EV/HEV Automotive Power Modules: Innovations and trends

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Electrification trends depend on the strategy of local car manufacturers, and local governments.

BEV: Battery Electric Vehicle
HEV: Hybrid Electric Vehicle
PHEV: Plug-in Hybrid Electric Vehicle

Non exhaustive list
To achieve further system cost and package volume reduction, it is common to integrate the electrical motor and the motor drive inverter. These offer new space saving solutions that require high power density electronics.
Power Module Issues

In Si modules, mismatching CTE (coefficient of thermal expansion) makes layers detach from one another.

With the introduction of SiC this problem is much more highlighted; in fact the main problem of SiC is thermal dissipation because of material density; thus an adapted package and system integration is needed.

Common failure in a power module is caused by thermal cycling.

Moreover, module package optimization is necessary to fully benefit of SiC technology advantages against silicon.
Toyota: Interconnections

Toyota Prius:
- Motor inverter, generator and boost have different die sizes
- Evolution of IGBT and Diode size and design
- Decrease of IGBT die size and thickness

Toyota all-in-1 design:
- Shared cooling systems
- Al wire/Al ribbon
- Reduction of wire connection.

Toyota Prius II (2004):
- Al wire

Toyota Prius IIIc (2011):
- Al ribbon
The standard solution for power module is the 6-in-1 module.

Infineon in 2012 proposed a solution with:

- 650V/600A
- Al wire bonding
- Silicon gel encapsulation
- Plastic case
- Cu Pin Fin
- SAC solder

Details DBC substrate: Cross-Section optical view
Semikron SKiM

Innovative Semikron solution:
- 1200V/300A
- Al wire bonding
- Central IGBT gate
- Silicon gel encapsulation
- Plastic case
- Ag sintering solder
- Cu/Al/Cu DBC

Details DBC substrate: Cross-Section optical view

- 1 mm
- 12µm
- Die Ag sintering
- Al wire bonding
- Silicon gel encapsulation
Mitsubishi Electric was one of the first companies to offer molded modules for automotive applications:

- 600V/300A capability
- Molded package
- Thick Cu layer of IMS

- Bring IMS from low power
- Organic insulator worst thermal conductivity but higher design flexibility
In 2017 ST proposed a SiC module:
- SiC MOSFET
- 650V/300A
- Epoxy encapsulation
- Al wire bonding
- Ag module sintering
- DBC substrate

Details substrate: Cross-Section optical view
Mitsubishi J1 serie

Mitsubishi innovates with J1 series:
✓ Cu leadframes
✓ Epoxy encapsulation
✓ Integrated substrate
✓ Double Ceramic substrate

Details substrate: Cross-Section optical view
In 2015 Toyota changed completely the module design:
✓ 750V
✓ DSC
✓ Epoxy encapsulation
✓ Al wire bonding
✓ Cu spacer/connection
✓ External Isolator

Details substrate: Cross-Section optical view

- Cu substrate
- Cu spacer
- SAC solder die & substrate
- Epoxy encapsulation

5.5 mm
In 2015 Toyota changed completely the module design:
- ✓ DSC
- ✓ No encapsulation
- ✓ Flex connection
- ✓ Ceramic layers

Details substrate: Cross-Section optical view

- SAC solder
- Die
- 2.76 mm
- Ceramic substrate
- Al layer
- AlN upper cover
- Al layer
- Cu connector
- Solder Sn
- AlN bottom cover
- Al layer
In 2017 Infineon too proposed a DSC:

- 700V/400A
- DSC
- Epoxy encapsulation
- Al wire bonding
- Alloy spacer
- DBC substrate
- Integrated isolation

**Details substrate: Cross-Section optical view**

- **DBC substrate**
- **Al wire bonding**
- **AlMg alloy**
- **SAC solder**
- 4.7 mm
Power Module Solutions

- **Die attach**
  - Tin soldering
  - Silver paste or film sintering

- **Baseplate**
  - Flat baseplate
  - Pin-fin baseplate

- **Substrate**
  - Double-side cooling with DBC
  - Integrated substrate

- **Encapsulation**
  - Silicone gel
  - Epoxy

- **Interconnection**
  - Aluminum wire bonding
  - Ribbon bonding
  - Copper leadframes

- **Case**
  - Overmolded

- **Heatsink**
  - Aluminum wire bonding
  - Ribbon bonding
  - Copper leadframes
Every manufacturer proposes its solutions; but some main trends are evident.
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