Wide Bandgap Devices

Enabling a Revolution in Power Electronics
Brief History of PowerAmerica

**Vision:** 2% Energy savings through deployment of WBG Power Electronics in Consumer, Industrial and Commercial Sectors and Developing a manufacturing base in US through:

(1) Achieving cost parity with Silicon in 5 years, and
(2) Training Grad. students in using WBG Semiconductors.

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
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<tbody>
<tr>
<td>PA announced by President</td>
<td>January 15, 2014</td>
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<tr>
<td>Budget Period 1 began</td>
<td>December 1, 2014</td>
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<td>Kick-off Meeting</td>
<td>January 21 &amp; 22, 2015</td>
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<td>First Quarterly Review</td>
<td>May 4-8, 2015</td>
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<tr>
<td>Budget Period 1 ends</td>
<td>January 31, 2016</td>
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Current PowerAmerica Partners

Institute Lead:
NC State University

University Partners:
Arizona State University
Florida State University
University of California, Santa Barbara
Virginia Tech

Lab Partners:
National Renewable Energy Laboratory
U.S. Naval Research Laboratory

Industry Partners:
ABB
Arkansas Power Electronics International (APEI)
Cree
Delphi
John Deere Electronic Solutions
Monolith Semiconductor
Toshiba
Transphorm
United Silicon Carbide, inc.
X-Fab

Partners on-board as of May 1, 2015
New PA Members

- Lockheed-Martin
- Raytheon
- Navitas Systems
- UChicago Argonne, LLC
- Rensselaer Polytechnic Institute (RPI)
- Tezzron Semiconductor
- GeneSiC Semiconductor
High Efficiency Requirement in IT

Total Energy in 2012
150,000 terawatt hours (TWH)*

Total Electricity consumption:
20,000 TWH*

1% efficiency improvement of power supplies in IT equipment?

Motor Drives
Lighting
Others

iT (2,000 TWH)

20 TWH saving = 5 Nuclear Power Plants

*Ref: http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=44&pid=44&aid=2
Impact of WBG on Data Center

- **Conventional Power Distribution**
  - MV 480Vac (50/60Hz)
  - AC/DC
  - UPS
  - DC/AC
  - 208Vac
  - 400V
  - AC/DC
  - DC/DC
  - Mother Board
  - 12V Bus
  - Efficiency: 94~97%
  - Efficiency: 92~96%

- **Proposed Power Distribution with WBG Device**
  - MV
  - SiC based Solid State Transformer
  - 400V Bus
  - GaN based DC/DC
  - Server Mother Board
  - 12V
  - Efficiency: >98%
  - Efficiency: >97%

- Advantages:
  - Simpler System
  - Higher Efficiency
High Impact - Computer Power Supplies

- **AC Power Adaptors and Power Supplies:**
  Servers, TVs, laptops, cell phones, tablets, printers, appliances...

  ![](image)

  **Product Features:**
  - Power Input: 100-240V ~ 50-60HZ 1.5A
  - Power Output: 19.5V == 4.62A
  - Peak Efficiency: 75-80%

- **Projected Impacts:**
  Easy marketing case as people don’t like to carry bulky power supplies – first adopter
  Subsequent penetration in cost sensitive markets such as TVs and appliances
  Eventually 1-2 % of all electricity can be saved in U.S. through higher efficiency

  ![WBG inside]

  **Peak Efficiency: 95%**
The best Device: GaN Lateral HEMT
Status: Commercialized by 3 or more vendors in US.
Strategy: Fund demonstrations and lower the cost by transfer to Foundry

3-4% of electricity used in households

- Server Power Supplies
- TVs
- Set top boxes
- PCs
- Monitors
- Game Consoles

200-600 V – Switch Mode Power Supplies
US Manufacturing Advantage by combining Several Key Technologies in an Integrated Approach

Traditional

13.8 kV 3 phase 60 Hz
Big 60 Hz Transformer

4.16 kV 3 phase 60 Hz
1-50 MW 60 Hz Motor 1800 RPM

Gear Box 1:G(5-10)
Compressor Fixed Speed 9 K-18 K RPM

20-40% energy is wasted with throttles and other mechanical devices

New Approach

13.8 kV 3 phase 60 Hz
Variable Speed Drive SiC Based

1-50 MW Gx60 Hz Motor G x smaller Volume

Compressor Variable Speed 9 K-18 K RPM

Delivered as one box

- Big 60 Hz Transformer replaced by small high frequency Transformer
- Motor size reduced by 5x – cheaper, less magnets
- 20-40% energy per motor system is saved due to Variable Speed Drive – pay-back < 3 years
- Gear Box eliminated
- Smaller Foot-print (up to 5x)
The U.S. would gain a competitive advantage over foreign competitors by designing and manufacturing a “Made-in-the-USA” integrated MV-class electric motor system.
Wide Bandgap Semiconductors: Power Split Hybrid

