# PowerAmerica Manufacturing Institute

**DE-E0006521.0011**

**North Carolina State University Managed Consortium**

**Budget Period 4: July 2018 – June 2019**

Presenter: Dr. Victor Veliadis, Deputy Director and CTO, PowerAmerica
North Carolina State University

U.S. DOE Advanced Manufacturing Office Program Review Meeting
Washington, D.C.
June 11-12, 2019

# PowerAmerica Overview

## Timeline

- Award issued in 2015
- Projected DOE End date June 2020
- Project 80% complete
- Project fully funded

## Budget

| | FY 15 Costs $ | FY 16 Costs $ | FY 17 Costs $ | FY 18 Cost $ | FY 18 Budget $ | Total $ |
|---|---|---|---|---|---|---|
| DOE Funded | 15.5 M | 12.4 M | 9.9 M | 13.1 M | 19.2 M | 70M |
| Project Cost Share | 17 M | 19.9 M | 13.8 M | 14.3 M | 12 M | 77M |

Total DOE: $70M

## Barriers

- The Key barriers to increased penetration of wide bandgap semiconductor technologies is high cost and reliability concerns. Establishing reliability, streamlining manufacturing, and training the workforce are needed to create component demand, which leads to mass production that reduces cost.

## Members

- PowerAmerica is located in Raleigh NC and managed by North Carolina State University.
- PowerAmerica has 49 members who provide key support in technology development, governance, and education
  - 47% industrial, 40% academic, 13% national lab and other consortia
  - Retention year to year at ~90%

*PowerAmerica addresses gaps in wide band-gap power technology to enable US manufacturing job creation and energy savings.*

V. Veliadis

# PowerAmerica is a 49 Member Driven Institute Active in All Areas of the Power GaN-SiC Supply Chain

**SiC Foundry**: Wolfspeed; X-FAB (Mixed-Signal Foundry Experts)

**SiC Devices Circuits & Modules**: USCi (United Silicon Carbide, inc.); Wolfspeed; GeneSiC Semiconductor; Sonrisa Research, Inc. (Creating Progress Through Revolutionary Innovation); ON Semiconductor; Monolith Semiconductor Inc.; Microchip; GlobalPower TechnologiesGroup; GE

**GaN Devices & Circuits**: Navitas Semiconductor; Infineon; HELLA

**WBG Systems**: GM; Toshiba; Raytheon; Atom Power; BAE Systems; ABB; John Deere; United Technologies Research Center; GE; Lockheed Martin; NIRE Group (Renewable Energy Solutions)

**Academic**: Texas Tech; UC Davis (University of California); UCSB (University of California Santa Barbara); Auburn University; Virginia Tech; Kettering University; Georgia Tech Center for Distributed Energy; UNC Charlotte; San José State University (1857); Arizona State University; The Florida State University (1851); NC State University; Rensselaer; The Ohio State University; The University of Akron; The University of Tennessee Knoxville; SUNY Polytechnic Institute; University of Alabama; University of Colorado Boulder

**Gov. Labs**: Naval Research Laboratory (Washington, DC); Argonne National Laboratory; Sandia; NREL (National Renewable Energy Laboratory)

**Consortia**: PEIC (Power Electronics Industry Collaborative); iNEMI (Advancing manufacturing technology)

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# Annual Competition, Open Innovation, and Member Initiated Projects Generate PowerAmerica Technology Portfolio

## Annual Competition

- Project selection through RFI, CFP, concept paper and full proposal review cycle
- Projects address technology barriers to accelerate WBG power electronics adoption

## Open Innovation Projects (Apply anytime)

- Target key time-sensitive gaps in PowerAmerica's portfolio that are too urgent to be postponed until the next annual competition
- Address technology barriers not currently tackled by other PA projects

## Membership Selected Projects

- Develop valuable pre-competitive WBG related technologies that members can leverage based on their strengths and technology focus
- Reviewed, selected, and managed by members (with PA in a facilitating role)

# PowerAmerica Foundry Projects Enable Low-Cost Large Volume SiC Device Manufacturing in the U.S.

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**1.1** Operations and Finance
**1.2** Technology Roadmap
**1.3** Sustainability
**1.4** Device/Module Bank
**1.6** Project Portfolio Management
**1.7** Membership, Industry Relations and Communications


### 2 Foundry and Device Development

**2.1** SiC Power Device Commercial Foundry Development **X-FAB**
**2.3** Development of Manufacturable Gen3 3.3 kV/50 mOhm MOSFET Fabricated on 150 mm 4HN-SiC Wafers Along With HTRB, HTGB, BDOL, TS, ESD, and TDDB Reliability Qualification **Cree/Wolfspeed**
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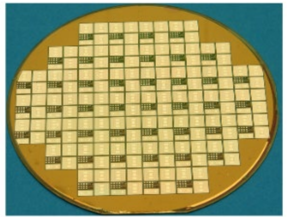

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**3.6** Developing Processes for BPD-Free Room Temp. Al Implantation/Annealing for MOSFETs and Lifetime Control for Bipolar Devices **NRL**

### WBG Power Electronics Applications

**4.1** Power-Dense Engine Coolant 200 kW 1050 V DC Bus SiC Inverter for Heavy-Duty Vehicles **John Deere Electronic Solutions**
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NEW MEMBERS shown in BLUE

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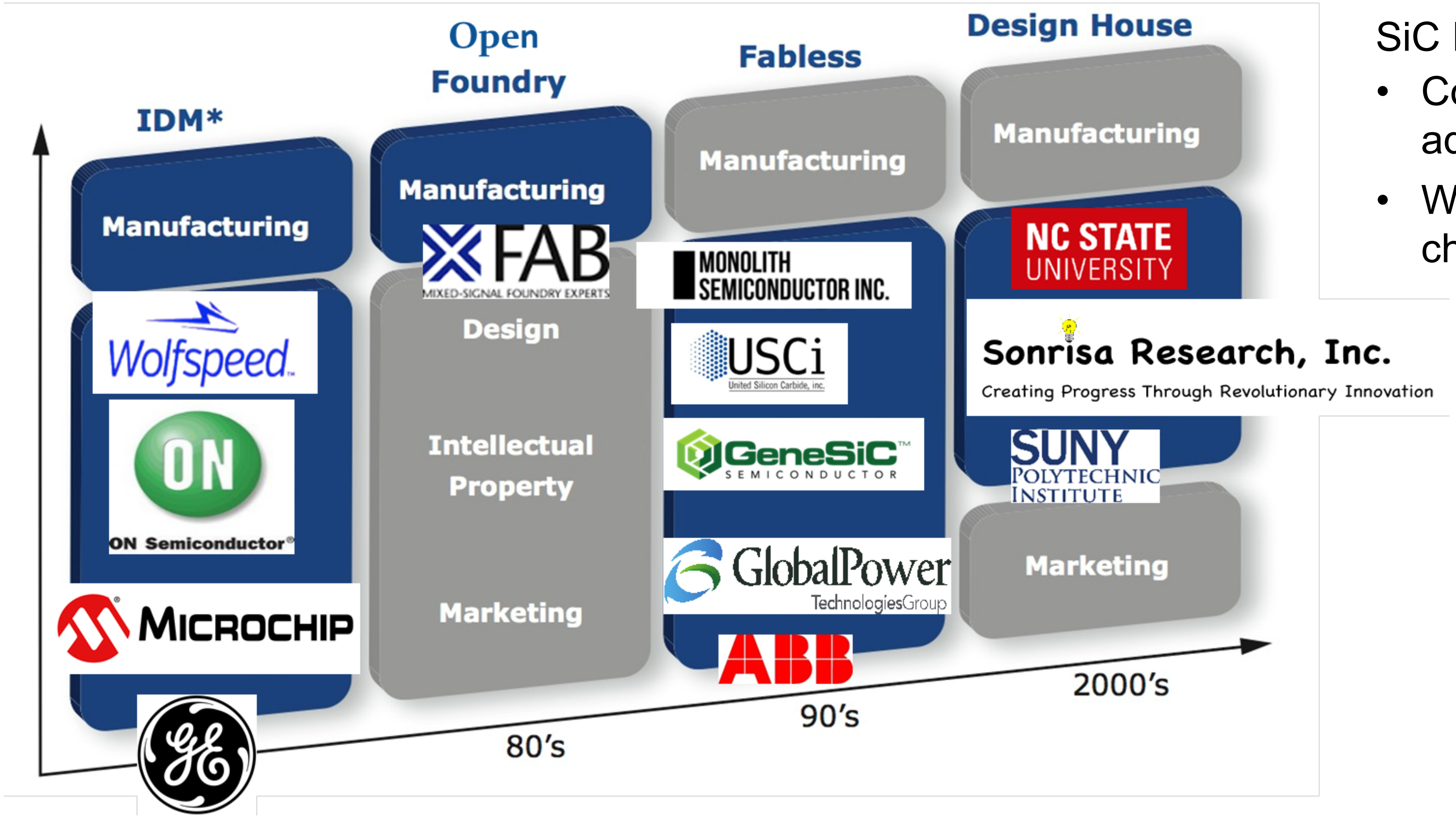
# PowerAmerica Stands/Supports SiC Foundry Infrastructure in the U.S.




