Ultra High Voltage SiC Bipolar Devices for Reduced Power Electronics Complexity

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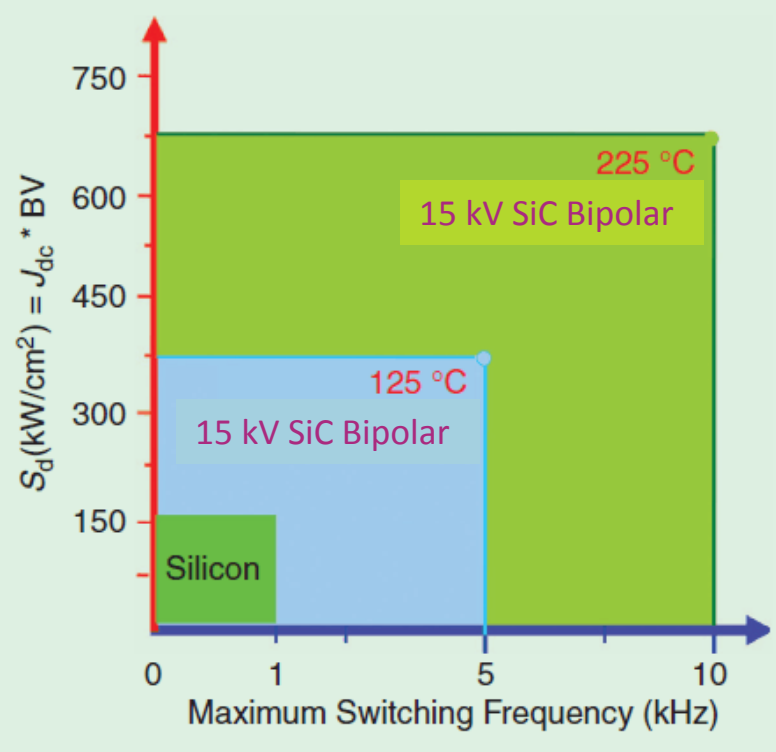
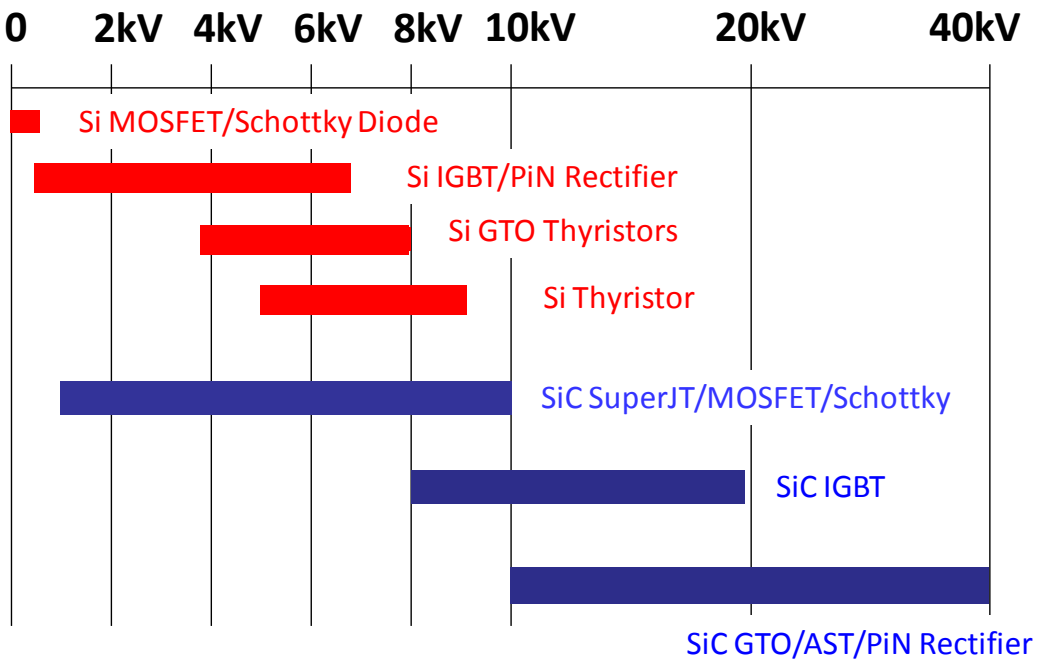
GeneSiC
SEMICONDUCTOR

Why UHV Silicon Carbide Power Devices?

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

Ratings of SiC and Si Devices

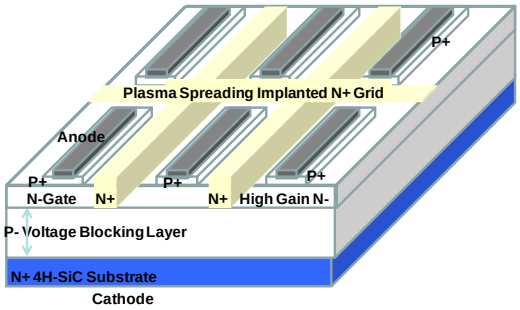


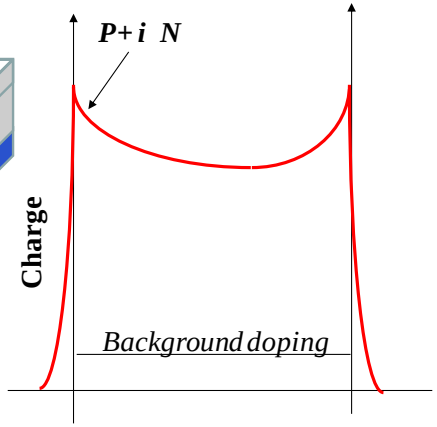


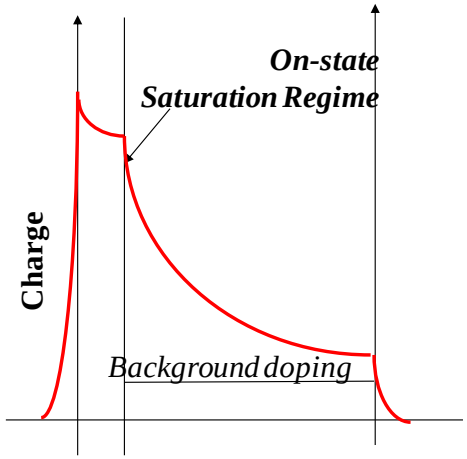
- Maximum Voltage and Current Ratings of UHV SiC Bipolar Devices significantly higher than theoretical capability of Si
- Further SiC offers unprecedented margins from failures

Two kinds of UHV Bipolar Devices being funded by ARPA-E

Anode Switched Thyristor

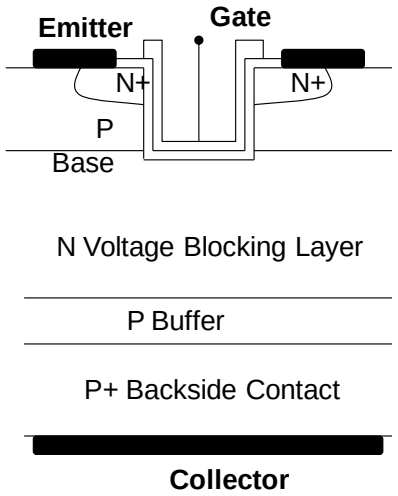






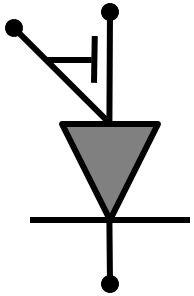
- "P-Type" Cathode – HV
- Lower On-State Drop
- Slower Switching speed
- Asymmetric Blocking
- Simple Fabrication/Si MOSFETs for switching

