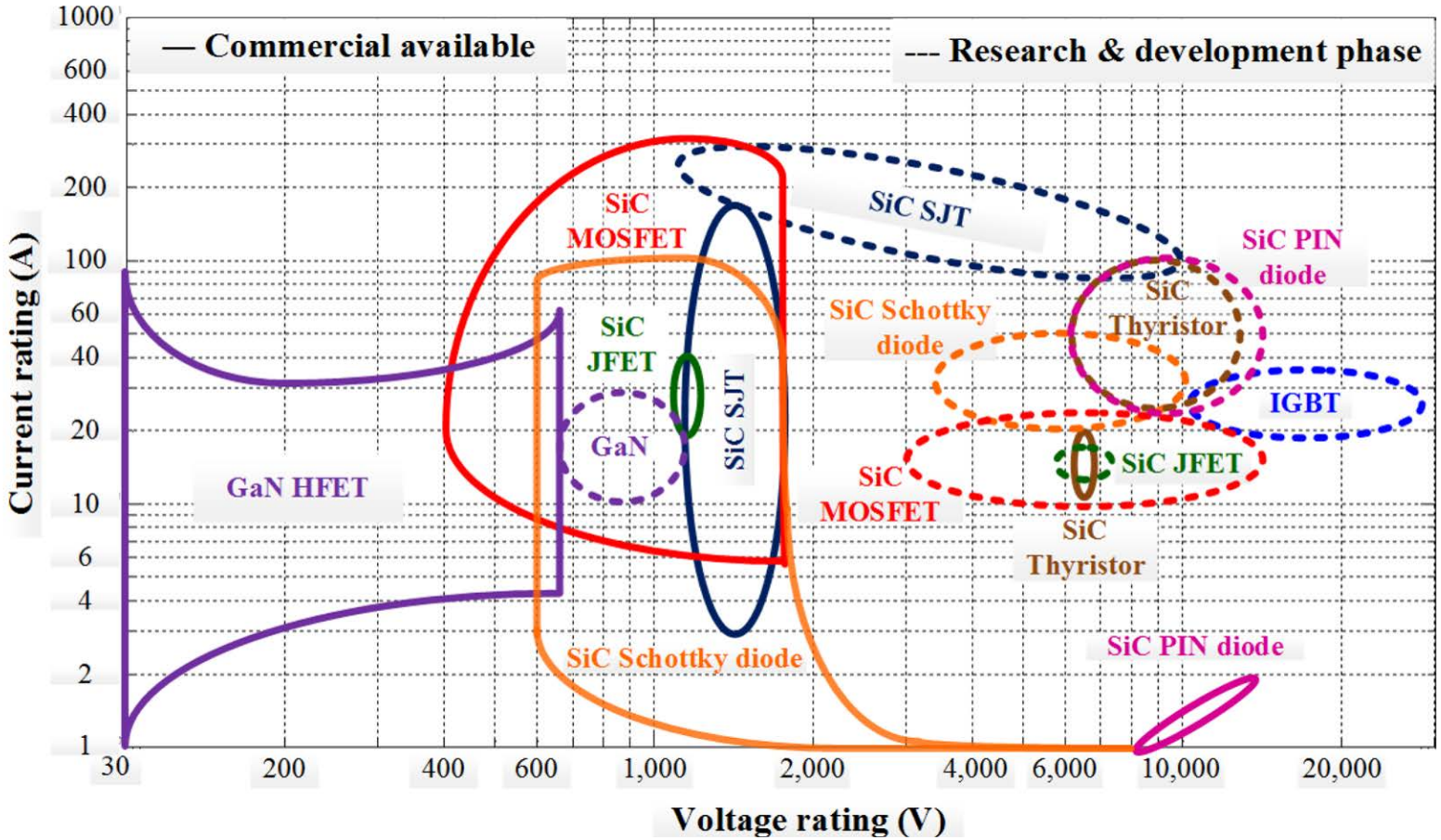
Summary of SiC and GaN Device Ratings

Voltage/Current Rating of Commercial and Research Phase WBG Devices*

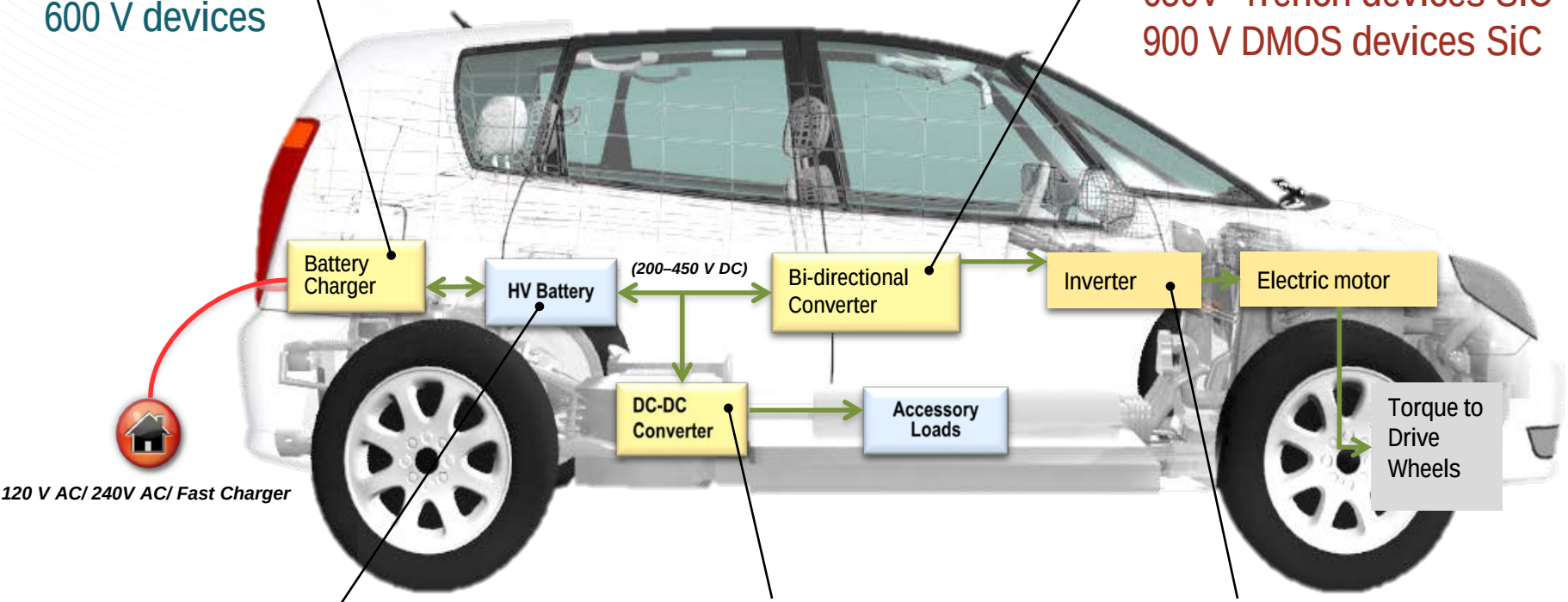


*report to be published soon

Projected Device Technology for Future

