Long-term reliability of SiC devices
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Manuafacturers of ultra reliable, high performance discrete semiconductors, power modules & hybrid microelectronic solutions designed to operate in any environment.

Through our flexibility and innovation, we aim to be recognised as trusted technology leaders in the aerospace, space, defence, medical and high-end industrial markets.

We research, design and manufacture an innovative range of MOSFETS, Bipolar Transistors, IGBTs, Power Modules, Diodes, Voltage Regulators and Customised Hybrid Microcircuits.
Who we are

Charcroft Electronics is a privately-owned specialist distributor of commercial, BS/CECC & Mil-Std passive, interconnect, hi-reliability discrete components, ICs and Emech components and also a manufacturer of leaded & SMT Metal® Foil Vishay-approved precision resistors & BS/CECC-approved radial MLCCs.

Supplying for 40 years into Military – Aerospace, Industrial & Audio - now focussing on niche markets who require Hi-Reliability components. Extensive product knowledge enables support of ongoing programs, full traceability and management of obsolescence issues.

Fully franchised for TT electronics, including Power & Hybrid. Staff have an excellent working knowledge of the product-range, capabilities and have worked with P&H customers for many years.
Long-term reliability of SiC devices
SiC devices

Property of SiC material

SiC (Silicon Carbide) is a compound semiconductor comprising of silicon (Si) and carbon (C). Compared to Si, SiC has properties including:

- 10 x dielectric breakdown voltage
- 3 x band-width
- 3 x thermal conductivity

<table>
<thead>
<tr>
<th>Property</th>
<th>Si</th>
<th>GaAs</th>
<th>4H-SiC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandgap at 300 K (eV)</td>
<td>1.11</td>
<td>1.43</td>
<td>3.26</td>
</tr>
<tr>
<td>Lattice parameters (Å)</td>
<td>5.43</td>
<td>5.65</td>
<td>a = 3.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>c = 10.08</td>
</tr>
<tr>
<td>Max. operating temp. (°C)</td>
<td>350</td>
<td>460</td>
<td>1200</td>
</tr>
<tr>
<td>Melting point (°C)</td>
<td>1410</td>
<td>1240</td>
<td>Sublimes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&gt; 2800</td>
</tr>
<tr>
<td>Electron mobility (10^4 m²/Vs)</td>
<td>1400</td>
<td>8500</td>
<td>900</td>
</tr>
<tr>
<td>Hole mobility (10^4 m²/Vs)</td>
<td>600</td>
<td>400</td>
<td>40</td>
</tr>
<tr>
<td>Breakdown electric filed (10^5 V/m)</td>
<td>0.3</td>
<td>0.4</td>
<td>2.2</td>
</tr>
<tr>
<td>Thermal cond. (W/m K)</td>
<td>150</td>
<td>54</td>
<td>490</td>
</tr>
<tr>
<td>Saturation drift velocity (10^5 m/s)</td>
<td>1.0</td>
<td>2.0</td>
<td>2.7</td>
</tr>
<tr>
<td>Dielectric constant</td>
<td>11.8</td>
<td>12.8</td>
<td>10</td>
</tr>
<tr>
<td>Mohs hardness</td>
<td>7</td>
<td>4-5</td>
<td>9.2-9.3</td>
</tr>
</tbody>
</table>
Advantages of SiC material for Power Device application

SiC devices can be made with higher doping concentrate and hence a higher breakdown Voltage (typ 600V+) and yet have a very low resistance.

**Si IGBT**
- ✓ high breakdown
- ✓ low on resistance
  
  *But...*
  
  ✗ Achieve at cost of switching speed

**MOSFETS**
- ✓ high breakdown
- ✓ low on resistance
- ✓ high switching speeds

*MOSFETS are majority carrier devices with higher breakdown*

BONUS; When properly packaged they can operate at  >>200⁰C

*Due to the injection into the drift region of the structure of minority carriers.*
So what about long–term reliability if used at these temperatures?
TT Electronics – Semelab Ltd’s initial thoughts were to verify a basic structure – Diode at elevated temperatures.

