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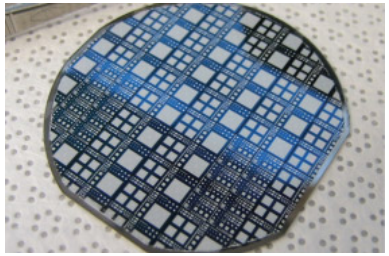


6.5 KV SILICON CARBIDE HALF-BRIDGE POWER SWITCH MODULE FOR ENERGY STORAGE SYSTEM APPLICATIONS

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U.S. DEPARTMENT OF ENERGY

Sandia National Laboratories

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- *DOE Topic Number 8:* ***High Voltage DC-Link Power Conversion System for Energy Storage Applications***
- *Subsection b.* ***Advanced Semiconductor Switches Modules for High Voltage Energy Storage Systems***
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USCi Partner:

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- Project Goals & Timeline
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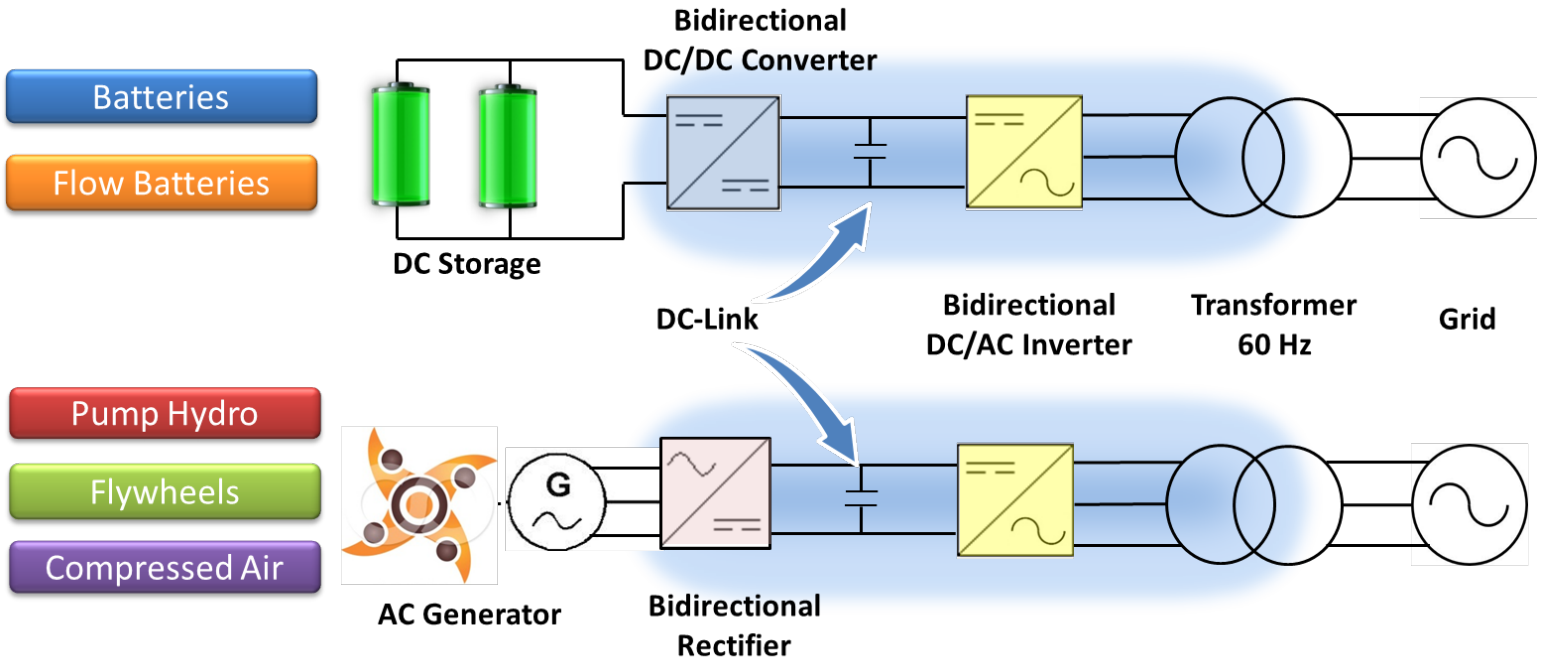
Storage Applications

- Every storage technique involves Power Conversion where the most common interface is a DC-Link.



