SAND2011-7507C

Commercialization of SiC Power Modules for High Performance Energy Applications

DOE OE Phase III XLERATOR , Award# DE-OE0000527
Energy Storage Program, Dr. Imre Gyuk
Sandia National Laboratories, Dr. Stan Atcitty
Principal Investigator: Jared Hornberger

presented by…

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ARKANSAS POWER ELECTRONICS INTERNATIONAL

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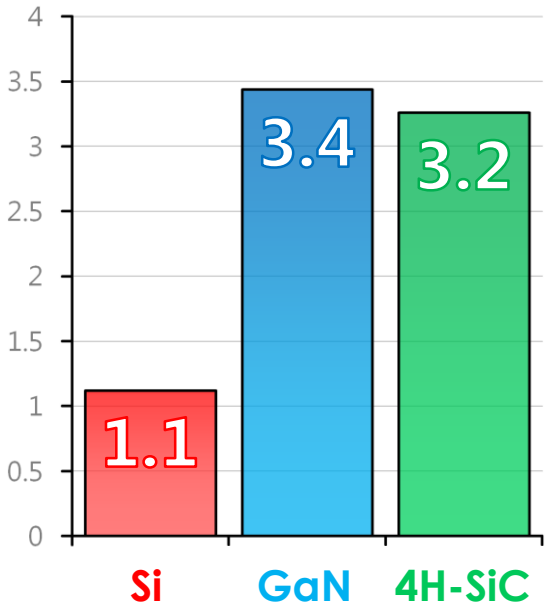
Overview

- Silicon Carbide (SiC) Intro and Applications
- APEI, Inc.'s Role in SiC Power Electronics
- Phase III XLERATOR overview
- Commercialization path
  - HT-2000 Module
  - Facilities
  - Process Optimization
  - Reliability Testing
- Conclusions

Wide Band Gap Semiconductors

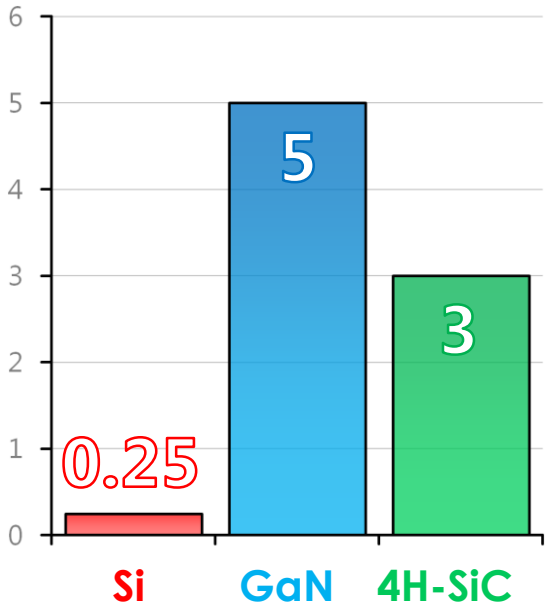
Band Gap
(eV)



larger band gaps mean...

- ↓ *Intrinsic Carriers*
- ↑ *Operating Temperature*

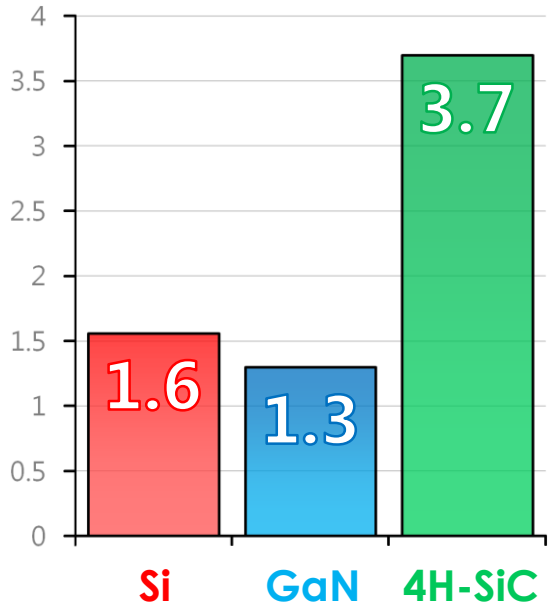
Breakdown Electric Field
($^{MV}/_{cm}$)



higher critical fields result in...

