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Applications for Wide Band Gap devices

Perspectives from ABB

Georgios Demetriades, Francisco Canales, **Sandeep Bala**, Andrea Bianchi, and Fabio Tombelli

ABB: A Pioneering Technology Leader

Company Snapshot

Businesses

Electrification

Industrial Automation

Motion

Robotics & Discrete Automation

Power Grids

Customers

Utilities
35 % of revenues

Industry
40 % of revenues

Transportation & infrastructure
25 % of revenues

Offerings

Products
– 58%

Systems
– 24%

Services
– 18%

ABB: Power converters portfolio

From a few-watts to hundreds of mega-watts

Power supply and UPS

Solar inverter and EVCI

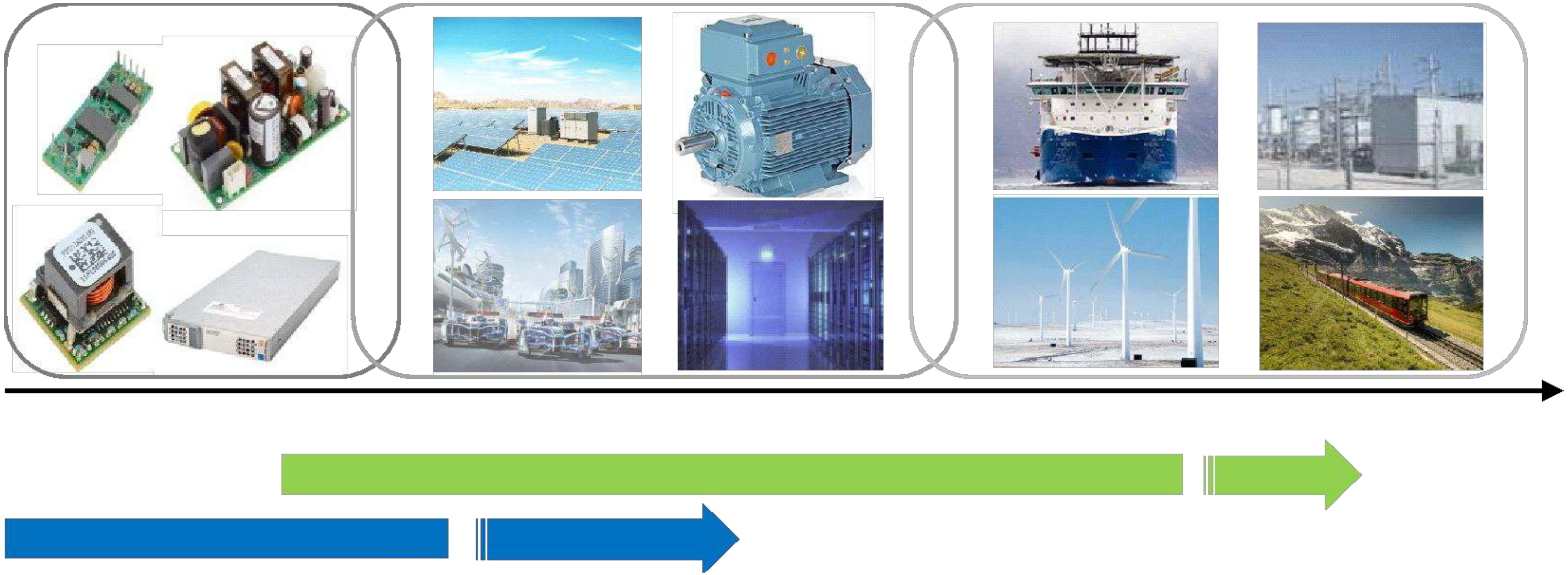
Drives and wind converter

STATCOM, FACTs, HVDC

Large portfolio of power converters for different applications

ABB: Potential applications for Wide Band Gap devices

And available choices at different voltage levels



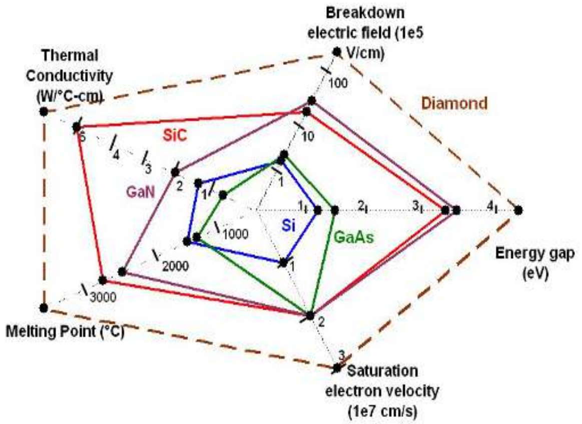
Challenge: Delivering higher customer value while maintaining reliability and profitability