The Present Cost of Power Conversion Stages is ~30% or Higher of Total System Cost!

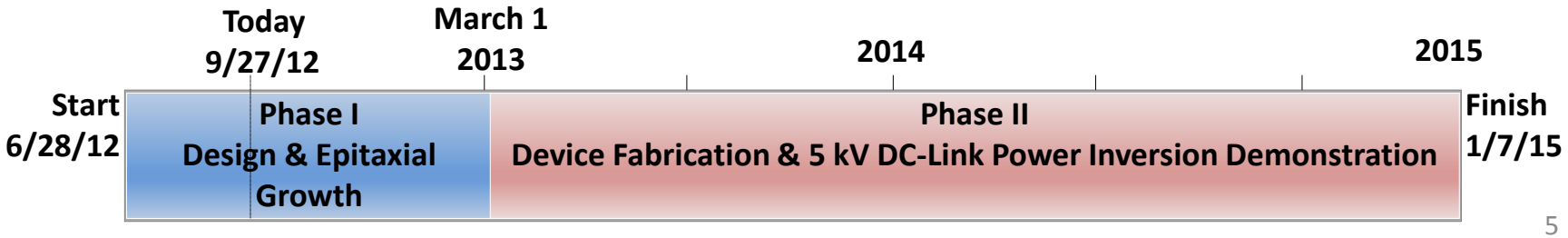
Project Goals & Timeline

- USCi proposes a 6.5 kV Switch Module that can enable a DC-Link Voltage up to 5 kV using SiC wide bandgap devices:
  - Junction Field Effect Transistors (JFETs) and Junction Barrier Schottky Diodes (JBS's)

- Presently, DC-Links reside at ~900 to 1100 V
  - Limited by the switch voltage ratings ~ 1200 V Si-IGBTs

- USCi has partnered with Princeton Power Systems to gain critical insight into the impact of a medium voltage switch on inverter systems

- **Phase I** – Design of SiC Power Module and Epitaxial Growth (9 months)
- **Phase II** – Fabrication of Power Module and Demonstration of 5 kV DC-link Power Inversion (2 years)

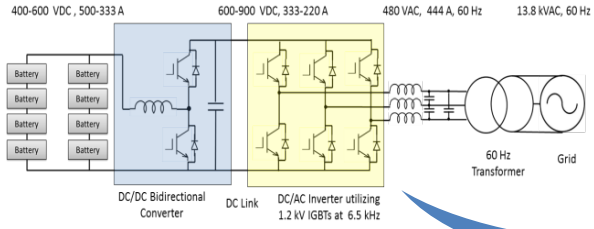


Overall Project Objective

- **How does higher DC-Link voltage help on the Power Conversion System Level?**
  - Higher Voltage Means Lower Current
  - Losses ~ I^2R and Switching- More Efficient, Smaller Systems, Less Cooling
  - High Operating Frequency– Reduces Magnetics Drastically
  - Reduced Footprint, Balance-of-System, and Cost

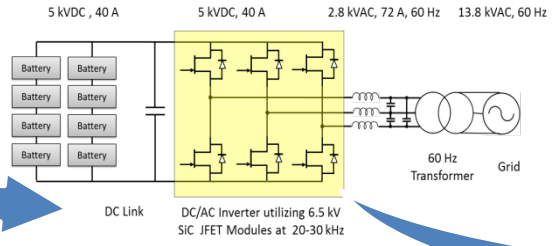
Next Generation Topologies

Si-IGBTs



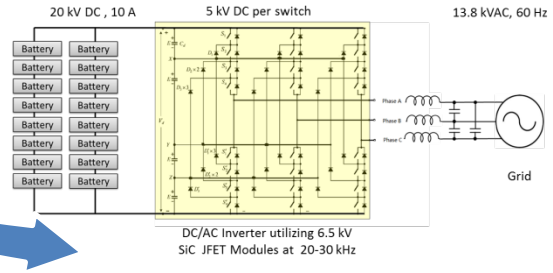
2 level Inverter
900 V DC-Link
I ~ 300 A/switch
***f* < 10 kHz**