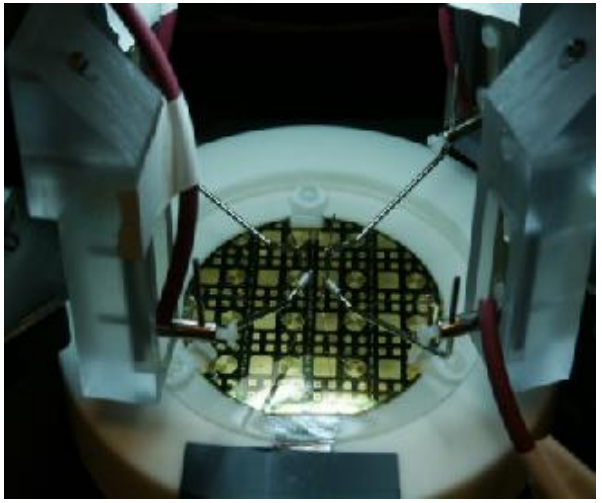
N-IGBT



- "N-Type" Collector + HV
- Higher On-State Drop
- Faster Switching speed
- Asymmetric Blocking?
- Complex Fabrication/ Integrated Device

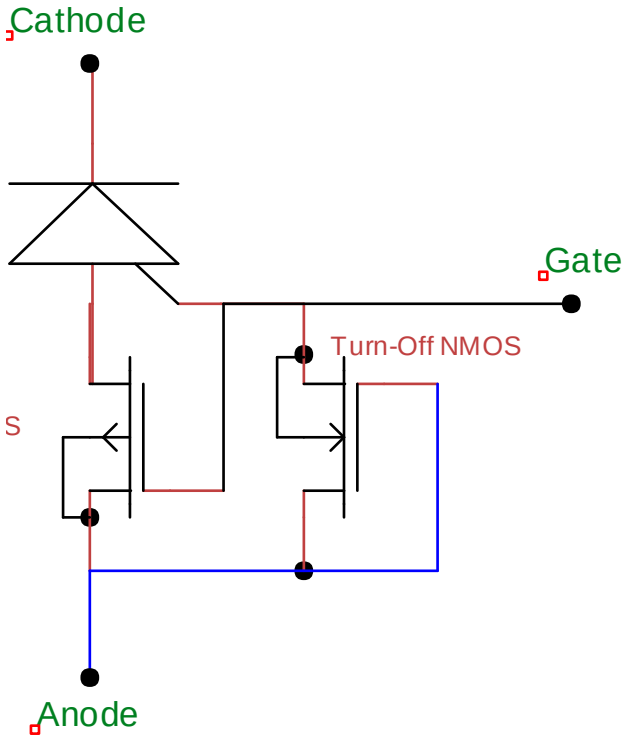
Goals for Anode Switched Thyristors

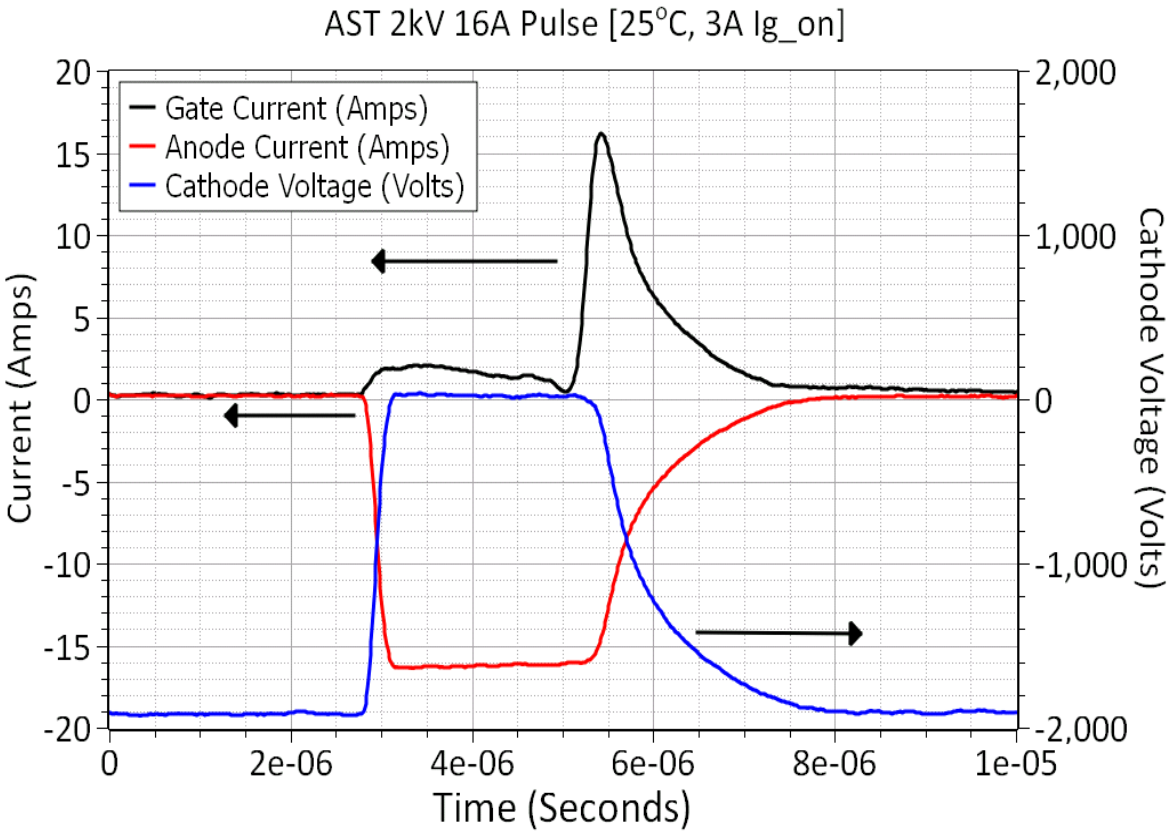




- Voltage >13 kV
- Current >50 Amp
- Operating Frequency >10 kHz

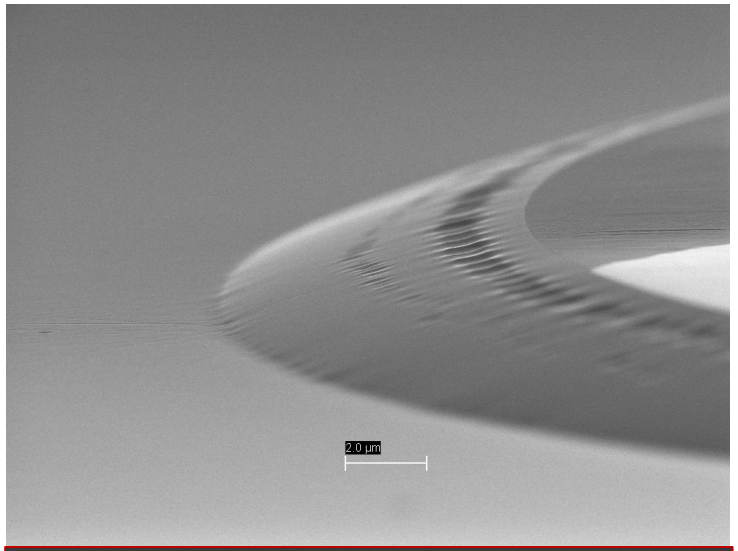
Anode Switched Thyristor (AST) Switching

