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Source: Proceedings of the IEEE, vol. 105, no. 11, Nov. 2017
INTRODUCTION-MOTIVATION

- WBG transistor technology improves on the bipolar junction transistor known as BJT and Silicon MOSFET technology of the 20th century.
- WBG transistors increase electronic systems efficiency, while decreasing size, weight, and power losses.
- SiC WBG devices can switch hundreds of KW of electrical power at high voltages and amperages. Eg. 1,200 V, 200 A
- GaN WBG devices can operate at high powers (up to 800W) at RF frequencies up to 550 GHz, not possible with other semiconductor technologies.
- WBG devices are transforming the electronics industry of the 21st Century
COMPARING Si, GaN and SiC Properties

Source: Proceedings of the IEEE, vol. 105, no. 11, Nov. 2017
APPLICATION SPACE FOR SiC AND GaN

- **Low-Voltage**: PFC/Power supply, Audio Amplifier
- **Medium-Voltage**: PV Inverter, Motor Control, EV/HEV, UPS
- **High-Voltage**: Ships & Vessels, Smart Power Grid, Wind Mills, Rail Transport

Voltage Levels:
- <200 V
- 600 V - 900 V
- 1.2 kV - 1.7 kV - 3.3 kV - 6.5 kV+

*GaN / SiC overlap*

SiC: Med – High Voltage
GaN: Low - Med Voltage
FUTURE OF GAN
SECTION 1 - HISTORY OF THE DEVELOPMENT OF WBG DEVICES AND FUTURE APPLICATIONS.

- BJT invented in 1947
- Si MOSFET invented in 1959
- IGBT invented in 1980
- SiC WBG transistor invented in 1990
- GaN WBG transistor invented in 1998
SECTION 2 - WIDE BANDGAP DEVICES

<table>
<thead>
<tr>
<th>Semiconductor Technology</th>
<th>Bandgap (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>1.1</td>
</tr>
<tr>
<td>SiC</td>
<td>3.2</td>
</tr>
<tr>
<td>GaN</td>
<td>3.4</td>
</tr>
</tbody>
</table>
SECTION 2 - WIDE BANDGAP DEVICES

MOSFETS used as electronic switches

Switching losses
Primary reasons for using WBG materials

Silicon carbide and gallium nitride-based semiconductors go beyond the limitations of silicon-based components. The wider band gap of SiC and GaN-based devices enables:

- Higher operating temperatures, frequencies & voltages
- And smaller, more efficient devices
- Leading to faster switching & lower power losses (compared to silicon)
Performance Advantages of SiC MOSFETs vs IGBTs. Source: Applied Materials, Inc.
SECTION 2 - WIDE BANDGAP DEVICES

Switching loss comparison of GaN Systems’ E-HEMT and Cree’s SiC MOSFET
**SECTION 3 - DEVICE STRUCTURE, OPERATION, AND TESTING PROCEDURE**

*n-channel E MOSFET: non-conducting (left), conducting (right)*
SECTION 3 - DEVICE STRUCTURE, OPERATION, AND TESTING PROCEDURE

n-channel D-MOSFET: conducting (left), non-conducting (right)
MOSFET classification. (Source: Tutorialspoint.com)
SECTION 3 - DEVICE STRUCTURE, OPERATION, AND TESTING PROCEDURE

E-MOSFET schematic symbol (left pair)  D-MOSFET schematic symbol (right pair)
SECTION 3 - DEVICE STRUCTURE, OPERATION, AND TESTING PROCEDURE

Source-drain body diode in lateral device (left), vertical device (right)
SECTION 3 - DEVICE STRUCTURE, OPERATION, AND TESTING PROCEDURE

MOSFET with intrinsic body diode symbol
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MOSFET relay analogy
SECTION 3 - DEVICE STRUCTURE, OPERATION, AND TESTING PROCEDURE

VMOS
SECTION 3 - DEVICE STRUCTURE, OPERATION, AND TESTING PROCEDURE

UMOS
SECTION 3 - DEVICE STRUCTURE, OPERATION, AND TESTING PROCEDURE

Trench MOSFET
SECTION 3 - DEVICE STRUCTURE, OPERATION, AND TESTING PROCEDURE

Planar SiC MOSFET
GaN HEMT Lateral Structure. Note: Conventional current flow is shown
SECTION 3 - DEVICE STRUCTURE, OPERATION, AND TESTING PROCEDURE

N-channel E-MOSFET TO-220 package
SECTION 3 - DEVICE STRUCTURE, OPERATION, AND TESTING PROCEDURE

Shorting MOSFET leads using long-nose pliers
SECTION 3 - DEVICE STRUCTURE, OPERATION, AND TESTING PROCEDURE

Testing the OFF-state
SECTION 3 - DEVICE STRUCTURE, OPERATION, AND TESTING PROCEDURE

Testing the ON-state
SECTION 3 - DEVICE STRUCTURE, OPERATION, AND TESTING PROCEDURE

Discharge of gate-to-source capacitance
SECTION 4 — DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

Overall system with voltage isolation and gate driver
SECTION 4 – DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