- ↑ *Blocking Voltages*
- ↓ *On-Resistance*
- ↑ *Switching Speed*

Thermal Conductivity
($^{W}/_{cm \bullet K}$)



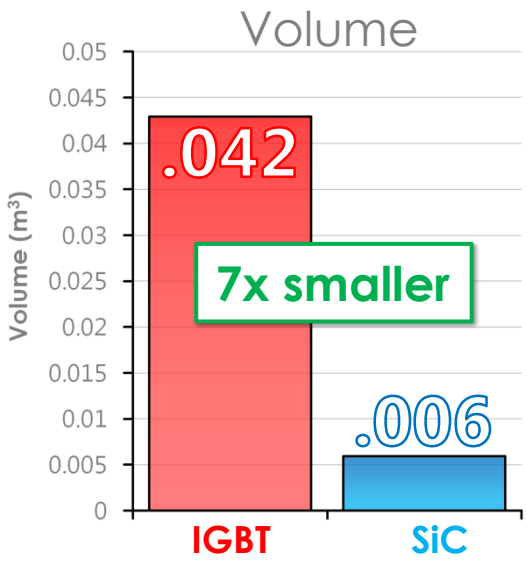
increased thermal cond. allows...

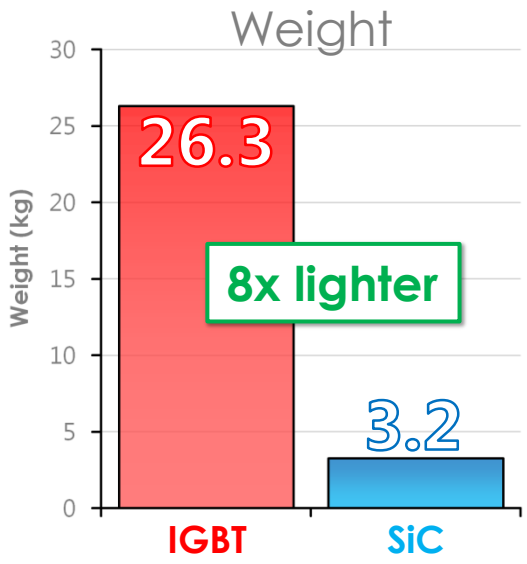
- ↑ *Heat Dissipation*
- ↑ *Power Density*

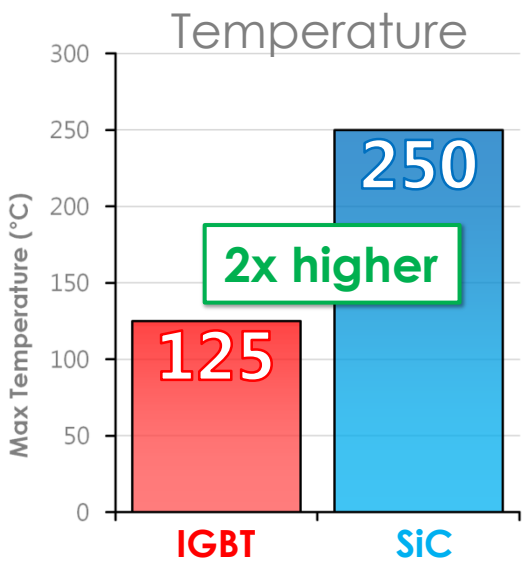
Power Conversion System Impact

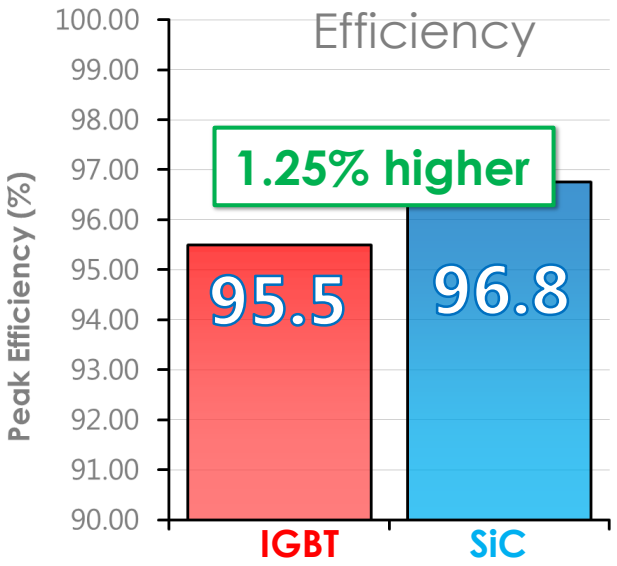
Comparison Inverter
IGBT Based (5kW)