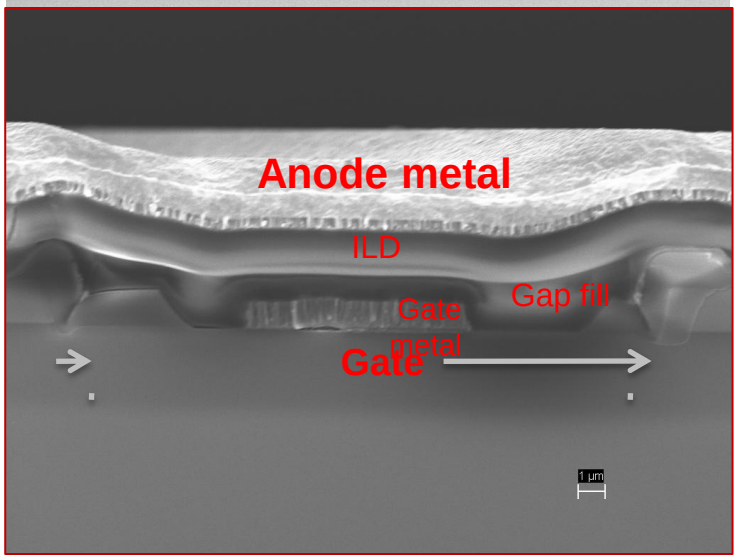




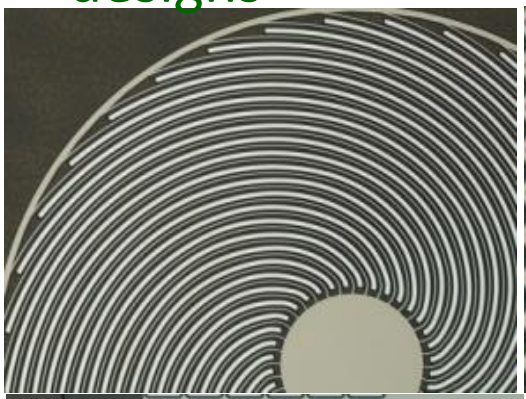
- 4 µsec (Max) On-Off cycle => 250kHz at low duty cycles
- Extracted Lifetime: 1.8µsec; Charge = 1.4E-4 C/cm^2

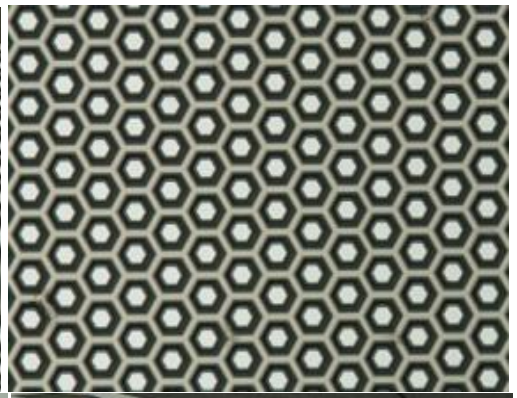
Key GTO Thyristor Innovations



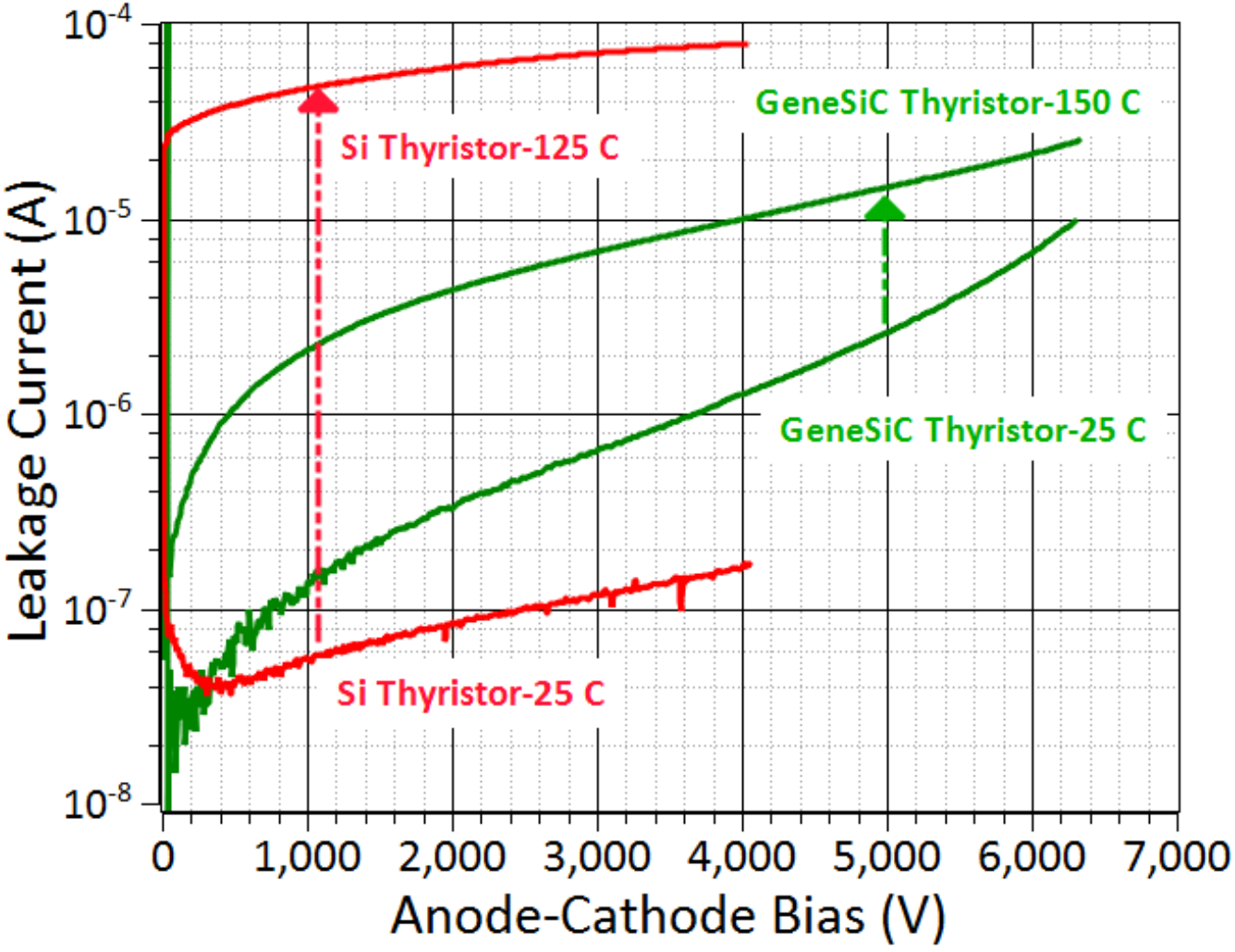


- Mesa etch for High Voltage/Yields
- Double-level metal for Low V_F
- High turn-off gain Interdigitated designs

