Mitsubishi Power Semiconductor Devices

Mitsubishi Electric Corporation
Power Device Works
12th May, 2009
Advancement of Power Module

- Simplifying User’s assembly work
- Extracting maximum of IGBT’s inherent ability
- Improving system’s performance

Discrete Power → IGBT Module → IPM

- Drive supply and system level functions (micro-computer)
- Integrated self intelligence (driving, protection and diagnostic)
- Integrated power circuit with appropriate isolation
- Integrated system level intelligence (protection, control and status/data communication)
Power loss reduction of power devices

Operational power loss in inverter circuit

Drastic reduction of power losses

Power losses

- Transistor turn-off loss
- Transistor on-state loss
- Transistor turn-on loss

1st Gen. 2nd Gen 3rd Gen 4th Gen 5th Gen 6th Gen

- '80 '85 '90 '95 '00 '05 '08

High hfe Bipolar Tr

1st Gen
2nd Gen
3rd Gen
4th Gen
5th Gen
6th Gen

Bipolar
Planar IGBT
Trench IGBT, CSTBT

Changes for the Better
Mitsubishi Electric

Progressing Package Technology

Category

Low Power
IPM/IGBT
- For Industry/
  Consumer/
  Automotive fields

Medium Power
IPM/IGBT
- For Industry/
  Consumer/
  Automotive fields

High Power
High Voltage
IPM/IGBT
- For Traction/
  Large drives

Transfer-molded type
- Version-3 DIPIPMTM
- High Rel. BIPIPMTM
- Low Rth, Small size
- 1.2kV/25A DIPIPMTM

Case type
- Metal base plate
  (Cu/Al2O3/AlN)
- Base plate-less

Direct lead-Bonded
(DLB) Housing

New Case type
(Nx series)
- Common platform
- Compact and Flexible
- Easy-to-use
- Standardized

New Mega Power

Progress based on DIPIPMTM technology

New VHV structure
- Compact
- Higher P/C & H/C endurance
- Higher isolation capability
- Lower thermal resistance

State-of-the-Art

Future Prospects

New concept
(Under feasibility study)
Figure Of Merit (FOM) = \( \frac{J_c}{v_{ce(sat)} \times e_{off}} \)

where,

\( J_c \) = device’s rated current density. [A/cm²]

\( v_{ce(sat)} \) = saturation voltage drop at rated current density conduction with Tj at 400K. [V]

\( e_{off} \) = turn-off switching energy per pulse of operation at rated current density and Tj at 400K. [mj/pulse/A]
Changes in IGBT cell structure

**Carrier storing effect: Trade-off improvement**

3rd Gen IGBT

- Planar (3um), PT

4th Gen IGBT

- Trench (1um), PT

5th Gen IGBT

- CSTBT™ (1um), LPT

6th Gen IGBT

- Epi to FZ

Optimization of CSTBT™ cell design
Advancement of CSTBT™ device structure

**5th Gen CSTBT™**
- Emitter electrode
- N+ carrier storing layer
- N drift layer
- N+ buffer layer
- P+ thin collector
- Thickness = 170 um
- First CSTBT™ concept

**5th Gen CSTBT™ (II)**
- Trench gate
- Dummy trench
- Thickness = 130 um
- Optimized vertical thickness

**6th Gen CSTBT™**
- High Tj capability
- Optimized Metallization
- Narrower cell pitch for higher cell density
- Retro-graded doping for optimizing CS layer

1200V design
Characteristics of 6th Gen IGBT

$V_{CE(sat)}$ vs. $E_{off}$ Trade-off Improvement

Mitsubishi 6th Gen

5th Gen

Company A

$T_j = 125^\circ C$

$I_c = 150A$

$E_{off}$ [mJ/pulse]

$V_{CE(sat)}$ [V]
**Characteristics of 6th Gen FW Diode**

*V_F vs. Q_{rr} Trade-off Improvement*

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- **6th Gen**
  - Anode
  - P+ anode layer
  - N-drift layer
  - N+ cathode layer
  - ≈ 250um

