PowerAmerica

Budget Period 2
Kick-Off Quad Charts

ABB Inc, Corporate Research

Affiliate Member

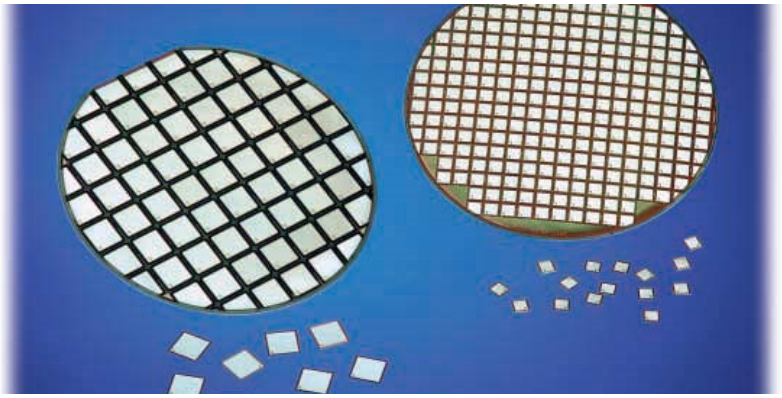
Project Title: 3.3 kV SiC MOSFET Device Development

Objectives: Qualify 150mm Si foundry for SiC processing

Major Milestones: Processed lot with >75% yield at wafer level

Significant Equipment Acquisition: N/A

Deliverables: Process developed, pathways determined for cost reduction in future budget periods.



SOPO Task No.: 2.12
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WBG Technology Impact

1. SiC MOSFET would challenge the Si IGBT technology, currently dominating at 3.3kV level
2. Market segments impacted: traction, motor drives
3. Timeframe for commercialization: pending better understanding of the manufacturing cost roadmap
4. This project will enable the Institute and ABB to evaluate in real applications the benefits of SiC devices at system level

e.g. improved powder density compared to Si devices,

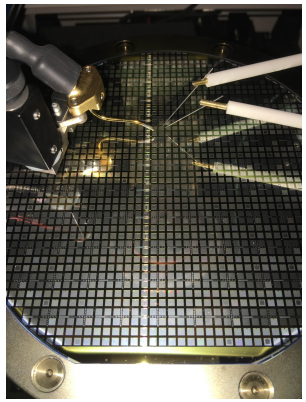
More WBG Impact and Additional impacts

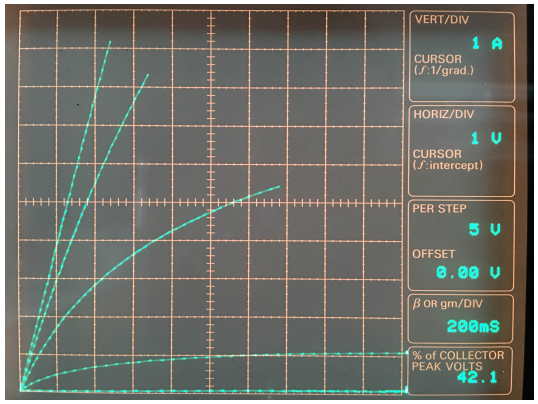
1. Impact on the cost of SiC compared to Silicon by using a foundry model

2. Potential for Job Creation & Economic impact – at the foundry

Project Title: *Integrated SiC MOSFET and JBS Diode*
Objectives: *The integration of the JBS diode with the 1.2kV Power MOSFET*
Major Milestones: *Fabrication of 1.2kV JBS diodes, MOSFETs, and JBSFETs*

Significant Equipment Acquisition:
Deliverables: *1.2kV/5A Power MOSFET containing integrated JBS diode with specific on-resistance of less than 12mOhm-cm^2 and leakage current < 5mA*





SOPO Task No.: 2.8.2
TPOC: Dr. B. J. Baliga
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WBG Technology Impact

1. This approach will save 40% chip area.
2. Simple process with 10-mask.
3. This approach will reduce the number of packages in half bringing down the cost of implementing this technology in power converters.
4. It will improve efficiency and increase switching frequency by eliminating the parasitic inductance between separately packaged devices.

More WBG Impact and Additional impacts

1. Impact on the cost of WBG compared to Silicon
2. Potential for Job Creation Economic impact
3. Workforce Development and Education if applicable

Project Title: *Novel Edge Termination for High Voltage SiC Devices*

Objectives: *Development of edge terminations for 3.3 and 4.5kV SiC devices with reduced space on the die surface*

Major Milestones /Deliverables: *Diodes using proposed edge terminations with 3.3 and 4.5kV blocking voltages fabricated with leakage currents < 1 mA/cm^2 normalized to total chip area.*

SOPO Task No.: 2.8.3
TPOC: Dr. B. J. Baliga
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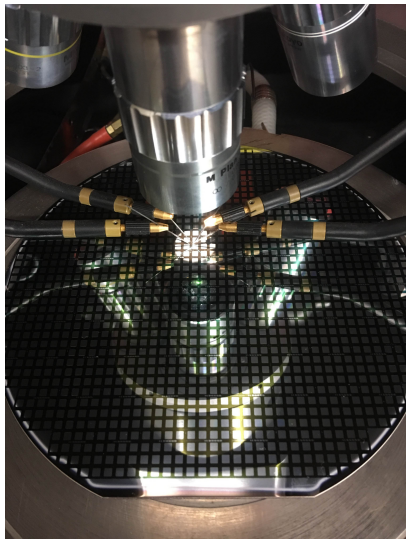


WBG Technology Impact

1. For discrete high voltage power devices, the edge termination, located at the periphery of the active area, can occupy 50% of the chip area.
2. This subtask will focus on development of edge terminations for 3.3 and 4.5kV SiC diodes with reduced space on the die surface.
3. Approaches to reduce the number of processing steps will be emphasized to reduce the cost of manufacturing of the devices.

More WBG Impact and Additional impacts

1. Impact on the cost of WBG compared to Silicon
2. Potential for Job Creation Economic impact
3. Workforce Development and Education if applicable

Project Title: **WBG Power Semiconductor Device Packaging and Characterization**

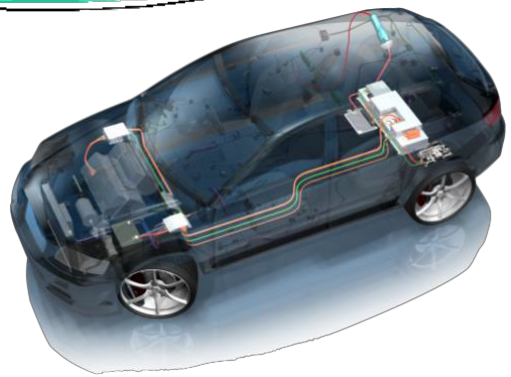
Objectives: **Develop WBG Packaged Device for Traction Drive Inverter**

Major Milestones:

M4.5.1 OEM Customer Specifications (Month 2)
M4.5.2 Detailed Device Specification (Month 4)
M4.5.3 Package Layout and Design Complete (Month 6)
M4.5.4 Build, Test and Characterization of Device (Month 12)

Significant Equipment Acquisition: Non Planned

Deliverables: Packaged Device and Characterization Data



SOPO Task No. 4.5:
TPOC: Name Monty Hayes
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WBG Technology Impact

- Reduce energy losses over vehicle drive cycle
- Reduce system cost and size/weight, compared to state-of-the-art Si IGBT devices
- Will commercialize WBG devices for automobiles and light-duty trucks, and potentially other applications
- Will contribute to US job growth, supply chain development utilizing skilled US workforce

More WBG Impact and Additional impacts

- Will help to drive demand for WBG devices, lowering system cost compared to Si devices
- Create additional U.S. jobs by growth of electrification products mfr'd in the U.S.
- Will provide opportunities for internships and workforce development related to the manufacturing of power electronics products in the US for vehicle electrification globally

GeneSiC Semiconductor Inc.