650V Trench devices SiC
GaN technology
600 V devices

600 V devices- GaN
1200V DMOS devices SiC
1200V Trench devices SiC
650V Trench devices SiC
900 V DMOS devices SiC



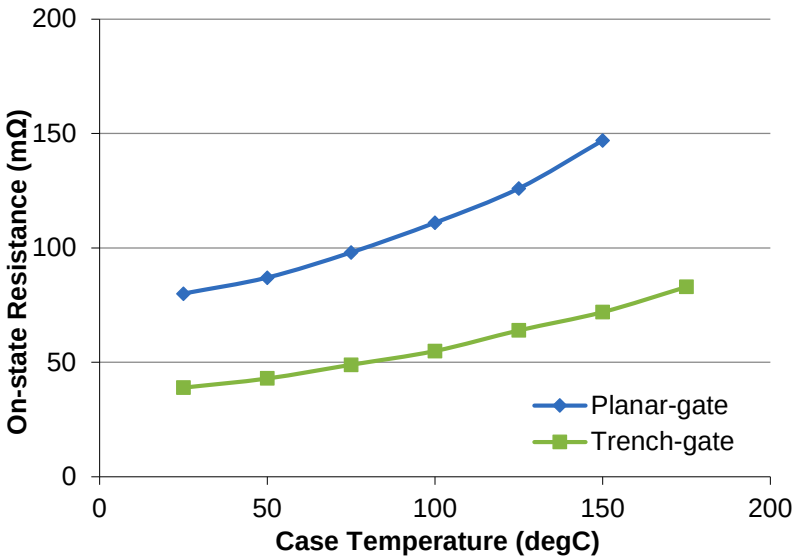
300 V, 600 V devices ?
GaN, Si
650V Trench devices SiC