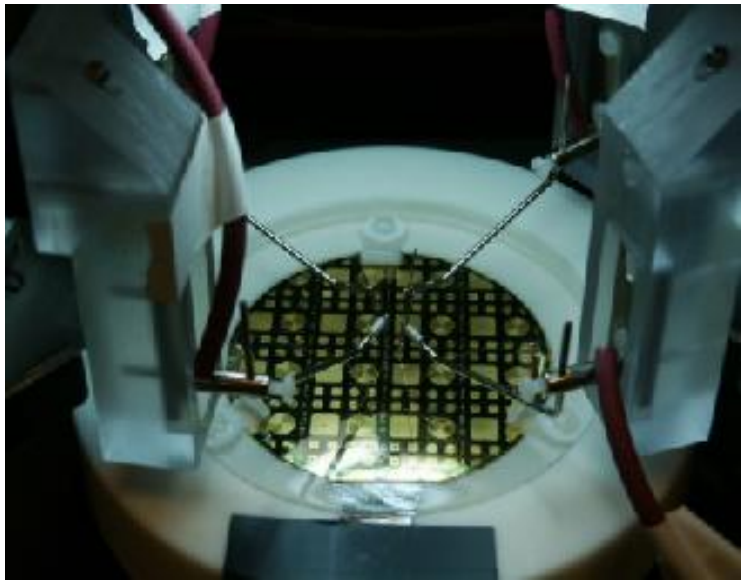


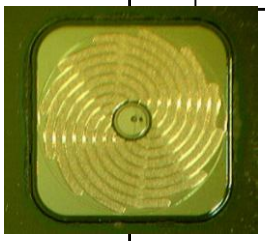


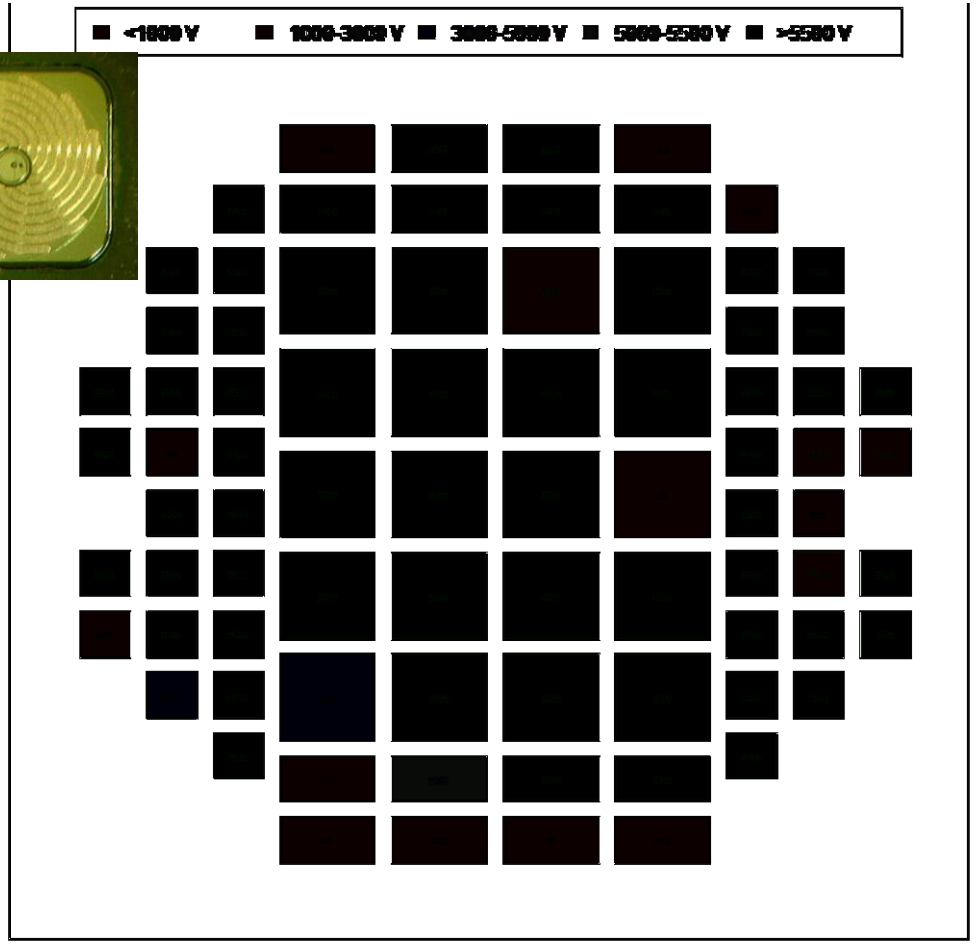
Forward Blocking Voltage I-V Curve



Ultra-high Voltage On-wafer Chars.

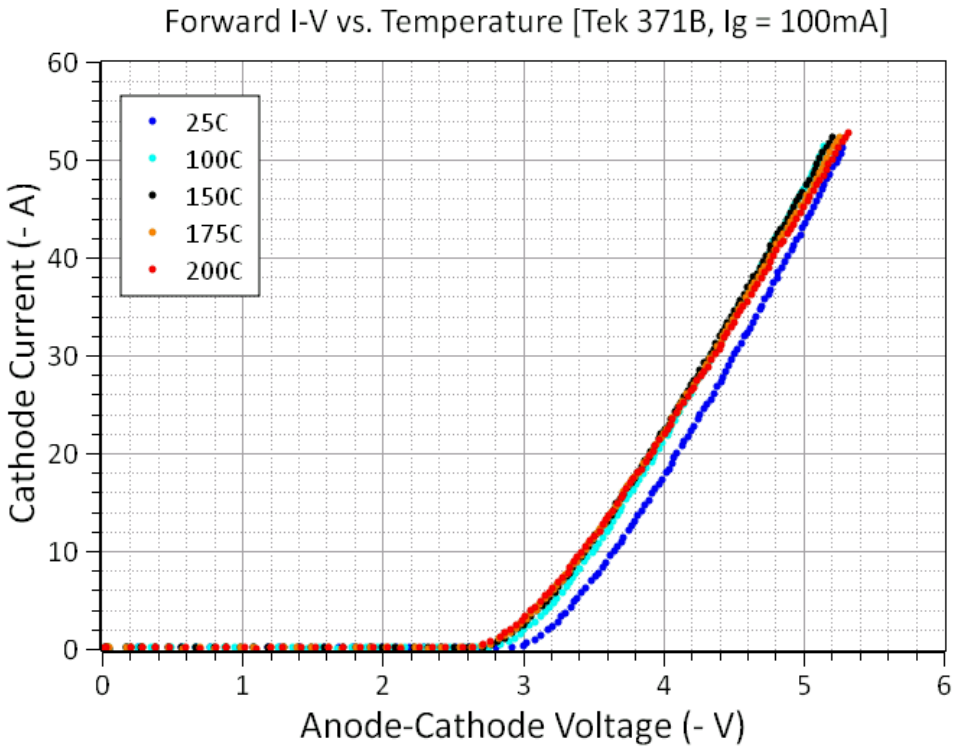


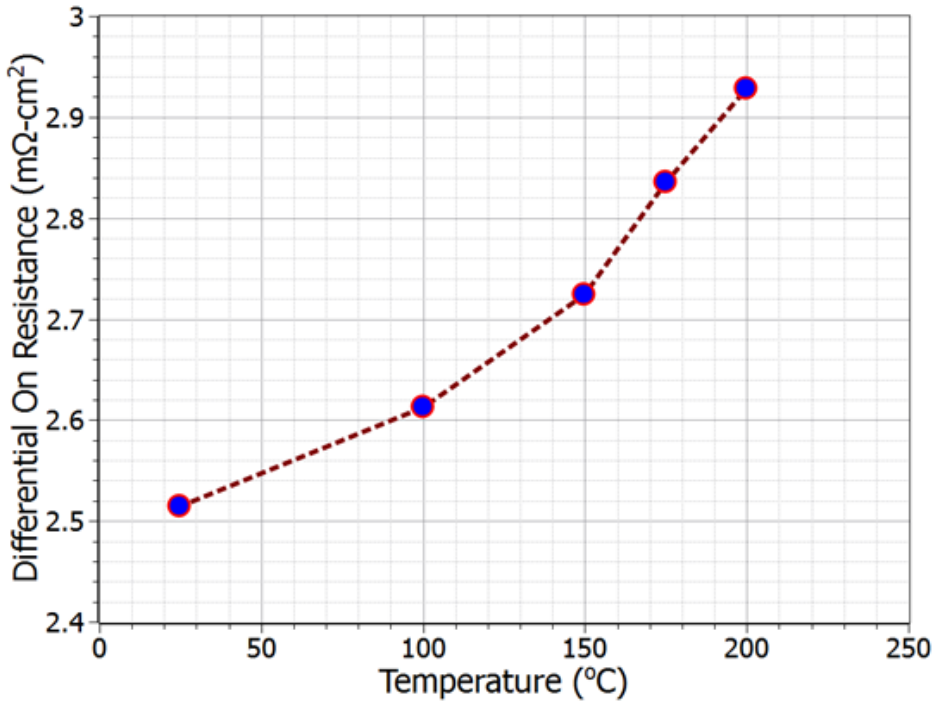




Automated measurements and statistical analysis conducted on 6.5 kV SiC Thyristors. **>85% yield on 8.8X8.8mm** devices