Figure adapted from: Yole Developpement, *“Si IGBT and SiC: which repartition for power devices?,”* APEC, March 2016

Applications for Wide Band Gap devices

Challenges and opportunities

Theoretical benefits



Physical Characteristics

WBG materials permits the devices to operate at :

- 10x higher blocking voltage
- 3x higher operating temperature
- 10x higher switching frequency
- 3x higher current density

Negligible switching losses – Higher efficiency

Challenges

High-current

- High dv/dt and di/dt
- Faster protection

High blocking voltage

- How to handle faults
- Insulation breakdown

High temperature

- Temperature compatibility
- High thermal fatigue

Power Integration

Issues to be addressed

High current

- Increase current density
  - Larger chips
  - etc
- High temperature
  - High temperature packaging
- Reliability
  - Increase the maturity
- Cost , cost , cost

Starting to realize these benefits in products

Applications for Wide Band Gap devices

Products launched

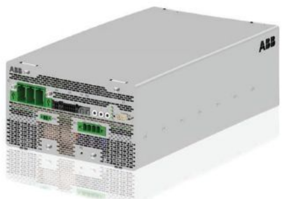
Products using Wide Band Gap devices

SiC MOSFET - 10 kW battery charger for trains

- Faster switching
- Higher temperatures
- High voltages
- Lower losses

$\underbrace{\hspace{4cm}}$

compared to today's Silicon devices



Volume reduction: **factor 10**
Weight reduction: **factor 8**

- Smaller passive components: transformers, inductors, capacitors, coolers, etc.

Primary customer driver	– Size, Weight – Efficiency – Wider temperature operating range
Key specifications	– 9.45kW @ 45°C – 37.8kW in parallel – η = 5% higher than prev. generation – 1kW/kg, 0.9kW/l – Output Voltage R1- 51-137.5V – Output Voltage R2 - 16.8-46V
Technology highlights	– Circuit topology – Integration technologies – System optimization – Silicon Carbide devices

Product launched in 2016

Products using Wide Band Gap devices

SiC MOSFET - 1-ph and 3-ph solar PV string inverters

Product	1-ph	3-ph
PV string inverters	5-6 kW 	100-185kW 
Boost stage	SiC diodes	SiC MOSFET discretes, modules
Inverter stage	SiC MOSFET modules	

Primary customer driver	– Reduced space/weight – Increased performance – Lower system cost
Key specifications (PVS-175-TL)	– 1500 Vdc @ 800 Vac □ 175 kVA @ 40 °C, 185 kVA @ 30 °C – 600 V to 1500 Vdc – 98.7% ηmax, 98.4% ηCEC – 12 independent MPPTs – IP65 (IP54 for cooling section) – 76 kg per module
Technology highlights	– All in one solution with integrated DC/AC recombiners – Fuse free design – Modular construction - detachable power module

Products launched 2016-2018

Products using Wide Band Gap devices

SiC MOSFET - 50kW EV charger

ABB Terra54 HV Dc Charger

- Extended dc capability up to 1000Vdc output
- Lower system cost
- Improved overall efficiency
- Lower acoustic noise emissions
- From discrete to module
- Expensive discrete ISOTOP IGBT replaced by custom SiC modules

Primary customer driver	– Lower system cost
Key specifications	– 50kW – 200-1000Vdc @ 125Adc max – >95.5% Ac/Dc efficiency – 1200x565x1900 mm – Multiprotocol (Chademo + CCS) – EMC class B
Technology highlights	– Single stage HF isolated resonant Ac-Dc converter

Product launched in 2018

Applications for Wide Band Gap devices

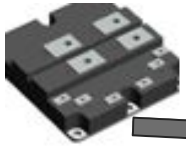
Recent R&D efforts

Recent R&D efforts with Wide Band Gap devices

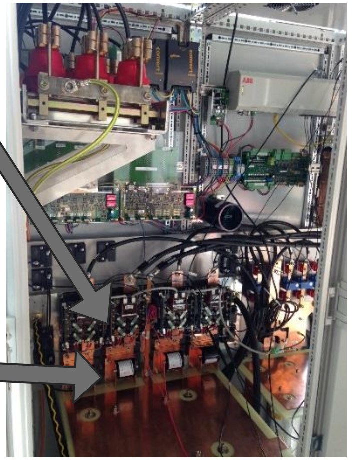
MV SiC MOSFET utilization - 240kVA modular cell for Solid State Transformer