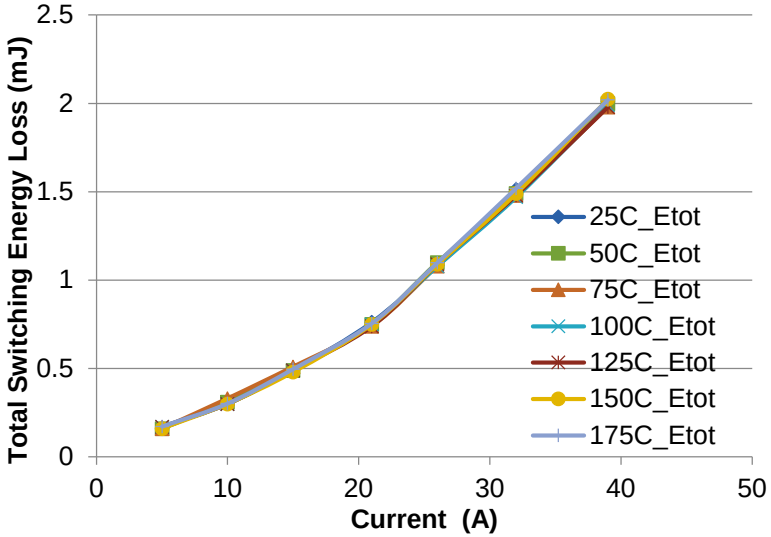
600 V devices and
50V/ 100 V devices
GaN, Si
650V Trench devices SiC

600 V devices – w/o boost GaN
1000V devices- w boost SiC
900 V DMOS devices SiC
1200V Trench devices SiC

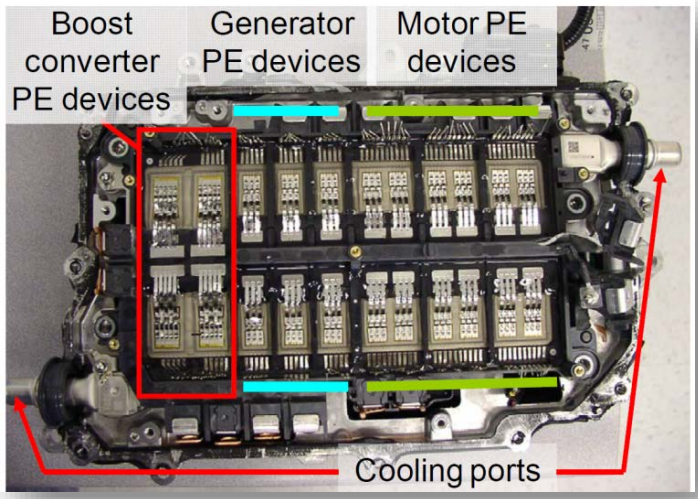
SiC Trench Technology

- The R_{dson} of SiC trench MOSFET is around one half of that of SiC DMOSFET
- Trench technology is not available in higher current ratings, e.g. 200A (55A maximum right now)
- Switching loss difference between trench and the DMOS is within 10%
- Switching loss is nearly temperature independent for Trench technology
- The current density of the trench technology is higher however the short circuit capability of the device could potentially be compromised

