ONR WBG Workshop

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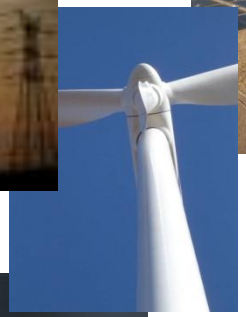
November 15/16, 2012

GaN Power Devices

- Multiple Markets:
  - Power Transmission:
    - The grid
    - Solar and Wind Farms/Distributed Power Generation
  - Electric Cars (hybrid, plug, fuel cells)
  - Industrial Drives
  - Merchant Fleet
  - Electric Trains
  - Military: Ships, Ground, Aircrafts



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Grid Solid State Power Electronics

- Utilities generate on average 20 % more electricity than is consumed at any given time.
- **It has been estimated that a mere 5 % reduction in power reserve margin would eliminate the need for $50 billion worth of new power plants within the next 25 years.**
- WBG power electronics would also enable as much as 50 % larger power capacities to be carried over existing powerlines.

NASA
http://www.grc.nasa.gov/WWW/SiC/power.html

Viable Device Technologies Must Be Capable of Supporting:

1. **Performance Demands**
2. **Manufacturability**
3. **Total Wafer Volume Demand**
4. **Cost**

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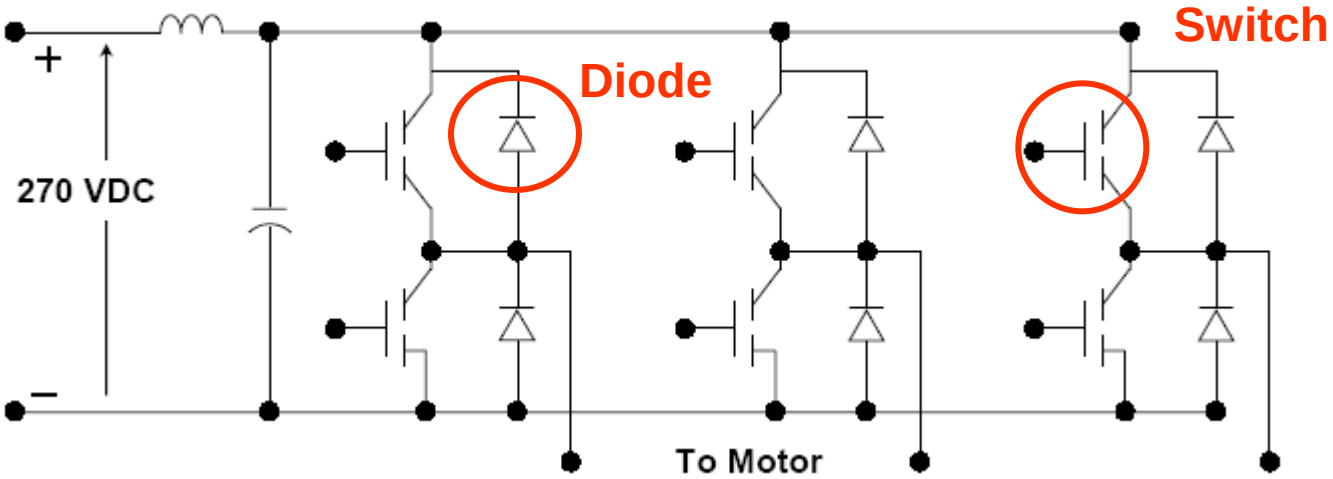
Typical Circuit Topology



Typical Inverter Topology

Building Blocks:

- **High Voltage/High Current Low Loss Diodes**
- **High Voltage/High Current Switching Device**

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Problem Statement

- Significant and impressive research results on the application of Wide Bandgap (WBG) Semiconductors to Power Electronics
- Limited availability of devices, which have limited capability, in the marketplace
  - Two Terminal Device
    - Diode Products to 1200V @ 50 A (CREE)
    - Diode Products to 600 V (Velox Semi)
  - Three Terminal Device
    - Small Start-up R&D efforts (SemiSouth 1200 V JFET)
    - No practical availability
  - U.S. Is dramatically trailing Japan in WBG Power Electronics
- GaN on SiC - Clearly has achieved best technical performance (with a significant cost penalty)
- GaN on Silicon
  - Focus of DOE funded effort
  - Long Term Goal is 5000V @ 50 A
  - Only Viable Economic Approach
  - Significant effort in Far East at 150mm & 200mm wafer sizes

Economically Viable Approaches Must Be Exploited to Create a Viable Industrial Base

Academic – Research – Industrial Collaboration

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Leading Academic Research Group focused on GaN Device Technology