SiC Foundry:

- Compete on Process in addition to Design
- Wafer quality and supply chain concerns

*IDM: Integrated Device Manufacturers

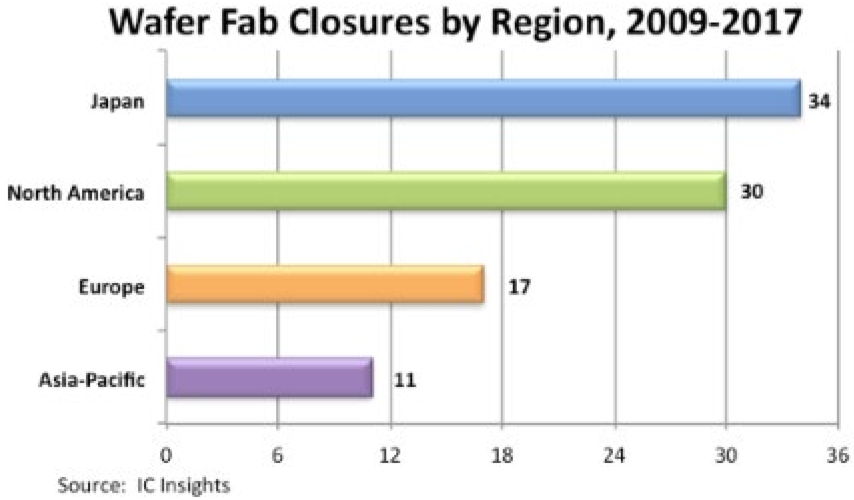
*Si* Foundry graph source: Successful Semiconductor Fabless Conference, Yole Mar. 2013

# X-FAB 150-mm SiC Open Foundry Leverages Existing Si Economy of Scale to Reduce SiC Manufacturing Cost

## X-FAB/PowerAmerica Manufacturing: SiC at the Economy Scale of Silicon

- Wafer fabrication dominated by fixed O/H costs (Management, Quality, EHS, IT)
- Economies of scale is the greatest factor in reducing cost: Use the scale established in Si to enable low-cost SiC manufacturing
- Standard SiC process blocks in development streamline fabrication

X-FAB 150-mm SiC open Manufacturing is fully integrated within a high volume Si foundry




X-FAB/PA SiC Users: ABB, GeneSiC, Microchip, Monolith, USCi, Global Power, Sonrisa, SUNY, and NCSU
Currently 11 SiC device companies running 59 SiC development projects

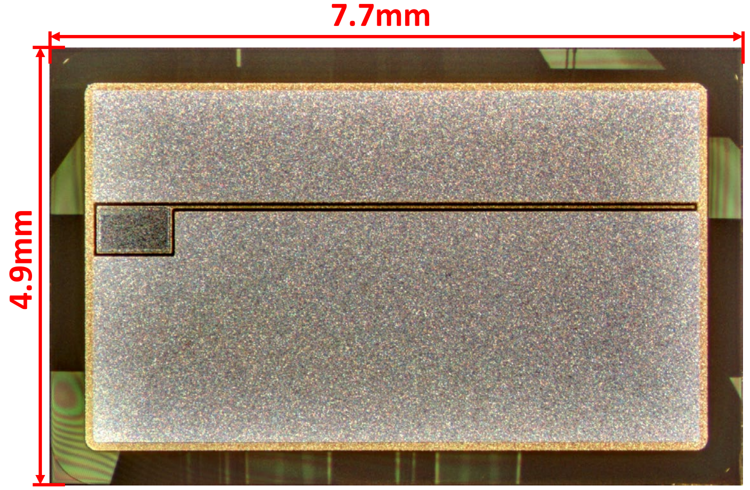
# Cree-Wolfspeed Manufactures and Qualifies 3.3 kV, 6.5 kV, and 10 kV SiC MOSFETs on 150-mm Wafers

**Project Title**:

Development of Manufacturable 3.3 kV, 6.5 kV, and 10 kV SiC MOSFETs on 150 mm wafers and JEDEC Qualification

**Objectives**:

Pass JEDEC Qualification of Manufacturable 3.3 kV, 6.5kV, and 10 kV SiC MOSFETs on 150 mm wafers




**3.3kV/50mΩ SiC MOSFET**

## WBG Technology Impact

- 3.3-10 kV SiC MOSFET Technology Provides Improved Efficiency, Increased Switching Frequency, and Lower Conduction Loss for Medium Voltage Power Applications
- Potential Applications: MV Motor Drive, UPS, Data Center Rail Traction, Solar Inverter, EV Charger, Grid-HVDC/SST
- Commercialization Timeframe: ~ 3 to 5 years
- Establish Manufacturable Fabrication Process & Complete HTRB, HTGB, BDOL, TS, TDDB, H3TRB, & ESD JEDEC Qualification of Gen3 3.3kV/50mΩ SiC MOSFET die fabricated 150 mm 4HN-SiC wafers.

## Accomplishments/Outcomes

- Cost Reduction of 3.3kV, 6.5 kV, and 10kV SiC MOSFETs through improved yields, and increased production volume enabled by fabrication on 150 mm SiC wafers.
- 3.3 kV, 6.5 kV, and 10 kV qualification will accelerate <u>Commercial Production of Medium Voltage SiC Power Technology</u>

V. Veliadis

# PowerAmerica Wafer Procurement Planning is Critical in Timely Execution of Device Fabrication Projects

Long lead times of SiC wafers can delay PowerAmerica fabrication projects that have a 12 month period of performance. We coordinate wafer acquisitions well in advance to ensure timely project execution.

| FA2 Proposal Title | Organization/Team | PI | wafer specs |
|---|---|---|---|
| NCSU Baliga BP-3 Proposal 1 | NCSU | Baliga,B. | XFAB has spec |
| NCSU Baliga BP-3 Proposal 2 | NCSU | Baliga,B. | XFAB has spec |
| 1.7KV AND 3.3KV SILICON CARBIDE (SIC) MOSFET SCALE-UP | Micromsemi Corporation | Faheem,Faheem | Proprietary |
| Commercialization of 1700V SiC Schottky Diodes Manufactured at X-FAB Texas | Monolith Semiconductor Inc. | Chatty,Kiran | |
| Development of a Manufacturable Gen3, 6.5 kV/100 mOhm MOSFET | Cree, Inc. | Degnan,Sharon | No contact needed for this performer |
| SiC Power Device Commercial Foundry Development | X-FAB Texas, Inc. | Wilson,Andy | No wafer orders |
| Development of 3.3kV/6.5kV/10kV SiC MOSFETs, JBS Diodes, and JBS Diode Integrated MOSFETs | State University of New York Polytechnic Institute | Sung,Woongje | Proprietary |
| Development of 600V SiC JBS Diodes and MOSFETs | State University of New York Polytechnic Institute | Sung,Woongje | |
| Development and Acceleration of 1200V SiC Device Manufacturing for High Efficiency, High Volume Applications | Alpha and Omega Semiconductor Inc. | Sheridan,David | |
| 3.3kV SiC MOSFET Development | GeneSiC Semiconductor Inc. | Singh,Ranbir | |
| Advanced SiC Trench MOSFETs: A Path to Record-Low Ron,sp and Record-Low ($/A) | Sonrisa Research, Inc. | Cooper,James | |
| Manufacturable, Cost Effective, Low RON-SP 3.3 kV SiC DMOSFETs | Global Power Technologies Group, Inc. | Woodin,Richard | |

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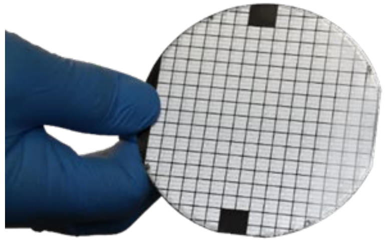
# Microchip Manufactures and Qualifies 3.3 kV MOSFETs and 6.5 kV Diodes at X-FAB 150-mm U.S. SiC Open Foundry

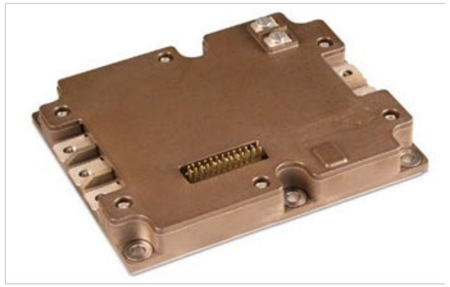
**Project Title**

Commercialization of 3.3 kV & Technology Development of 6.5 kV Silicon Carbide Devices