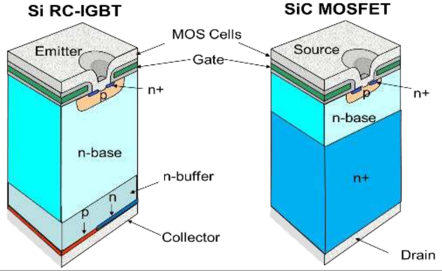
Fast Si IGBTs and Si Enhancement Trench BIGTs and SiC MOSFETs – BXS with 50% Si/SiC active area

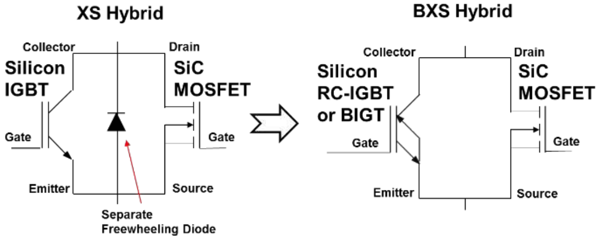
LinPak
3.3kV modules



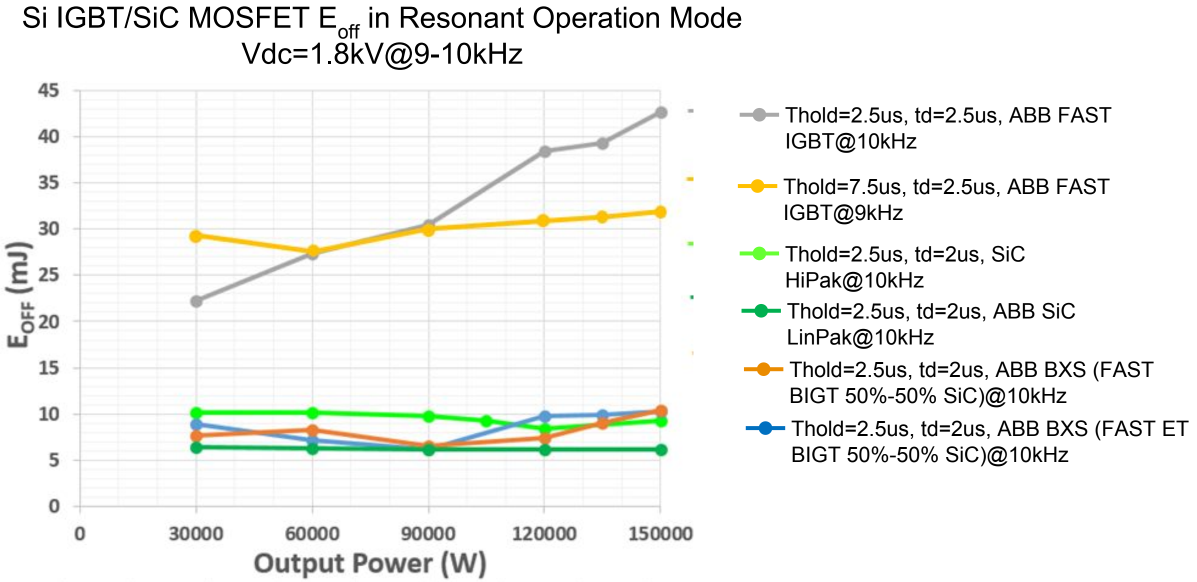
E1
3.3kV modules







Experimental measurements: Turn-off losses



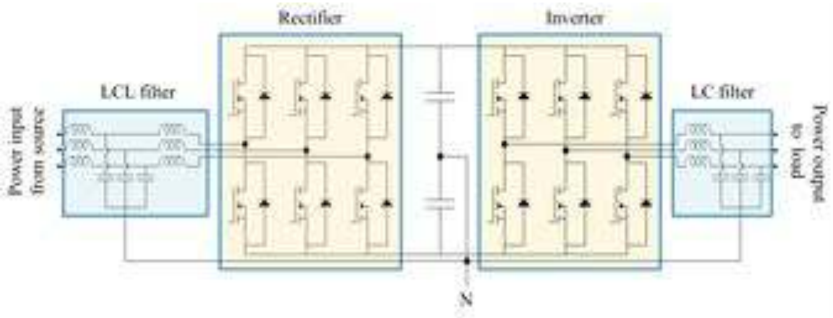
SiC Provides 30-35% Higher Power but BXS provide 20-25% Higher Power at Reduced Cost