APEI, Inc. XT-1000 Inverter
SiC Based (5kW)









Applications

Motor Drives

Military
Hybrid / Fully Electric Vehicles

Commercial
Hybrid / Fully Electric Vehicles

Aerospace
More Electric Aircraft

Power Converters

Solar / Wind
Grid-Tie Inverters

Geological
Down Hole Instrumentation

Aerospace
Power Conversion

High Voltage

Industrial
Modernized Power Grid

Commercial
Fault Current Limiter

Military
Advanced Warships

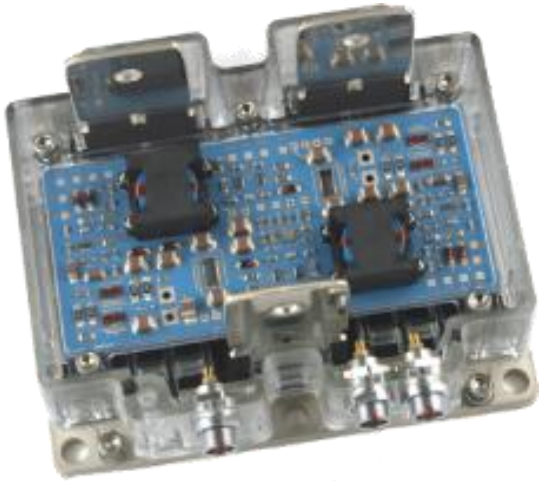
Wireless Telemetry

Industrial
Power Turbine Sensors

Aerospace
Jet Engine / Turbine Sensors

APEI, Inc.'s Role in SiC Power Electronics

- APEI is a small business dedicated to advancing state of the art power electronic systems.
- APEI's Main Focus
  - Power Modules
  - Device Packaging
  - Power Electronic Systems



APEI, Inc.'s R&D100 Module Joint project with DOE Energy Storage Program, Sandia National Labs, University of Arkansas, & Rohm, Ltd.

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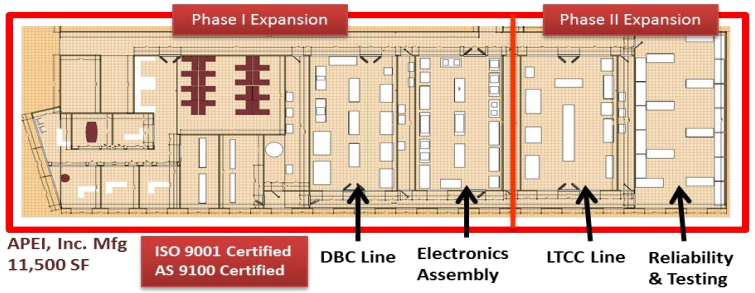
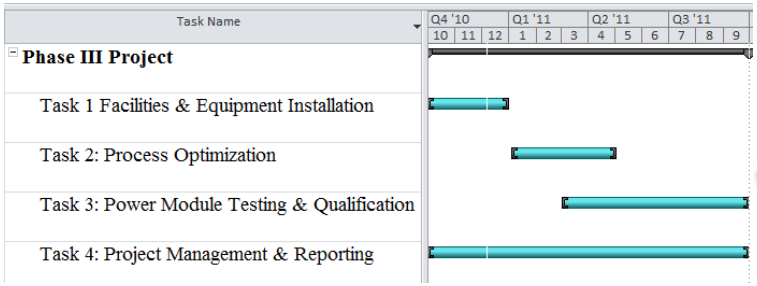
U.S. DEPARTMENT OF ENERGY

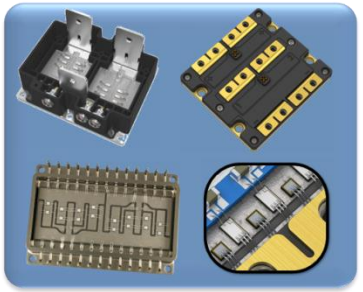
APEI, Inc. – DOE Phase III XLERATOR At A Glance





Phase III Facilities

Phase III Product Qualification



Manufacturing & Sales

Commercialization of SiC Power Modules. Reliability Testing & Qualification ($2.2M)
DOE Phase III XLERATOR ($500,000), State of Arkansas ($515,000), APEI, Inc. ($1,166,000)

