Wide Temperature Operating Range of High Isolation HV-IGBT Modules

Mitsubishi Electric has developed new High Voltage Insulated Gate Bipolar Transistor (HV-IGBT) modules called the ‘R-Series’ with a high isolation package, which can be used with a wide operating temperature range from -50°C up to 150°C. The newly developed chip set achieves stable operation and high SOA capability over a wide temperature range. In addition, the new package design is optimized for high isolation. The new HV-IGBT R-series has been developed to meet the requirements of high reliability applications for cold latitudes and to increase the inverter output power without increasing the equipment size. Kenji Hatori, Shuichi Kitamura, Shigeru Hasegawa, Shinichi Iura, Power Device Works, Mitsubishi Electric Corporation, Japan; Masuo Koga, Fukuryo Semicon Engineering Corporation, Fukuoka, Japan; Eugen Stumpf, Mitsubishi Electric Europe B.V., Germany

High-voltage IGBT modules are widely installed in high power applications, such as railway and large industrial drives. High reliability of the modules is requested for these applications. Recently, lower temperature operation has been requested for applications in cold latitudes. Also, higher temperature operation is requested for increasing the inverter output power. Therefore, the newly developed high isolation package module of HV-IGBT is able to operate from -50°C to 150°C.

Several issues had to be addressed for achieving the wide temperature operation. At first, a chip set with high SOA capability at Tj=150°C was achieved without thermal destruction. It has been already reported that the new planar IGBT structure for 3.3kV IGBT module has a high SOA capability at Tj=150°C [1, 2]. The second point was the optimization of package design. The optimization of the layout of the power terminals and chips is done by current sharing analysis in order to satisfy Short Circuit Safe Operating Area (SCSOA) at Tj=150°C. The excellent SCSOA robustness at Tj=150°C could be achieved by optimizing the current sharing. The third issue is the operation at Tj=-50°C. Stable operation is achieved by optimized lifetime control. The last item is the silicone gel for wide temperature operation, which has the same isolation capability as conventional modules even at very low temperatures.

R-Series chip set

The new HV-IGBT module called the R-Series (Figure 1) achieves larger current rating with wide safe operating area (SOA). Low on-state losses are achieved by three technologies: Carrier enhanced N layer, thinner N-drift layer and LPT (Light Punch Through) structure (as shown in Figure 1). Because of reducing the on-state losses, increased current rating by 25 - 33% is achieved (see Figure 2).

The LPT structure with optimized lifetime control achieves low leakage current and positive temperature...
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short circuit operation. Therefore, it is important to evaluate the influence of mutual inductance and also design a module to keep the current sharing balanced.

The calculation result of current sharing in new high isolation package under short circuit operation is shown in Figure 8. The electromagnetic influence on the gate circuit is avoided and excellent current sharing is achieved. The waveform of the high isolation package with 3.3kV IGBT is measured under short circuit condition ($V_{CC}=2800V$, $T_j=150^\circ C$, $V_{GE}=16.5V$), shown in Figure 9. It is confirmed that the new module can turn off at such harsh conditions without destruction.

Silicone gel
The silicone gel material is one of the key components for insulated modules. The characteristics of new silicone gel are less dependent on the temperature than the conventional one. Therefore, the new silicone gel has tougher characteristics even at the wider temperature range of -50°C up to 150°C. Of course, the new silicone gel has a good adhesive capability that achieves stable isolation at 10.2kVms for 1 minute and partial
discharge characteristics according to IEC 61287-1.

The new HV-IGBT R-series has been qualified for the storage temperature test at -55°C and 150°C. In addition, in spite of the expansion of operational temperature, the new module achieves the same lifetime as the conventional module at the same temperature cycling condition.

**Characteristics of HVIGBT**
The characteristics for three different voltage classes are shown in Table 1.

![Figure 7: R-series package (size: 190mm x 140mm x 48mm)](image)

![Figure 8: Calculation result of new high isolation package with 3.3kV IGBT (Vcc=2800V, Tj=150°C, Vg=16.5V, L=80nH)](image)

![Figure 9: Measurement of the new high isolation package with 3.3kV IGBT under short circuit condition (Vcc=2800 V, Tj=150°C, Vg=16.5V, L=80 nH)](image)

![Figure 10: Output Characteristic of new 4.5kV IGBT (Ic=1200A)](image)

![Figure 11: Output Characteristic of new 4.5kV diode (Ic=1200A)](image)