R&D demonstration completed in 2016

Recent R&D efforts with Wide Band Gap devices

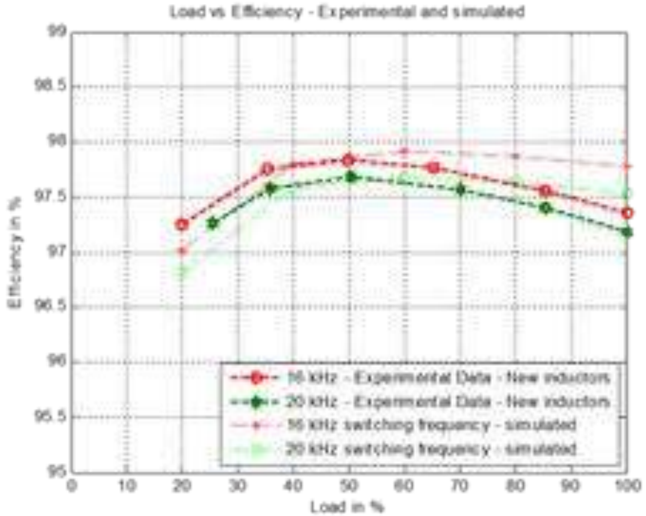
SiC MOSFET Utilization- 100kW rectifier-inverter system

Schematic



Demonstrator

Performance



50% lower losses vs prior generation
20% lower losses vs latest Si technology

R&D demonstration completed in 2017

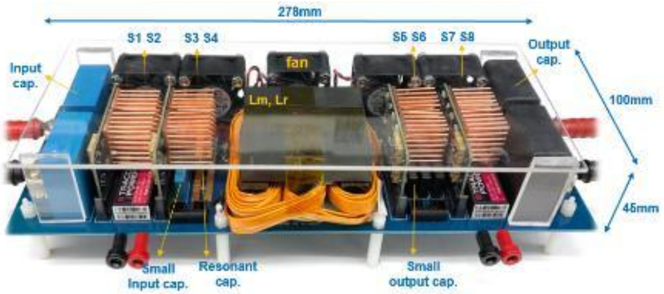
Effort partly funded by DOE/PowerAmerica

Recent R&D efforts with Wide Band Gap devices

GaN HEMT application explorations, in collaboration with universities

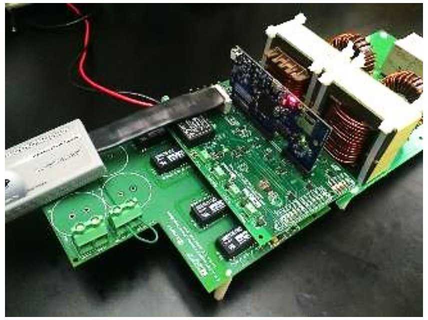
400V in, 10kW LLC converter – VT

LLC with synchronous rectifier
- 400 kHz resonant
- 150…500 V output
- η_{pk} = 98.0% (incl. filters)
- 8 kW/L



400V in, 4.5kW 1-ph inverter – UTK

1-ph inverter
- Tested up to 4.5 kW
- 130 kHz switching frequency
- η_{avg} > 97.0%



400V in, 10kW 3-ph inverter – OSU

2L 3-ph inverter
- 10 kW, 400 Vdc
- 50 kHz
- η_{pk} = 98.7% (excl. filters)

Total box volume: 14.6 cm * 9.3 cm * 5.2 cm = 0.706 Liter

R&D demonstrations completed 2016-2018

Applications for Wide Band Gap devices

Technology Challenges - Observations from R&D activities

Applications for Wide Band Gap devices

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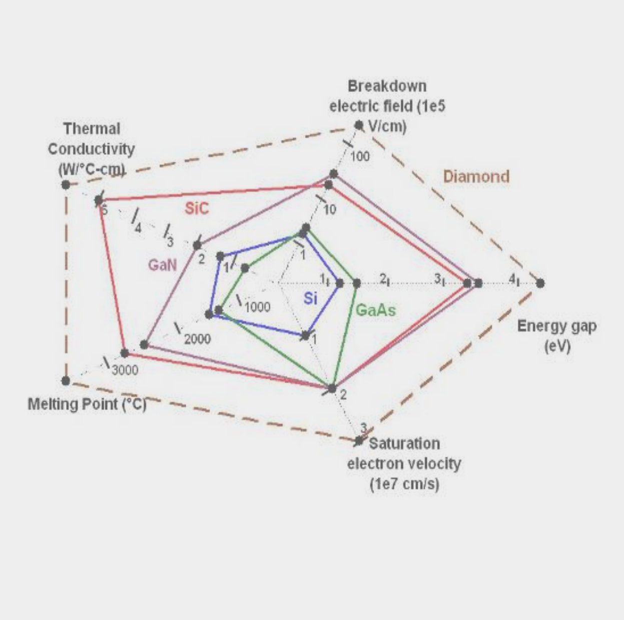