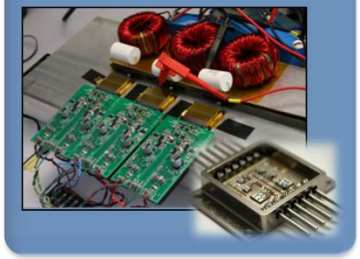
2005

DOE Phase I SBIR

3 kW single-phase SiC VJFET inverter prototype

2006 - 2008

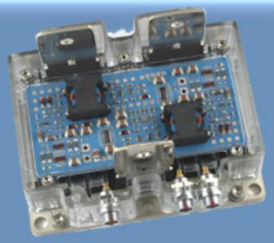
DOE Phase II SBIR



10 kVA, 98.5% eficiency, three-phase SiC VJFET inverter prototype

2007 - 2009

Beyond Phase II Commercial R&D100

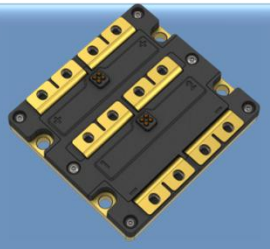


Commercial Partner: Rohm Ltd.

180A pk, 50 kW SiC Half-bridge power module

2010 - 2011

APEI, Inc. Next Generation SiC Module

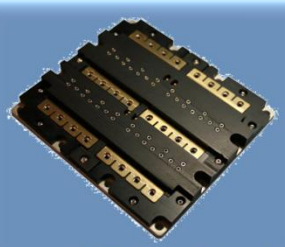


Commercial Partner: SAIC

300A pk, 100 kHz, low profile, light weight, SiC power module

2010 - 2012

APEI, Inc. Future Generation SiC Module



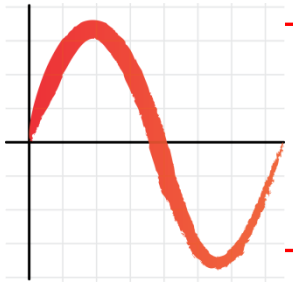
Commercial Partners: Rohm, Ltd.,

500A pk, 100+ kHz, low parasitics, wire bondless interconnects SiC module

HT-2000 Series

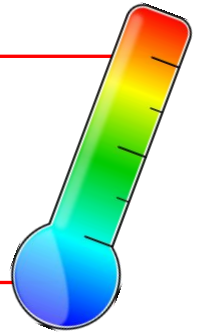
High temperature, high frequency, high power density all SiC half or full-bridge power stage.



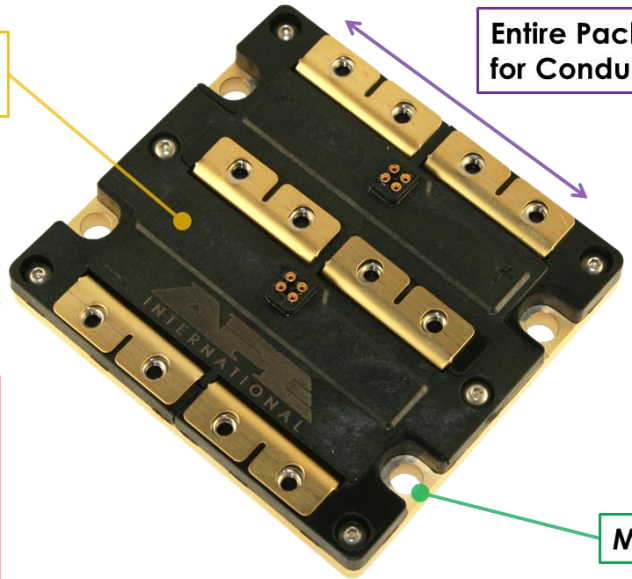



Ratings
1200V
>150A

Temperature
250°C peak
(packaging)