On-State vs Temperature Curves





- Near-Theoretical On-State I-V curves obtained
- Record Lowest Differential On-Resistance obtained

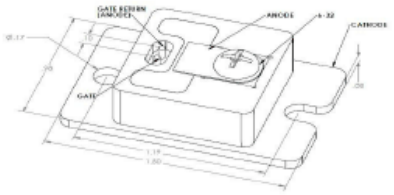
6.5kV, 40-80 A SiC Thyristor Deliveries

GeneSiC SEMICONDUCTOR **GA040TH65**

Silicon Carbide Thyristor

V_{FBM} = 6500 V
$I_{T(AVM)}$ = 40 A
Q_{rr} = 1.8 µC

Applications
- Grid tied Solar Inverters
- Wind Power Inverters
- HVDC Power Conversion
- Utility scale Power Conversion
- Trigger circuits/Ignition circuits



Features
- 6500 V Asymmetric SiC NPNP Thyristor
- 150 °C operating temperature
- Robust compact fully soldered package
- SOT-227 (ISOTOP) base plate form factor
- Fast turn on characteristics
- Lowest in class $Q_{rr}/I_{T(AVM)}$

Maximum ratings

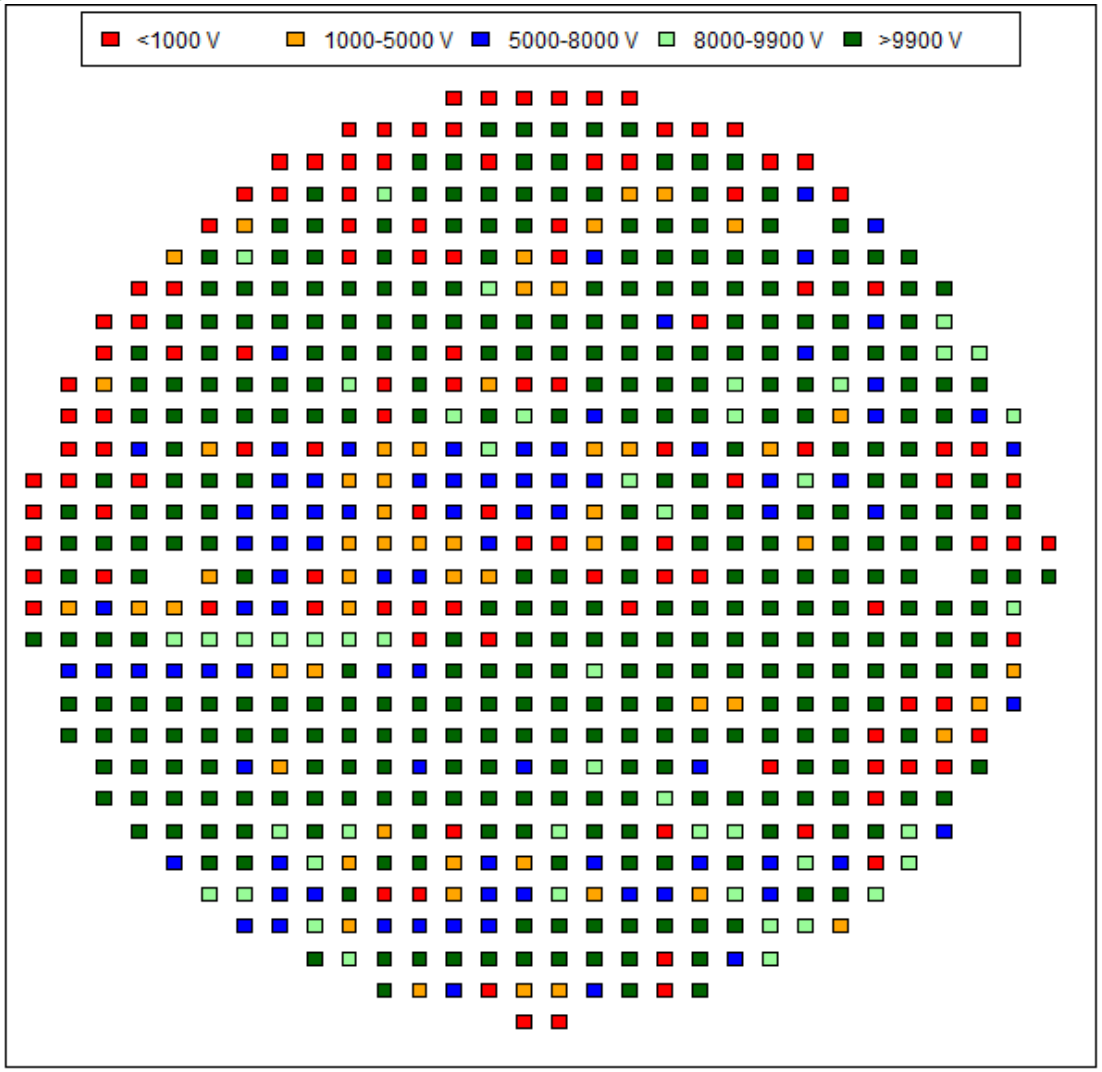
Parameter	Symbol	Conditions	Values	Units
Repetitive peak forward voltage	V_{FBM}	T_J = 25 °C	6500	V
Repetitive peak reverse voltage	V_{RBM}	T_J = 25 °C	50	V
Maximum average on-state current	$I_{T(AVM)}$	$T_C \leq$ 120°C	40	A
RMS on-state current	$I_{T(RMS)}$	$T_C \leq$ 120 °C	69	A