Cree CPWR/CPW2 Schottky barrier die family were chosen for our initial design of experiments. These were mounted in the TO-257AA and DLCC3 package.

The aim of the experiment was to monitor Vf and Ir over a period of time (in excess of 6000 hours) at elevated temperatures i.e. 225°C
<table>
<thead>
<tr>
<th>Section</th>
<th>Operation</th>
<th>Conditions</th>
</tr>
</thead>
</table>
| DC Operational Test          | DC Test                    | (T1) $V_{F} @ I_{F} = 10A$, Limit $< 1.8V$  
(T2) $I_{R} @ V_{R} = 600V$, Limit $< 200\mu A$ |
| Pre-Screen                   | High Temp Stabilization Bake (HTSB) | Temperature $= 200^\circ C$  
Duration $= 24$ hrs |
|                              | Temperature Cycling (Temp.C.) | 20 Cycles at $-35^\circ C$ to $+175^\circ C$ with cycle time of 16 mins |
|                              | Constant Acceleration (Accel) | 20,000g force in Y1 axis for 1 min duration |
|                              | Intermittent Electrical (ET0) | (T1) $V_{F} @ I_{F} = 10A$, Limit $< 1.8V$  
(T2) $I_{R} @ V_{R} = 600V$, Limit $< 200\mu A$ |
|                              | High Temperature Reverse Bias (HTRB) | $V_{R}$ $= 480V$ (80% of 600V)  
Temperature $= +215^\circ C$  
Duration $= 1000$ hrs |
|                              | Intermittent Electrical (ET1) | (T1) $V_{F} @ I_{F} = 10A$, Limit $< 1.8V$  
(T2) $I_{R} @ V_{R} = 600V$, Limit $< 200\mu A$ |
| High Temperature Reverse Bias (HTRB) | Intermittent Electrical (ET2) | (T1) $V_{F} @ I_{F} = 10A$, Limit $< 1.8V$  
(T2) $I_{R} @ V_{R} = 600V$, Limit $< 200\mu A$ |
| Life Test (6000Hrs Total)    | High Temperature Reverse Bias (HTRB) | (T1) $V_{F} @ I_{F} = 10A$, Limit $< 1.8V$  
(T2) $I_{R} @ V_{R} = 600V$, Limit $< 200\mu A$ |
|                              | Intermittent Electrical (ET3) | (T1) $V_{F} @ I_{F} = 10A$, Limit $< 1.8V$  
(T2) $I_{R} @ V_{R} = 600V$, Limit $< 200\mu A$ |
|                              | High Temperature Reverse Bias (HTRB) | (T1) $V_{F} @ I_{F} = 10A$, Limit $< 1.8V$  
(T2) $I_{R} @ V_{R} = 600V$, Limit $< 200\mu A$ |
|                              | Intermittent Electrical (ET4) | (T1) $V_{F} @ I_{F} = 10A$, Limit $< 1.8V$  
(T2) $I_{R} @ V_{R} = 600V$, Limit $< 200\mu A$ |
|                              | High Temperature Reverse Bias (HTRB) | (T1) $V_{F} @ I_{F} = 10A$, Limit $< 1.8V$  
(T2) $I_{R} @ V_{R} = 600V$, Limit $< 200\mu A$ |
|                              | Intermittent Electrical (ET5) | (T1) $V_{F} @ I_{F} = 10A$, Limit $< 1.8V$  
(T2) $I_{R} @ V_{R} = 600V$, Limit $< 200\mu A$ |
|                              | High Temperature Reverse Bias (HTRB) | (T1) $V_{F} @ I_{F} = 10A$, Limit $< 1.8V$  
(T2) $I_{R} @ V_{R} = 600V$, Limit $< 200\mu A$ |
|                              | Intermittent Electrical (ET6) | (T1) $V_{F} @ I_{F} = 10A$, Limit $< 1.8V$  
(T2) $I_{R} @ V_{R} = 600V$, Limit $< 200\mu A$ |
|                              | High Temperature Reverse Bias (HTRB) | (T1) $V_{F} @ I_{F} = 10A$, Limit $< 1.8V$  
(T2) $I_{R} @ V_{R} = 600V$, Limit $< 200\mu A$ |
|                              | Final Electrical (ET7)      | (T1) $V_{F} @ I_{F} = 10A$, Limit $< 1.8V$  
(T2) $I_{R} @ V_{R} = 600V$, Limit $< 200\mu A$ |
Long Term Reliability Tests – 8,000 hour at 225°C, 1200V DLCC3 Diode SiC