**Objectives**

(a) Validate the reliability of 3.3kV MOSFET and SBD, then ramp up to production in 150-mm foundry
(b) develop and prototype next-generation 6.5 kV SBDs



Microsemi
a MICROCHIP company

## WBG Technology Impact

1. High current density, junction temperature, efficiency, faster switching, lower volume
2. Application sector – Transmission & Distribution, Medical, Defense, Traction
3. Timeframe for commercialization: 1.5 years

## Accomplishments/Outcomes

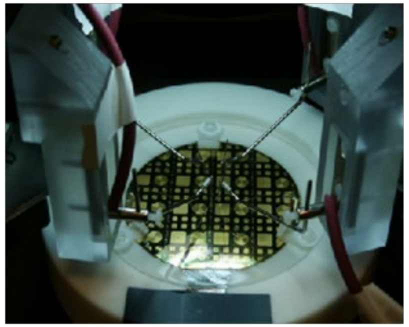
- Cost reduction of SiC compared to Silicon: Using 150-mm Si CMOS foundry drastically reduces $/Amp; commercial foundry reduces defects & increases yields, R&D cycle times reduced
- Job Creation & Economic impact: U.S. based design & fabrication creates high-tech U.S. jobs, and increases US competitiveness in semiconductors

V. Veliadis

# GeneSiC Manufactures and Qualifies 6.5 kV MOSFETs at X-FAB 150-mm U.S. SiC Open Foundry

**Project Title**
6.5kV SiC MOSFET Development

**Objectives**
Transfer 6.5 kV SiC MOSFET process to 150 mm foundry (X-Fab)



GeneSiC™ SEMICONDUCTOR

Digi-Key Electronics
Mouser Electronics
Arrow Electronics, Inc.
Newark
Premier Farnell
element14 Be in your element
onlinecomponents.com

## WBG Technology Impact

1. Applications: Traction/Grid-tied Inverters
2. Key Outputs: Qualified 6.5 kV SiC MOSFETs
3. GeneSiC will commercialize the widest range of SiC offerings, capitalizing on the 150 mm foundry model to advance the technology at lower cost.

## Accomplishments/Outcomes

1. Transition to 150-mm volume foundry and technology maturity will lead to cost parity with silicon
2. All GeneSiC employees are US-based. The company continues to grow and hire personnel with limited SiC experience, training them in this booming high-tech area.

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# PowerAmerica Foundry and Device Manufacturing Accomplishments

- 150-mm wafer XFAB SiC Open Foundry: SiC at the Economy Scale of Silicon for low cost U.S. SiC manufacturing
  - 150 mm wafer Si U.S. foundry repurposed for low cost SiC production creating/retaining jobs at a time when similar U.S. Silicon foundries are closing
  - Completed full SiC equipment installation and qualification (no process outsourcing)
  - 11 customers with 59 projects; 9 PowerAmerica members have utilized XFAB
  - Asian fabless companies are fabricating at U.S. XFAB
  - Developed Standard Process Blocks to standardize and thereby accelerate fabrication
  - **Customers utilizing the now available SiC standard process blocks are experiencing shorter fabrication cycle-times and costs, and the high-level goal of "SiC processing at the Si economy of scale" is rapidly becoming a reality**
  - Industry projects at XFAB secure U.S. manufacturing leadership
- CREE-Wolfspeed transitions from 100-mm to 150-mm wafers with PowerAmerica support reducing device cost by over 50%. Qualification of 3.3 kV MOSFETs maintains U.S. manufacturing leadership in the medium voltage market
- Microchip is qualifying 3.3 and 6.5 kV SiC devices at 150-mm XFAB foundry strengthening U.S. manufacturing leadership in the medium voltage market
- GeneSiC is qualifying 6.5 kV SiC MOSFETs at 150-mm XFAB foundry strengthening U.S manufacturing leadership in the medium voltage market

# Module and Reliability Funding Bridges the Gap Between Device Readiness and Commercial Adoption

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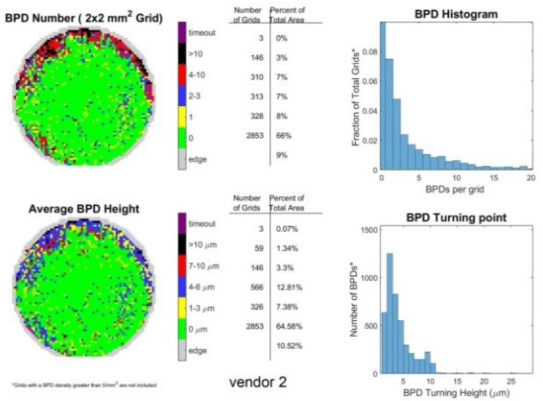


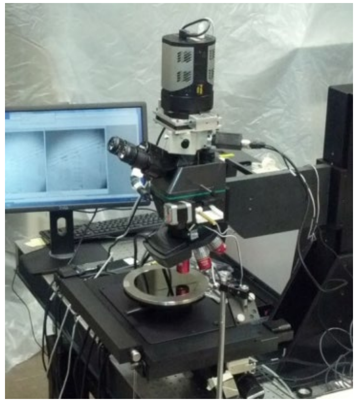

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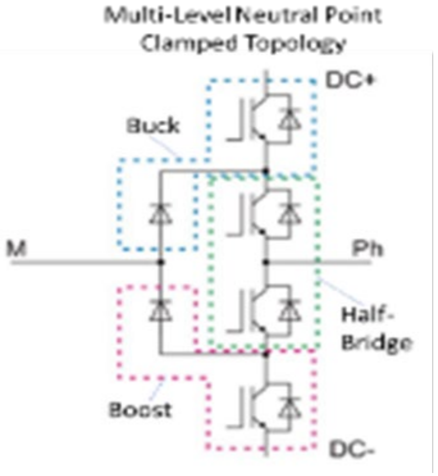
# Wolfspeed is Developing 3.3 kV, **6.5 kV**, and 10 kV SiC Modules with Customizable Device Configuration




Optimize SiC modules in industry standard footprints for 6.5 kV medium voltage markets

Target Applications

- Rail
- High-speed MV drives
- Grid-tied distributed generation and energy storage
- FACTS controllers applied to sub-transmission & transmission systems

Modules designed to replace their Si IGBT counterparts and offer increase in end-system performance and available topologies. Use of industry standard footprints for ease of adoption.

# GE is Developing SiC and GaN Modules with Danfoss in Utica NY as an Open Mass Production Facility

## GE SiC MOSFET Module Portfolio

600A, 1200V
½ bridge HTMP

400A - ½ bridge

200A, 1200V Dual

1600A, 1200V
½ bridge

250A, 1700V – 6 pack

250A, 1700V - Dual

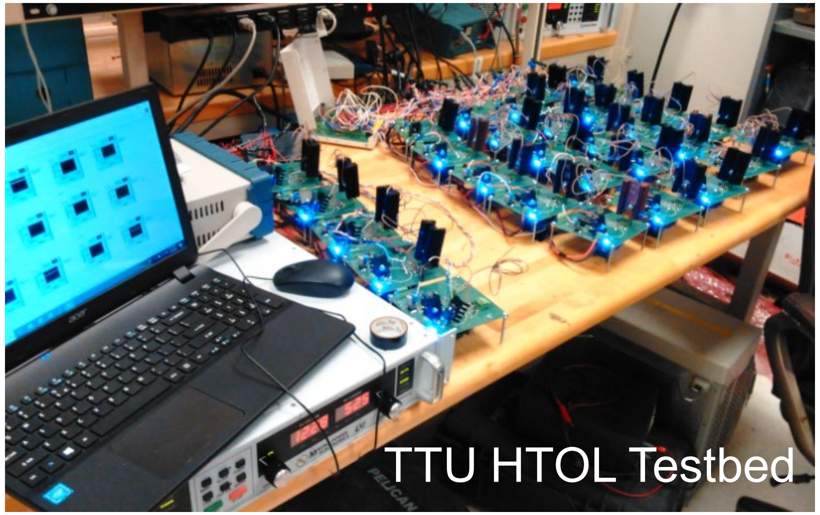
300A, 1200V
3 Channel SSPC

550A, 1700V – Dual
650A, 1200V - Dual

# Texas-Tech/NIR Inc. Member Selected Project: Establish an Independent Facility to Perform Reliability Analyses of WBG Semiconductor Devices