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  - Larger chips
- High temperature
  - High temperature packaging
- Reliability
  - Increase the maturity
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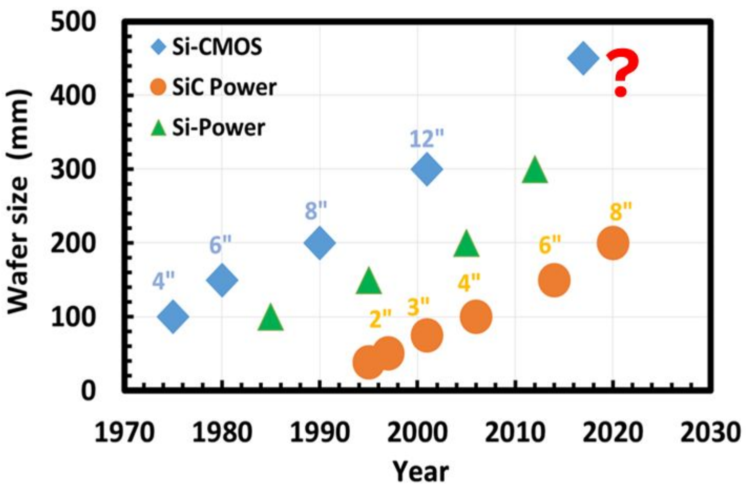
Challenges with Wide Band Gap devices

Cost reductions

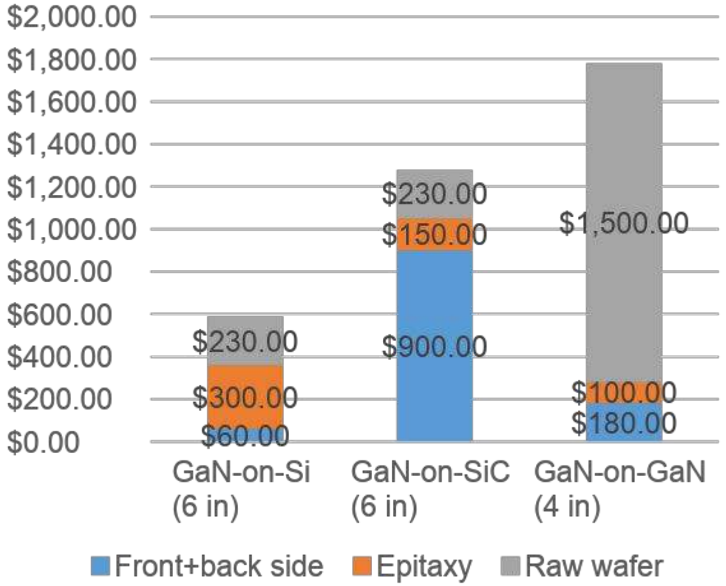
Cost determining factors

– Yield
– Epitaxy thickness
– Wafer size
– Production volume
– Competition

Wafer size projections for Si, SiC



Cost gap for vertical GaN



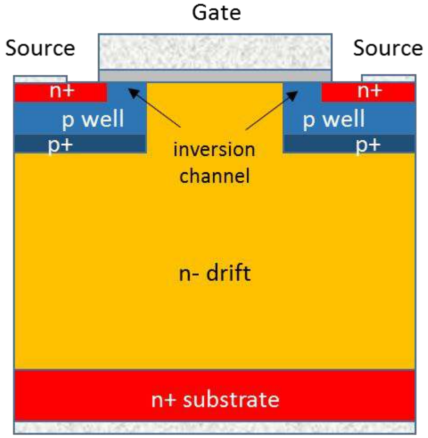
Costs need to decrease further for wider adoption

Ref. SystemPlus consulting, https://www.acreo.se/sites/default/files/pub/acreo.se/Events/SCAPE_2018_Presentations/Workshop/Day_2/7_elena_barbarini_system_plus.pdf