Multiple Material Choices Based on Application



Devices
up to 16 die in parallel per switch position

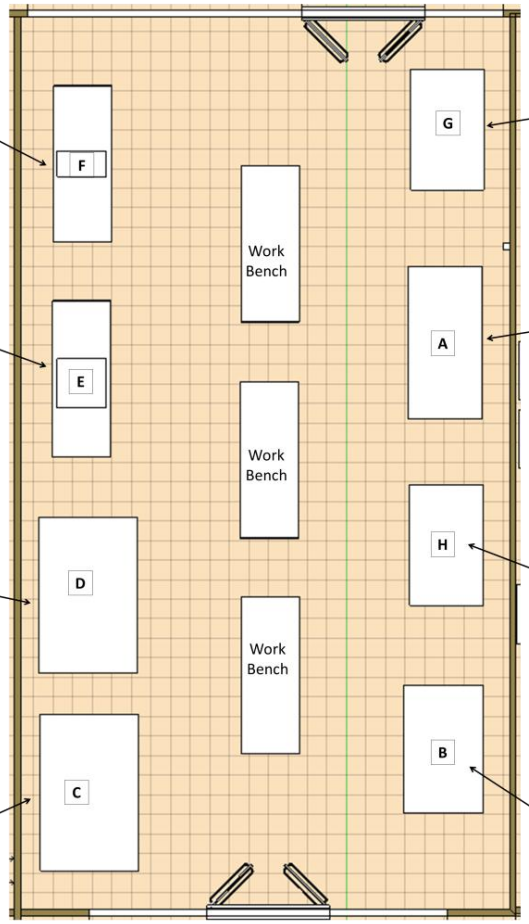
Facilities: Power Substrate Line

Chemcut SA2315S Stripper

Chemcut SA2315E Etcher

Chemcut SA2315D Developer

Workhorse PhotoSharp UV Exposure

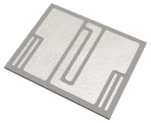


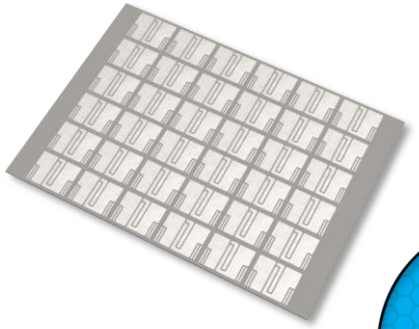
Chemcut Electroless Nickel Plating Line

Amerimade Wet Bench

Disco DAD320 Dicing Saw

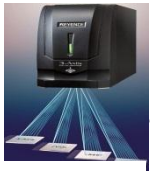
Western Magnum Photo Laminator





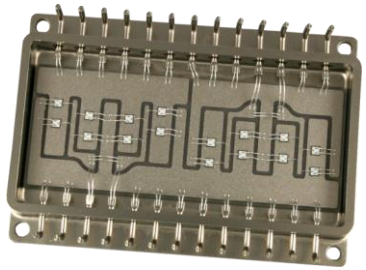
Facilities: Assembly Line


Leak Tester

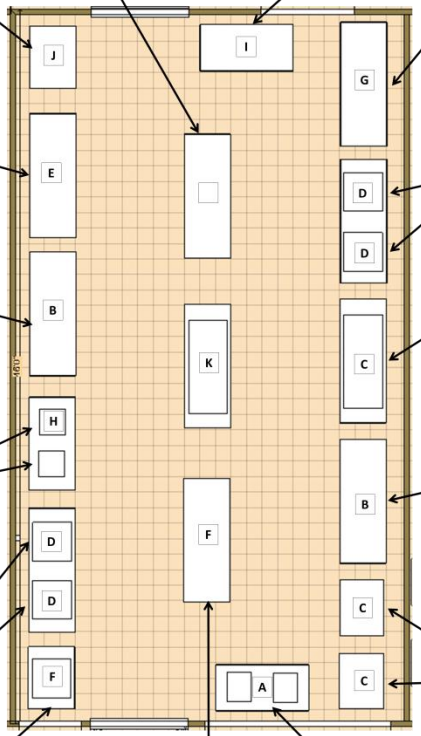

Laser Marker


Polaris Venus
IV Lid Sealer


Encapsulation




Epoxy Bonding



F&K 5600 Series Wire Bonder


Pick and Place equipment

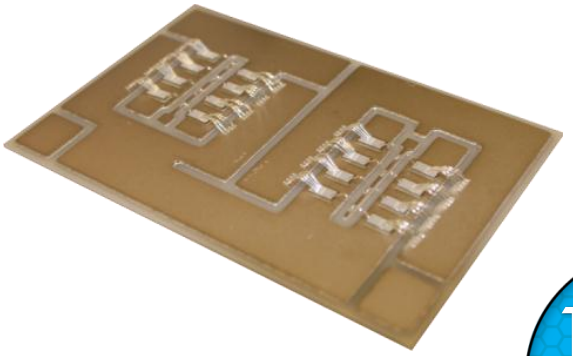

Sikama Falcon 5C Reflow Oven


Binder VD-53 Drying
Ovens


Pick and Place equipment


F&K 5600 Series Wire Bonder


SST 5100 Vacuum Reflow Oven




Dage 4000 Bond Tester


VHX1000 Digital Microscope


March AP-300 Plasma

Component Testing

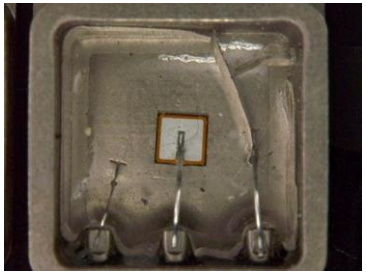
Encapsulation Testing

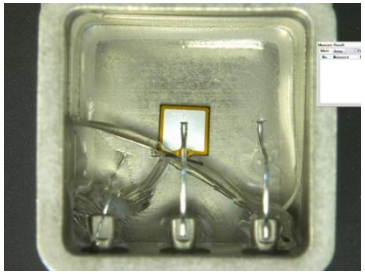
Thermal Cycle Conditions

- -50 °C to +250 °C for 1000 cycle