Startup Member

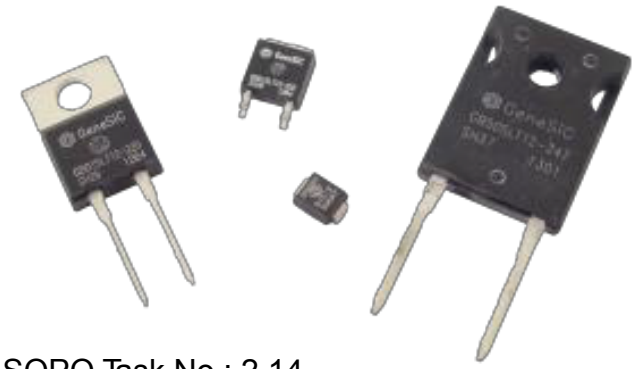
Project Title: Transfer of 1.2 kV diode process to a 150 mm Foundry line for Commercialization

Objectives: Achieve state-of-the-art performing SiC Schottky diodes at X-Fab

Major Milestones: Achieve low leakage current; low on-resistance, on 1200 V SiC Schottky Diodes

Significant Equipment Acquisition: N/A

Deliverables: 1200 V SiC Rectifiers on 150 mm SiC wafers



SOPO Task No.: 2.14
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SiC Schottky Rectifiers Impact

1. GeneSiC offers SiC devices with well known performance advantages over Si and other SiC counterparts.
2. Applications: UPS Inverters, Power Supplies, Chargers, Motor Drives, Automotive
3. Key Outputs: Qualified 1200 V SiC MPS Recitiers
4. GeneSiC will commercialize the widest range of SiC offerings, capitalizing on the 150 mm foundry model to advance the technology at lower cost.

More WBG Impact and Additional impacts

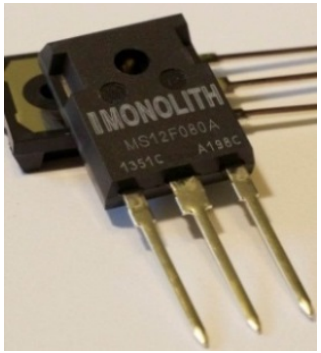
1. Switching and robustness of GeneSiC's SiC Schottky rectifiers are 5-10X superior to best-in-class Si devices
2. All GeneSiC employees are US-based. The company continues to grow and hire additional personnel with little prior WBG experience, train them in the area of WBG, as it has done in the past.
3. GeneSiC will continue to host graduate and undergraduate level interns as it has done over past 12 years.

Project Title: 1.2kV Diode Commercialization and Production

Objectives: Commercialization of 1.2kV SiC diodes at X-Fab Texas

Major Milestones: Availability of diode engineering samples manufactured at X-Fab

Significant Equipment Acquisition: None
Deliverables: Engineering samples to partners



SOPO Task No.: Task 2.4
TPOC: Kiran Chatty
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Phone: 802-238-4163

WBG Technology Impact

1. Reliable, low-loss SiC switches and diodes manufactured in high volume fab at low cost.
2. Applications : Solar inverters, motor drives, power supplies, automotive.
3. Timeframe for commercialization: 2016

More WBG Impact and Additional impacts

1. Current SiC switches and diodes are >5x expensive compared to silicon, Monolith's HV switches will enable cost within 1.5-2x of silicon, can reach cost parity.
2. Create semiconductor manufacturing jobs in US.

Naval Research Laboratory

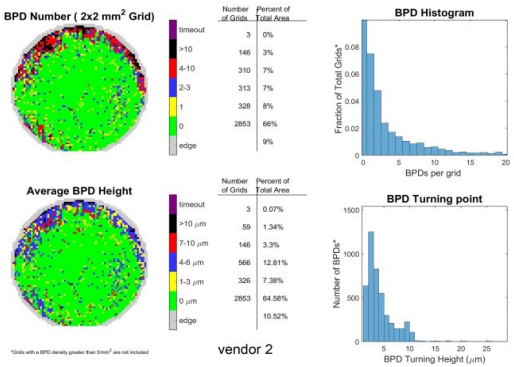
Project Title: Study of Defects in SiC epilayers through Ultraviolet Photoluminescence and Leakage Current Measurements

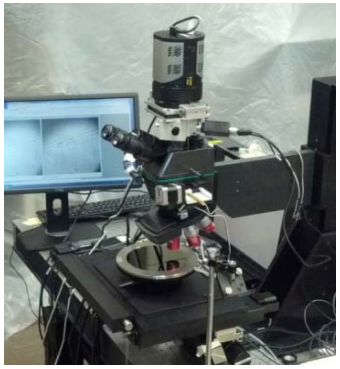
Objectives: Cost effective monitoring device-degrading materials defects such as BPDs

Major Milestones: Show effectiveness of UVPL imaging to diagnose and suppress materials defects

Significant Equipment Acquisition: none

Deliverables: Pre- & post-fab wafers and die analyzed for BPDs and other materials defects





TPOC: Robert Stahlbush
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WBG Technology Impact

1. Market segments impacted: All markets affected by lower cost, higher performance SiC power devices.
2. Timeframe for commercialization: N/A
3. For non-destructive detection and tracking of materials defects in SiC epi that adversely affect devices, the imaging systems that NRL has developed are the state-of-the-art. NRL will aid fab partners to cost effectively suppress these materials defects.

More WBG Impact and Additional impacts

1. Cost effective screening of materials defects in SiC will increase wafer yield and decrease die costs.
2. Job creation economic impact comes by helping fabrication partners more quickly control materials defects.
3. TRLs for UVPL imaging N/A.

United Silicon Carbide, Inc.

Affiliate Member

Project Title: USCI 6inch SiC Foundry Based Products

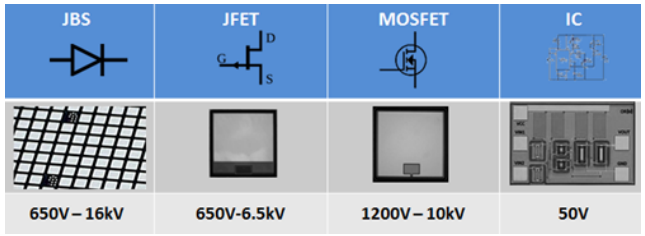
Objectives: Enable 6inch SiC foundry

Major Milestones: Qualify JBS Diodes, Setup MOSFET process

Deliverables from 6inch foundry Year 1:

- Qualified 100A, 1200V JBS.
- Samples 1200V, 40m MOSFETs

USCi
United Silicon Carbide, inc.



SOPO Task No.: 2.2
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Phone: 408 506 1987

WBG Technology Impact

1. USCi offers SiC devices with well known performance advantages over their Si counterparts.
2. Applications: Power supplies, Chargers, UPS, Inverters, Motor Drives, Automotive, Avionics, Rad-hard
3. Key outputs Yr 1: 1200V JBS Diodes 2016, 1200V MOSFET
4. USCi will bring to market a range of SiC products exploiting the 6inch foundry model to drive both technology and cost – accelerating market growth for SiC.

More WBG Impact and Additional impacts

1. Transition of 6inch, combined with technology improvement will lead to 2-4X ASP reduction with volume.
2. Impact on US and world wide energy efficiency will be significant.
3. SiC power business growth creates employment opportunities for SiC supply chain providers, as well as advanced system developers.

CREE

Full Member

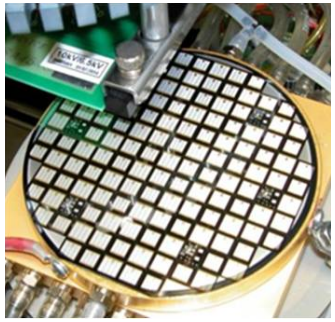
Project Title: **HTRB of 3.3kV/10kV SiC MOSFET & 10kV SiC JBS Diode & 3.3kV SiC Module**

Objectives: **Establish Manufacturable Fab Process & HTRB Qualification of 3.3kV/10kV SiC MOSFET & 10kV SiC JBS Diode & Demo 3.3kV SiC Module**

Major Milestones: **Complete HTRB Qualification of 3.3kV/10kV SiC MOSFET & Demo 3.3kV SiC Module**

Significant Equipment Acquisition: **Establish 3.3kV/10kV SiC Device HTRB Test Capability**

Deliverables: **3.3kV & 10kV SiC MOSFETs, 10kV SiC JBS Diodes, 3.3kV SiC Modules, Datasheets, HTRB Test Results**



10kV/350mΩ SiC MOSFETs On 100 mm 4HN-SiC Wafer

3.3kV/10mΩ SiC Half H- Bridge Evaluation Module

SOPO Task No.: **2.3**
TPOC: **David Grider**
Email: **david_grider@cree.com**
Phone: **(919) 407-5345**

WBG Technology Impact

1. **3.3 kV & 10 kV SiC MOSFET Technology Provides Improved Efficiency & Increased Switching Frequency for Medium Voltage Power Applications**
2. **Potential Applications: MV Motor Drive, UPS, Data Center Rail Traction, Solar Inverter, EV Charger, Grid-HVDC/SST**
3. **Commercialization Timeframe: ~ 2 years**
4. **Establish Manufacturable Fabrication Process & Complete HTRB Qualification ⇒ Critical Transition for Commercial Production of 3.3kV/10kV SiC Power Technology for Improved Efficiency & Higher Switching Frequency for MV Power Applications**