MIT Lincoln Laboratory

Leading Research Institute focused on Advanced Materials and Device Technology

MACOM Technology Solutions

Leading Industrial Supplier of Silicon and Compound Semiconductor Device

KOPIN

Leading III-V Epitaxial Wafer Foundry focused on GaN Materials Technology

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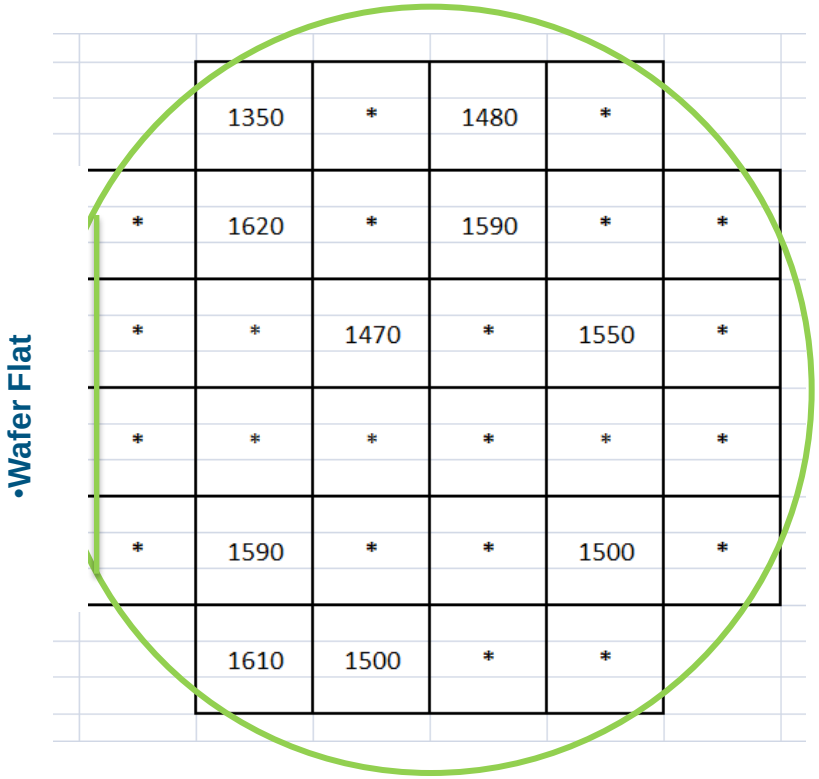
Three Terminal HEMT – Vb Distribution

- GaN on Silicon
- Free Standing Gates
- Trapezoidal Gate
- No Field Plates
- 5μm to 20μm Gate-to Drain Spacing
- High Vds Reverse Breakdown
  - Gate Pinched Off at -6 volts
  - No Center-to-Edge Discrepancy
  - **Average Vds (15μm GD) - 1526 volts**
  - **Peak Vds (15μm GD) – 1620 volts**
  - **Peak Vds (20μm GD) – 1644 volts**
  - **Very Low Baseline Leakage 0.01 ma/mm**