Reverse Leakage Current

Thermal Impedance

SiC experiments 1 – Test results
SIC Schottky Diode, no minority carrier recombination thus zero reverse recovery. Recovery time shown is due to a small junction capacitance charge and is independent of junction temperature.

Zero Reverse Recovery – Junction Capacitance charge related effects only – constant over temperature.
SiC experiments 2

Having shown the success of SiC diode reliability, Semelab Ltd went on to analyse both Cree and Rohm 1200 Volt 80 mΩ Mosfets co-packed with a SiC diode.

H.T.R.B (high temperature reverse bias) was carried out for 2000 hours at a temperature of 225°C.

Engineering samples were assembled using each of the die types co-packed in a To-258 package with an anti-parallel diode. As previous engineering trials; it was found that the MOSFET body diode had a high forward voltage (VSD).

HTRB configuration

The devices were bias at a VDD 80% of the maximum rating with a gate to source Vs = Vg = 0 Volts
SiC experiments 2 – test results
Conclusion…

After a period of 2000 hours H.T.R.B, neither the Cree or Rohm Devices are showing significant changes in electrical performance and continues to meet the test specifications…
Semelab is presently working with ESA (European Space Agency) to undertake SEU (single event upset) testing

- No problems detected during beam exposure for Gate/Drain current
- Gate sensitivity was detected during PIGS (Post irradiation stress test) after the heavy ions test (PIGS tests performed during intermediate measurements)
- The threshold for the Gate degradation was found around LET = 16MeV/cm²·mg
- After all data is processed, results will show if there is correlation between Drain and Gate Voltage during beam exposition
- Results should be available in 2-3 weeks

- Total dose campaign is also scheduled:
  - Dose rate of 3.6Krad/hour till reaching 300Krad accumulated dose
Die attachment to achieve greater reliability

**Non-Pressure Large area 20mm Square Ag sintering**
- Gold plated alsic base plate on gold plated DBC
- Samples have been temperature cycled from -40°C to 250°C (minimum of 3 hours at each extreme)
- 4 of 6 samples delaminated after 50 cycles

**Ag sintering on Ag thick film 5 mm sq chip**
- The samples have completed 3000 temperature cycles -55/150°C with no signs of delamination of the die attach seen
• ‘Pressureless’ Ag sinter die attach has been tested from 0°C to 350°C using a Ag backed SiC device and a Au plated substrate with 310 cycles completed

• 2000hrs H.T.S.B @ 300°C and 2000hrs H.T.R.B @ 300°C have been completed
Cross sections of the Ag sinter paste before and after testing has revealed that the sintering process continues.

Tests by Warwick University
SiC and GaN manufacturer’s have been tested as bare die above 300°C
High Temperature Materials Research

CreeG1 MOSFET

Rohm MOSFETs

Fairchild BJT

GaN Systems HEMTs

Tests by Warwick University
High Temperature Hybrids

Pressure & Temperature sensing for down hole operation at 200°C

- HTCC Substrate/Package
- Double sided cavity/assembly
- Qualified at 200°C
- Wire bonded bare die in dual hermetic cavities

Double sided hermetically sealed High Temperature Co-fired Ceramic Module
We are presently working on the next generation of Aero-engine FADEC’s which will be placed closer to the engine and need to operate at 200°C.
Thank you...

further details are available at

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