Additional Impacts

1. **Considerations for Cost of 3.3kV/10kV SiC Power Technology Compared to 3.3kV/6.5kV Si Power Technology**
   - **Reduced Balance of System Costs Resulting in Lower Total System Costs**
   - **Reduced System Size/Weight**
   - **Simplified/Reduced Cooling Requirements**
   - **Reduced Cosmic Radiation Sensitivity Enabling Higher Voltage Operation**
2. **Leading 3.3kV/10kV SiC Power Technology**
   ⇒ Early Supplier For MV Power Systems
   ⇒ Address ~ $800M/Yr MV Power Market

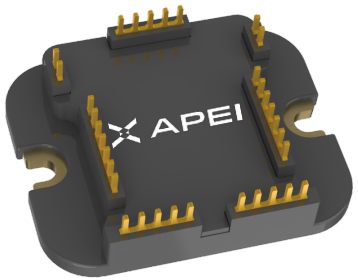
Project Title:
Power Module Development and Manufacturing

Objectives:
Improve packaging foundry test / automation and commercialize additional power modules for 1200 V, 1700 V, & 3.3 kV SiC devices

Major Milestones:
Compact H-bridge power module (1200 V, 50A)
High performance half-bridge module @ 1700 V
Design/develop 3.3 kV module & gate driver

Significant Equipment Acquisition: None

Deliverables: New product releases to market



SOPO Task No.: 3.1
TPOC: Jared Hornberger
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Phone: 479-443-5759 x8310
BPOC: Ty McNutt, x8170
Email: tmcnutt@apei.net

WBG Technology Impact

1. Increase in efficiency, reduction in size and weight, and increase in capabilities of power electronic systems
2. Market segments impacted: Motor drives, HEVs/ EVs/Automotive, Down-hole, Grid-Tied
3. Commercialization of two industry leading products
4. Packaging designed specifically for WBG enables system cost savings
5. Presentations/literature on technology for industry education

More WBG Impact and Additional impacts

1. WBG high performance modules start to approach legacy Si with economy of scale
2. Job creation through MFG and Qualification focus
3. Publications/app notes/datasheets on high performance module/system design for industry education

X-FAB Texas, Inc. Membership Level: Full

Project Title:
SiC Device Foundry Development

Objectives:
Reduce cost of SiC wafer processing

Major Milestones:
Equipment installed, qualified
Process Installation Kit (PIK) development

Significant Equipment Acquisition:
HT Furnace, BG Tool, BSM Sputter, BS Anneal

Deliverables:
Qual reports, PIK, HT Implant Evaluation

X-FAB SEMICONDUCTOR FOUNDRIES

SOPO Task No.: 2.1
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WBG Technology Impact

1. Advances over silicon, or conventional approaches.
2. Market segments impacted. Application Spaces: (ex. Automotive, motor drives, inverters, etc)
3. Timeframe for commercialization:
4. Quantitatively describe the state of the art and note how this project will provide a significant advance towards WBG based Power Electronics products.

e.g. improved powder density compared to Si devices,

More WBG Impact and Additional impacts

1. Impact on the cost of WBG compared to Silicon
2. Potential for Job Creation Economic impact
3. Workforce Development and Education if applicable

Arizona State University — Academic partner

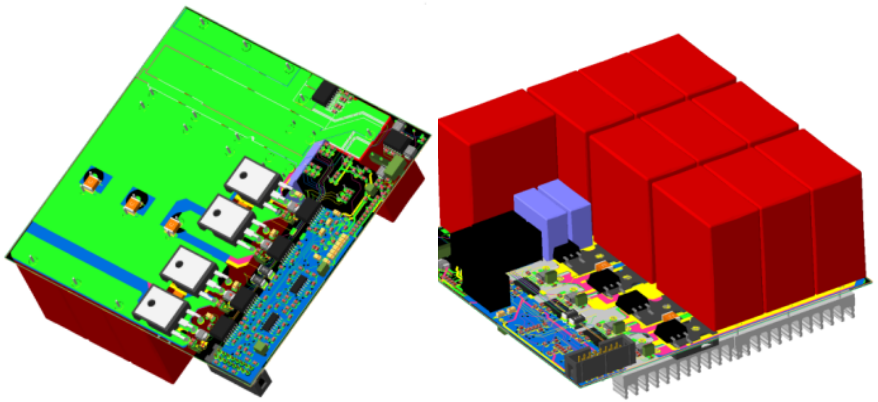
Project Title: **SiC/GaN Based High Performance PV String Inverters and Micro Inverters**

Objectives: **95-97% efficiency, 5-10X vol. reduction, all film capacitors, at fs > 100kHz**

Major Milestones: **Development and validation of architecture and topologies for each type of inverter; demonstration of WBG advantages**

Significant Equipment Acquisition: PV emulators

Deliverables: 3 hardware string and micro inverter prototypes at the target power density and CEC efficiency



SOPO Task No.: 4.15
TPOC: Raja Ayyanar
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WBG Technology Impact

1. Enables 10X increase in switching frequency without compromising efficiency (95-97% CEC) leading to power density improvement by 5X (>8W/in3) in micro, and 10X (> 10W/in3) in string inverters
2. Enables use of high voltage film capacitors (1200V) for 120 Hz power decoupling; develops high frequency magnetics and gate drive solutions
3. Primary market segment impacted is PV string and microinverters, and can be extended to other renewable and transportation applications.

More WBG Impact and Additional impacts

1. Directly supports 1 post doc and 3 PhD students who will potentially be leaders in WBG applications
2. Impacts more than 100 students at ASU through power electronics courses
3. Through Workforce Development and Education tasks, develops several publicly available educational videos on WBG devices and power electronics

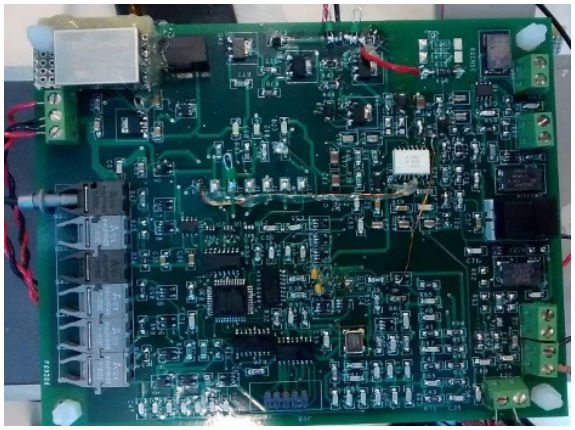
Project title: Medium Voltage Gate Drives

Objectives: To develop a Medium Voltage Gate Drives to enable fast switching of 10 kV SiC power transistors with minimum isolation voltage of 15 kV, should include desaturation protection, junction temperature protection and low capacitance power supply

Major Milestones: Fully functional Medium Voltage Gate Drives

Major Equipment Acquisition:

Deliverables: Demonstration of Medium Voltage Gate Drives operation in boost-buck circuit at 6kV dc, Reports and presentations



TPOC: Subhashish Bhattacharya
Email: sbhatta4@ncsu.edu
Phone: 919-744-1428 (cell)

WBG Technology Impact

- Enables SiC based Medium Voltage converters which are highly efficient compared to Si based converters
- Increases reliability of these high power density converters
- Market segments impacted: High Speed Machines, PV, Wind Energy
- Time frame for commercialization: 2 years
- Easily adaptable to different SiC devices such as 6.5kV JFET, 15kV IGBT

More WBG Impact and Additional impacts

- Reduction in the weight and volume of Si based MV drives using gears for compressor applications
- With large scale production, the cost will come down since the electricity saving is significant
- Potential for Job Creation, Economic impact
- Workforce Development and Education if applicable

Florida State University

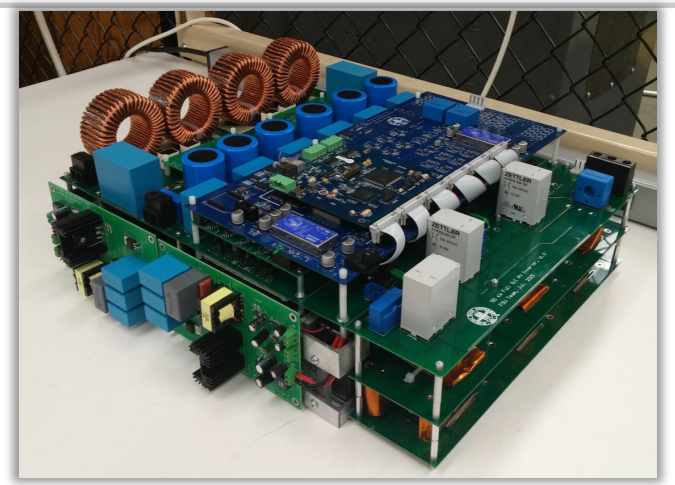
Academic Member

Project Title: PV converter development R&D

Objectives: Develop a 50 kW SiC-based PV converter using 1.2 kV SiC MOSFETs with high efficiency and high power density will be designed, built and demonstrated.