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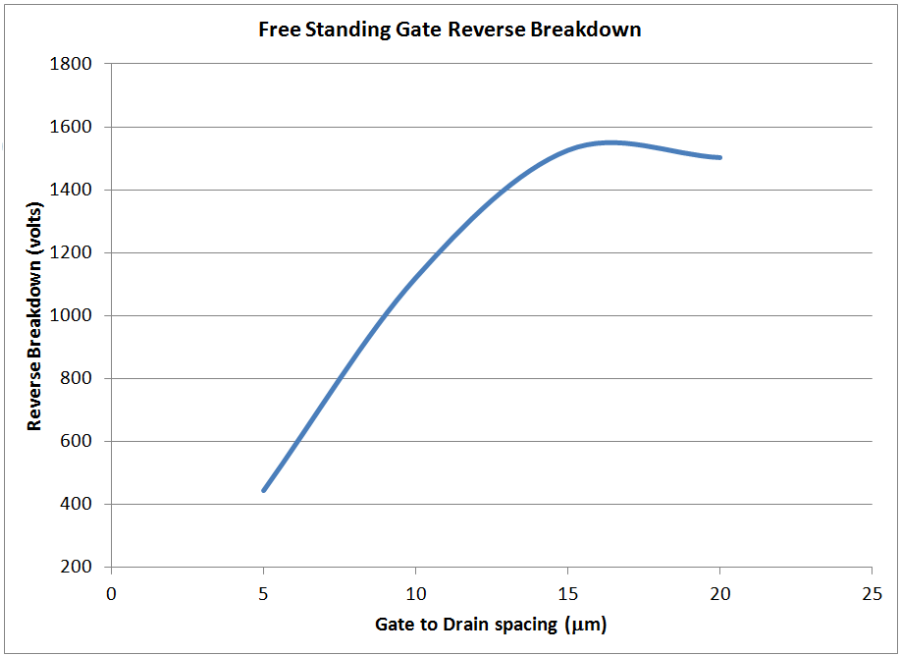
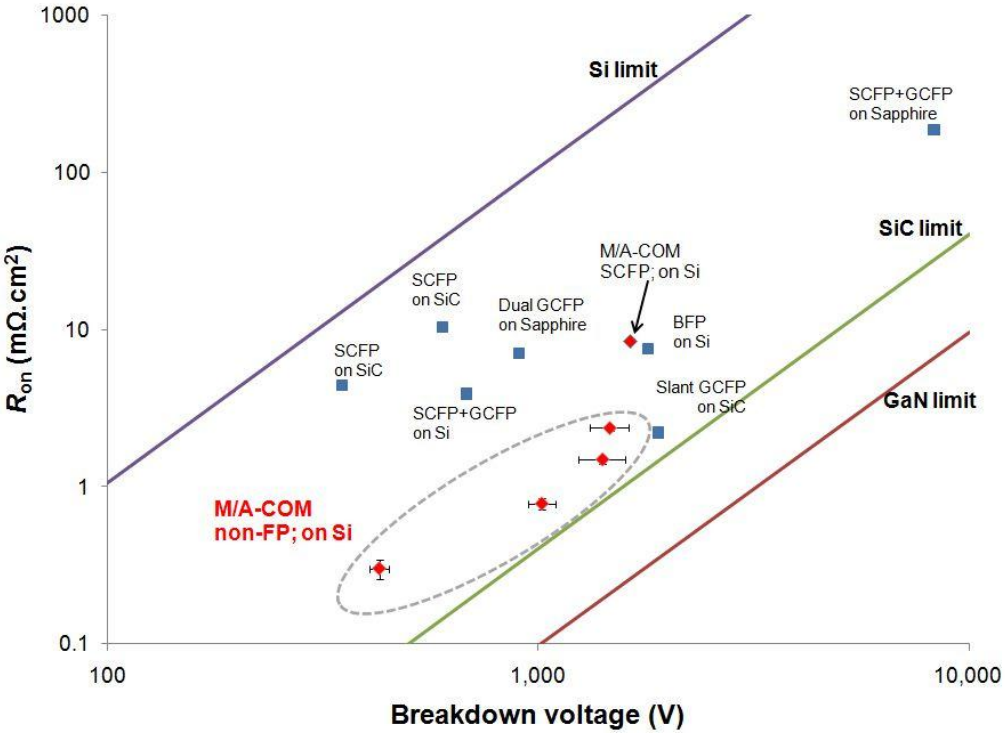
Three Terminal HEMT– Vb vs GD Spacing

- Free Standing Gates
- Trapezoidal Gate
- No Field Plates
- Average Vds vs Gate-to Drain Spacin
- Vds Linear through 15μm GD
- Peak Field Strength
  - 108 v/μm (1.08×10^6 v/cm) @ 15μm GD
  - 82.2 v/μm (8.22×10^5 v/cm) @ 20μm GD
- Vds Saturation
  - No Field Plates
  - Buffer Leakage
  - ≈1600 volts



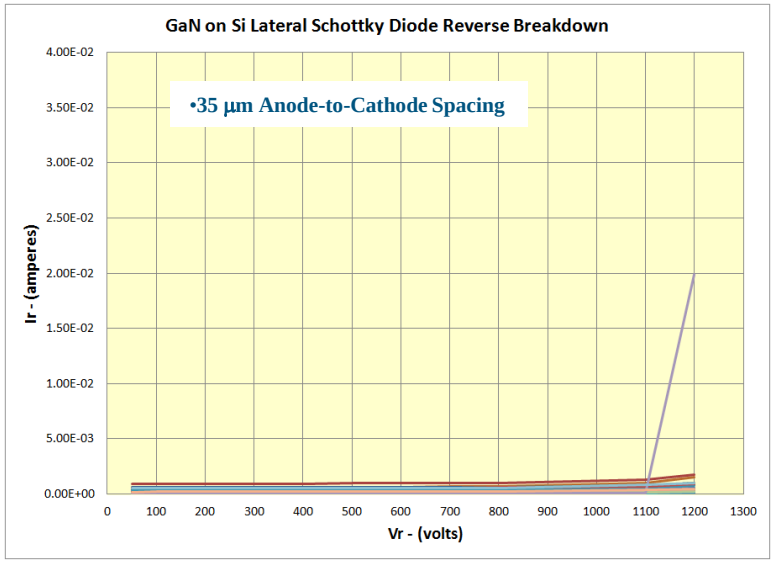
MTS GaN HEMT - Comparison to Literature/Industry