6.5 KV SiC-JFETs



2 level Inverter
5 kV DC-Link
I ~40 A/switch
***f* >20 kHz**

SiC-JFETs



5 level Inverter
20 kV DC-Link
I ~40 A/switch
***f* >20 kHz**

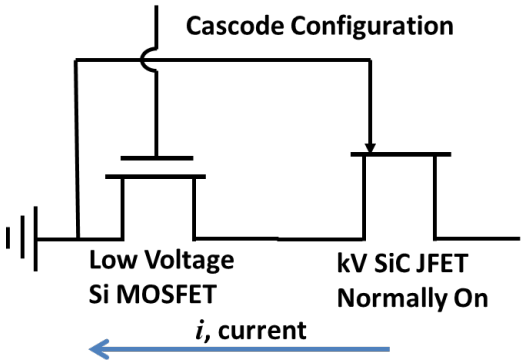
Impact of an all SiC Power Module on Systems

- How does a 6.5 kV SiC Switch Module Impact Storage Systems?
  - Costs and Efficiency of Power Conversion Stages

Parameter	Improvement over Si-IGBTs	Comment
System Efficiency	**1.5-2.0%** ***(~96 to 98%)***	*JFETs & JBSs both contribute to efficiency improvements of module*
Switch Frequency	**2-5 X** ***(<10 kHz to > 20 kHz)***	*Greatly Impacts Magnetics*
Operating Current	**X 10 Reduction** ***(~400 A to 40 A)***	*Greatly Impacts Magnetics & BoS*
Operation Temperature	***1.5 X (150 C to 250 C)***	*Reduces Cooling Complexity*

Why a Normally-off SiC JFET?

Switch type > Property	Norm Off SiC JFET	SiC MOSFET	SiC Bipolar	Si IGBT Stack
kV	>>6.5 kV	>>6.5 kV	>>>6.5 kV	<6.5 kV
Switching speed	>20 kHz	>20 kHz	<20 kHz	<5 kHz
Switching Loss	1X	1X	~5X	~5X
Driver Complexity	Simple	Simple	Complex	Moderate
Operational Tj	>250°C	150°C	>250°C	150°C
Reliability	No MOS Gate - Robust	MOS Gate - Reliability Concern	V drift (BPD) - Reliability Concern	Robust

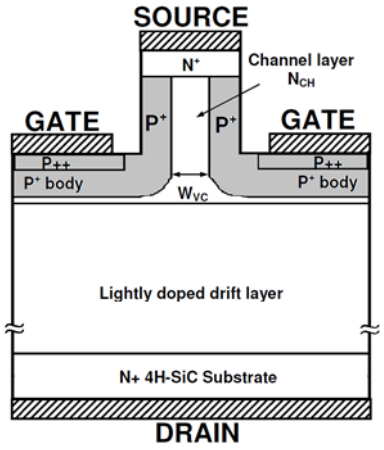


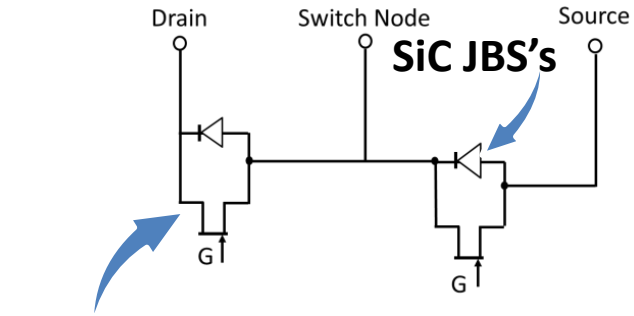
- Cascode Configuration can utilize normally-on SiC JFETS - Very attractive option
- But is limited in operation temperature by the Si MOSFET
- USCi targets high temperature operation to reduce cooling needs –> SiC Normally-off JFET

JFET Design Approach

- **Design Focus on Reliability**
  - Utilize only N-type 4H-SiC Material for all devices in the module
    - Unipolar SiC devices more mature than bipolar - not sensitive to Basal Plane Defects
  - No MOS Gate
    - High Mobility N-channel
  - Modest Current Densities - keep heat generation low (50 A/cm^2)
    - Less Stress on Packaging
  - Existing SiC Schottky Diode Market Proof of N-type SiC Material Reliability