Major Milestones: Topology Development, Converter Paper Design, Ground Leakage Current Suppression Method

Significant Equipment Acquisition: PV emulator; high bandwidth oscilloscope and probes.



SOPO Task No.: 4.10 TPOC: Dr. Hui "Helen" Li
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WBG Technology Impact

By employing WBG devices , the PV converters of target power rating can achieve the goal of high power density (≥ 8 W/in3 & ≥ 1 kW/kg) and high efficiency (≥ 98%) , which is 50% smaller and lighter than the Si-based peers. A new topology and control will be applied to reduce the passive components size and enable the power density goal achieved. The application of 1200V SiC device allows the technology to be quickly transferred to new generation commercial PV converters, therefore accelerate the commercialization pace. The developed technology can be applied to other grid-tied inverters.

More WBG Impact and Additional impacts

1. Manufacturing of new generation PV converters using SiC device will create more job opportunities in SiC industry and inverter industry.

2. To aid in the workforce development, this project will contribute by educating graduate students with WBG circuit design and system design training .

North Carolina State University — Academic Partner

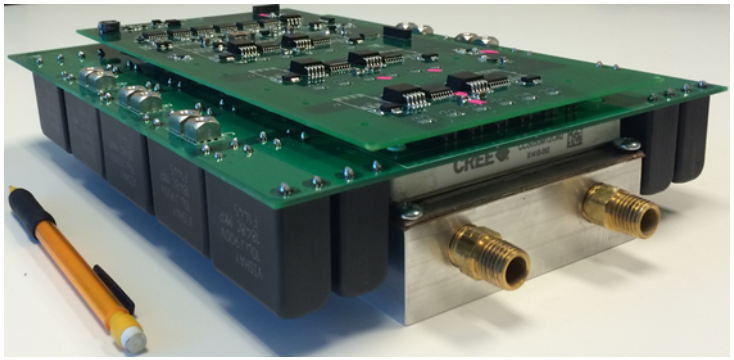
Project Title: SiC Inverter for Electric Vehicle Traction Drive

Objectives: Development of an automotive EV inverter platform using WBG power devices

Major Milestones: Specifications development, gate driver design, Passive component sizing

Significant Equipment Acquisition: Active Load Emulator in BP2

Deliverables:55kW EV Traction Inverter hardware



SOPO Task No.: 4.12
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Phone: (919)-513-5927

WBG Technology Impact

1. Integrated multi-physics design to provide platform for SiC EV inverter development
2. Establish the viability of WBG inverter for Traction applications in an “open Source” manner
3. Improved power density (2.9 times) EV inverter compared to the state of the art (4.1 kW/L) using Si devices

More WBG Impact and Additional impacts

1. Strong teaming opportunities exist with PowerAmerica automotive and industrial drive partners
2. Establish the starting point of commercialization of a new product line for the automotive industry
3. Skilled workforce development for power electronics and motor drives design

Lead Institution

Project Title: Fast Charger using WBG Devices

Objectives: Develop MV Fast Charger using WBG Devices

Major Milestones: System Demonstration at 25kVA at the end of BP1

Significant Equipment Acquisition: High Performance Scope and Probes

Deliverables: 25kVA MV Fast Charger Unit

SOPO Task No.: 4.13
TPOC: Srdjan Lukic
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WBG Technology Impact

1. Establish MV Rectifier test platform for the center
2. Testbed for Institute-developed devices in MV applications
3. Improved power density fast charger compared to state of art with reduced installation cost
4. Results serve as input into roadmapping activities

More WBG Impact and Additional impacts

1. Demonstrator/building block for potential new product lines
2. Strong teaming opportunities exist with Power America foundries and industrial equipment partners
3. Graduated Students will form the new WBG workforce experienced in MV applications

NCSU

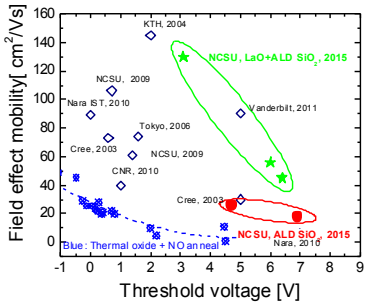
Project Title: **High mobility SiC & E-mode GaN Devices**

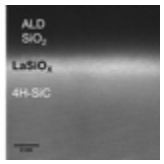
Objectives: **Use rare earth and ALD dielectrics for high mobility SiC and flash memory stacks for E-mode GaN**

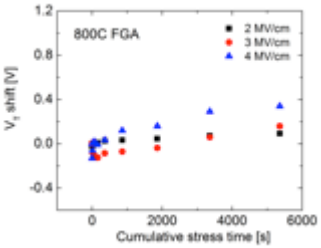
Major Milestones: **Develop High mobility SiC device & E-mode GaN Devices using gate stack engineering**

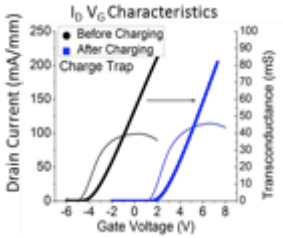
Significant Equipment Acquisition: N/A

Deliverables: **SiC device with mobility > 50 cm^2/V-s, $\Delta V_T < \pm$ 0.5V under ±4MV stress and E-mode GaN device with V_T>3V and <0.5V shift**









TPOC: Veena Misra,
Email: vmisra@ncsu.edu,
Phone: 919-515-7356

WBG Technology Impact

1. WBG SiC and GaN provide high temperature, high voltage, and high speed operation. High mobility SiC and e-mode GaN devices will further improve device property while reducing a die size and driver circuits resulting in cost advantages.
2. Medium voltage range applications (~1700V) such as automotive, industrial motors, consumer electronics, PV inverters, etc.
3. Timeframe for commercialization: BP-3
4. Improving SiC mobility by ~50% will reduce on-resistance by ~20% for power device up to 1700V and result in smaller die size and cost. E-mode GaN will simplify gate driver circuit and improve safe and reliable operation.

More WBG Impact and Additional impacts

1. Our technology can overcome the tradeoff in SiC mobility vs. threshold voltage. With our technology high V_T (3V) is also achieved while maintaining high mobility.
2. Create a single device solution for e-mode GaN and not be limited to the tradeoffs using a two device solution involving Si. Combine both device and circuit techniques to achieve a positive V_T with sufficient retention times.

Project Title: Device and Process Flow Development for WBG Training and Foundry Operations

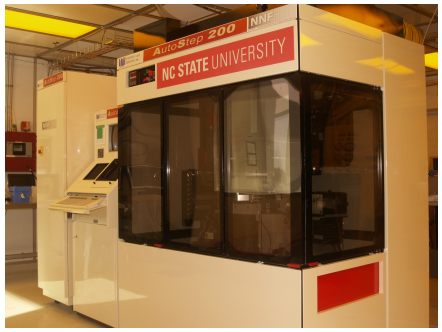
Objectives: a) Provide a platform for teaching WBG semiconductor processing for power electronics; b) Support academics and small companies to innovate, fabricate and test devices

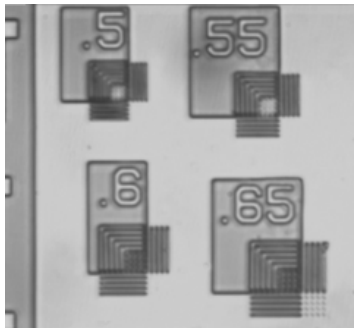
Major Milestones: a) Acquisition and installation of an i-line stepper with 0.6 um resolution; b) Equipment purchase evaluation plan

Significant Equipment Acquisition:

GCA Autostep 200 I-Line Stepper

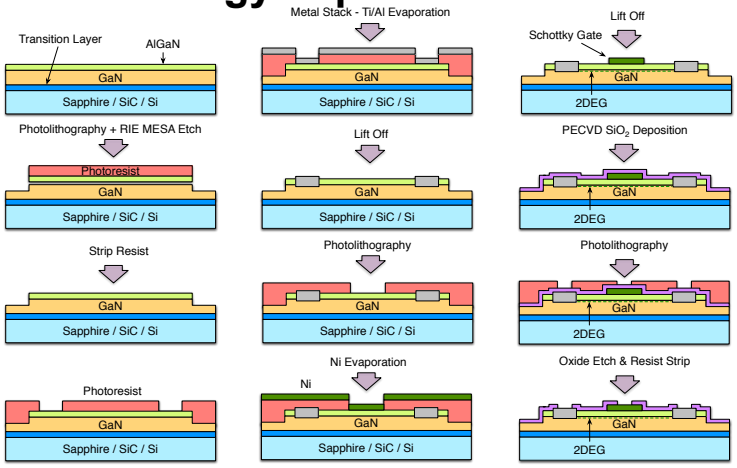
Deliverables: Installation & Testing of the i-line stepper