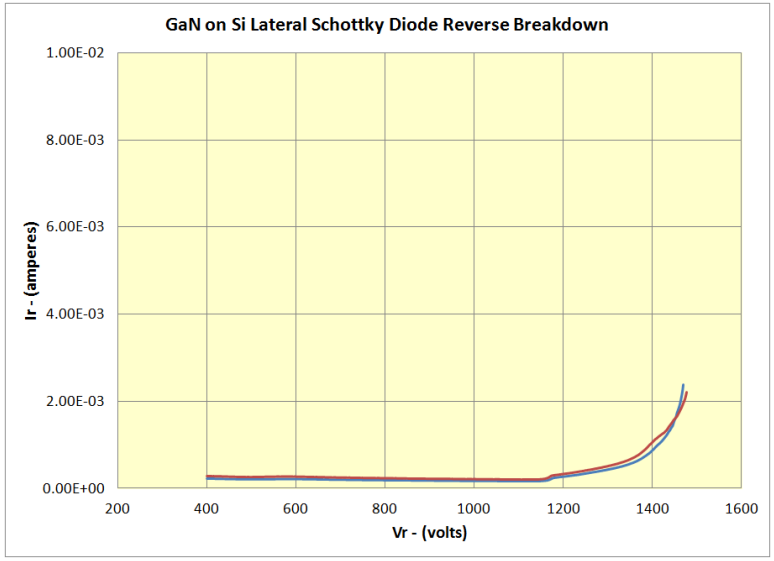
- **Metric**
  - On-Resistance as a Function of Breakdown Voltage
- **Fundamental Material Limits**
  - Silicon, GaN, SiC
- **SCFP, GCFP, Slant GCFP, Combined SCFP+GCFP, BFP, Dual GCFP**
- **GaN Substrates**
  - Silicon
  - SiC
  - Sapphire
- **Updated Results**
  - Free Standing Devices
  - 5μm to 20μm Data
  - 15μm Closet to Theoretical Limit (SiC)
  - World Class Result (esp NO FIELD PLATES) !!!!



GaN on Si Lateral Schottky Diode Reverse Characteristic

- Single Anode Schottky Diode
- Anode Connected Field Plate – Spreads Peak Field in Cathode
- 500 μm of Anode Periphery
- 35 μm Anode-to-Cathode Spacing
- 28 Devices Measured for Across Wafer Distribution
- Reverse Breakdown
  - >1200 volts
  - Limit of M/A-COM Tester
- Utilized 3000 volt Tester at MIT
- Reverse Breakdown
  - ≈1500 volts





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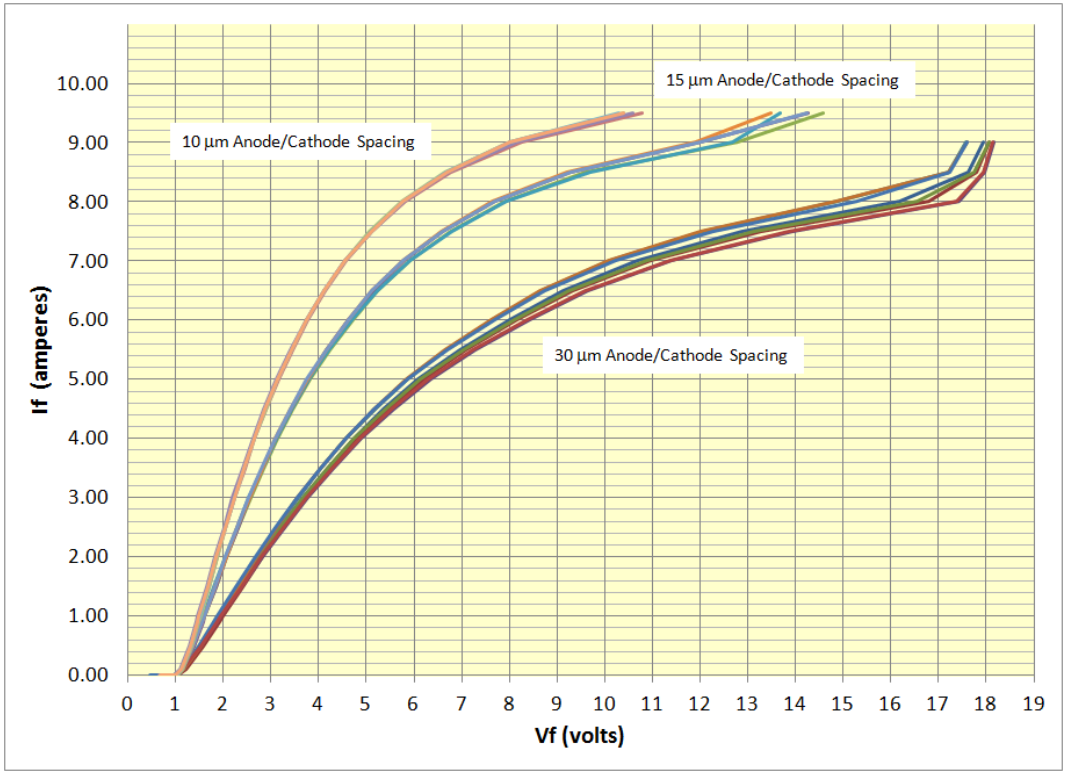
GaN Lateral Schottky Diode Current Handling

