Silicon Carbide Devices for Energy Efficient Infrastructure

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Energy Efficient Infrastructure Elements

- Power Conversion for more efficient Datacenters, EV chargers and Industrial Buildings
- Auxilliary Power supplies and 1700 V SiC switches using simplified Flyback Circuits
- Inverters for Motor Drives
- SiC devices and configurations for Utility Grid-voltage applications
- Conclusions
Future Belongs to DC Microgrid

»DC-Grid Manager«

Local Power Supply

Static Energy Storage

Mobile Energy Storage

Public Power Supply

Loads

Prosumer

Lighting

\[ \sum_{i} P_i = 0 \]
HVDC Infrastructure/Magnetics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Voltage</td>
<td>800V</td>
</tr>
<tr>
<td>Battery Voltage</td>
<td>400V</td>
</tr>
<tr>
<td>AC RMS Voltage</td>
<td>Around 1kV-1.4kV ac, 60Hz</td>
</tr>
<tr>
<td>Transformer switching frequency</td>
<td>10 kHz-100kHz</td>
</tr>
<tr>
<td>Output Power of the module</td>
<td>50kW-100kW</td>
</tr>
<tr>
<td>Transformer Cores</td>
<td>Nano-crystalline, ferrite, powdered/soft ferrite</td>
</tr>
<tr>
<td>Transformer winding insulation type</td>
<td>&gt;1mm Plastic insulation over winding</td>
</tr>
<tr>
<td>Inter winding Insulation type</td>
<td>Insulating Tape(Kapton, 3M)</td>
</tr>
<tr>
<td>Geometry of cores</td>
<td>Multi-limb. Planar, co-axial</td>
</tr>
</tbody>
</table>

Courtesy: NCSU Bhattacharya
Value Proposition – SiC Power Devices

- Higher speed of SiC devices critically enables ~10X higher operating frequencies and higher efficiencies in power circuit
- Results in significant reduction in size, cost, weight of power systems
- Example DC-DC converter circuit at relevant voltage levels
**SJT Structure and Advantages**

- Lowest $V_{DS(ON)}$ as compared to any other commercial SiC switch
  - $R_{on,sp} = 2 \, \text{m$\Omega$-cm}^2$ demonstrated
- Suitable for connecting an anti-parallel diode
- Gate oxide free SiC switch
- Positive temperature coefficient for easy paralleling
- High Operating Temperature
- Best in class temperature independent switching
- Excellent Short Circuit Robustness
- Easy to drive using commercial drivers
- Low gate charge, Low intrinsic capacitance,
- High Yielding, Smaller size, Lower cost
• Current Gains in excess of 100
• $R_{\text{on}} (25^\circ\text{C}) = 2.3 \text{ m}\Omega\cdot\text{cm}^2$
• Positive temp co-efficient of $V_{\text{CE,\text{sat}}}$
• Low leakage, $B V_{\text{CES}}$ even at $T>200^\circ\text{C}$
• Switching 50 A at full rated voltage (1200 V)
• Sub-50 ns switching transients (need additional care to avoid ringing)
• Temperature invariant switching behavior confirms lack of minority carrier storage in Collector region.
What Controls SJT Switching Speed?

- $Q(I_B) \approx Q_{BE}(-5..3V) + Q_{CB}(0..800\,V)$

- SJT Switching speeds are **solely limited** by terminal capacitances
High Voltage DC (HVDC) Full Bridge Bread Board

- Control and Driver Circuit
- Transformer
- Secondary Rectifiers and Filters

Input DC

Full Bridge with GeneSiC SJT (PN: GA20SICP12-263) Underneath

Side-View
**800V Input 500KHz (1MHz interleaved) Switching Full Bridge Test**

- Input 800V
- Open loop – duty cycle 42%
- Channel 1 is control drive signal C
- Channel 2 is Full bridge voltage waveform.
- Channel 3 is control drive signal D
Issues with Existing Silicon technologies
IGBTs; SiC Enabler

- MOSFET has limited voltage ratings
- MOSFET has lower Vgs maximum rating.
- MOSFET has higher Rds_on at high temperature.
- IGBT is limited switching frequency (<100KHz)

- GeneSiC’s SiC devices enables higher input voltage operation at high switching frequency and fast rise time.
- It presents high voltage DC down conversion for solar, industrial HVDC bus applications.
- It proves high voltage and switching performance and is ready for implementation a complete power converter design.
Energy Efficient Infrastructure Elements

• Power Conversion for more efficient Datacenters, EV chargers and Industrial Buildings

• **Auxilliary Power supplies and 1700 V SiC switches using simplified Flyback Circuits**

• Inverters for Motor Drives

• SiC devices and configurations for Utility Grid-voltage applications

• Conclusions
Flyback Inverters and Power Supplies

- **Flyback Circuits offer significant advantages** (Isolation through Xformer, Minimal energy storage, Can be made Bi-directional)

- **Disadvantage:** Switch voltage $>2$ DC Voltage => for 400 Bi-directional DC-DC, Switch needs to be $>850$ V rated
SiC Junction Transistors Offer Significantly Higher Efficiency, Simpler Flyback Circuits

- Generally, these are low power (<500W) power supplies with low current (<5A) ratings
- SJTs can be driven using feedback from Transformer and <10 V drive circuits
- High Voltage/Low Cost/Low conduction losses offer significant value to these applications
**1700 V SJT-Si IGBT Output Characteristics**

- Benchmarked with best-in-class 40-75 A 1700 V Si IGBTs
- The SJT’s $V_F$ is 50% lower than either IGBT at high operating temperatures
The conduction power loss of the SiC SJT is 2.2x smaller than the best Si IGBT during 150°C operation.
• The SJT’s leakage current increases marginally from 200 nA at 25°C to 1.5 µA at 175°C.