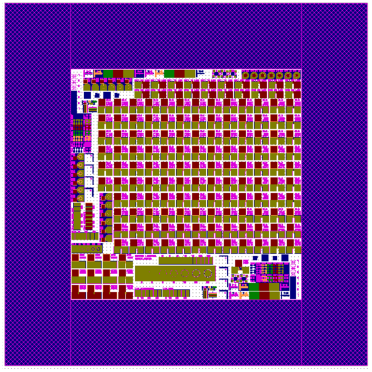
GCA Autostep 200 Stepper has been acquired & installed, demonstrated excellent uniformity with 0.5 um resolution

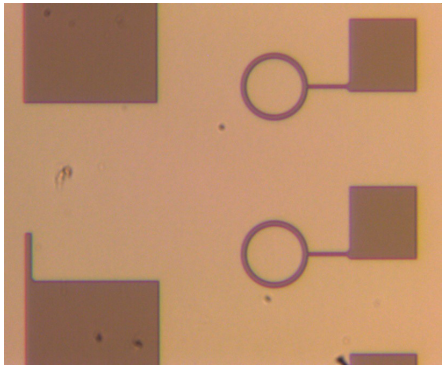
WBG Technology Impact



GaN transistors fabricated using the above process sequence are planned to be incorporated in a graduate level, hands-on fabrication course (ECE739) The process in based on the Misra flow used in the Power America project

More WBG Impact and Additional impacts





A mask set has been designed for GaN transistor fabrication, ordered and received. This mask will be used in the graduate course to fabricate GaN transistors.

Note: This work was not included in the original milestones. It is part of the new proposal.

Project Title: High-Density High-Efficiency Adapter

Objectives: Develop a GaN based adapter with operating frequency above 500 kHz to achieve at least 2X size reduction comparing to today's product.

Major Milestones: Power density >=25W/in3

Efficiency >=92%.

Significant Equipment Acquisition:

Deliverables: Circuit topology and transformer structure that are suitable for 500kHz adapter

SOPO Task No.: 4.7
TPOC: Fred C. Lee
Email: fclee@vt.edu
Phone: 540-231-7716

WBG Technology Impact

- The adapter is highly driven by efficiency and power density for all forms of portable electronics. Todays, most of the adapters are only operating at relative low frequency (<100 kHz) with the state-of-the-art efficiency up to 91.5%. However, the low frequency operation limits the adapter power density at 8-11W/in^3. The emerging gallium-nitride (GaN) device is deemed as a game changing device in this particular application with improved efficiency and significant size reduction. It is anticipated that we will gain a 2~3X size reduction to achieve 25W/in^3 in power density with an efficiency of 93-94% .

More WBG Impact and Additional impacts

•The successful of this project will help to introduce GaN device to the market of consumer electronics, which has great potential to use large volume of GaN device.

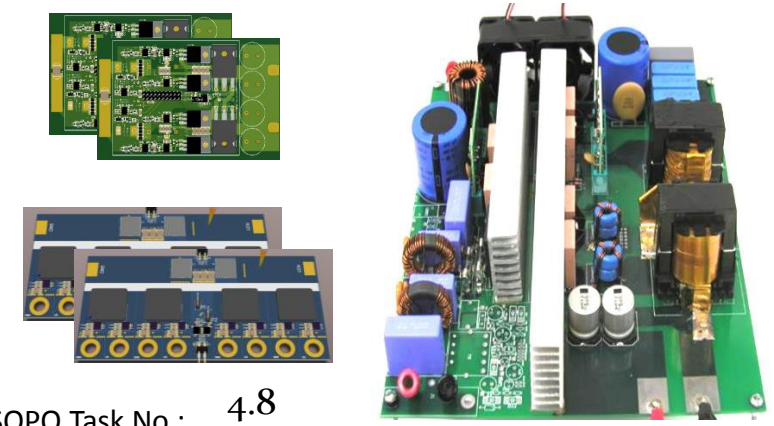
Project Title: **High Frequency GaN Converters for Distributed Power Systems**

Objectives: A 1kW data server power system will be demonstrated with GaN based building blocks to increase efficiency and also achieve 2-3X size reduction.

Major Milestones:

System power density >=100W/in^3, system efficiency >=94%.

Deliverables: GaN module suitable for 1-5MHz



SOPO Task No.: 4.8
TPOC: Fred C. Lee
Email: fclee@vt.edu
Phone: (540) 231-7716

WBG Technology Impact

In the proposed effort, we will use GaN in the front-end converters to push its frequency from today's 50-100kHz to 1-5MHz. As a result, the power density of front-end converter can be dramatically increased from today's 30-50 W/in^3 to 100-150 W/in^3. It is envisioned that the front-end power processing will be fully modularized in a form of standard building blocks. In this manner, a customized power system can be synthesized with highly efficient building blocks, which can be automated, instead of the labor intensive assembly process for current custom designed products, which will help the commercialization of GaN devices for all forms of switch-mode power supplies.

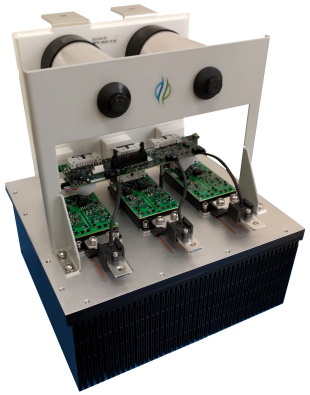
Additional Impacts

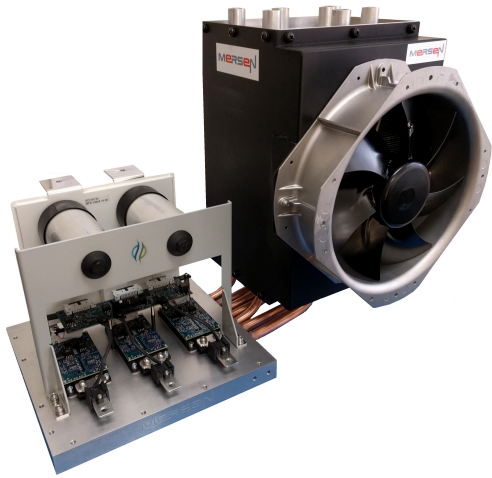
The successful demonstration of high-density high-efficiency GaN module based Distributed Power Systems will lead to wide spread use of GaN converters to replace the Silicon counterparts for all forms of switch-mode power supplies including but not limited to computer, telecommunication, network products, data centers, PV inverters, battery chargers industrial and consumer electronics products. This paradigm shift is accompanied with significant improvement of efficiency, power density and cost. Furthermore, design and fabrication of power conversion system with GaN based modules should be aimed fully automated manufacturing for volume.

Project Title: Promote SiC and GaN Applications through development of "WBG Power Stack" Systems

Objectives: 50% or greater improvement in Power Stack Energy Density

Deliverables: APEC 2016 - Demonstration of WBG Power Stacks, Industry Session paper. 2 WBG Power Stacks to PowerAmerica for student research





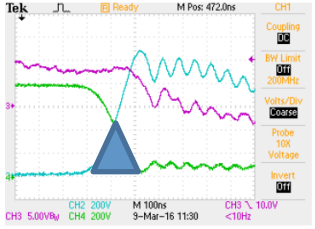
SOPO Task No.: 2.15
TPOC: AgileSwitch, LLC
Email: info@agileswitch.com
Phone: (484) 483-3256

WBG Technology Impact

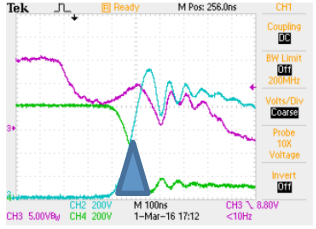
1. Advanced driving and fault protection
2. Broad range of applications – Solar, Energy Storage, Military, Motor Drive, Induction Heating, Medical Imaging
3. Expedited time to market for OEMs considering WBG
4. >62% improvement in Stack Energy Density compared to equivalent Si IGBT based Power Stack achievable
5. Higher switching frequency drives lower system cost and eliminates negative audio impact

More WBG Impact and Additional impacts

1. Improved efficiency leading to increased cost savings
2. Cost savings may justify higher spending on WBG Power Modules eventually leading to reduction in cost of WBG implementation



Rohm 800V 266A 5.6Ohm N2LTO



Rohm 800V 266A 4.5V LTO 0 Ohm

CoolCAD Electronics, LLC — Startup Member

Project Title: Electrical Models for Commercial SiC JFETs and GaN Based Power Devices

Objectives: Development of WBG device SPICE circuit models and CAD tools.