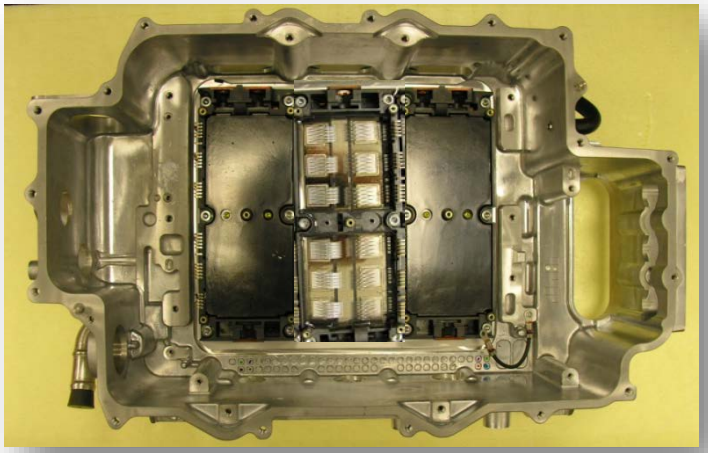




Limitations of WBG Devices for Automotive Applications



Toyota Prius'10 Module

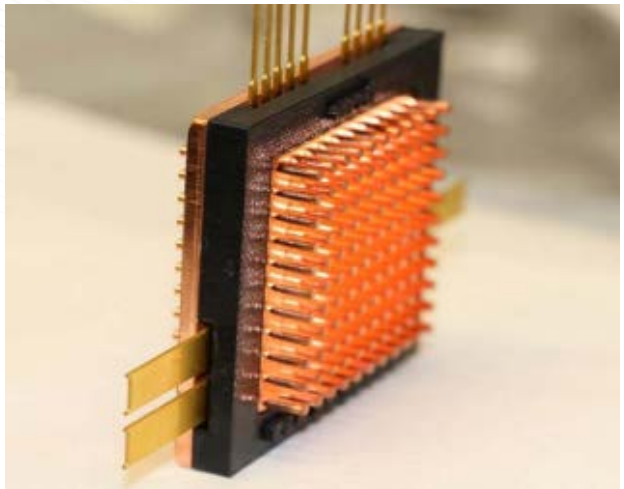


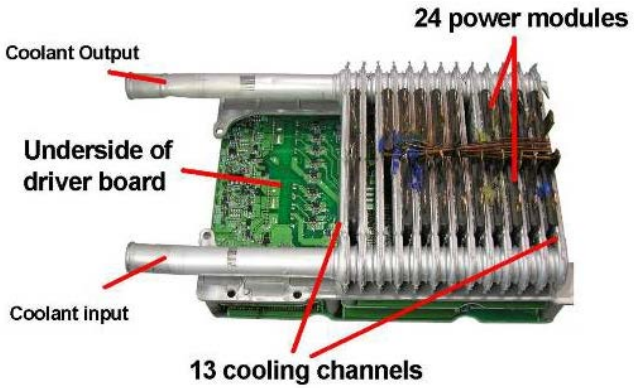
Nissan LEAF Module

- **Packaging**
- **Scaling the device to realize higher power**
- **Gate driver technology not being mature**
- **Long term reliability needs more testing**
- **Protection circuits for faster WBG devices**

WBG Module Packaging

Double-side cooled packages are being pursued as the solution for realizing the attributes of the WBG technology





Toyota LS600 Module

Advantages

- Low parasitics for high frequency operation
- Higher thermal efficiencies
- Higher reliability because of no wire bonds
- Less manufacturing costs – one step process

Disadvantages

- Lack of top metallization needed for die attach
- Difference in die thickness to match the height
- Possibility of localized electric field failures without proper filler material to avoid gaps
- CTE mismatch with multi layered structure
- Assembly costs could be higher because of lack of scaling ability

WBG Module Gate Driver Technology

Gate Driver Requirements

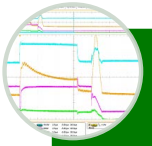
- Galvanic isolation
- High sinking and sourcing current
- Active miller clamping/crosstalk suppression
- Undervoltage lockout (UVLO) function
- Thermal protection function
- Short circuit protection function
- Soft turn-off function for short circuit protection
- Supporting both zero and negative voltage