- 30 minute dwell at each temperature
- No electrical bias

Characterization

- Every 100 cycles, starting at 0 cycles
- Forward conduction (0 – 3V, 20A compliance)
- Reverse leakage (0 – 1200V)
- Continuity test between pins 1 and 3 to case
- Visual inspection





200 Thermal Cycles complete before mechanical failure of most devices. Other materials will begin testing soon.

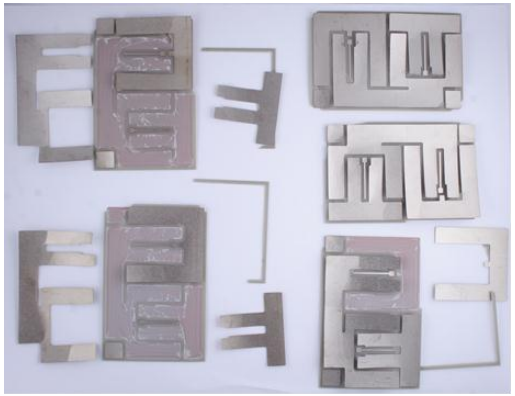
Substrate Testing

Thermal Cycle Conditions

- -50 °C to +250 °C for 1000 cycle
- 30 minute dwell at each temperature

Characterization

- Every 100 hours or 100 cycles
- Scanning Acoustic Microscopy (SAM)
- Visual Inspection



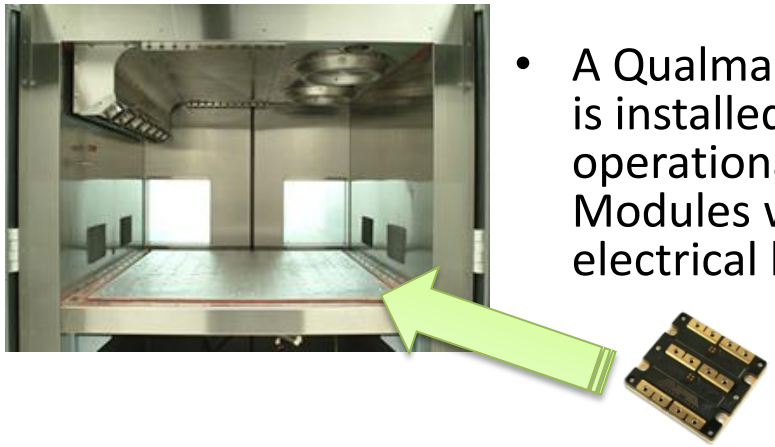
200 Thermal Cycles complete. DBC results show failure, DBA & AMB substrates continue to pass all tests

Module Testing: HALT Chamber

HALT = Highly Accelerated Life Testing

- Reliability test method focused on finding defects before becoming field issues
- Simultaneous vibration and temperature cycle
- Stresses are incrementally applied while DUT is continuously monitored for failures.
- Reveal defects in a matter of hours or days compared to traditional tests
- Once failure mechanisms are identified and corrected, operating margins can be extended