Major Milestones: Model Development and Evaluation of Manufacturers' Models

Significant Equipment Acquisition: none

Deliverables: New Models and CAD Tools

SOPO Task No.: **2.13**
TPOC: Name: Akin Akturk
Email: akin.akturk@coolcadelectronics.com
Phone: 301-405-3363

WBG Technology Impact

1. Advances, Conventional Approaches: Developing new device circuit models that don't ordinarily exist.
2. Market Segments Impacted, Application Spaces: All organizations that perform circuit design
3. Timeframe for Commercialization: Commercialized as soon as models are developed. Within the year.
4. Advance towards WBG Based Power Electronics Products: Facilitate very cost-effective circuit design and fabrication using WBG devices.

More WBG Impact and Additional impacts

1. Impact on the Cost of WBG Compared to Silicon: Modeling will reduce design and production cycles and enable reduction in size of passives, thereby increasing WBG competitiveness.

2. Potential for Job Creation, Economic Impact: Modeling will help facilitate getting the most out of or new WBG devices, giving rise to increased power efficiency, energy conservation and mobile electronics applications, & new job opportunities for development.

3. Workforce Development and Education: Students will use new CAD tools to practice circuit design.

JDES

JOHN DEERE

Affiliate Member

Project Title: SiC Inverter for Heavy-Duty Vehicles

Objectives: 200 kW 1050 Vdc WBG Inverter manufacturing and commercialization

Major Milestones: Assembly and test verification of bench-top inverter

Significant Equipment Acquisition: None

Deliverables: Back-to-back dyno testing of inverter completed and data for design improvements collected

TPOC: Brij N. Singh
Email: SinghBrijN@JohnDeere.com
Phone: (701) 552-8516

WBG Technology Impact

1. Higher DC bus voltage, higher switching frequency, higher junction temp and heat flux, higher kW/L and kW/kg, smaller passives and system level advantages.
2. Heavy-duty off-highway and on-highway vehicles.
3. Commercialization by end of 2019
4. Switching frequency (> 15 kHz with SiC versus 8 kHz with Si). DC bus cap (300 µF - 400 µF with SiC versus 1500µF with silicon). Inverter power density (> 25 kW/L with SiC versus 17 kW/L with silicon)

Additional Impacts of WBG Technology

1. Engine coolant power electronics
2. WBG tech offers **5C solutions** and system cost reductions by; cable size, capacitor size, copper content, case of inverter, and cooling system of inverter could be simplified
3. WBG product manufacturing jobs in Fargo
4. WBG power electronics workforce development
   - Summer internship opportunities at JDES
   - Co-op student opportunities at JDES
4. Current Technology Readiness Level: TRL 3/4
5. Projected TRL at end of project: TRL 6/7

Navitas Semiconductor, Inc.

Project Title: 50W High-Efficiency Wireless Charger

Objectives: Create a commercially compelling platform that sets an industry standard in energy efficiency & power density for AirFuel wireless charging & is manufacturing proven and volume ready for US OEMs.

Major Milestones: Jan – 1st proto, Feb – eval & optimization, Mar– final design, Apr – mfg validation & release

Significant Equipment Acquisition: None

Deliverables: Wireless charger ref designs with design, performance & manufacturing collateral

50W High-Efficiency Wireless Charger

50W AirFuel Wireless Charging

50% better efficiencies
ACDC adapter eliminated
Higher density & lower cost

TPOC: Dan Kinzer
Email: dan.kinzer@navitassemi.com
Phone: 408-386-8041

WBG Technology Impact

1. Advances over silicon or conventional approaches: *Advancement & commercialization of 6.78Mhz wireless charging with Navitas GaN power ICs*
2. Markets impacts: *acceleration of wireless charging adoption (consumer electronics)*
3. Timeframe for commercialization: *Q2 2016*
4. Quantitative benefits over state-of-the-art: *50% improvement in energy efficiency with higher densities, simplified design and at a **lower** cost per watt*

More WBG Impact and Additional impacts

1. Impact on the cost of WBG compared to Silicon: *A high-volume platform that demonstrates WBG superiority over silicon in performance and cost*
2. Potential for Job Creation Economic impact: *Significant job creation for US manufacturing partner(s) & US OEMs*
3. Workforce Development and Education: *All R&D and manufacturing is 100% based in the US with significant workforce development and education with Navitas, suppliers, partners and customers*

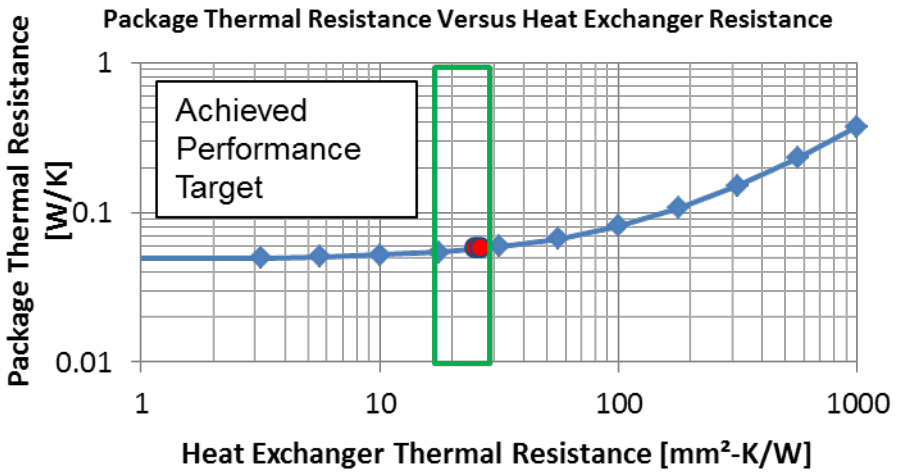
Project Title: John Deere Inverter for Heavy-Duty Vehicles

Objectives: Thermal management and thermomechanical reliability support

Major Milestone: Provide thermal management solutions using appropriate thermal interface materials and cooling technologies

Significant Equipment Acquisition: None

Deliverable: Support for Design and Development of Hardware Parts for Generation 1 SiC Inverter



SOPO Task No.: 4.1
TPOC: Kevin Bennion
Email: kevin.bennion@nrel.gov
Phone: (303)274-4447

WBG Technology Impact

1. Higher temperatures create challenges for component performance and reliability
2. Supports off-highway and on-highway heavy-duty vehicle inverter applications
3. Refer to John Deere Electronic Solutions overall project summary: 200 kW $1050V_{DC}$ $710V_{AC}$ SiC Dual Inverter

More WBG Impact and Additional impacts

1. WBG systems leading to system cost advantages
2. US based design and manufacturing
3. Reliability of high-temperature inverter components
4. WBG thermal and reliability traineeship through internship opportunities

Toshiba International Corporation — Affiliate member

Project Title: SiC Device-based Small Commercial PV inverters
Objectives: Commercialize SiC based small commercial PV inverter
Major Milestones: Year 1: specification, system design, prototype
Deliverables: Year 1: specification, system design, prototype

SOPO Task No. 4.3
TPOC: Peter Liu
Email: peter.liu@toshiba.com
Phone: (713) 466-0277 x3554

WBG Technology Impact

1. Key CTQ: efficiency, weight and cost
2. WBG device: increase efficiency, reduce system weight and might reduce system cost
3. Commercialize it in 2-3 years.

More WBG Impact and Additional impacts

1. Toshiba International Corporation commit design and manufacture in US
2. Large volume of SiC devices will reduce the cost of Sic devices.

transphorm

Membership Level: Associate

Project Title: GaN Power Switches & Applications for Accelerating Market Development

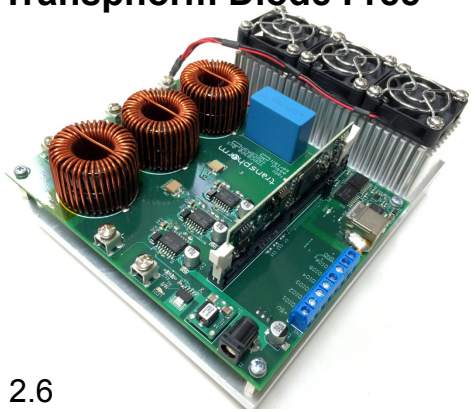
Objectives: GaN Switches covering compact adapters & high power inverters

Major Milestones: GaN switches of 600V at >5MHz & 900V with >98.5% inverter eff.