Normally – Off N-type Vertical JFET

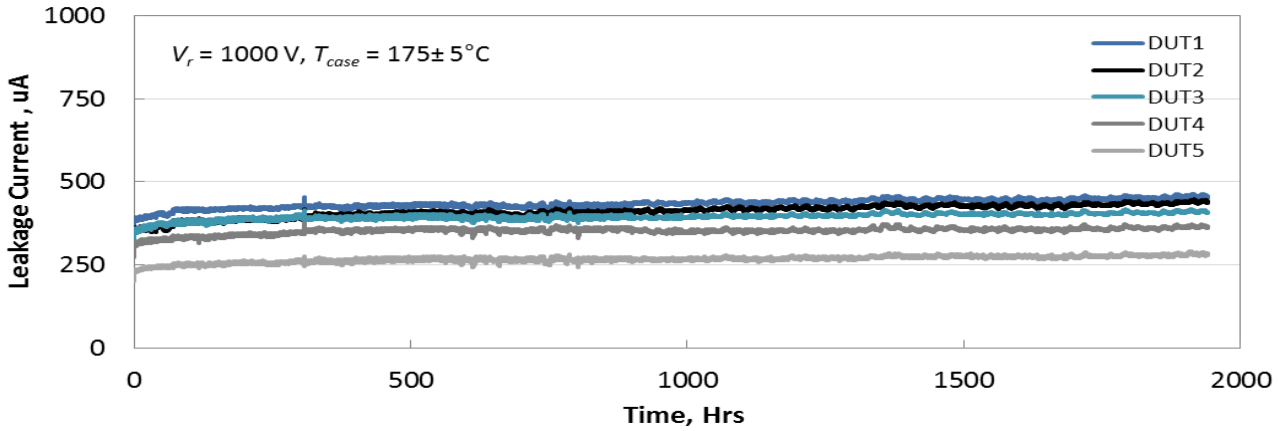




Half-Bridge Module

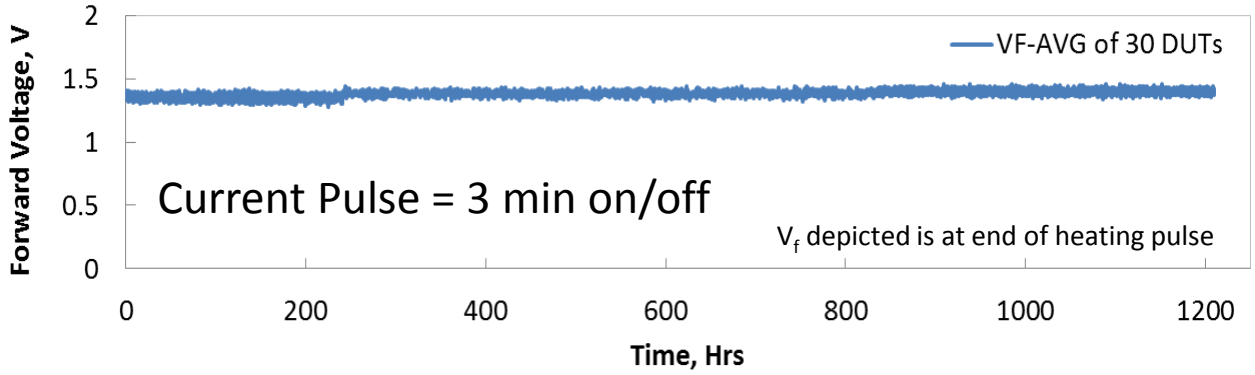
USCi Schottky Reliability N-type Unipolar Epitaxy