![Figure 12: Turn-off switching waveform of 4.5kV IGBT at nominal condition at Tj=125°C](image)

\[
\begin{array}{|c|c|c|c|}
\hline
\text{VCE} & \text{VCE (sat)} & \text{VCE (Vg)} & \text{VCE (Vg)} \\
\hline
\text{3.3kV Module} & 3.10V & 2.30V & \\
\text{4.5kV Module} & 4.40V & 2.80V & \\
\text{6.5kV Module} & 4.90V & 3.40V & \\
\hline
\end{array}
\]

Figures 10 and 11 show output characteristic of the 4.5kV / 1.2kA modules. It can be seen that both collector-emitter saturation voltage and diode forward voltage at nominal current are reduced. A positive temperature
The waveform during turn-off switching of the 4.5kV module at nominal condition at $T_j=125^\circ$C is shown in Figure 12. It operates smoothly without oscillation. A significantly low switching energy $E_{\text{off}}=4.30\text{J/P}$ is achieved with $R_{\text{g(off)}}=100\Omega$.

Figure 13 shows the waveform during turn-on switching of the 4.5kV module at nominal condition. The new module can increase $\text{di/dt}$ to reduce turn-on switching energy by a smaller $R_{\text{g(on)}}$ compared to conventional one. This significant improvement is achieved by installing new diode chips. Turn-on switching energy is $E_{\text{on}}=5.50\text{J/P}$ with $R_{\text{g(on)}}=2.7\Omega$ and no capacitance between gate and emitter.

The waveform during diode reverse recovery is shown in Figure 14. The behavior is very soft and the reverse recovery current is low resulting in low reverse recovery peak power $P_{\text{rr}}$. The reverse recovery energy is $E_{\text{rec}}=2.50\text{J/P}$ with $\text{di/dt}=3.6\text{kA/s}$.

It is important to have a wide Safe Operating Area (SOA) for HV-IGBT modules. Figure 15 shows the turn-off switching waveform of 4.5kV IGBT under over-current conditions at $V_{\text{cc}}=3500\text{V}$ and $T_j=125^\circ$C. Three times nominal current ($i=3600\text{A}$) is successfully turned off (Figure 16). Figure 17 shows typical short circuit waveform of 4.5kV IGBT at $V_{\text{cc}}=3500\text{V}$, $T_j=125^\circ$C and pulse time $=10\mu\text{s}$.

A wide Reverse Recovery Safe Operating Area (RRSOA) was the objective for R-series diode design. Figures 18 and 19 are showing the reverse recovery waveform of 4.5kV
diode at V_{cc}=3500V, T=125°C, I=2400A and di/dt ≥ 6kA/μs. The resulting P_{rr} reached 9MW without destruction. This is 3 times the RRSOA-limit and an indication for very robust diode design.

In general high-voltage diodes have a tendency to oscillation during reverse recovery at low temperature, low current and high DC-link voltage conditions. The new 4.5kV diode has no oscillation as shown in Figure 20 at the critical condition T=−40°C, V_{cc}=3200V, I=300A (1/4 nominal current). A stable reverse recovery operation over the whole temperature range is achieved.

**Conclusions**

Mitsubishi has developed the new HV-IGBT R-Series module with high isolation. It has been confirmed that the new module is able to operate safely within a wide temperature range. The new module has an excellent robustness of SOA both for the IGBT and diode part without sacrificing performance. This high performance has been achieved by an optimized design combination of both the chip and the package. The new HV-IGBT R-Series with high isolation completely satisfies the extended needs, such as increasing current rating and operation in cold latitudes.

**Literature**


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**XPT-IGBT**

**Features:**

- Easy paralleling due to the positive temperature coefficient
- Rugged XPT design results in:
  - Short Circuit rated for 10 μsec.
  - Very low gate charge
  - Square RBSOA @ 3x I_c
  - Low EMI
- Advanced wafer technology results in low V_{ce(sat)}
- 10-50 A in 1200 V

<table>
<thead>
<tr>
<th>TYPE</th>
<th>Configuration</th>
<th>Package</th>
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<tr>
<td>MIXA20WB1200TED</td>
<td>CBJ</td>
<td>E2-Pack</td>
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**Used in:**

- AC motor drives
- Solar inverter
- Medical equipment
- Uninterruptible power supply

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email XPT@ixys.de or call Petra Gerson: +49 6206 503249