Significant Equipment Acquisition: NA

Deliverables: Devices and app. product samples

Transphorm Diode Free™



SOPO Task No.: 2.6
TPOC: Y Wu, R Lal & P Parikh
Email:ywu@transphormusa.com
Phone:805 456 1300

WBG Technology Impact

1. **Advantages over silicon approaches**: Figure of merit (Ron*Qrr) improvement of 20x
2. **Market segments impacted**: Mobile computing, data centers, PV inverters, factory automation and motor drives for fractional to few hp motors
3. **Timeframe for commercialization**: 2016
4. **Extending the state of the art**: GaN switches for:
   (a) Increasing power density of adapters 3x; &
   (b) High performance 480 VAC for bridge apps; &
   (c) Novel 900 V FQS' for new PE topologies

More WBG Impact and Additional impacts

1. **Impact**: System cost reduction by 2x due to low cost GaN/Si switch & device performance at high frequencies
2. **Potential for Job Creation**: R&D workforce and substantial production in US when GaN switch enabled power electronics takes off
3. **Workforce Development**: Transphorm's applications boards could be used in initial laboratory setups for training of WBG systems engineers and technicians

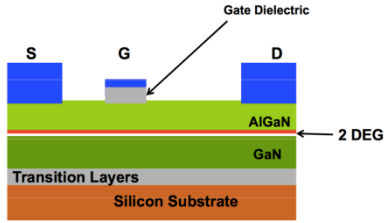
Project Title: Reliability Benchmarking of Lateral GaN Power HEMTs on Si Substrates and Assessment of GaN/Si Epitaxy

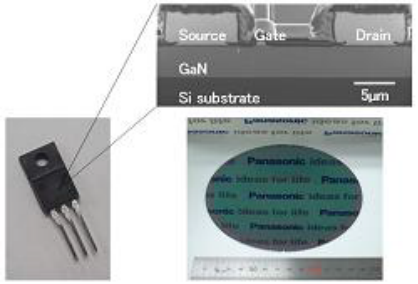
SOPO Task No.: Task 3.3

Objectives: Comparative evaluation and reliability analysis of commercial GaN HEMTs.

Major Milestones: Reports for every task completion (at least one per quarter)

Deliverables: GaN Power HEMT reliability data and comparisons

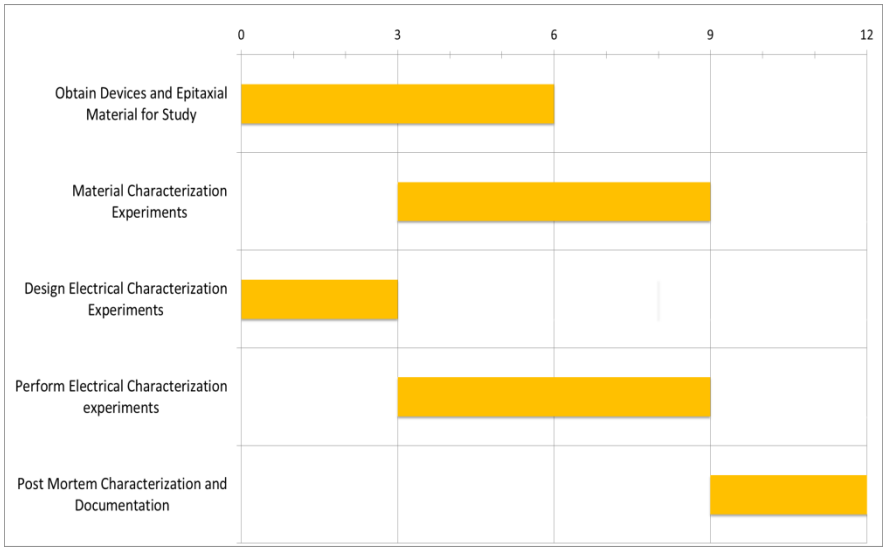




TPOC: Dr. T. Paul Chow
Email: chowt@rpi.edu
Phone: (518) 276-2910

WBG Technology Impact

1. Establish GaN power HEMTs as a viable technology with performance superior to Si counterparts.
2. Low to medium power, discrete and integrated power electronics applications.
3. Timeframe for commercialization: 1-3 years
4. No comparative reliability analysis of commercial GaN power HEMTs has been performed. Our proposed project would be the first.



Argonne National Laboratory

Federal Partner

Project Title: Reliability benchmarking of SiC MOSFETs
SOPO Task #: BP2-3.2 CFP51
Objectives: Develop reliability tests, collect reliability performance data & perform benchmarking
Major Milestones:
Develop and validate test circuits, perform tests, catalogue data, perform statistical data analysis, and identify failure mechanisms
Deliverables: project report outlining procedures, data, conclusions and recommendations

TPOC: John Hryn
Email: jhryn@anl.gov
Phone: 630-252-5894

WBG Technology Impact

1. Develop reliability bench-marking
2. Develop new reliability standards
3. Develop an understanding of the role of defects on a specific reliability mechanism
4. Establish dedicated third party Reliability Lab for PowerAmerica and WBG industry

More WBG Impact and Additional impacts

1. Impact on the cost of WBG compared to Silicon
   - Once reliability of WBG devices is demonstrated to be superior to comparable Si devices, if any, market penetration will improve, which will increase production volumes and drive cost down
2. Potential for Job Creation Economic Impact
   - Higher production volumes mean more manufacturing jobs as well as higher-paying application development jobs
3. Workforce Development and Education if applicable
   - Project will educate students in reliability testing

Atom Power Startup Member

Project Title: Mass Market SiC Solid-State Circuit Breaker Development

Objectives: Develop higher amp capacity SiC-based 3-phase circuit breakers for the commercial and industrial building markets

Major Milestones: Scalable, unified architecture for 3-phase circuit breakers up to 480V, 4000A

Significant Equipment Acquisition: High-current injection test kit, High power electronic load

Deliverables: Commercially viable 3-phase, 480VAC, 800A solid-state circuit breaker

TPOC: Ryan Kennedy
Email: rkennedy@atompower.com Phone: 704-687-0454

WBG Technology Impact

1.Atom Power will utilize SiC MOSFET as the core switching technology for commercial/industrial grade circuit breakers. The opportunity for mass market penetration is significant based on the quantity of circuit breakers deployed across the industry.

2.Mass market approach for WBG devices (see above) will secure a significant demand for Atom Power products as well as for the discrete WBG components within our products driving SiC manufacturing costs down.

3.Timeframe for commercialization: full-spectrum delivery and mass-market in mid 2017.

4.The current state of the art for commercial circuit breakers revolves around mechanical switching. Atom Power will deliver reliable, cost competitive SiC circuit breakers.

More WBG Impact and Additional impacts

1. It is the goal of Atom Power to decrease the cost of discrete SiC power MOSFETs based on the significant quantities required for large commercial deployments of our solid-state circuit breakers.

2. Atom Power has a core belief that design, production, and distribution of our products occur within the United States, specifically within our region of North Carolina. We see neighboring component manufacturers as strategic to this ecosystem of sourcing locally, employing locally, and production within our community.

3. Atom Power is significantly involved in funneling talent from the North Carolina university system, specifically with UNCC, into the envelope of Atom Power. That is, most of our employees and new-hires were sourced locally from UNCC and it is our objective to continue this in the future.

Auburn University

Project Title: Development of an open gate dielectric process for SiC MOSFET manufacturing

Objectives: Nitrogen free high stability SiC MOSFETs based on Ultra –high temperature (UHT) oxides and counter doped interfaces.

Major Milestones: (1) HT oxide characterization, (2) UHT counter-doped devices, (3) BSG device (4) Strained Ge implanted device (5) Fab run UHT counter-doped DMOSFETs

Deliverables: Oxidation Process, Lateral MOSFETs, Vertical DMOSFETs

TPOC: Sarit Dhar
Email: szd0024@auburn.edu
Phone: 334-844-4618

WBG Technology Impact

1. N free oxide foundry compatible process technology for open gate process development.
2. Higher mobility compared to standard SiC devices.
3. Current DMOS have a field effect mobility of ~20 cm^2/Vs. With this new devices values of 60 cm^2/Vs are expected.
4. Increased mobility will open lower voltages (900-600V) markets for SiC
5. Product rated DMOSFETs to be fabricated at the end of year 1 by partner Monolith Semiconductor

More WBG Impact and Additional impacts

1. Impact on the cost of WBG compared to Silicon:

New process will replace expensive NO annealing resulting in lower cost.