- Forward Diode Characteristic
  - Linear Plot
  - Absolute Diode Current
  - 20μA to 10A
- Multiple Anode Schottky Diodes
- 20 mm Lateral Diode Periphery
- Multiple Anode-to-Cathode Spacing
  - 10 μm, 15 μm, 35 μm
- Current Handling
  - Linear Region Varies as the Anode-to-Cathode Spacing
  - All Diodes Ramped to 10 A (500mA/mm)
  - 100% Survivability



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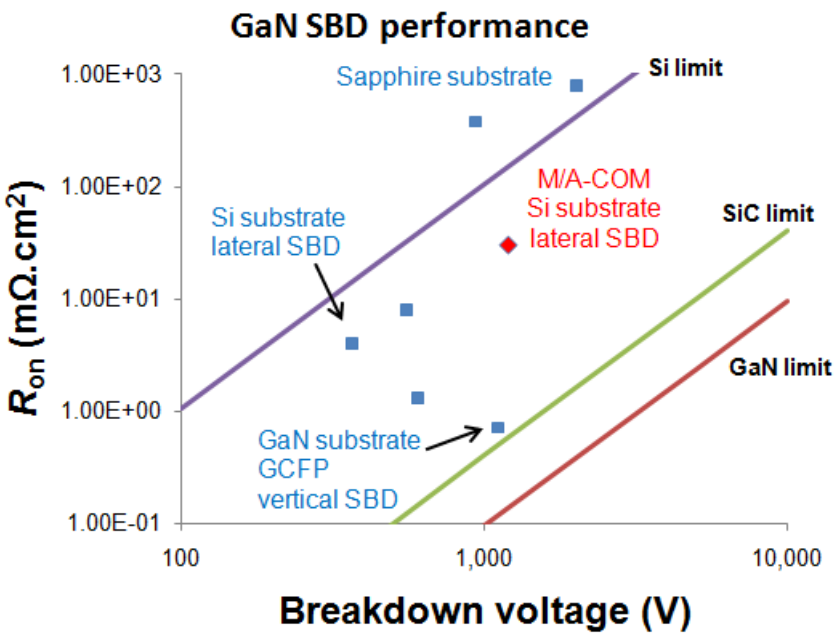
MTS GaN on Si Lateral Schottky Diode Comparison to Literature/Industry

- Metric
  - On-Resistance as a Function of Reverse Breakdown Voltage
- Fundamental Material Limits
  - Silicon, GaN, SiC
- Lateral & Vertical Schottky Diode Designs
- Anode Connected Field Plates
  - None Disclosed
- GaN Substrates
  - Silicon
  - SiC
  - Sapphire
  - GaN



- **MTS GaN on Silicon**
  - Single Anode Device with 35μm Anode-to-Cathode Spacing
  - Typical Device – 1500 volts & ≈20 mΩ cm²
- **WORLD CLASS RESULT!!**

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Summary

- Three Terminal Device GaN on Silicon HEMT Breakdown Voltage of >1600 volts Achieved
- WORLD CLASS GaN on Silicon Lateral Schottky Diode Reverse Breakdown Voltage of ≈1500 volts Achieved
- GaN on Silicon Lateral Schottky Diode Forward Current Handling of 10A Achieved on a 20mm Periphery ACFP Structure
- Need to Break the 1500-1600 volt Barrier
  - Both HEMT & Diodes
  - Understand Trapping Behavior
  - Field Plate, Epitaxy, & Substrate Optimization