## Tests and Services offered

- High temperature reverse bias (HTRB)
- High temperature gate bias (HTGB)
- High temperature operating life (HTOL)
- Temperature humidity biased test (THBT)
- Intermittent operating life (IOL)
- Time dependent dielectric breakdown (TDDB)
- Avalanche (MOSFET and diode)
- Diode surge current
- Short Circuit
- di/dt and dV/dt
- Continuous switching


TTU HTOL Testbed

TTU HTRB and HTGB Testbed

# PowerAmerica Module and Reliability Accomplishments

**High Voltage/Current/Temperature/Frequency Modules** enable full SiC/GaN performance and are not available from Si, creating an opportunity for U.S. manufacturing:

- Wolfspeed 3.3 kV, 6.5 kV and 10 kV SiC Modules enable U.S. medium voltage manufacturing leadership
- GE SiC/GaN modules have path to open U.S. mass production in Utica NY

**Reliability and ruggedness concerns** are barriers to SiC/GaN technology wide adoption. PowerAmerica efforts build confidence in SiC/GaN system integration:

- Texas Tech/NIR provides independent "honest broker" reliability analysis to confirm SiC/GaN power electronics readiness for system insertion
- CoolCad establishes SiC/GaN power device ruggedness under terrestrial and other radiation exposure
- OSU short-circuit fast protection gate drives accelerate SiC/GaN system insertion

# PowerAmerica Applications Projects Boost Manufacturing by Showcasing Compelling WBG System Advantages

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V. Veliadis

# PowerAmerica SiC Power Electronics Projects Have Significant U.S. Manufacturing Potential

## Low Voltage SiC

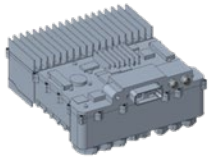
- Power-Dense Engine Coolant 200 kW 1050 V DC Bus SiC Inverter for Heavy-Duty Vehicles, *John Deere Electronic Solutions*
- Modular SiC based three-phase AC/DC Front End Rectifier with 99% efficiency, *ABB*
- Isolated, Soft Switching SEPIC (single-ended primary-inductor converter) with Active Clamp for 480 V AC to 400 V DC Rectifier for Data Centers, ASU

## High Voltage SiC

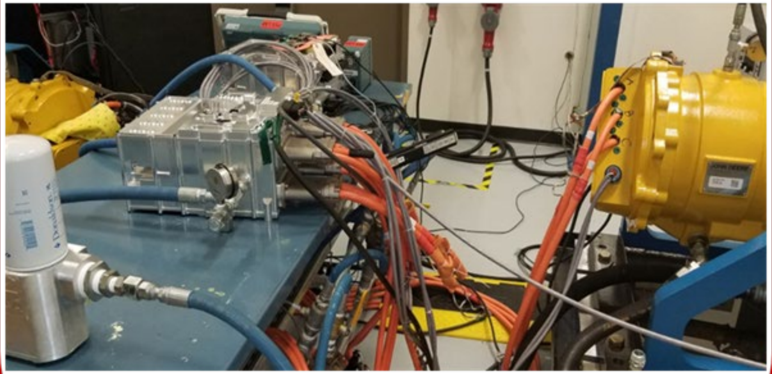
- Development, Demonstration and Commercialization of SiC Based 1 MW Medium Voltage Motor Drive System, *Toshiba*
- Direct-to-Line Central Inverter for Utility-Scale PV Plants Using 10 kV SiC MOSFET Devices, *VA Tech*
- Transformer-less Medium Voltage Central PV Inverter, *FSU & GE*
- Asynchronous Microgrid Power Conditioning System, *NCSU*
- Multi-functional High-efficiency High-density MV SiC Based Asynchronous Microgrid Power Conditioning System Module, *UTK*
- Introduction of WBG Devices for Solid State Circuit Breaking at MV, *UNCC*

# John Deere Power-Dense Engine Coolant 200-kW 1050-V DC Bus SiC Inverter for Heavy-Duty Vehicles Allows for 25% Fuel Savings

Gen-1 SiC Inverter
18 kW/Liter, 105°C Coolant



Gen-2 SiC Inverter
43 kW/Liter, 115°C Coolant



Back-to-Back Motor Dynamometer Driven by High Temperature 200 kW 1050 VDC Gen-1 SiC Inverter


**Project Objectives:**

- 200 kW 1050 V DC bus SiC manufacturing and commercialization
  - WBG technology development and SiC inverter commercialization in heavy-duty vehicles

**Achievements:**

- Proposed power density of SiC inverter: > 20 kW/Liter
  - **Power density achieved: 43 kW/Liter**
- SiC inverter efficiency: 97%
  - **> 98% efficiency achieved over coolant temperature**
- Develop engine coolant (maximum 115°C WEG coolant) SiC inverter
  - **Gen-2 SiC inverter designed for 115°C WEG coolant**

**Project impact:**

- Accelerating commercialization of the SiC inverter in heavy-duty off-highway and on-highway vehicles
- Power-dense, engine-coolant, and high-efficiency SiC inverter simplifies vehicle architecture and system level integration

***PowerAmerica Support Accelerated Effort by 5 Years***

V. Veliadis

# ABB Modular SiC Based Three-phase AC/DC Front End Rectifier has 99% Efficiency

**Project Title**:
Modular SiC based three-phase AC/DC Front End Rectifier with 99% efficiency

**Objectives**:
Accelerate the adoption of WBG in high volume power electronic applications

SOPO Task No.: BP4-4.2
TPOC/PI: Name: Jing Xu
Email: jing.xu@us.abb.com
Phone: (919) 582-3233

## WBG Technology Impact

1. Single stage, high frequency, innovative topology to achieve high efficiency and power factor correction – enabled only by the use of SiC MOSFET
2. Market segments impacted: datacenters
3. Timeframe for commercialization: 2019-2020
4. Incumbent technology that this project will compete against: double stage conversion UPS for AC datacenters, or dual stage AC/DC conversion for DC systems, with 70% more losses that this proposed innovative technology

## Accomplishments/Outcomes

The ABB project develops and demonstrates a 20 kW single-stage three-phase indirect matrix rectifier using SiC MOSFETs. The rectifier converts universal AC input voltage (380VAC – 480VAC) to 400VDC nominal (290V – 400VDC).

# PowerAmerica SiC Power Electronics Projects Have Significant U.S. Manufacturing Potential

## Low Voltage SiC

- Power-Dense Engine Coolant 200 kW 1050 V DC Bus SiC Inverter for Heavy-Duty Vehicles, *John Deere Electronic Solutions*
- Modular SiC based three-phase AC/DC Front End Rectifier with 99% efficiency, *ABB*
- Isolated, Soft Switching SEPIC with Active Clamp for 480 V AC to 400 V DC Rectifier for Data Centers, *ASU*

## High Voltage SiC

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- Introduction of WBG Devices for Solid State Circuit Breaking at MV, *UNCC*

# PowerAmerica Device/Module Bank Eliminates the Long Lead Times of Pre-production WBG Engineering Samples

Device/Module Bank Benefit:

The PowerAmerica Device/Module Bank eliminates the long lead times of pre-production WBG engineering samples

Device/Module Bank Fit to PowerAmerica Mission:

Timely availability of pre-production engineering samples is a catalyst in accelerating next generation WBG power electronics

# Toshiba's 1 MW Medium Voltage Motor Drive System Addresses An Area Responsible for 40% of U.S. Electricity Consumption

**Project Title**:
Development, Demonstration and Commercialization of SiC Based 1 MW Medium Voltage Motor Drive System.

**Objectives**: Commercialize SiC based Medium Voltage Motor Drive.

PI: Dr. Peter Liu

## WBG Technology Impact

1. Key metrics: efficiency, weight and cost.
2. Application Space: Medium Voltage Motor Drive.
3. Timeframe for commercialization: 2-3 years.
4. Higher efficiency, and Si compatible cost.