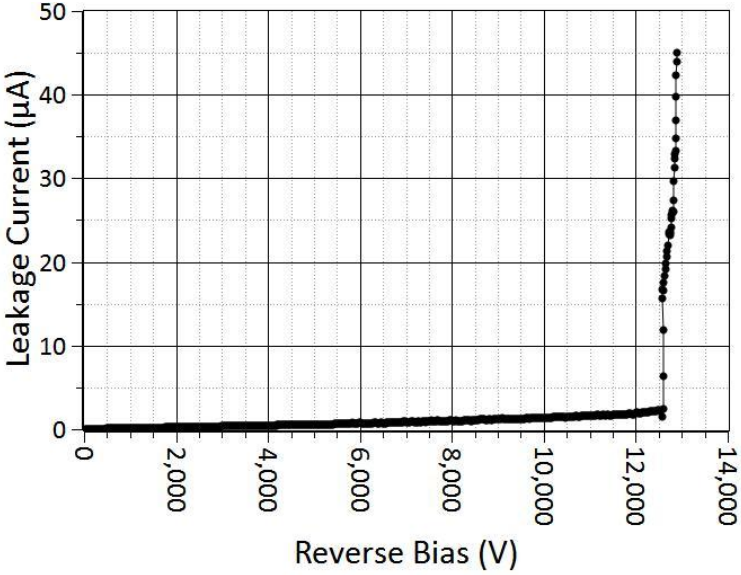
Wafer 15

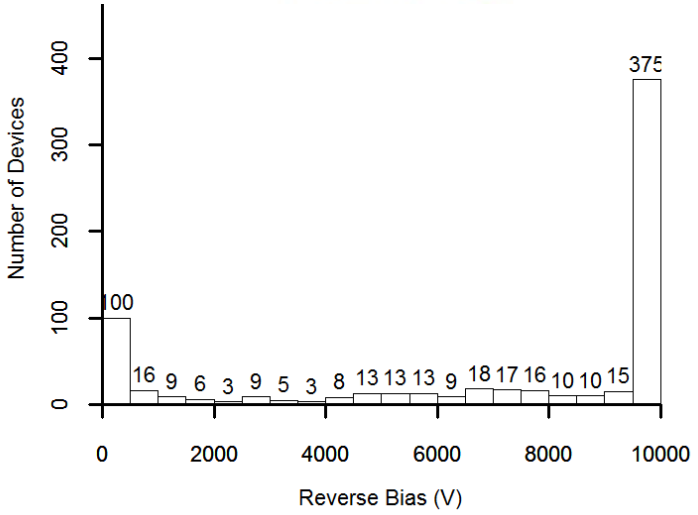
Type	Position	APP Serial #	Assembled	Rag	Vag @ 10mA	ReverseBV_HV	Notes	Forward
TH04/05 4x4mm Style 3	R-2-1	3860	10/11/2010	Inf.	2.6V	-6.97 µA at -6.48 kV		
TH04/05 4x4mm Style 3	R-2-2	3847	10/11/2010	3.8Ω	0V	-6.44 µA at -6.5 kV		Short G-A
TH04/05 4x4mm Style 3	R-3-1	3848	10/12/2010	Inf.	2.6V	-9.57 µA at -6.46 kV		
TH04/05 4x4mm Style 3	R-3-2	3861	10/12/2010	0Ω	0V	-5.03 µA at -6.48 kV		Open G-A
TH04/05 4x4mm Style 3	R-4-1	3862	10/12/2010	Inf.	2.6V	-14.81 µA at -6.46 kV		
TH04/05 4x4mm Style 3	R-4-2	3846	10/12/2010	Inf.	2.6V	-2.34 µA at -6.46 kV		
TH04/05 4x4mm Style 3	R-4-3	3849	10/13/2010	1.4kΩ	2.6V	-3.34 µA at -6.46 kV		
TH04/05 4x4mm Style 3	R-5-1	3850	10/13/2010	Inf.	2.6V	-1.9 µA at -6.48 kV		
TH04/05 4x4mm Style 3	R-6-1	3842	10/13/2010	Inf.	2.7V	-27.73 µA at -6.37 kV		
TH04/05 4x4mm Style 3	R-7-1	3843	10/14/2010	Inf.	2.6V	-28.46 µA at -6.47 kV		
TH04/05 4x4mm Style 3	R-7-3	3844	10/14/2010	Inf.	2.7V	-28.27 µA at -6.13 kV		