2. Workforce Development and Education :

- 2 Undergraduate students trained in semiconductor fabrication and SiC MOS processes
- 1 PhD trained in fabrication and characterization of SiC MOS devices

Academic Member

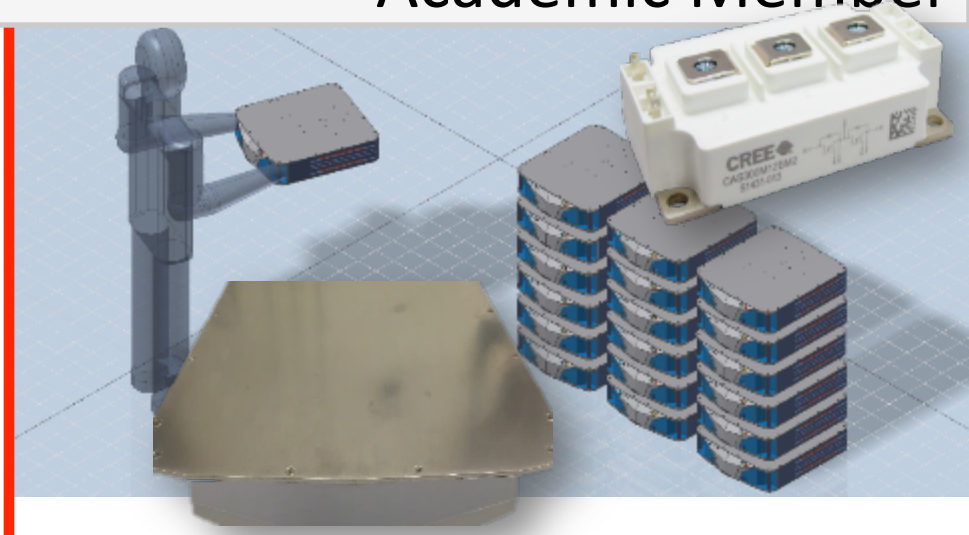
Project Title: EMI Mitigation and Containment in SiC-Based Modular UPS for Commercial Applications

SOPO Task No. 4.7

Objectives: Develop EMI mitigation and containment strategy in SiC-based UPS power modules meeting emission standards and ensuring the reliable UPS operation

Major Milestones: develop EMI model of UPS, active PWM scheme, and design and test EMI filter

Deliverables: Design strategy and EMI filter



TPOC: Rolando Burgos
Email: rolando@vt.edu Phone: +1.540.231.0034

WBG Technology Impact

1. Enables adoption of SiC in high-power modular converter structures, e.g., UPS, MV Drives, etc.
2. Market: high-power commercial UPS segment (100 kW to 3 MW, 480 V)
3. Timeframe for commercialization: 2-3 years (est.)
4. SiC adoption will enable power density > 50 W/in^3, online UPS efficiency > 98 %
5. EMI mitigation and containment strategy will enable distributed power architecture (DPA) in ABBmodular UPS system

More WBG Impact and Additional impacts

1. High-power UPS market will reach 1 BUSD in 2016
2. WBG-based design and manufacturing capability for US power electronics industry
3. Multi-team effort in coordination with ABB Corporate Research in Raleigh, NC, and ABB Thomas & Betts in Richmond, VA
4. TRL level

   At Project start: 3

   Projected at completion: 5

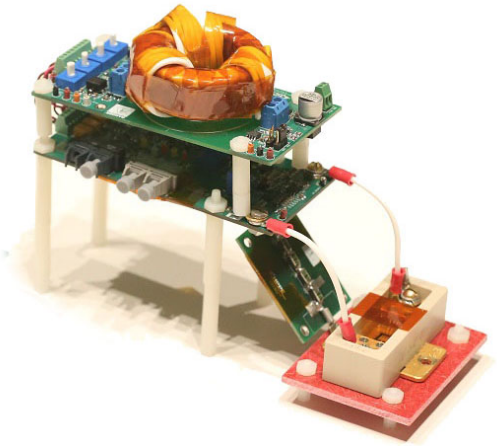
Project Title: Medium Voltage Gate Drive with Comprehensive Protection Functions

SOPO Task No.: 4.16

Objectives: to research and develop gate drive circuits with comprehensive protections for medium voltage SiC (Silicon Carbide) devices.

Major Milestones: bench level (month 6) and near product (month 12) circuit prototypes.

Deliverables: prototypes and integration of research into a undergraduate/graduate level class.

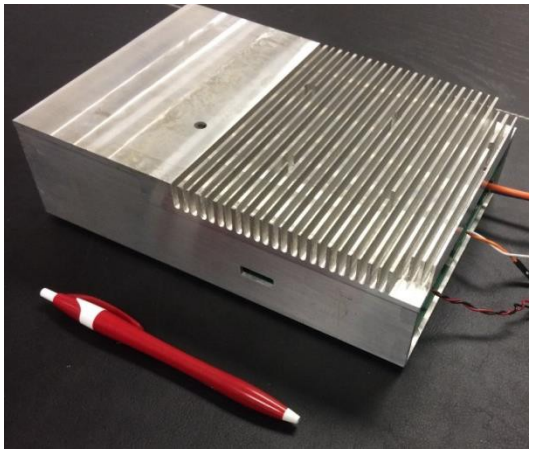


TPOC: Jin Wang
Email: wang.1248@osu.edu Phone: 614-688-4041

WBG Technology Impact

1. The gate drive will be suitable for both single medium voltage devices and multilevel circuits that requires high isolation voltages for gate drives.
2. The success of the project will help the demonstration and future implementation of medium voltage SiC devices.
3. Proposed technology can be applied to locomotive, shipboard, pulse power, and utility applications.
4. The project will help medium voltage SiC devices or SiC based multilevel circuits to achieve performance that can not be matched by silicon devices and silicon based circuits.
5. Undergraduate and graduate student assistant will be trained in designing circuits for medium voltage SiC devices.
6. Students enrolled in the high voltage class will have opportunity to learn basics of the medium voltage device and associated circuits and see demonstrations of the gate drive prototypes.
7. TRL level: 2-3 at project start; 6-7 at project completion.

Project Title: Comparison of SiC and GaN 7.2 kW Chargers
Objectives: to use SiC devices to build a >97%-efficiency 7.2 kW fast chargers and compare with the previous GaN based charger
Major Milestones: to finish building the charger by Mar, 2017 and finish full-power test by Jun, 2017
Significant Equipment Acquisition: No
Deliverables: 1) a 7.2 kW SiC based charger prototype 2) enhanced 2 power electronics courses and 3) 2~3 short courses.



One GaN HEMTs based 7.2 kW charging module (experimental efficiency is ~98%, PF=0.997)

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WBG Technology Impact

1.To advance applications of SiC devices over the conventional silicon devices and compare to the approach of using 650V GaN switches.
2.To increase the efficiency and power density of level-2 charger through using SiC devices. We expect >97% efficiency in contrast to most present ~94%, ~4kW/L power density in contrast to ~1 kW/L for existing Si chargers.
3.To generate a systematic methodology of designing WBG power electronics system including magnetics, thermal, gate drivers, packaging and control.

More WBG Impact and Additional impacts

1.This project will expedite the applications of SiC in the electric vehicle industry particularly on-board chargers;
2.We will help EV manufacturers build the pipeline of power electronics expertise in WBG power electronics domain through involving research engineers, graduate and multiple undergraduate students;
3.We will enhance present graduate courses and develop several short courses addressing WBG devices. These course modules will be shared with industrial partners.

Project Title: Manufacture vertical GaN devices on bulk GaN wafers

SOPO Task No.: 2.5

Objectives: Demonstrate 10 A vertical GaN FET with BV > 1200V, R_{on} < 3 mΩ-cm²

Major Milestones: Develop n- & p-ohmic contacts and thick interconnect or overlay metal processes and fab 1200V/10A FET

Deliverables: 1200V/10A die test data

Key Improvements:
- 2x higher Conduction current density
- BV increased to 2200 V
- 3x Reduction in R_{on} to ~0.8 mΩ-cm²
- 4x reduction in AlGaN thickness for better reliability:
  - reduced stress
  - reduced peak electric fields

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WBG Technology Impact

1. High power: >1200V, >100A operation
2. Market segments impacted: military, aviation, motor drives, & inverters
3. Timeframe for commercialization: Yr 2020 to 2025
4. Leverage GaN's high – breakdown field, carrier mobility & switching speed
5. High manufacturability: 100/150mm wafer scale, target yield > 90%

More WBG Impact and Additional impacts

1.>10X lower cost/Amp of WBG devices and power modules

2.Commercialization of industry led projects & enhance U.S. manufacturing competitiveness

3. Enhance U.S. expertise in WBG power electronics

4. TRL level

At Project start: TRL3

Projected at completion:TRL4