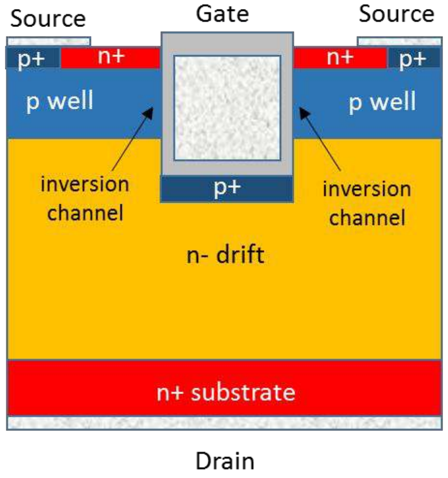
Challenges with Wide Band Gap devices

SiC MOSFETs: Cell design, Short Circuit performance - Ron trade-offs

Ron improvement - Planar vs trench design



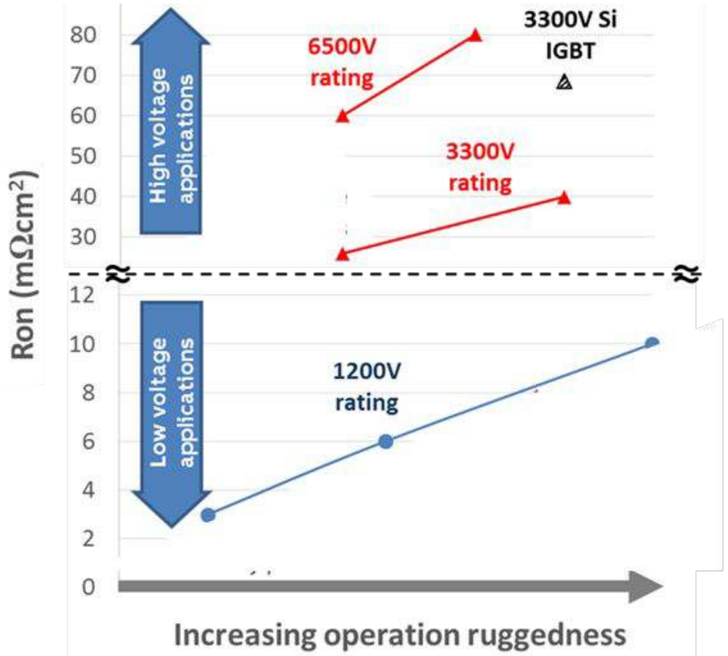
Planar cell



Trench cell

Still best in class Ron	Ron improvement
Simpler processing	Increased fabrication complexity

Ron vs operation ruggedness (experimental)



Strong trade-off between Ron (static losses) and operation ruggedness

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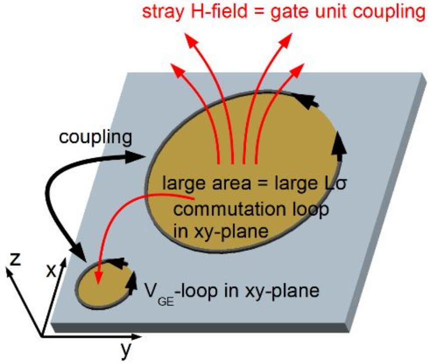
Challenges with Wide Band Gap devices

Towards reliable HV/MV Power Module: High Frequency and High Temperature Requirements

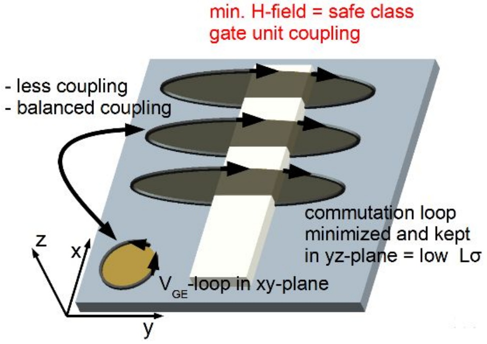
Optimized high performance module

- **Fast switching capability**
  - Low stray inductance (Lσ)
  - Well-balanced current sharing
- **High temperature operation**
  - Packaging and Interconnection technologies

