Accelerate Wide Adoption of WBG Semiconductor Devices in PE Systems

**Vision**

**Strategy**

- **Highlight Performance Advantages of WBG Devices**
  Stress high voltage at low resistance, high temperature, and high frequency WBG device operational advantages over those of Si counterparts

- **Establish Reliability of WBG Devices**
  Leverage Si Reliability best practices in developing WBG reliability standards

- **Showcase System Insertion Advantages of WBG Devices**
  - Develop packaging technology that allows for full WBG performance potential
  - Demonstrate WBG PE system value proposition in terms of higher efficiency, and smaller weight/volume at low overall additional system cost

- **Reduce Cost of WBG Devices**
  Leverage mature Si fabrication practices, and qualify WBG specific processes to enable multiple source high-yield volume production

- **Train Workforce in WBG devices/modules/systems**

**Benefits**

Job Creation, Accelerated Technology Innovation, Energy Savings, Smaller Environmental footprint
WBG Ecosystem Spans Numerous Industries

- Device Design Houses
- Wafer Suppliers
- Wafer Fabs
- Reliability and Packaging Fabs

WBG Roadmapping requires a clear understanding of industry interplay

Market Demand Feedback

OEMs
Manufacturing volume lowers wafer costs. Larger area wafer lowers device cost.

*Modified from DOE Quadrennial Technology Review Ch 6N*
• **Strategic Government Policy Documents**
  
  - Quadrennial Energy Review (QER)
  - Quadrennial Technology Review (QTR)-CH 6N.
  - Advanced Manufacturing Partnership 2.0
    - (NEC / PCAST 2014/ OSTP 2014)
  - Quadrennial Defense Review (QDR)
    - Naval S&T Strategic Plan
    - Army S&T Campaign Plans 2015-2035

• **WBG Power Semiconductor Roadmaps**
  
  - USDRIVE, Electrical and Electronics Technical Team Roadmap, June 2013
  - PEIC, *Driving Collaboration for Power Electronics Technology Roadmapping Review*, Nov. 2015
• Market Driven Roadmaps

  • *GaN and SiC Devices for Power Electronics Applications*, August 2015
  • *GaN and SiC and WBG Materials for Power Electronics Applications*, October 2015
  • *GaN Devices for Power Electronics – Patent Investigation*, 2015
  • *Wide Band Gap Power Electronics: A Path Toward CO2 Emission Decrease*, Yole presentation at Semicon West Conference, July 2014
  • *Market and Technology Trends in WBG Materials for Power Electronics Applications*, Yole presentation at the CS MANTECH Conference, May 2015
  • Ampere Laboratory, INSA de Lyon, *Wide Bandgap Power Devices GaN and SiC*, March 2015
# Roadmap Drives Investment and Project Selection

## Driving Cost

1. Complete X-Fab investment to provide ability to run process without outsourcing steps.

2. Facilitate Introduction of companies to Foundry Model.

3. **Develop PowerAmerica Fabrication Process.**

4. Continue support of vertical integration with packaging.

## Driving Reliability

1. Establish connections with PELs working group for SiC devices.

2. Establish connections with Texas Instruments, Infineon about JEDEC.

3. **Develop Independent Reliability Center.**

## Accelerating Commercialization

1. Showcase System Insertion Advantages of WBG Devices.

2. Train workforce.

3. **Establish device bank to reduce lead time and improve accessibility.**
**SiC Strategic planning**

**FA2: Device Fabrication**
US Maintains Competitive WBG Fabrication of Devices and Modules

- Diodes for Volume MOSFETs for Potential transfer of existing Processes
- PA enabled 1st products X-fab In House Process complete
- PA Process Used by Academia, Industry?

**Initial SiC Foundry Capital Equipment Investment**

- HV Diode, MOSFET Processes
- 1st Devices Delivered to Device Bank
- Packaging of improved through teaming and R&D. More focus on 3.3-10 kV
- Reliability WBG Established

**Big Road Mapping Questions:**
How low in voltage will SiC Go? (Impact on Automotive, GaN)
Enough U.S. HV Packaging Expertise?
How can reliability best be communicated?