QUALMARK TYPHOON INFERNO	
Table Size	48” x 48” (can be used as 4, 12” x 12” independent quadrants)
Temperature Range	-100 °C to 250 °C
Thermal Ramp Rate	70 °C to 100 °C/minute
Acceleration	5 to 75 gRMS
Electrical Service	480 V, 150 A, 3-phase
Compressed Air Service	30 HP compressor with 120 gal holding tank
Liquid Nitrogen Usage	up to 20 gal (75 L)/temperature cycle

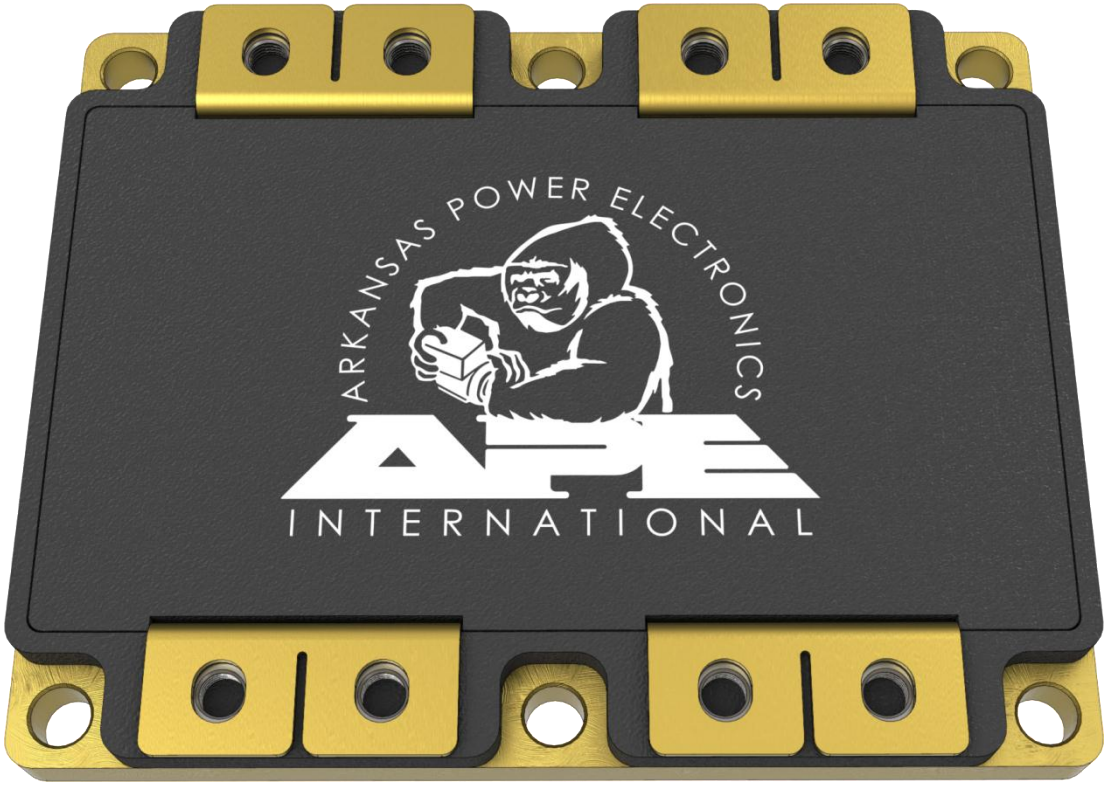


- A Qualmark Typhoon 4.0 Inferno is installed and will be operational in next 4 weeks. Modules will be tested under electrical bias.

Conclusions

- SiC power electronics has many benefits over Si and has the potential to revolutionize power systems
- APEI's Phase III XLERATOR program seeks to help in the commercialization of SiC power modules
- The commercialization path for the HT-2000 module includes:
  - Facilities
  - Process Optimization
  - Reliability Testing
  - Product Sales
- Funding for this commercialization effort
  - APEI Funds: $1.2M
  - State of Arkansas: $0.5M
  - DOE Phase III: $0.5M
- Current project status:
  - Facilities and process setup is finished.
  - APEI has already fabricated and sold HT-2000 engineering sample modules to several customers
  - Component testing is underway
  - Module testing will begin when HALT chamber is operational
- Impact on power conversion systems
  - Increased efficiency
  - Reduced volume & weight
  - Reduced cooling/size
  - Potential overall system cost reduction

Thank You!



Acknowledgements

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