Conventional Package

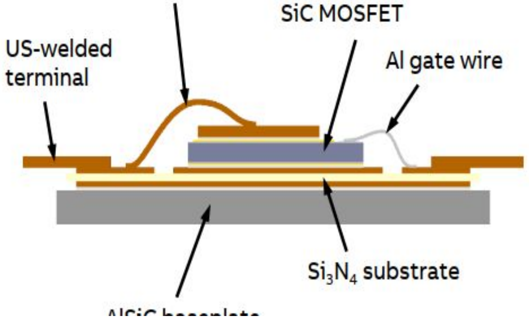


Strip-Line Concept

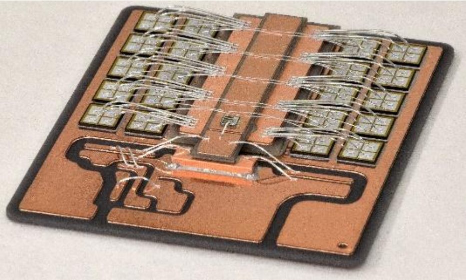


Optimal layout design

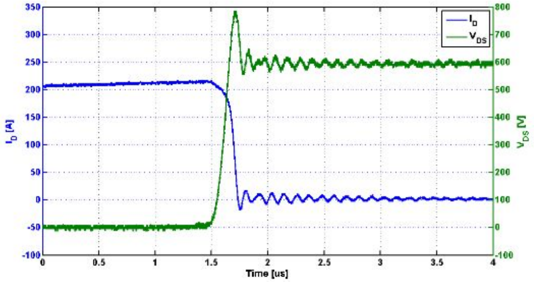
Cross-section of the power module concept



Module assembly ready for terminals bonding

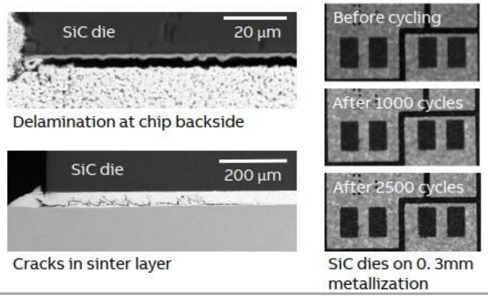


Turn-off switching characteristics

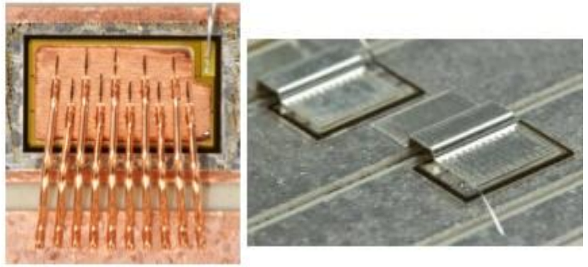


Reliable interconnection technologies

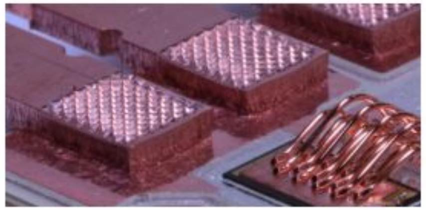
AG-sintering for die attach



Topside interconnection



US welded Cu terminals



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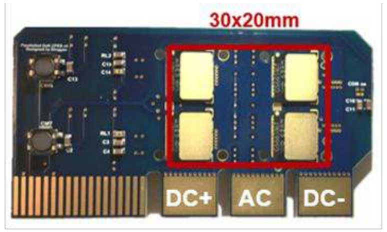
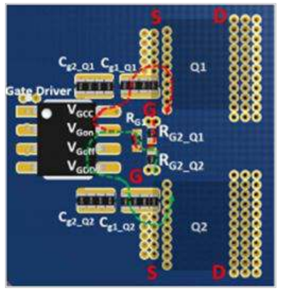
Challenges with Wide Band Gap devices

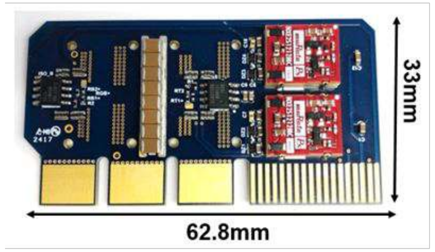
Controlling parasitics in circuit-level layout

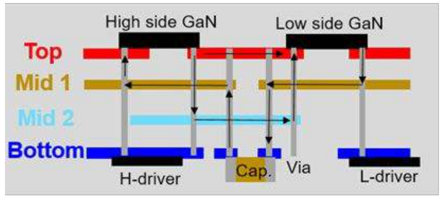
Minimize parasitics in both gate loop and power loop
- Shorten PCB traces as much as possible
- Takes advantage of magnetic field self-cancellation

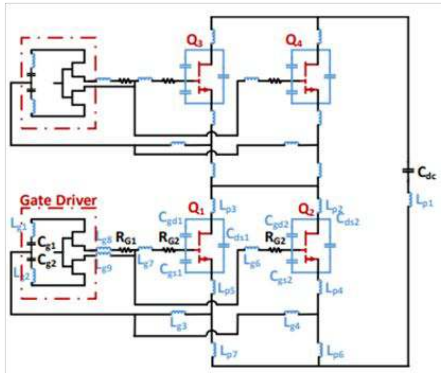
Symmetrical design for paralleled devices
- Split gate resistors to attenuate gate loop differences
- Split decoupling capacitors around each paralleled device gate loop