- >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

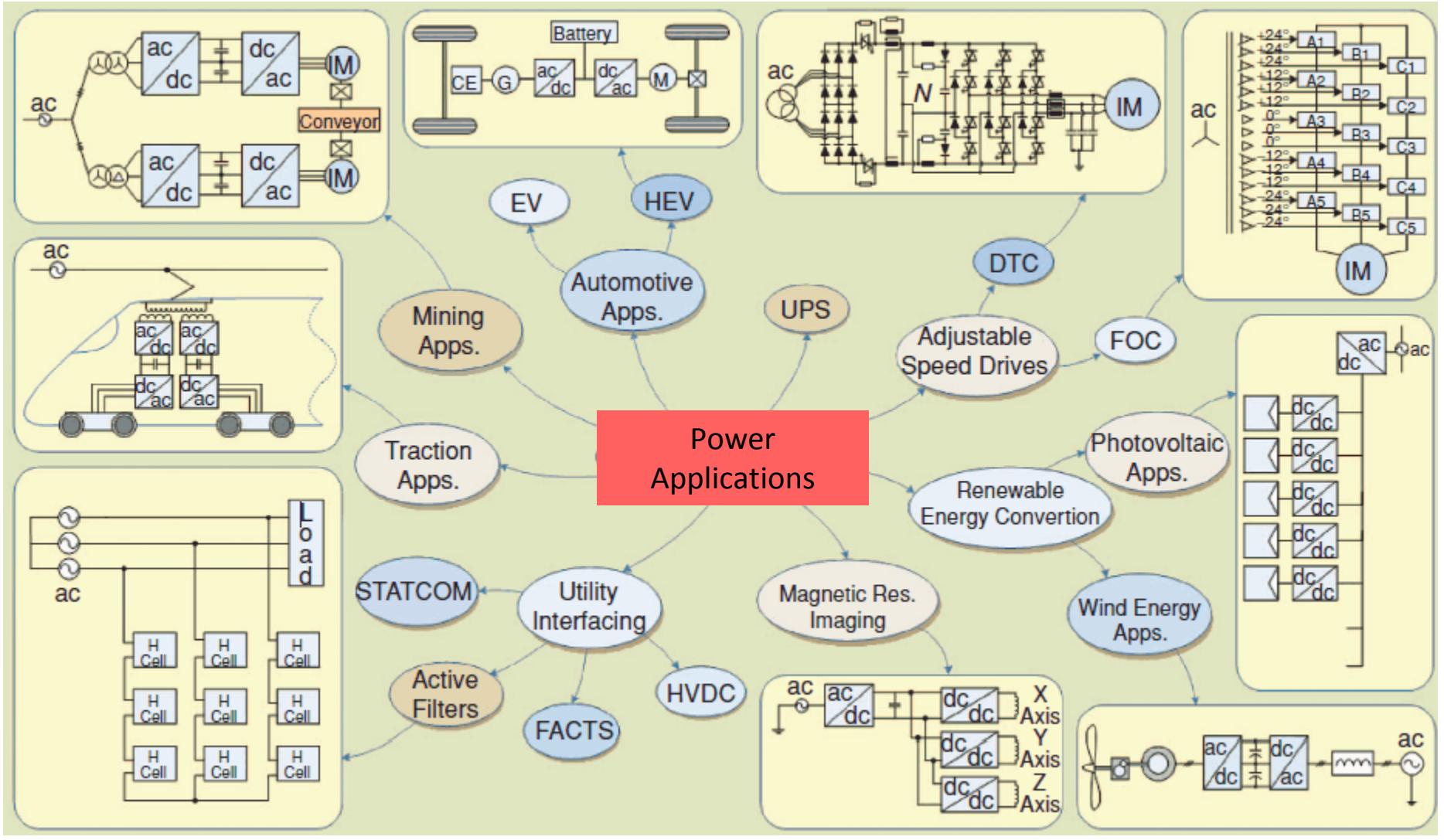
Wafer Map >12 kV PiN Epiwafer







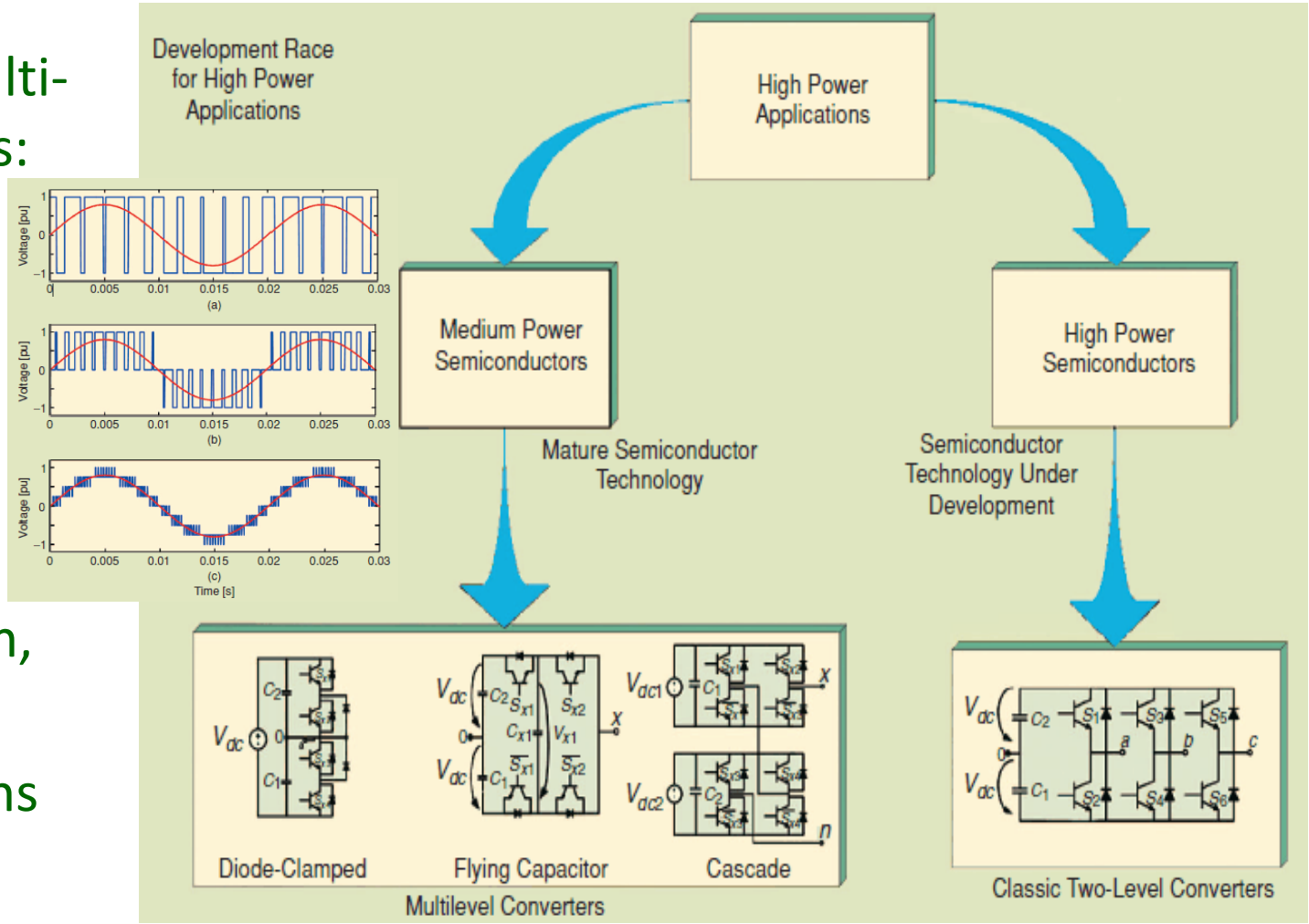
Power Conversion Applications



Options: Multilevel vs Two-Level Converters

Trade-Offs in Multi-level converters:

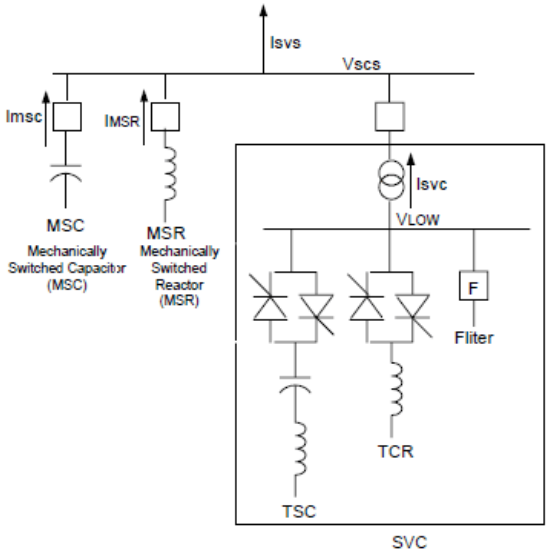
- Efficiency
- Robustness
- Modularity
- Design Implementation, Complexity
- Control concerns
- Fault Tolerance

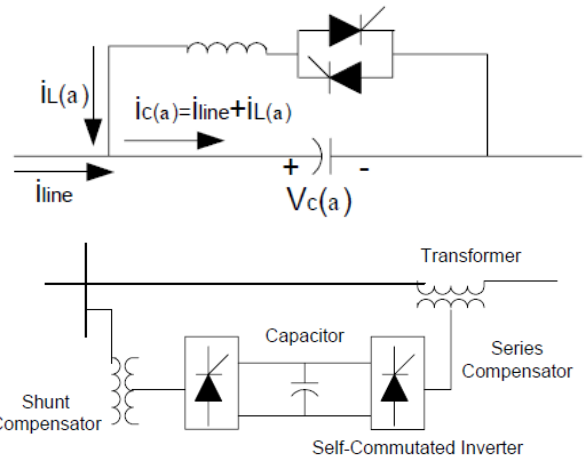


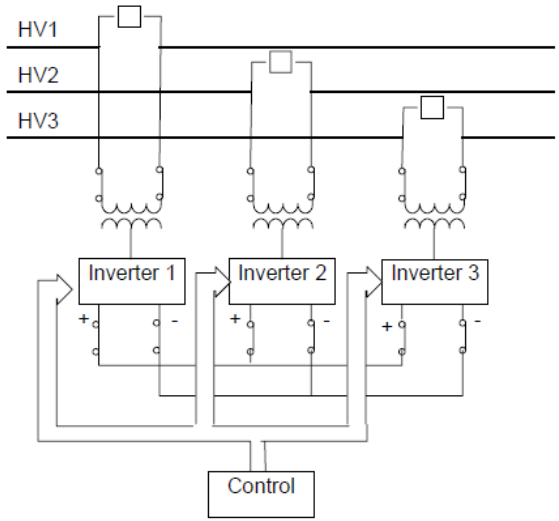
From: Franquelo et al.