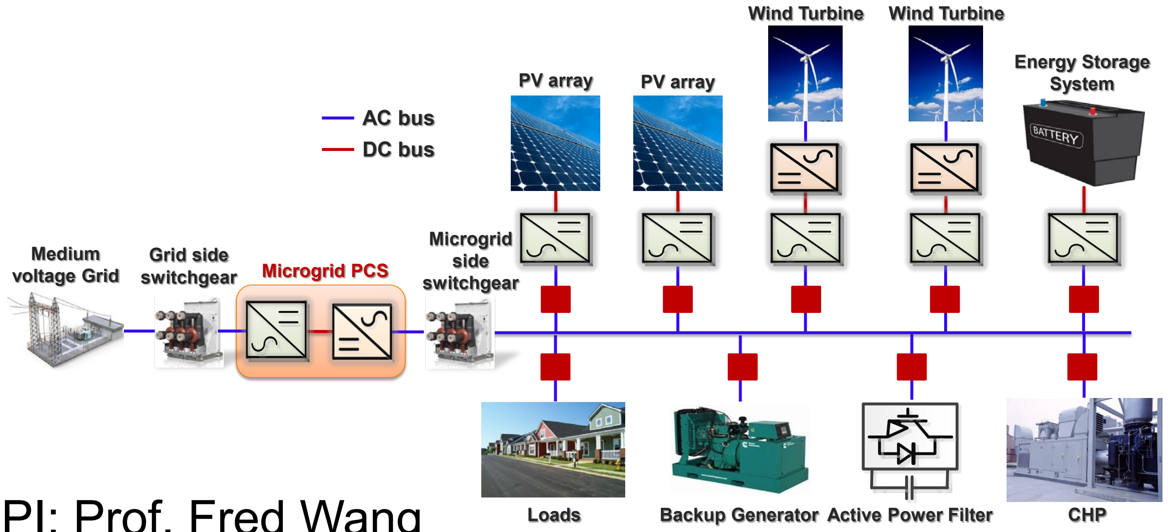
## Accomplishments/Impacts

The expected outcome of this project is an industry-level 1 MW SiC MVD system tested with 4 kV 1 MW motor and 4.16 kV Grid. The inverter portion achieves 99.2% efficiency and the active rectifier portion achieves 99% efficiency under full-load conditions.

# University of Tennessee Develops a Medium Voltage SiC Based Asynchronous Microgrid Power Conditioning System Module Using 10 kV SiC MOSFETs

**Project Title**:
Multi-functional High-efficiency High-density Medium Voltage SiC Based Asynchronous Microgrid Power Conditioning System (PCS) Module

**Objectives**: Develop a multi-functional PCS module at Medium Voltage level (13.8 kVac) using 10 kV SiC power semiconductors.




PI: Prof. Fred Wang

## WBG Technology Impact

1. Fast switching high frequency for improved efficiency, density, control bandwidth, and resultant multiple grid facing functions compared to Si devices
2. Promote proliferation of power electronic converters in medium-voltage distribution and microgrids
3. Timeframe for commercialization: 2 to 3 years
4. A > 100 kW three-phase high voltage SiC based PCS prototype (single PCS converter)

## Accomplishments/Impacts

1. Reduces SiC cost by accelerating the proliferation of high-voltage SiC devices in grid applications.

2. Creates jobs in distribution grid and HV SiC converter manufacturing areas.

3. Hands-on Medium Voltage SiC power electronics training for next-generation workforce;

4. Improves U.S. competitiveness on renewable energy integration and microgrid technologies.

V. Veliadis

# PowerAmerica GaN Power Electronics Projects Have Significant U.S. System Integration Manufacturing Potential

## High Frequency GaN

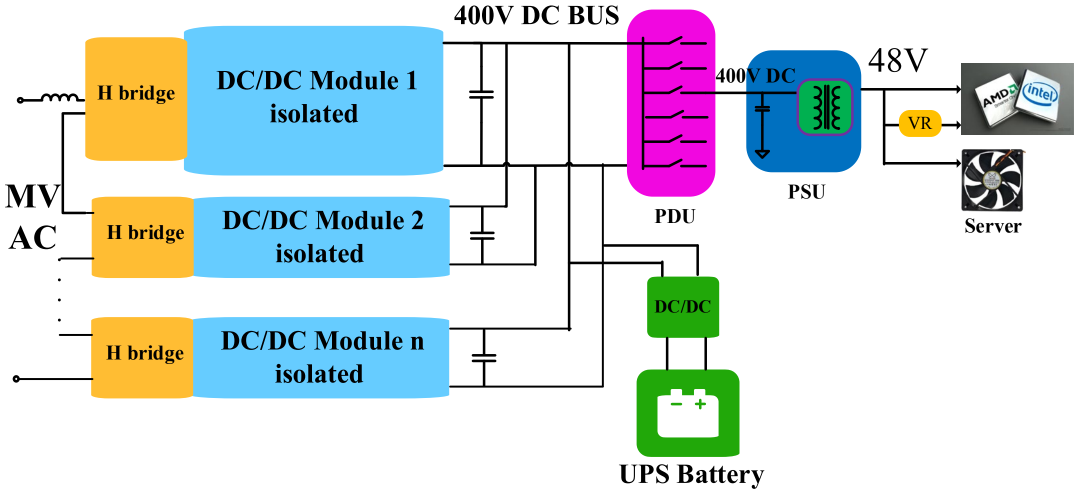
- MV (Medium Voltage) AC to Low Voltage DC Power Conversion for Data Center, *VA Tech & Infineon*
- High Speed Energy Efficient HVAC Drive, *UTRC*
- 600V GaN Dual Gate Bi-directional Switch, Infineon
- GaN-based High Efficiency Multi-Load Wireless Power Supply, *UTK*
- Dual-Inductor Hybrid Converter for Direct 48V to sub-1V PoL DC-DC Module, *U-CO Boulder*

# Infineon & VA Tech 15kW 800/400V DC/DC and 3kW 400/48V DC/DC Converters for Data Centers Enable 15% Energy Savings

Objectives: Develop a SiC and GaN based cascade high frequency isolated converter to directly step down MVAC to 400VDC, then from 400V to 48V DC.

Major Milestones:

1. 1200V SiC full bridge circuit with high frequency (>400kHz) driver
2. Matrix transformer with 99% efficiency and MV insulation capability




**VA Tech & Infineon Collaboration**

## WBG Technology Impact

Due to the increased use of cloud computing and big data, the power consumption of data centers alone will reach 10% of the total worldwide electrical power consumption by 2020. The current AC data center power architecture has many stages, which cause excessive power loss. Furthermore the 480V AC distribution bus leads to a very bulky and costly transmission bus and high conduction losses.

We will develop a SiC and GaN device based cascade high frequency isolated rectifier to directly step down MV AC to 400V DC, then from 400V to 48V DC. The proposed system is modular and easily scalable, and has much higher power density. The proposed system will not only use MV AC as distribution bus and but also eliminate several power stages of conventional date centers. Overall, the proposed data can save more than 15% of the energy consumption in conventional data centers.

## VTech/Infineon Applications and Accomplishments

The proposed cascade high frequency isolated converter is basically a power conditioning system block with bi-directional power flow capability. Its application is not only in DC data centers. It can be used in a broad range of applications, such as EV charge stations, energy storage systems, PV farms, and other micro-grids related applications.

Key results:

1. DC/DC module with 98% efficiency and MV insulation capability.
2. 1MHz 380V/48V converter with 98% efficiency

V. Veliadis

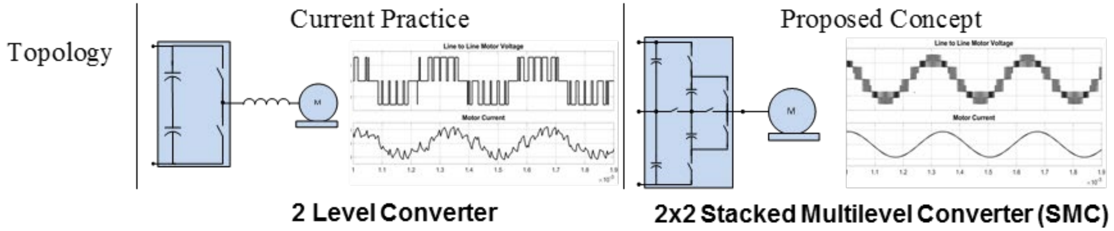
# UTRC High-Efficiency High-Speed HVAC Drive has Motor Drive, Inverter, and Converter-for-Aerospace Applications

**Project Title**:
High Efficiency High Speed HVAC Drive

**Objectives**:
Develop a WBG based high-efficiency high-speed HVAC drive for a newly developed low GWP (Global Warming Potential) compressor


Light Commercial
(5 to 25 tons )


Residential
(1.5 to 5 tons)




## WBG Technology Impact

1. Market segments: Motor drives, Inverters, converters for aerospace.
2. Timeframe for commercialization: Field trial TRL 8 demonstration in 2020-21 followed by initial customer installations by 2022.
3. Advances over silicon, or conventional approaches.

## UTRC Accomplishments/Outcomes

The project will: (1) Develop a WBG based 5 kW at 460 V high speed motor drive based on a five level stacked topology with the following features: a) Capable to synthesize up to 3300 Hz fundamental, b) Efficiency higher than 98% at full load, c) Motor current THD lower than 8% so that smoothing inductors are not required, d) drive total volume lower than 2 liters and e) dV/dt applied to the motor windings lower than 5kV/us so that no dV/dt filter between the drive and the motor is required; and (2) Demonstrate the inverter operation in a low Global Warming Potential (GWP) compressor system (TRL 5).