Issues

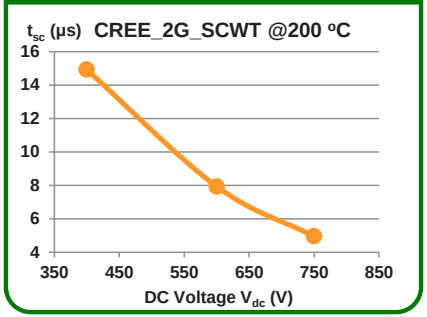
- Commercially available gate drive solutions are for discrete devices and modules with limited functions
- Increase in functionality will increase cost
- Also the number of components used will decrease the power density of the system
- Lack of IPM based solutions from device manufacturers
- Noise Immunity for high power systems

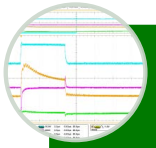
Example:

Requirements for Active Protection Schemes

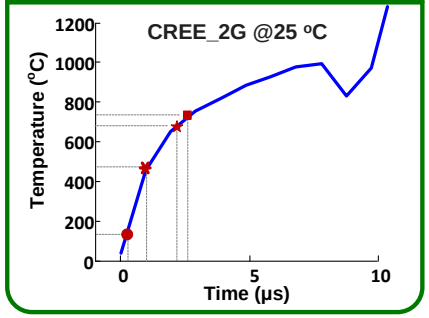


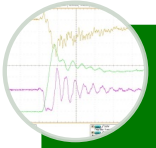
Single-event Short Circuit



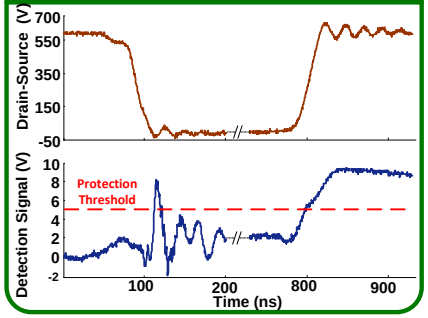


Repetitive Short Circuit

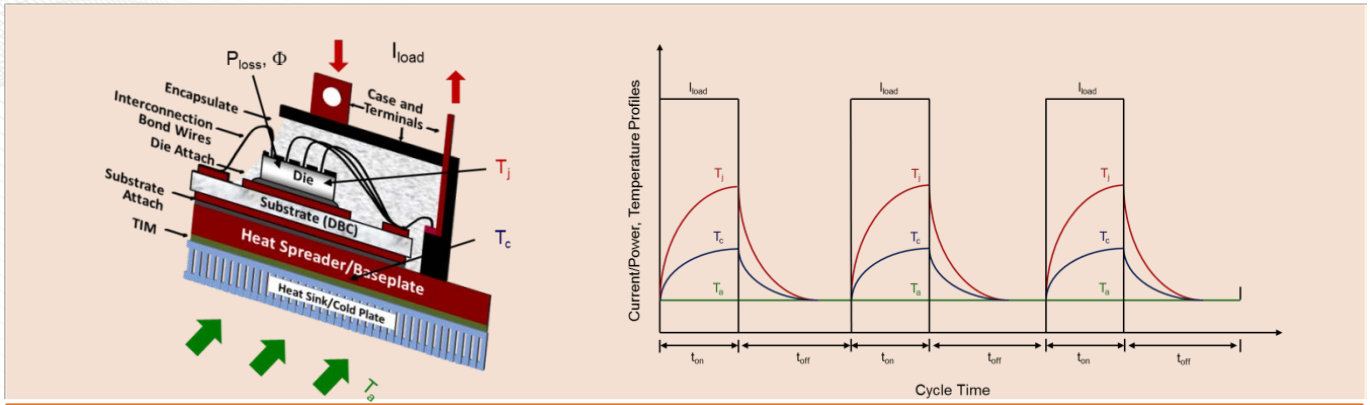




Noise Immunity

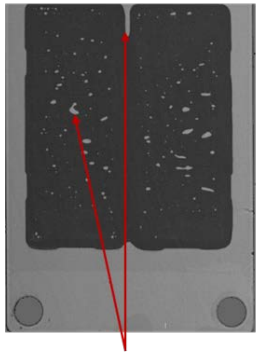


WBG Power Module Reliability



Si Test Standards: CENELEC; IEC 60747-34; JESD22-A122

Bond layer image of substrate on base plate

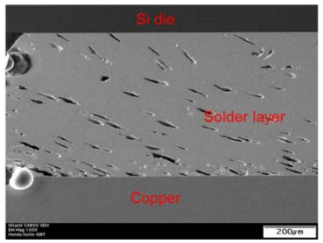


Voids and cracks in solder layer

Need for WBG Test Standards

- Different temperature requirements
- Bonded Interface issues with new materials
- Dynamic blocking voltage reliability
- Dynamic forward resistance and blocking resistance issues
- Reduced die area size and thickness