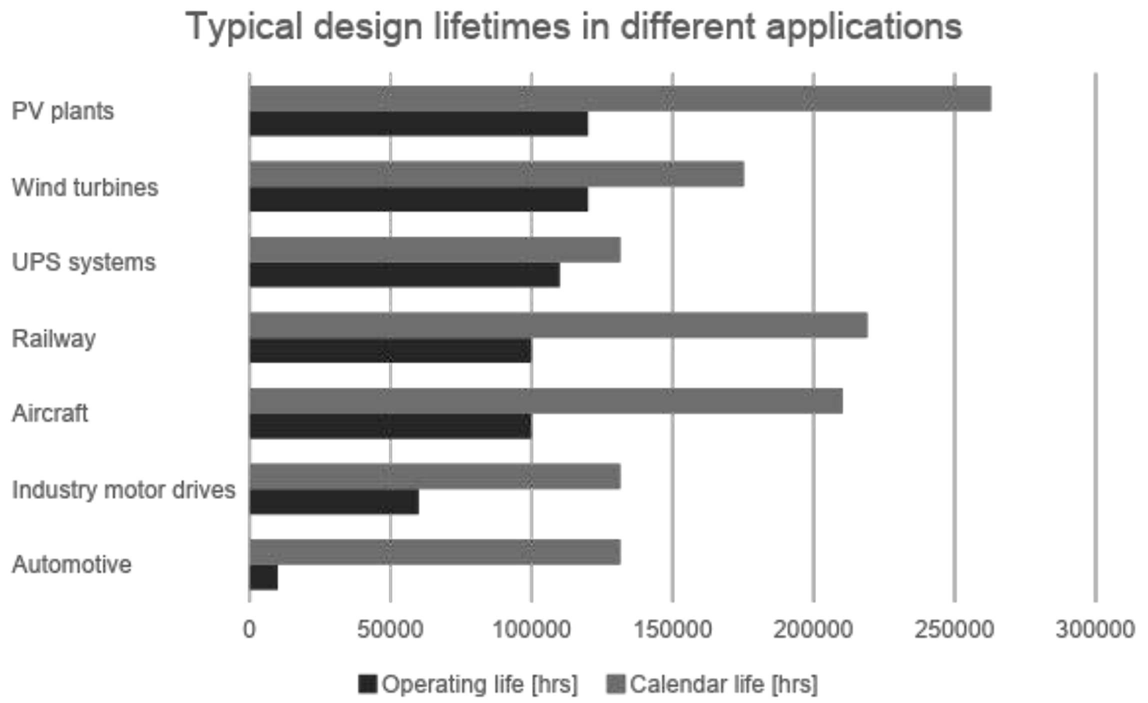


Paralleling while high speed switching requires special care

Challenges with Wide Band Gap devices

Reliability qualification tests

- JEDEC new standard for WBG devices is being developed
- Depending on application, may need to qualify devices for performance under:
  - High temperature reverse bias (HTRB)
  - High temperature gate bias (HTGB)
  - High temperature, high humidity and high reverse bias (H3TRB)
  - Thermal cycling (TC); Power cycling (PC)
  - Unclamped inductive switching (UIS)
  - Short circuit tests (SC)
  - Cosmic rays
  - Vibration; Mechanical shock



Qualification needed for each application with their different utilization levels, mission profiles, design lifetimes

Applications of Wide Band Gap devices

Outlook for ABB

Applications of Wide Band Gap devices

What needs to happen for widespread adoption

Typical ABB customer drivers

Application	Demand
Power supplies / datacenters	Improved efficiency and size at lower system cost
EV chargers	Lower system cost at acceptable efficiency
Solar inverters	Lower system cost with good reliability
Onboard units (trains, ships)	Reduced space/weight requirements for power converters
Motor drives	Higher speed/bandwidth drives (potentially new functionality)
Embedded power converters	Reduced board space at acceptable cost
Medium voltage utility applications	Improved efficiency with improved reliability

Necessities for wider WBG adoption

Improved technology, enabled by

– New package designs

– Advanced protection capabilities

Demonstrated reliability, enabled by

– Stringent, standardized tests

– Field experience

Lower costs, enabled by

– Larger wafer sizes and increased production volumes

– Improvements in processes