V. Veliadis

# PowerAmerica "WBG Power Electronics Applications" Accomplishments

**PowerAmerica's 15 SiC/GaN power electronics projects address all major applications** including automotive and rail traction, on board chargers, aerospace, photovoltaic, flexible alternative current transmission systems, high voltage DC systems, microgrids, energy storage, motor drives, and data centers.

Execution of these seed projects demonstrates SiC/GaN competitive system advantages. The outcomes are creation of high-tech manufacturing jobs and energy savings; both crucial to U.S. economy and national security.

# Strategic **University** PowerAmerica Projects Provide Hands-on Training to the Next Generation of WBG Engineers (85 Full-time Trainees)

V. Veliadis

## Funding Period 4: July 2018 – June 2019

### 1 Management and Operations

**1.1** Operations and Finance
**1.2** Technology Roadmap
**1.3** Sustainability
**1.4** Device/Module Bank
**1.6** Project Portfolio Management
**1.7** Membership, Industry Relations and Communications

### 2 Foundry and Device Development

**2.1** SiC Power Device Commercial Foundry Development **X-FAB**
**2.3** Development of Manufacturable Gen3 3.3 kV/50 mOhm MOSFET Fabricated on 150 mm 4HN-SiC Wafers Along With HTRB, HTGB, BDOL, TS, ESD, and TDDB Reliability Qualification **Cree/Wolfspeed**
**2.14** 6.5 kV SiC DMOSFET Development on 150mm Platform **GeneSiC**
**2.20** Commercialization of 3.3 kV & Technology Development of 6.5 kV SiC Devices **Microsemi**
**2.24** Low Ron-SP 3.3 kV SiC DMOSFETs in a 150 mm Foundry **Global Power**

### 3 Module Development & Manufacturing

**3.1** Industry-Driven MV SiC Power Module Manufacturing **Cree Fayetteville**
**3.6** Developing Processes for BPD-Free Room Temp. Al Implantation/Annealing for MOSFETs and Lifetime Control for Bipolar Devices **NRL**

### WBG Power Electronics Applications

**4.1** Power-Dense Engine Coolant 200 kW 1050 V DC Bus SiC Inverter for Heavy-Duty Vehicles **John Deere Electronic Solutions**
**4.2** Modular SiC based three-phase AC/DC Front End Rectifier with 99% efficiency **ABB**
**4.3** Development, Demonstration and Commercialization of SiC Based 1 MW Medium Voltage Motor Drive System **Toshiba**
**4.7** Direct-to-Line Central Inverter for Utility-Scale PV Plants Using 10 kV SiC MOSFET Devices **VA Tech/Burgos**
**4.8** MV AC to Low Voltage DC Power Conversion for Data Center **VA Tech/Li+ Infineon**
**4.10** Transformerless Medium Voltage Central PV Inverter **FSU/Li+GEAS**
**4.11** Asynchronous Microgrid Power Conditioning System **NCSU/Bhattacharya**
**4.23** High Speed Energy Efficient HVAC Drive **UTRC**
**4.15** Isolated, Soft Switching SEPIC with Active Clamp for 480 V AC to 400 V DC Rectifier for Data Centers **ASU/Ayyanar**
**4.28** Multi-functional High-efficiency High-density MV SiC Based Asynchronous Microgrid Power Conditioning System Module **UTK/Wang**
**4.32** GaN-based High Efficiency Multi-Load Wireless Power Supply **UTK/Costinett**
**4.33** Dual-Inductor Hybrid Converter for Direct 48V to sub-1V PoL DC-DC Module **U-CO/Maksimovic**
**4.34** Introduction of WBG Devices for Solid State Circuit Breaking at MV **UNCC/Manjrekar**
**4.36** 600V GaN Bi-directional Switch **Infineon**

### 5 Education and Workforce Development

**5.1** Education and Workforce Pipeline Development
**5.4** Undergraduate Research Scholars
**5.5** Pre-College Education
**5.6** WBG Short Courses
**5.13** Documentation of Design and Process of GaN Power HEMTs **RPI/Chow**
**5.14** WBG Power Converter Design Space Exploration **NCSU/Lukic**
**5.16** Universal Platform of Education, Research, and Industrial Rapid Prototyping of High Power WBG Applications **NCSU/Husain**
**5.17** Graduate WBG Semiconductor Power Device Lab **NCSU/Pavlidis**
**5.18** Power electronics teaching lab incorporating WBG switches and circuits **UNCC/Parkideh**

**$6.8M** in18 Member University applied projects train the next generation of WBG Engineers:

*21 undergrad, 55 grad, and 9 Post-docs*

# PowerAmerica 19 Member Universities Educate the Next Generation of Wide Bandgap Power Engineers

***530** Graduates in Power Electronics courses

***312** Undergraduates in Power Electronics courses

55 graduates, 21 undergraduates 9 post-docs FTEs in hands-on PowerAmerica projects

**174** WBG lectures have been integrated into power electronic programs

*Data for Spring and Fall 2018

V. Veliadis

# PowerAmerica's Industry Requested LinkedIn Student Portal Connects Students to Industry

PowerAmerica

Advancing Silicon Carbide and Gallium Nitride technologies.

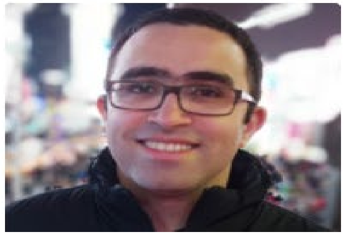
About | Membership | Education and Workforce Development | Funding Opportunities | 2018 Call for Projects | Short Course | News | Calendar

## PowerAmerica-Affiliated Students

Through its member universities, PowerAmerica is affiliated with a talented pool of undergraduate and graduate students who represent the best and brightest of the future power electronics workforce. These students, who already work with wide bandgap applications, are available for internships and employment. Contact them directly via their LinkedIn profiles.

### Jared Baxter

**School/year:** The University of Tennessee-Knoxville, Ph.D.
**Major:** Energy Science and Engineering
**Concentration:** Energy Conversion and Storage
**Project:** Unified Design Framework for Power Electronics
**Project Description:** Development of a tool that streamlines the design process of power converters through advanced analysis, simulation, and optimization.
**Area of Expertise:** Power Converter Analysis, Simulation, and Optimization
**Graduation Date:** Spring 2021



### Mehrdad Biglarbegian

**School/year:** University of North Carolina – Charlotte, Ph.D.
**Major:** Electrical Engineering
**Concentration:** Power Electronics
**Project:** High-frequency power GaN converter digital twin
**Project Description:** Development of real-time prognostics for reliability awareness of high-

PowerAmerica University affiliated students have held internships at companies including:

- ABB
- John Deere
- GE
- Lockheed Martin
- Raytheon
- Eaton
- Schneider Electric
- XFAB
- UnitedSiC
- GeneSiC

# PowerAmerica Industry Driven SiC/GaN Power Technology Short Course Trains Existing Workforce

POWERAMERICA

## WIDE BANDGAP DEVICES & APPLICATIONS SHORT COURSE

November 13–15, 2018 | NC State University, Raleigh, NC

SOLD OUT

### COURSE BENEFITS

Enable power electronics engineers to incorporate SiC and GaN technology into products and systems, and fully utilize the benefits of this technology.

**Earn Professional Development Hours (PDH) and/or Continuing Education Units (CEU) upon completing the short course.**

### COURSE OBJECTIVES

Provide the basics of SiC and GaN power electronics technology. Participants gain proficiency through instruction of WBG fundamentals, application-specific case studies and hands-on laboratory demonstrations.

### WHO SHOULD ATTEND

- POWER ELECTRONICS APPLICATIONS ENGINEERS
- POWER DEVICE ENGINEERS
- SIC & GaN TECHNICAL MARKETING PROFESSIONALS
- POWER ELECTRO... BUSINESS & P...UCT LINE M...GERS

### INSTRUCTORS

**Victor Veliadis, PhD**
Deputy Executive Director and CTO, PowerAmerica

**David Levett, PhD**
Power Electronics Design and Applications Engineer, Infineon Technologies

**Elif Balkas, PhD**
R&D Manager-Materials, Wolfspeed

**Al Burk, PhD**
R&D Manager –Epitaxial Growth, Wolfspeed

**Qiang Li, PhD**
Professor, Virginia Tech

**Jon Zhang, PhD**
WBG Device Director, PowerAmerica

**Fred Wang, PhD**
Professor, University of T...

**Kevin Bai, PhD**
Professor, Unive... TN, Knoxville

**Stephen Bay... PhD**
Professor, Tex... ch University

**Iqbal Husain, PhD**
Professor, North Carolina State U...ity

**...ian Lukic, PhD**
...or, North Carolina State Univers...

**Do... ...pkins, PhD**
Profe... ...rth Carolina State ...rsity

**...ubhas... ...hattach... PhD**
...essor, N... ...roli... ...e University

**...Styles**
Di... of Busine... ...evelopment, GaN... ...ems

### EARN CREDIT

Continuing Education Units (CEU) ...2
Professional Development (PDH) ...20

### CO...RSE F...

$1200 PowerAmerica m...
$1800 ...ica non-member
C... ...ructi... ...aterial, ...ast, break sn... ...and lunches

### ...CATION

PowerAmerica Institute
North Carolina State University
Raleigh, NC 27606

**REGISTRATION ONLINE** ...owerAmericaInstitute.org/shortcourse

### SCHEDULE

Day 1 8 a.m. – 5 p.m.
Day 2 8 a.m. – 5 p.m.
5:30 – 7 p.m. Networking Reception
Day 3 8 a.m. – 2:30 p.m.