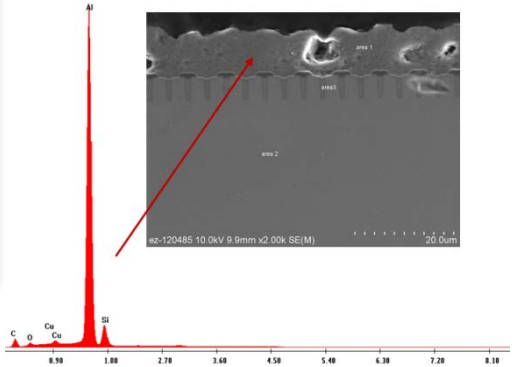
Cross-sectional side view of solder layer

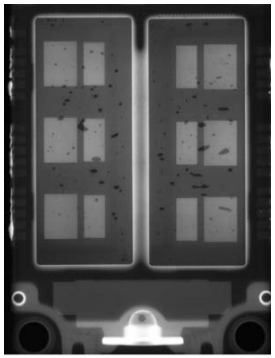


Better resolution of voids in solder layer than SAM

SAM (Scanning Acoustic Microscope)

SEM (Scanning Electron Microscope)



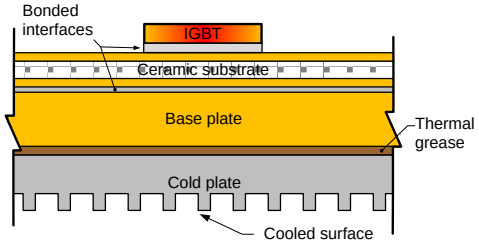


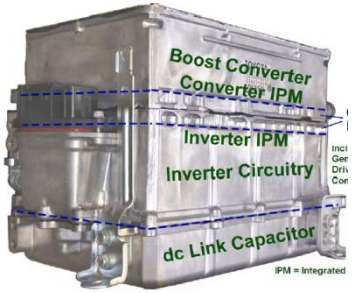
X-Ray Microscope

Images of voids in multiple stacked layers

Evolution of Power Electronics Thermal Management Strategies

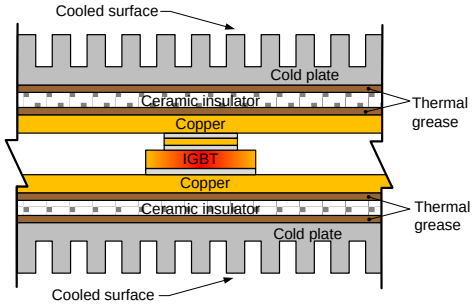
Power module on heat sink using thermal grease

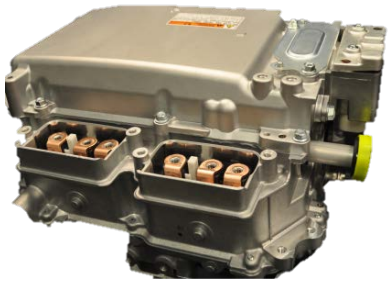




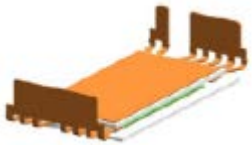
2007 Toyota Camry Hybrid

Double-side cooled modules



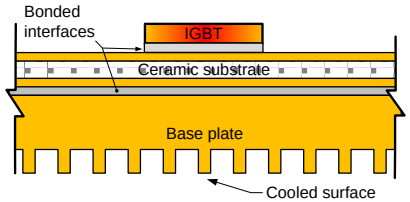


2013 Toyota Camry Hybrid



2016 Chevy Volt

Direct-cooled module baseplate (eliminate thermal grease layers)



2014 Honda Accord Hybrid

2016 BMW i3