Ultra High Voltage SiC Bipolar Devices for Reduced Power Electronics Complexity

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Why UHV Silicon Carbide Power Devices?

<table>
<thead>
<tr>
<th>Property - Silicon Carbide vs Silicon</th>
<th>Performance of UHV SiC Bipolar Dev.</th>
<th>Impact on Power Circuits</th>
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<tbody>
<tr>
<td>Breakdown Field (10X)</td>
<td>Lower On-state Voltage drop for 5-20 kV Devices (2-3X)</td>
<td>Higher Efficiency of circuits</td>
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<tr>
<td>Smaller Epitaxial Layers (10-20X)</td>
<td>Faster Switching speeds (100-1000X)</td>
<td>Compact circuits</td>
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<td>Higher Thermal Conductivity (3.3-4.5 W/cmK vs 1.5 W/cmK)</td>
<td>Higher Chip Temperatures (250-300°C instead of 125°C)</td>
<td>Higher pulsed power Higher continuous current densities,</td>
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<td>Melting Point (2X)</td>
<td>High Temperature Operation (3X)</td>
<td>Simple Heat Sink</td>
</tr>
<tr>
<td>Bandgap (3X) (10^{16}X smaller n_i)</td>
<td>High Intrinsic Adiabatic Pulsed Current Level (3-10X?)</td>
<td>Higher Current Capability</td>
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</table>
Maximum Voltage and Current Ratings of UHV SiC Bipolar Devices significantly higher than theoretical capability of Si

Further SiC offers unprecedented margins from failures
Two kinds of UHV Bipolar Devices being funded by ARPA-E

Anode Switched Thyristor

- “P-Type” Cathode – HV
- Lower On-State Drop
- Slower Switching speed
- Asymmetric Blocking
- Simple Fabrication/Si MOSFETs for switching

N-IGBT

- “N-Type” Collector + HV
- Higher On-State Drop
- Faster Switching speed
- Asymmetric Blocking?
- Complex Fabrication/Integrated Device
Goals for Anode Switched Thyristors

- Voltage: >13 kV
- Current: >50 Amp
- Operating Frequency: >10 kHz
Anode Switched Thyristor (AST) Switching

- 4 μsec (Max) On-Off cycle => 250kHz at low duty cycles
- Extracted Lifetime: 1.8μsec; Charge = 1.4E-4 C/cm²
Key GTO Thyristor Innovations

- Mesa etch for High Voltage/Yields
- Double-level metal for Low $V_F$
- High turn-off gain Interdigitated designs
Forward Blocking Voltage I-V Curve

Leakage Current (A)

10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4}

Anode-Cathode Bias (V)

0 1,000 2,000 3,000 4,000 5,000 6,000 7,000

Si Thyristor-25 C
GeneSiC Thyristor-25 C
GeneSiC Thyristor-150 C
Si Thyristor-125 C
Ultra-high Voltage On-wafer Chars.

Automated measurements and statistical analysis conducted on 6.5 kV SiC Thyristors. >85% yield on 8.8X8.8mm devices
On-State vs Temperature Curves

- Near-Theoretical On-State I-V curves obtained
- Record Lowest Differential On-Resistance obtained
6.5kV, 40-80 A SiC Thyristor Deliveries

• >85% Yields obtained on 6.5kV/80 A Thyristors
• Almost 450 packaged Thyristors delivered
• Detailed Test Data, Wafer maps, Full Wafer-level, on-wafer, package-level traceability covered
• Full Datasheets created/offered
Wafer Map >12 kV PiN Epiwafer
Power Conversion Applications
Options: Multilevel vs Two-Level Converters

Trade-Offs in Multi-level converters:

- Efficiency
- Robustness
- Modularity
- Design Implementation, Complexity
- Control concerns
- Fault Tolerance

From: Franquelo et al.
FACTS and HVDC – HV, Thermal, HF limits

- Static VAR Compensators
- STATCOM
- Series Compensator
- Unified Power Flow Controller
- Phase Angle Regulator
- Convertible Static Compensator
- Intelligent Universal Transformer

From: Tolbert et al.
Si IGBT / SiC Rectifiers – Rectifiers are Key!
GeneSiC’s offerings/under development

- SiC Schottky Rectifiers
  - 1200V-1700V: 1-50A
  - 3300V-10 kV: 50-20A
- Si IGBT/SiC Rectifiers
  - 1200V-1700V: 35-300A
  - 3300-6500V: 20-100A
- SiC SuperJTs
  - 1200V-1700V: 35-300A
  - 3300V-10 kV: 20-100A
- SiC Thyristors/PiN Rectifiers
  - 6.5kV: 25-100A
  - 13kV: 25-100A
GeneSiC Nationwide/Worldwide Distributors/Sales Representatives

- Aggressive Sales and Marketing strategy adopted
- Largest network of Sales Representatives
- Blue-chip distributors
- Chip-level and packaged level distribution network/logistics
Example of FACTS Element: SST

- For such high power levels, a direct tap into ship bus may be required (bus voltages: 4.16 kV, 6.6 kV and 13.8 kV)
- Lack of availability of high voltage (>4.5 kV) devices key limitation towards solid state power conversion