### COURSE OUTLINE

**Opening Session:**
Executive Overview

**Silicon, GaN and SiC: There's Ro... ...r All**
- Market trends and drivers
- Implications to system performance
- Device performance... ...plications
- Challenges for a... ...nologies

**Practical Im... ...entation of SiC M... ...ETs for Power Conv... ...er Design**
- Si IGBT's and ... MOSFET's similarities and difference... ...erview
- Gate driver des... ...d PCB layout
- Thermal design a... ...aging
- Real world design exa... ...ve
- Long term reliability and design margin

**W... Modules & Packaging and Imp... ...on Circuit Design**
- Elect... design challenges for WBG devices
- Packa... processes, materials and desig... ...quirements
- Ad... ...d packaging technologies
- ... Introduction to multiphysics ...ncepts and analysis
- System level considerations of WBG power modules
- Full design case study and hands-on lab experience

**SiC Power Device Technology**
- Bulk Substrate
- Epitaxy
- Design and Fabrication

**WBG Power Electronics Case Studies:**
**Medium Voltage EV Fast Charger System**
- Converter topology selection
- Device selection and characterization
- System modeling and simulations
- Control system specification
- Prototype development and testing
- Schematics and PCB design, hardware assembly and testing
- Control code development and debugging
- System optimization to meet the design requirements
- Demo: MV SiC fast EV charger

**SiC T... ...n Inverter for El... ...and Hybrid Vehicles**
- ...owertrain system modeling and si... ...n WBG EV traction inverter
- Powe... ...e, gate driver, and controller
- WBG ci... ...esign for high frequency, high tempe... operation and EMI suppression
- Passive comp... ...sizing and selection
- System benefits ... ...G insertion

**...h Voltage SiC Power Device ...acterization and Converter Applications**
- ... voltage SiC device characterization
- ... drive isolation, short circuit protection and ...tching performance
- ...ower converter design considerations
- High frequency magnetics
- Solid state transformers and MV motor drives
- Autonomous grid connector — for grid interconnection of microgrid to grid / microgrid

**WBG Based High Efficiency Power Architectures for Data Centers**
- WBG based power architectures for data centers and their benefits
- Magnetic components for high frequency data center power converters.
- EMI suppression for high frequency data center power converters
- Digital control for high frequency data center power converters

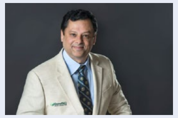
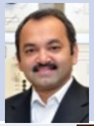
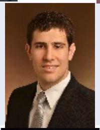
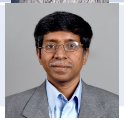
**Power Electronics for Grid Applications**
- Overview of power electronics for grid application
- Emerging needs and challenges
- Opportunities and research needs introduced by WBG and other new technologies
- Highlights of ongoing research and development

**GaN Automotive Power Electronics**
- GaN based EV Charger: topology and simulation
- Design of power loop, gate-drive loop, and controller
- Thermal analysis and design
- GaN in EV accessory power module (APM) and inverter

**WBG Power Electronics Demonstration/Lab Tour**

2.5 day duration
Nov. 13-15, 2018

# Monthly Technical Webinars by PowerAmerica Member Experts are Well Attended, Open to All, and Promote SiC/GaN Power Electronics

| Date | Speaker | | Title |
|---|---|---|---|
| September 5, 2018 | Jon Zhang - PowerAmerica |  | Current Status and Future Perspectives of Wide Bandgap Semiconductor Power Devices and Applications |
| October 3, 2018 | David Ricketts – NC State |  | Integrated Gan for 100 MHz + DC-DC Switching Converters |
| November 7, 2018 | Akin Akturk - CoolCAD |  | Quantifying Power Device Reliability due to Terrestrial Radiation |
| December 5, 2018 | Ranbir Singh - GeneSiC |  | State of the art SiC Schottky MPS Rectifiers and High Voltage MOSFETs |
| January 16, 2019 | Madhav Manjrekar – UNCC<br>Clint Halstead – UNCC Student |   | Practical considerations for GaN Based Implementation |
| March 6, 2019 | Daniel Costinett - UTK |  | Multi-Receiver Wireless Power Transfer for Consumer Electronics Leveraging WBG |
| April 3, 2019 | Han-Phuc Le – U CO |  | Converters for Large Conversion Ratios and High Current Density |
| May 1, 2019 | Raja Ayyanar – U AZ |  | Isolated, Soft Switching SEPIC with Active Clamp for 480V AC to 400V DC Rectifier for Data Centers |

# PowerAmerica Wide Bandgap Conference Tutorials Educat… Participants and Promote Mission and Sustainability (… …endees)

**450 Tutorial Attendees in 2018-2019**

## PowerAmerica Summer Workshop SiC/GaN Tutorials (A… …endees

1. "SiC Power Devices: Power MOSFETs, IGBTs, and GTOs"- S…
2. "GaN Power Devices: Impacts of GaN Devices on Pow… …inia Tech
3. "Modules and Packaging: Achieving High Perfor… …ies"- *Richard Eddings, GE.*

## PowerAmerica Annual Meeting S… …0 Attendees

1. SiC Devices - *Ranbir Singh, Gene…*
2. GaN Power Devices and Ap… …*ruments*
3. WBG Module Standar…
   - *Rick Eddins, G…*
   - *Ty McN…*

## IEEE … …ongress (ECCE) Sept. 2019

"The Po… …ture: Do Internships and Apprenticeships Really Pay Off?"
Victor Ve…

## 6th IEEE W… …Wide Bandgap Power Devices and Applications (WiPDA 2018)

"Silicon Carbi… …r Devices: Making the Transition from Silicon", Victor Veliadis – **120 attendees**

# PowerAmerica Education and Workforce Development Accomplishments

A workforce well trained in SiC/GaN power electronics is key in creating the large component demand that will spur mass manufacturing with its cost-lowering benefits. The power electronics industry is traditionally slow to change and adapt to new technologies, and a workforce lacking expertise in WBG will be reluctant in its adoption and unable to exploit its full performance potential. To address this challenge, PowerAmerica implemented a strategic WBG educational effort that seeks to train the existing workforce, educate students to form the next generation of WBG professionals, and facilitate internships and highly specialized talent recruitment:

- *$6.8M strategically allocated in 19 University applied projects train 85 FTEs*
- *Addition of 174 SiC/GaN lectures to power electronics curricula at PowerAmerica Universities*
- *PowerAmerica's Industry Requested LinkedIn Student Portal connects student to industry (internships performed at ABB, John Deere, GE, Lockheed Martin, Raytheon, Eaton, Schneider Electric, XFAB, UnitedSiC, and GeneSiC)*
- *Annual SiC/GaN short course offering with content driven by industry*
- *Monthly webinars by PowerAmerica member experts*
- *Tutorials at PowerAmerica events and conferences draw 450 attendees*
- *"Education" projects produce SiC/GaN labs, courses, and application reference drawings*

*"A skilled workforce is key in creating the large WBG demand that will spur mass manufacturing with its cost-lowering benefits"*, Veliadis 2018

# Results and Accomplishments

- Where are you in the project? Completing 4th of 5 years
- What milestones have you completed? 800 milestones completed on over 100 projects in the 4 years of DOE PowerAmerica. 31 projects in 2018-2019
- What accomplishments have been made to-date? The focus should be on results obtained since the last Review in 2018 (if applicable). New projects should focus on planned milestones and planned accomplishments.

Have robust U.S. SiC microelectronics industry. Fabless companies fabricate in U.S. (not overseas). Projects with industrial members close to launching products.

- Describe the results so far. Described in previous slides.
  - Present quantitative data and compare to the state-of-the-art and/or goals of project

Device fabrication in U.S. foundries, industry launching traction/PV/data centers

- Describe work to be completed between now and the end of the project, as applicable Final +32 PowerAmerica team projects have been selected

# Transition (beyond DOE assistance)

- Describe the expected strategy for further technology development and eventual commercialization after completion of the project.