• On the other hand, the IGBT leakage currents are in the mA range at 150°C
  – Excessive off-state power loss > 5 W estimated
Turn-off Comparison 1700 V SJT with Si IGBTs

- SJT shows MOSFET-like fast turn-off waveforms, due to unipolar operation.
- The bipolar IGBTs feature a long tail current, which increases the switching losses.
SiC SJT offers the lowest switching energy loss at all temperatures due to:

- Small chip size
- Lack of minority charge storage, also resulting in temperature invariant switching

• ~4x higher switching energy loss measured on the Si IGBTs.
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Avalanche Ruggedness – Unclamped Inductive Switching

- UIS Energy of 47 mJ (6.1 J/cm²) measured
- Optimized design supports avalanche currents 42 A
  – > 20x rated currents
Short Circuit Ruggedness

- Simultaneous application of operating voltage and full, rated current
- >10 μsec short circuit testing successful
Utility Grid Applications (eg. Intelligent Universal Transformer)

Courtesy: Prof. Lai, Virginia Tech
10 kV BJT Blocking I-V Characteristics

7.3 mm x 7.3 mm BJTs (active area = 28 mm²)
• Turn-on transition: $I_C$ rise time < 30 ns; $V_C$ fall time < 200 ns
• Turn-off transition: $I_C$ fall time < 150 ns; $V_C$ recovery time <100 ns
• Switching Speed limited by package and circuit parasitics
- No difference in switching performance at 25°C and 150°C
  - Confirms lack of conductivity modulation in the n-collector layer.
### 10 kV SiC BJT vs. 6.5 kV/25 A Si IGBT

<table>
<thead>
<tr>
<th>Device</th>
<th>BV</th>
<th>I&lt;sub&gt;C&lt;/sub&gt;</th>
<th>Temp.(C)</th>
<th>V&lt;sub&gt;CE,sat&lt;/sub&gt; (V)</th>
<th>Eon (mJ)</th>
<th>Eoff (mJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiC BJT</td>
<td>10 kV</td>
<td>8 A</td>
<td>150°C</td>
<td>6.4</td>
<td>4.2</td>
<td>1.6</td>
</tr>
<tr>
<td>Si IGBT*</td>
<td>6.5 kV</td>
<td>10 A</td>
<td>125°C</td>
<td>4</td>
<td>80</td>
<td>40</td>
</tr>
</tbody>
</table>

- SiC BJT achieves 19 x lower turn-on energy loss and 25 x lower turn-off energy loss, as compared to a commercially available 6.5 kV/25 A Si IGBT

* Si IGBT switching data sourced from device datasheet
3.65 mm x 3.65 mm SiC BJT turned on to a short-circuited load at a DC link voltage of 4.5 kV.

A short-circuit withstand time of \( \geq 20 \mu s \) observed at \( V_{CE} = 4.5 \) kV and \( T_C = 125^\circ\text{C} \)
- Near-infinity output resistance (and Early voltage) results in \( V_{CE} \) invariance of \( I_{SC} \)
Series Connection of SiC devices – a Cheaper Solution Available Right now

- High speed of SiC Switches allows easier series connection
- Avalanche rated devices easier to connect with no snubbers
- 1700 V/10 mOhm SJTs already available, making 6500 V/35 A transistors easily possible
- Auxilliary Power Supplies in 4160 3Φ AC systems
## SiC Junction Transistors

### Table of SiC Junction Transistors

<table>
<thead>
<tr>
<th>Rated Blocking Voltage (V)</th>
<th>Current Rating / $R_{DS(ON)}$ (mA)</th>
<th>TO247</th>
<th>TO-263 / D2PAK</th>
<th>SOT-227</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200</td>
<td>15A / 180mA</td>
<td>GA05JT12-247</td>
<td>GA05JT12-263</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25A / 100mA</td>
<td>GA10JT12-247</td>
<td>GA10JT12-263</td>
<td></td>
</tr>
<tr>
<td></td>
<td>45A / 50mA</td>
<td>GA20JT12-247</td>
<td>GA20JT12-263</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100A / 20mA</td>
<td>GA50JT12-247</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>160A / 10mA</td>
<td></td>
<td></td>
<td>GA100JT12-227</td>
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<tr>
<td>1700</td>
<td>15A / 180mA</td>
<td>GA04JT17-247</td>
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<td>45A / 50mA</td>
<td>GA16JT17-247</td>
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<td>100A / 20mA</td>
<td>GA50JT17-247</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>160A / 10mA</td>
<td></td>
<td></td>
<td>GA100JT17-227</td>
</tr>
</tbody>
</table>
GeneSiC Nationwide/Worldwide Distributors/Sales Representatives

- Aggressive Sales and Marketing strategy adopted
- Largest network of Sales Representatives
- Top Tier distributors
- Chip-level and packaged level distribution network/logistics
• SiC Devices are making significant inroads into the next generation energy efficient infrastructure, eg.:
  – Datacenters, EV chargers and Industrial Buildings
  – Auxiliary Power supplies on Flyback Circuits
  – Inverters for Motor Drives
  – Utility Grid-voltage applications using series connected and 3.3kV, 6.5kV and 10 kV devices

• Future is bright for SiC!