**FA4: Accelerate Commercialization**
PA enabled devices in John Deere Toshiba, ABB, and other U.S. Products

- PV (due to Volume)
- Increased Automotive Data Center, UPS, Solid State Fuse
- Increased HF magnetics, Passives
- HV Grid

Wafer costs assumed to reduce over time due to increased volume

|------|------|------|------|------|------|------|------|------|------|
**GaN Strategic Planning**

- **Triquint/RFMD Merger.** Tranphorn Fab. Japan Navitas @TSMC
- **GaN Foundry in US** could be important Second source, allow GaN Innovation.
- **FA2:** Device Fabrication GaN US maintains competitiveness in design, I.P. and GaN Innovation
- **GaN Projects to US manufacturing Applications**
- **Improved Packaging, Improved P.E. Manufacturing Methods (Fred Lee)**
- **1st Devices Delivered to Device Bank**
- **Reliability WBG Established**
- **PV (due to Volume)**
- **Increased Automotive?**
- **Data Centers, Consumer Elect. Adapters, Wireless Power**
- **Increased HF magnetics, Passives**
- **Wafer costs assumed to reduce over time due to increased volume**

**Big Road Mapping Questions:**
- Timing of GaN Market Growth?
- What Voltage will power GaN Excel?
- Importance of Gate Drive Integration?
- How to Leverage RF foundries?

**FA4:** Accelerate Commercialization PA enabled GaN Applications Manufactured in US.
## Silicon Carbide Roadmap Drives Long Term Strategy

**Enablers:**
- Packaging for low thermal impedance, +200°C, and low stray inductance
- Soft Magnetics
- Gate driver design

### Table: Silicon Carbide Roadmap 2015-2024

<table>
<thead>
<tr>
<th>Year</th>
<th>Applications</th>
<th>Devices</th>
<th>Frequency/Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>PFC, PV 5-10 kW</td>
<td>AEC-Q101 qual high-(i_{\text{on}}) chips</td>
<td>40-100kHz LF DMOS</td>
</tr>
<tr>
<td>2016</td>
<td>Power Supply, UPS/HVAC/SSCB, PV 50-250kW, 1.5kV bus</td>
<td>175°C is (T_{\text{max}}) for qual</td>
<td>50-500kHz HF DMOS, 40-100kHz LF DMOS</td>
</tr>
<tr>
<td>2017</td>
<td>EV Traction</td>
<td>1.2kV FET 40 c/A</td>
<td>40-100kHz LF DMOS</td>
</tr>
<tr>
<td>2018</td>
<td>MV VSD Automotive Chargers, Central PV 1-10 MW</td>
<td>1.2kV FET 30 c/A</td>
<td>50-500kHz HF DMOS</td>
</tr>
<tr>
<td>2019</td>
<td>DC dis. Data Servers, Wind</td>
<td>1.2kV FET 25 c/A</td>
<td>40-100kHz LF DMOS</td>
</tr>
<tr>
<td>2020</td>
<td>Grid power Flow</td>
<td>1.2kV FET 20 c/A</td>
<td>50-500kHz HF DMOS</td>
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<tr>
<td>2021</td>
<td></td>
<td>1.2kV FET 15 c/A</td>
<td>40-100kHz LF DMOS</td>
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<tr>
<td>2022</td>
<td></td>
<td>1.2kV FET</td>
<td>40-100kHz LF DMOS</td>
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<tr>
<td>2023</td>
<td></td>
<td>1.2kV FET</td>
<td>40-100kHz LF DMOS</td>
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<td></td>
<td>1.2kV FET</td>
<td>40-100kHz LF DMOS</td>
</tr>
</tbody>
</table>

**Device design services**
- Open access foundry services
- Workforce training
- Device bank to be introduced Fall 2016
<table>
<thead>
<tr>
<th>Year</th>
<th>SiC &amp; Si Substrates</th>
<th>GaN Substrates &amp; Vertical Devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>&lt;200 V HFET</td>
<td>650 V HFET</td>
</tr>
<tr>
<td>2016</td>
<td>650 V HFET</td>
<td>900 V HFET</td>
</tr>
<tr>
<td>2017</td>
<td>900 V HFET</td>
<td>900 V SBD, 900 V JFET</td>
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<tr>
<td>2018</td>
<td></td>
<td>1.2 kV SBD, 1.2 kV JFET</td>
</tr>
<tr>
<td>2019</td>
<td></td>
<td>10 kV JFET</td>
</tr>
<tr>
<td>2020</td>
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<tr>
<td>2024</td>
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</tbody>
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### Challenges:
- Not clear when GaN Market will mature.
- GaN community needs to unite for 2nd source foundry capacity.
- SiC moving into GaN voltage space.

### Opportunities:
- GaN is increasing in voltage and reliability.
- GaN Gate Driver Integration
- GaN at lower voltages beats silicon in size and performance.