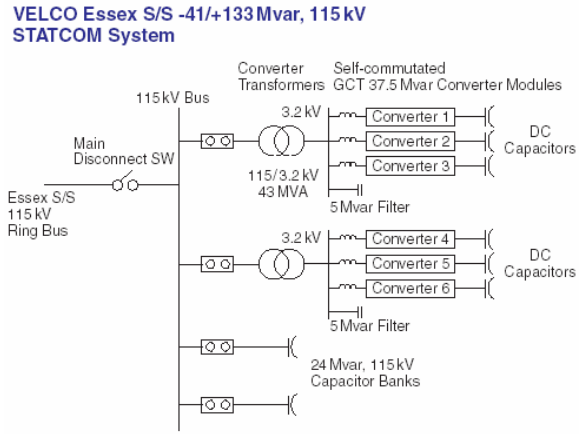
FACTS and HVDC – HV, Thermal, HF limits

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



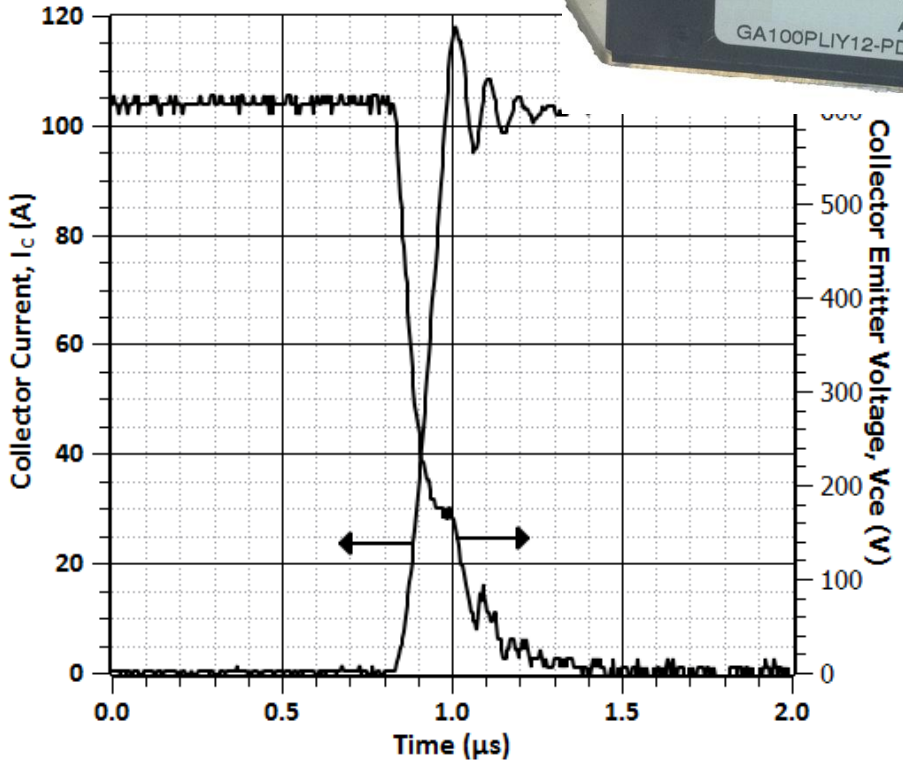


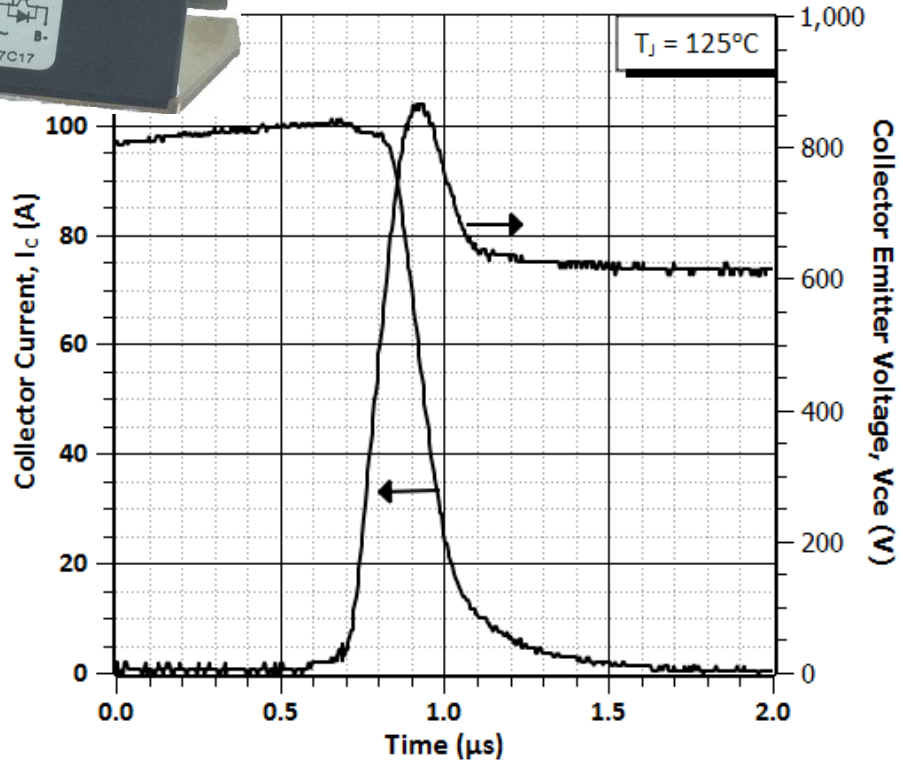




From: Tolbert et al.

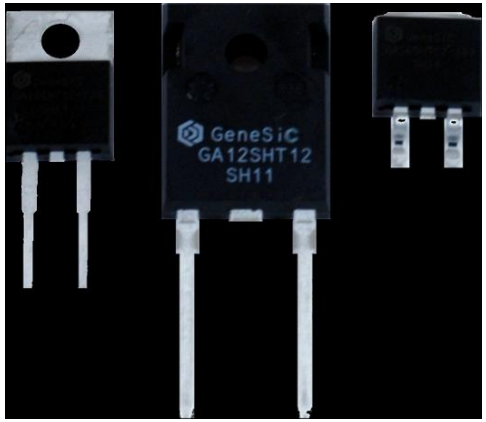
Si IGBT / SiC Rectifiers – Rectifiers are Key!

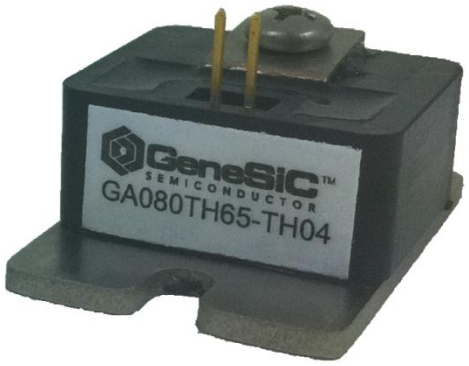




GeneSiC's offerings/under development

- 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

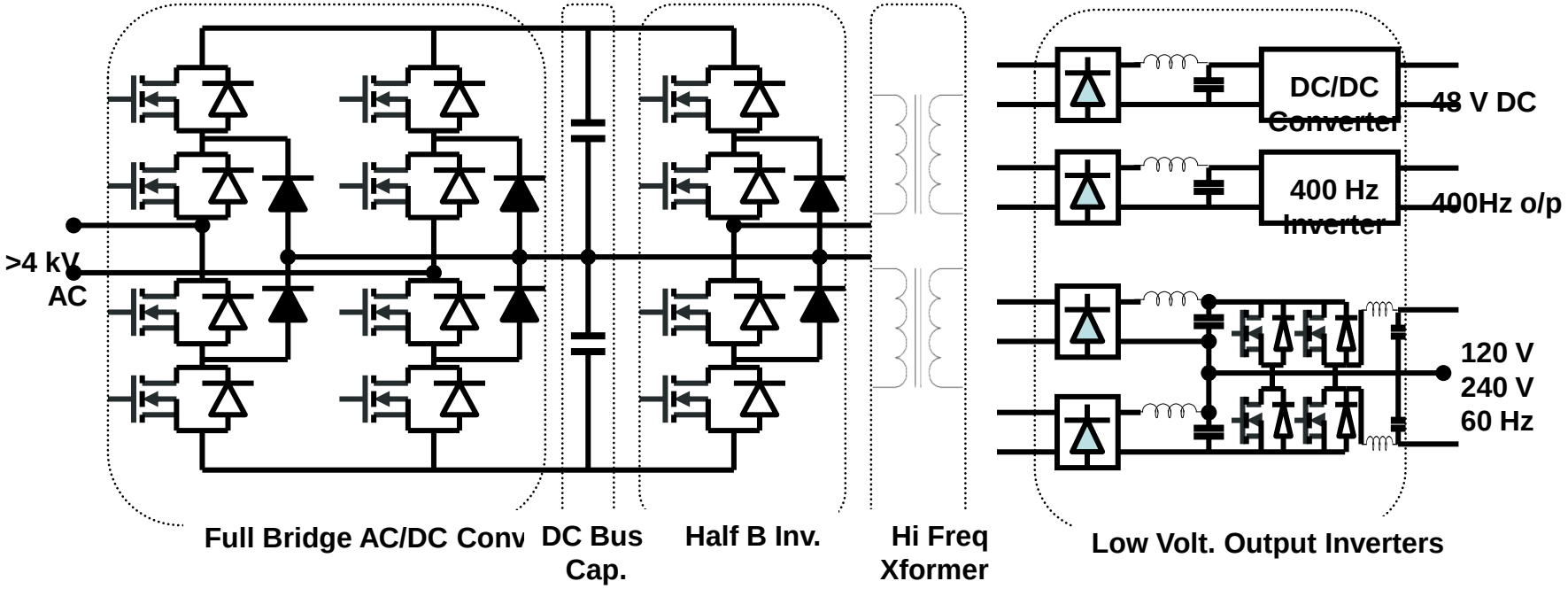




GeneSiC Nationwide/Worldwide Distributors/Sales Representatives

- 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