- **6th Gen**
  - Anode
  - P+ anode layer
  - N-drift layer
  - N+ cathode layer
  - ≈ 120um

**Trade-off improvement by employing thin-LPT vertical profile concept**

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Company A

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Changes for the Better
6th Gen IGBT Module series using new chip technologies

FOM of IGBT (1200V)

<table>
<thead>
<tr>
<th>Generation</th>
<th>Relative FOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>5th</td>
<td>1.00</td>
</tr>
<tr>
<td>6th</td>
<td>1.31</td>
</tr>
</tbody>
</table>

30% up

FOM of FWD (1200V)

<table>
<thead>
<tr>
<th>Device</th>
<th>Relative FOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>conventional diode</td>
<td>1.00</td>
</tr>
<tr>
<td>new diode</td>
<td>1.33</td>
</tr>
</tbody>
</table>

30% up

FOM = $J_{C(sat)} / (v_{CE(sat)} \times e_{OFF})$

Evolution of advanced IGBT Modules

5th Gen NFA series → 6th Gen

5th Gen Nx series → 6th Gen

MPD Series → New MPDs

Superior performance (New Gen chip technology)

☆ Lower loss, higher operational Tj
☆ Lower EMII
☆ Retaining packaging compatibility
☆ Line up extended higher current range by structural advancement
5th Gen IPM

Integrated functions

- Supply Voltage Detection
- On Chip Temperature Detection
- Fault Logic
- Auxiliary Emitter Current Measurement
- Gate Drive adjustment for EMI optimisation

Better performance:
(Combined effect of newer power chips and IC technologies)
☆ Loss reduction
☆ Lower EMI

More functions:
☆ Enlarging diagnostic, protection and communication features
☆ Programmable Driver
☆ Integrated self biasing scheme

Smarter construction:
☆ higher reliability and higher power density by new structural concept
**Concept and Features of DIPIPMTM**

- **All-silicon solution**
- **Transfer-Molded Package**

**Configuration**
- 3-phase power circuit (IGBT + Diode)
- Circuitry for IGBT gate drive, protection and isolation (HVIC and LVIC)
- Dual-In-Line type package outline
Ver.4 DIPIPMTM
(High current type)

Better performance:
(Combined effect of newer power chips and IC technologies):
☆ Loss reduction
☆ Lower EMI

More functions:
☆ Improved current sensing and OC protection scheme
  (without any external shunt)
☆ Lower circuit biasing current
☆ Enhanced protection features
☆ Integrating peripheral functions

Smarter construction:
☆ Continuous improvement of thermal conductivity by newer thermal-sheet technology
☆ Higher power density
Evolvement of Power Module Technologies

Power chip technologies

- 5th Gen IGBT/FWD → 6th Gen IGBT/FWD → Next Gen Devices
  - 600~6500V
  - Improving FOM/ Higher Tj/ Improving ruggedness

Integrating peripheral functions

- Advancement of HVIC and LV-ASIC
  - Refining process (0.8um → 0.5um → 0.2 um), use of SOI technology
  - Integrating memory function (ROM, Flash)
  - New trimming/sensing technologies → Higher functionality

Smarter, robust standardize housings

- Advancing transfer-molded and case-type packaging solutions for higher power density and higher reliability
  - Solder-less terminal
  - Better thermal conductivity
  - Higher operating temperature
  - Higher integration level
  - Newer bonding technologies
Power Density Enhancement

Projected Growth of Power Density in Power Electronics System Designs

Power Density (w/cc)

Year


New technologies
- New material
- Higher Integration
- New Packaging

Note:
- IPM: Intelligent Power Module
- DIP-IPM: Dual In-line Package IPM
- EV-IPM: IPM for EV and/or HEV applications
- HEV Inverter: Inverter systems for hybrid vehicles

Equipment’s Power Density = \( \frac{P_{out} (W)}{\text{Volume (cc)}} \)