Diagram showing the components of a power split hybrid system:
- Generator
- Engine
- Motor

The image illustrates the integration of these components in a circular arrangement, indicating their role in a power split hybrid system.
Wide Bandgap Semiconductors: Power Split Hybrid

Cruising/Steady Speed Example

- Hybrid system controls engine speed through motor and generator
- 4% total roundtrip efficiency improvement with 2% from each inverter
Wide Bandgap Semiconductors: Power Split Hybrid

Regenerative Braking to Acceleration Assist Example

- Motor recharges battery through regenerative braking, then uses stored energy to assist in acceleration.
- 8% total roundtrip efficiency improvement with 2% from motor inverter and boost converter each way.
Application of WBG Devices in Heavy Duty Vehicles

644 Loader for Construction and Agriculture: used to be hydraulic

200 kW Si Based Dual-Inverter (VSD) saves 37% fuel for same Ton of load moved & 25% gallons/hr

- 700 V DC bus, 6 kHz switching
- Higher productivity since Operator does not have to manage pedal and brakes at the same time
- Easier operation due to VDS power-train

Use of WBG devices will result in additional 15% fuel savings if measured in gallons/hour

- 1050 V DC Bus, 10 kHz to 15 kHz switching
- Lower Copper weight due to reduced line current
- Smaller motor and generator due to higher voltage
- Lower magnetic losses in the motor and generator due to reduced ripple
- Only one coolant loop as inverter could use engine coolant loop
- Built in DC to DC converter (20 kHz and beyond) – saves regenerative energy
- 2 speed as opposed to 3-speed transmission
- Can be scaled to 0.5 MW inverter for larger vehicles
EV Fast Chargers- Essential for EV Adoption

- SiC can make Fast Chargers Cheaper and more Efficient – Charge an EV in 10-15 min. or less

- 30-50 kW Charger
- Input Power: 480 V, 3 Phase AC
- Input Current: 79 A Max
- Efficiency Rating: >94.6%
- Weight: 1422 lb
- Total Capital + Operating Cost: $ 75 K

Delta DC Quick Charger

WBG Inside
Barriers to Acceptance

• High Cost of WBG Chips
  – Lower systems cost arguments don’t work with 10x higher semiconductor cost
  – Must reduce cost of WBG Semiconductors – Achieve parity with Si costs in 5 years

• PE Community slow to change and adapt new technologies
  – Lack of experience with WBG semiconductors
  – False perceptions of poor reliability of WBG semiconductors
  – Must train Graduate students to use WBG devices in Power Electronics
Benefits of Using Commercial Si Foundry

- Typically only 10-20% capacity of commercial foundry utilized
  - 90% of the processes are the same

- Innovation by researchers, small companies and students through design and access to *fabless model*—similar to MOSIS

- Reduce technology risk...encourage investments by VC firms
  - $10-15 M is required to create a product as opposed to $100 M

Goal: Achieve 10 cents/amp for 1200 V switches in x yrs
SiC and GaN devices can be competitive with Silicon

$\$/A for 1200 V, 20 A SiC MOSFET

- 100 mm dedicated Foundry Low Volume
- 150 mm Commercial (Substrate + Epi costs dominate)
- 100 mm Commercial (Reduced process cost & higher yield)
- 150 mm Commercial High Volume, Fabless

Current Silicon IGBT
Overcoming Reluctance to Adoption

Education and Training

• Establish programs at different educational levels in:
  – WBG technology
  – Power Electronics applications with WBG devices

• Grow experienced workforce

• Generate future leaders in power electronics

• Develop text book on design and processing of WBG power devices
  – Equivalent to Mead & Conway - 1979

Goal: Train at least 100 Graduate students in 5 years
WBG Power Semiconductor Roadmap

• Reduce chip costs 50% every 2 years with improved performance
  – Achieve 10 cents/amp in x years
  – Manufacturing 8-inch wafers in 5-8 years

• WBG devices replacing 600V-1700 V Si in mainstream applications within 5 years

• Development of 10-15 kV devices enabling new applications in MV motor and Grid Power Control

*The market for WBG devices will double every 2 years from $100M to $3B in 10 years*