As outlined in the previous slides, PowerAmerica has identified and strategically funded all aspects of the SiC/GaN supply chain that synergistically culminate in accelerated commercialization. The infrastructure has been seeded with over 120 PowerAmerica projects; 31 in this period. PowerAmerica education efforts have enhanced the SiC/GaN ability of the workforce and are training the next generation of SiC/GaN power professionals. Industrial upper management has taken notice of the competitive SiC/GaN advantages and is fueling further growth in the tune of billions of dollars. Free markets will push the technology/partnerships forward. At least one company from China is currently manufacturing SiC semiconductors in a U.S. foundry; this reversal trend is a huge success for U.S. manufacturing and testament to the work PowerAmerica has accomplished with its members.

- Who will be the commercialization partners?

As described in the previous slides, device companies partner with module companies and applications end users to exploit the efficiency/weight/volume advantages of SiC/GaN systems. The U.S. is represented by numerous companies in every aspect of the supply chain who are now teaming with other U.S. and foreign companies per free market principles.

# PowerAmerica is Transitioning to a "Member Governed" Sustainable SiC/GaN Power Technology Manufacturing Institute

**Executive Committee**: consists of 10 experienced industrial, academic, and government leaders, in an advisory role

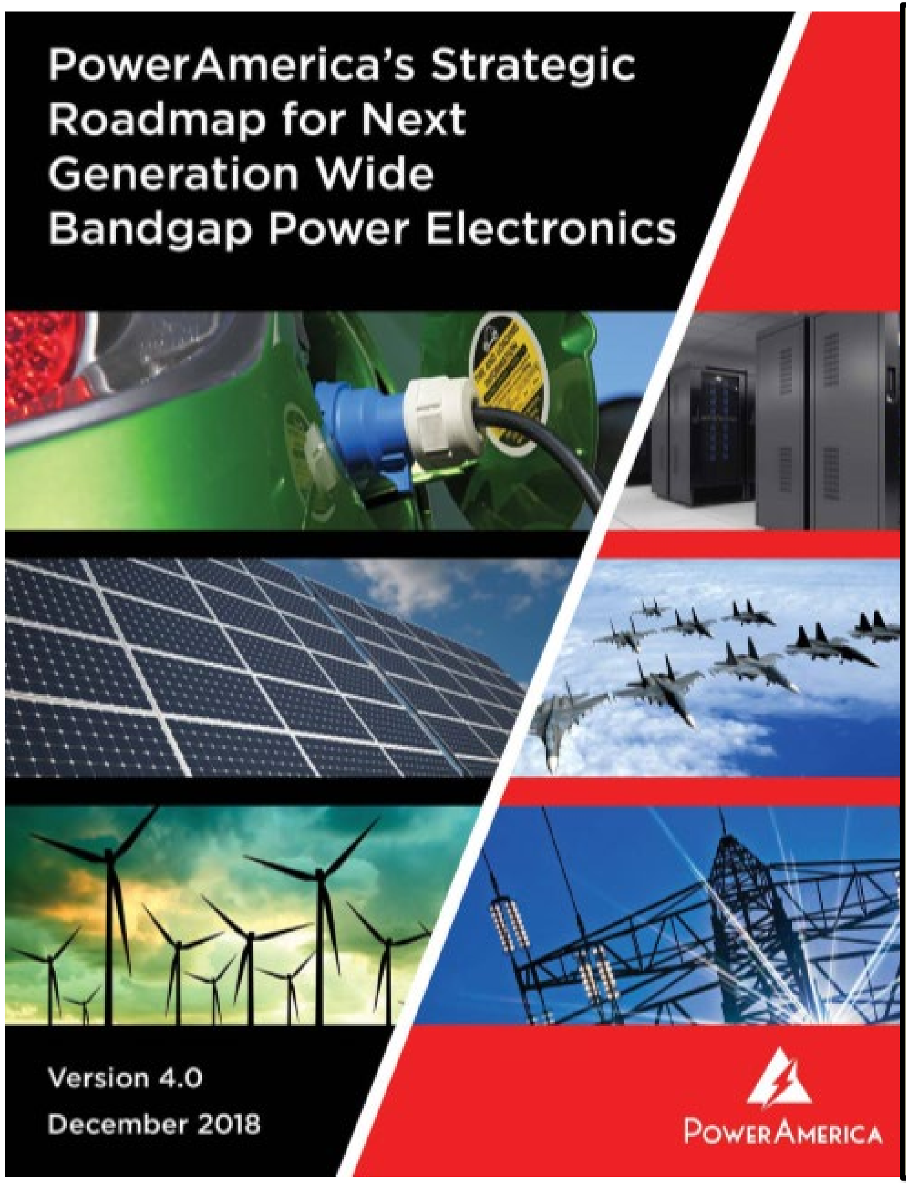
**Member Advisory Committee (MAC):** Consists of all members, has an elected chair and vice-chair, meets quarterly. <u>PowerAmerica uses MAC input to</u>:

- Develop initiatives to address member needs
- Create WBG Tutorials to train the workforce
- Integrate member ideas into PowerAmerica programs
- Enhance PowerAmerica value proposition for members
- Formulate post-DoE funding sustainability
- Review and provide revisions, if necessary, to PowerAmerica by-laws including:
    - Intellectual Property rights
    - annual dues and benefits for each membership level
- Define Executive Committee composition

# TRANSITION: PowerAmerica Provides Value Beyond DOE Funding and Will Continue to Accelerate SiC/GaN Technology Manufacturing

- **Networking**
  - Summer/Winter member meetings
  - Summary presentation of all PA projects at meetings
  - Long networking breaks at meetings
- **Access to Universities and Recruitment**
  - Student presentations, internships
  - Job opportunities posted on website
  - Collaborative research projects
- **Education and Workforce Development**
  - WBG short course offering with industry driven content
  - Tutorials presented at major WBG conferences
- **Timely Access to PowerAmerica Device Bank Engineering samples**
- **WBG Ecosystem Benefits** such as member initiated projects, roadmaps, industry perspectives, technical consulting, and promotion of SiC and GaN power technology

# PowerAmerica Technology Roadmap Compiled on 12/2018 with Member Input Drives Commercialization Strategy




PowerAmerica Roadmap Incorporates:

- ✓ **June 2018 member survey** input regarding the challenges facing the adoption of WBG semiconductor technology
- ✓ **August 2018 member road-map workshop** feedback
- ✓ **New market forecast** for WBG power electronics, analysis of SiC and GaN device cost based on market information, and input from PowerAmerica's Device Bank
- ✓ **Key markets and application areas** for SiC and GaN PE, **the performance targets** GaN and SiC technologies are expected to meet over time, **technical barriers** to achieving those targets, and **technical activities** needed to overcome those barriers
- ✓ **IEEE International WBG roadmap** (ITRW) collaboration

# Project Management & Budget

- What is the duration of the project? 5 years

- Describe the project task and key milestone schedule
  - How will progress be measured?

Accelerate commercialization of SiC/GaN power technologies. About 1000 milestones will be completed over the 5 year project duration strengthening all areas of the supply chain.

Progress will be measured by creation of manufacturing jobs, products launched, cost reduction, and competitiveness of U.S. industry in this field.

- Include project budget in table format:

| Total Project Budget | |
|---|---|
| **DOE Investment** | $70M |
| **Cost Share** | $77M |
| **Project Total** | $147M |

# Measure of Success

- If you're successful, what difference will it make? What impact will success have? How will it be determined?

Success is a robust U.S. microelectronics industry instead of overseas; repurposing older foundries. U.S. fabless companies doing foundry work in U.S. Module production in U.S. (almost entirely overseas today for Silicon). Product launch of U.S. devices, modules, and systems (traction, data centers, chargers, motor drives, PV). Success will create U.S. repurposing of foundries, novel technologies, manufacturing jobs, energy savings.

- Describe the key technical measures that need to be met.

SiC/GaN system reliability/ruggedness, and cost comparable to Silicon.

Cost of devices (~3X more expensive than Si at this point) and modules will be reduced through large adoption enabling mass production with its cost lowering benefits.

Device reliability/ruggedness established through honest broker third party testing. System cost already comparable to Silicon in PV, innovation/volume to reduce cost of other systems.

# Questions?

*A workforce well trained in WBG power electronics is key in creating the large device demand that will spur volume manufacturing with its cost-lowering benefits.*

*WBG device fabrication in large-volume Si foundries exploits economies of scale and is key in lowering cost.*

*Minimizing capital expenditures by exploiting the mature Si-processing capability lowers fabrication costs.*

*PowerAmerica funds building-block projects in multiple areas of the WBG supply chain that synergistically culminate in large-scale WBG power electronics adoption.*

PowerAmerica

PowerAmerica accelerates SiC/GaN commercialization