Session 4b
Leslie
Power Module Packaging & Integration

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Power Semiconductor Module Integration - Outline

- **Trends in IGBT Chip Technology**
  - Size, Voltage, Power Losses & Frequency
  - Impact on Packaging

- **Intelligent Power Modules**
  - Integrating Gate Drive & Protection Features in the Module Package

- **System in a Module**
  - Further Integration of System Components within a Module Package

- **High Voltage Power Modules**
  - Integrating Chip Cooling in the Module
  - Integrated Power Sub-Systems
Power Semiconductor Device Evolution

Discrete Assemblies
- SCR / Diode / GTO Discretes
- BJT / MOSFET Discretes

Module Assemblies
- SCR / Diode Modules
- Darlington Transistor / MOSFET / IGBT Modules
- Intelligent IGBT Modules (IPM)

Complete Power System
- Standard & Application Specific
  - Powerex Pow-R-Pak
  - Semikron Skiip Pak

Power Switch
- Electrical Isolation Integrated
- Gate Drive & Protection Integrated
- Low Power System in a Module
- High Power System

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IGBT Chip Design Evolution

- Vertical channel requires less area compared to the horizontal channel of planar structure
- No $R_{JFET}$ between adjacent cells

- Greater cell density
- More uniform current flow through chip
- Robust Turn-Off Switching Capability
- Greater cell density
- Lower $V_{CE(SAT)}$
More Switching Power in a Smaller Package

50 – 60% Reduction in Module Footprint Due to Decrease in IGBT Chip Losses Over Last 15 Years

Power Loss (W)

<table>
<thead>
<tr>
<th>Generation</th>
<th>IGBT Conduction Loss</th>
<th>IGBT Turn-off Loss</th>
<th>IGBT Turn-on Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Gen.</td>
<td>100W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd Gen.</td>
<td>75W</td>
<td></td>
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<tr>
<td>3rd Gen.</td>
<td>50W</td>
<td></td>
<td></td>
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<tr>
<td>4th Gen.</td>
<td>40W</td>
<td></td>
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<tr>
<td>5th Gen.</td>
<td>33W</td>
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</tbody>
</table>

Overall power loss reduced to 1/3

1200V, 400A IGBT Module in Half H-Bridge Configuration

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IGBT Switching Frequency Now Up to 50 kHz

Conduction vs Switching Loss Trade-Off

Vcc = 600V, Ic = 100A, 50% Duty Cycle -- Calculated

Power Dissipation Density Increases With Switching Frequency

Gen 3 (1992)
Gen 4 (1998)
Gen 5 (2000)
Module Design Reduces System Inductance & Complexity

1200V, 900A Mega Power Dual IGBT Module with Internal Laminated Bus
Integrated “Intelligent” Power Module = IGBT + Smarts

- Gate drive, temperature sensing & protection elements are integrated in the power switch package
- Protection for:
  - Overtemperature
  - Overcurrent & short circuit
  - Low/high gate supply voltage
  - Fault signal feedback
- Improves switch performance since protection functions are integrated in package
IGBT Module Integration – Sensing & Protection

On chip current & temperature sensing

Gate drive & protection circuitry

Power switches
Fault Types & Intelligent Power Module Countermeasures

- Chip Overtemperature
  - Gate Drive Turns IGBT Off – Fault Signal Sent to Controller

- Over Current/Short Circuit
  - Short Circuit & RBSOA (Switching Protection)
    - Gate Drive Turns IGBT Off – Fault Signal Sent to Controller

- Gate Drive Supply Under Voltage
  - Gate Drive Turns IGBT Off – Fault Signal Sent to Controller
Complete Power System Integration in a Module

Small 3-Phase Motor Drive System Integrated in an ASIPM Module

Conventional IPM

Rectifier

Current Sensor

Optocouplers

600V, 50A & 1200V, 25A
Integration of Passives in Power Semiconductor Modules
HV-IGBT Voltage Ratings Now Up to 6.5kV
Standard Power Module Cooling

IGBT Die
Solder
DBC Copper
Aluminum Nitride Ceramic
DBC Copper
Solder
Baseplate/Heatsink
Thermal Interface Material
Heatsink

Cooling Medium

Heat Flow

Module

Standard Cooling System

Cooling Medium
Modules with Built-In Heatsink – Reduced Heat Flow Path

IGBT Die
Solder
DBC Copper
Aluminum Nitride
Ceramic
DBC Copper
Solder
Baseplate/Heatsink

Cooling Medium

Heat Flow

Module

Normal Flow Microchannel Cold Plate

"Pin Fin" Baseplate

Built-In Chill Plate

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Modules with Integrated Heatsink – Reduced Heat Flow Path

- IGBT Die
- Solder
- DBC Copper
- Aluminum Nitride
- Ceramic
- DBC Copper

Heat Flow

Cooling Medium

Module

Integrated Chill Plate

Pin Fins on AlN Substrate

Power Devices

AMB Substrate

Microchannels Machined in AlN Substrate (GECRD)

Copper

Micro-channels

Ceramic

A1N/Cu Substrate Micro Channel Cooler (Curamik)

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Thermal Resistivity Comparison of Paths to Cooling Medium

![Graph showing thermal resistivity comparison for Standard Module / External Chill Plate, Built-In Chill Plate, and Integrated Chill Plate. The categories include External Chill Plate, Thermal Compound, Cu Baseplate, Substrate Solder, Bottom DBC Cu, AlN, Top DBC Cu, Die Solder, and Silicon Die.]
Assembly Subsystems – Beyond Systems in a Module

- Power switches
- Energy storage devices
- Current sensing
- Gate drives
- Protection
- Cooling

Powerex Pow-R-Pak
Air Cooled

Semikron Skiip Pack

Liquid Cooled
System Integration

Motor Leg Inverter

Converter & Brake Chopper

Air Cooled
Power Module Packaging & Integration

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