- High Temperature Reverse Bias, T_{case} = 175°C

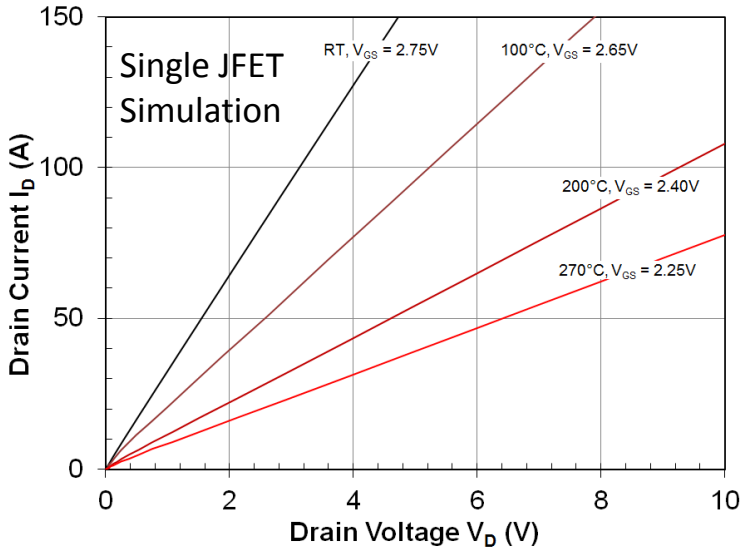


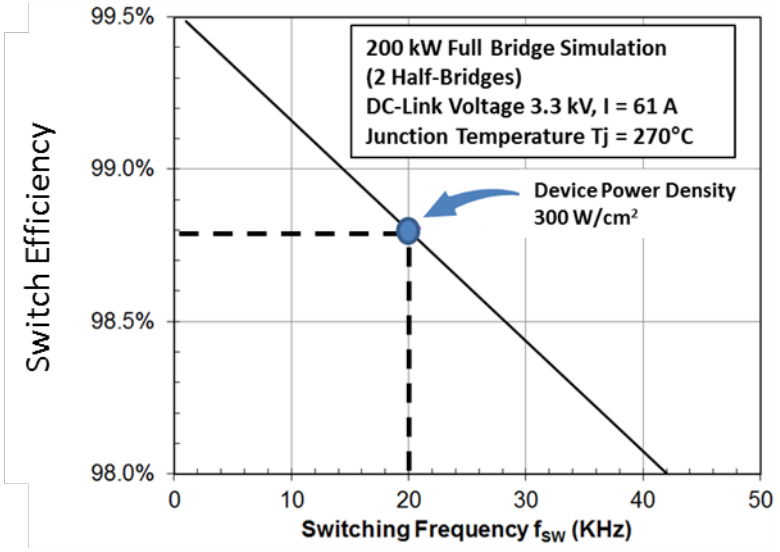
1200 V, 10 A
Junction Barrier
Schottky Diode
TO-220

- Intermittent Operation Lifetime ΔT_j = 100°C



6.5 kV Half-Bridge Expected Performance





Parameter	Target
Max DC-Link Voltage	~ 5 kV
Max Current	61 A
Target R_{on} (RT)	33 mΩ
Switching Speed	~20 kHz
Max Ambient Temp	~100°C
Max Junction Temp	~270°C

- Full Device Simulation using TCAD Sentaurus
- Device Simulation Complete
- Packaging Simulation in Progress
- Gate Driver Design in Progress

Next Steps

- Phase I Tasks
  - ✓ Device Module Simulations
  - ✓ Packaging Simulations
  - Gate Driver Design
  - ✓ Define Manufacturing Concept
  - **Epitaxial Growth of 6.5 kV JFET and JBS material**

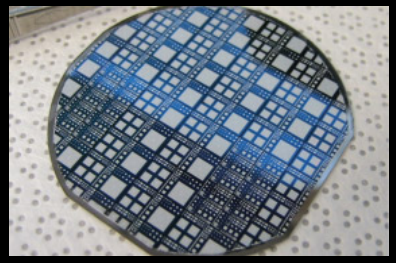
USCi's New SiC Epitaxial Growth Facility

- Future Phase II Tasks
  - Device Fabrication
  - Module Assembly
  - Half-Bridge Module Demonstration with Princeton power Systems
  - **Target:** Alpha prototype by end of phase II (TRL 6)

USCi's Class 100 Pilot Wafer Fab

Conclusions

- **United Silicon Carbide is proposing a tractable approach to developing a 6.5 kV medium voltage half-bridge switch module**
  - Will enable a 5 kV DC-Link voltage which will greatly impact Storage Systems by reducing costs of power conversion stages
  - Impact current system designs as well as create a platform for highly innovative inverter/converter designs
- **Module is based on an all SiC half-bridge module**
  - Utilizes Vertical JFETs and JBS's
  - Focusing on reliability aspects of SiC materials
  - All N-type SiC material system
  - No MOS–Gate material
- **Currently in Phase I**
  - Device Simulations Completed
  - Current Efforts focused on Epitaxial Growth of 6.5 kV material




Thank You!

USCi Welcomes Your Questions

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