MOSFET gate as a simple capacitor
SECTION 4 – DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

Gate driver circuit responses as a function of gate resistance
Gate drivers (left to right): Low side, high side, low side or high side
Synchronous gate drivers (left to right): Half bridge, full bridge, three-phase driver
SECTION 4 — DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

Opto-isolator
SECTION 4 — DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

Magnetic isolation
SECTION 4 – DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

Capacitive isolation
SECTION 4 — DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

Traction inverter block diagram
SECTION 4 — DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

TI reference design TIDA00366 three-phase inverter
SECTION 4 — DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

Gate driver UCC21530 for three-phase inverter
Isolation amplifier AMC1301 for three-phase inverter
The new technology ecosystem

To be effective, new power transistor developments require ecosystem improvements across multiple areas. It’s rarely a case of simply exchanging the old for the new.

Source: Texas Instruments

Issues in transitioning to WBG devices
SECTION 4 – DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

UCC27524A dual-channel gate driver
SECTION 4 – DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

UCC21520 isolated dual-channel gate driver
SECTION 4 – DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

UCC21520 isolated gate driver with half bridge and microcontroller
SECTION 4 – DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

Half bridge current loop
Multilayer half bridge cross-section
SECTION 4 – DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

Multilayer half bridge cross-section
Parasitic capacitance arising from floating heatsink connection in half bridge configuration
SECTION 4 — DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

Surface mount GaN HEMT
GaN HEMT mounted on PCB with vias conducting heat to heatsink below
SECTION 4 – DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

Heatsink with thermal adhesive
SECTION 4 — DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

Heatsink with screw attachment
SECTION 4 — DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

Improved version of heatsink with screw attachment
SECTION 4 — DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

Heatsink with clip attachment
ATS cold plates providing uniform surface temperature
SECTION 4 — DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

Hitachi double-sided cooling power module
SECTION 4 — DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

Typical EV battery system
SECTION 4 — DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

Charging station
SECTION 4 — DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

TI TIDA010054 dual-active bridge board with vertically-mounted UCC51230 drivers and heatsink mounted below the PCB
SECTION 4 — DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

TI TIDA010054 gate driver board
SECTION 4 — DEVICE DRIVING ISSUES AND TYPICAL CIRCUITRY UTILIZING WBG DEVICES APPLICATIONS

TI TIDA010054 block diagram
SECTION 5 — APPLICATIONS AND SAMPLE CIRCUIT BLOCK DIAGRAMS

WBG application space
Switching power device application space
Applications where WBG devices can displace Si
SECTION 5 — APPLICATIONS AND SAMPLE CIRCUIT BLOCK DIAGRAMS

WBG applications: ICE automotive

- 48V – 12V Power Distribution
- LiDAR
- High-Intensity Headlights
- Ultra-Hi-Fi Infotainment Systems

(Source: EPC)

Automotive applications of WBG devices
Automotive applications of WBG devices
SECTION 5 — APPLICATIONS AND SAMPLE CIRCUIT BLOCK DIAGRAMS

Simplified LIDAR system block diagrams
48V-12V power distribution

- Increasing electrification leading to higher voltages: from 48V to 400V
- EVs and HEVs require both uni- and bi-directional power conversion: DC/DC, AC/DC & DC/AC
- GaN, SiC, and Si technologies will all be used

(Source: Texas Instruments)

48-12 V power distribution system
More electric aircraft (MEA)
Electric propulsion system (EPS)
SECTION 5 – APPLICATIONS AND SAMPLE CIRCUIT BLOCK DIAGRAMS

Block diagram of a typical solar power inverter system
SECTION 5 — APPLICATIONS AND SAMPLE CIRCUIT BLOCK DIAGRAMS

Data center layout
SECTION 5 — APPLICATIONS AND SAMPLE CIRCUIT BLOCK DIAGRAMS

Offline/standby UPS
Online/double conversion UPS
A typical SMPS block diagram
SECTION 5 – APPLICATIONS AND SAMPLE CIRCUIT BLOCK DIAGRAMS

Traditional grid (left), smart grid (right)
WBG devices find potential application in the power electronic interfaces of modern microgrids.
SECTION 5 – APPLICATIONS AND SAMPLE CIRCUIT BLOCK DIAGRAMS

Domestic microgrid arrangement
SECTION 5 – APPLICATIONS AND SAMPLE CIRCUIT BLOCK DIAGRAMS

Microgrid arrangement in a factory environment
SECTION 5 – APPLICATIONS AND SAMPLE CIRCUIT BLOCK DIAGRAMS

Power dissipation during switching transition
SECTION 5 – APPLICATIONS AND SAMPLE CIRCUIT BLOCK DIAGRAMS

Block diagram of a typical 48 V robot system
Efficient and compact power supplies and charging functions play an essential role in mobile robots.

SiC and GaN will increase power density by factor 2-5

Shorter charging time for mobile robots

Mobile robots utilizing WBG devices
The flexibility of a robot’s arm is driven by the integration of motors and motor drive into the arm as well as the reduction of wires.

Robot arm with external cabling, drive, and motor
Reduced complexity robot arms
SECTION 6 — CASE STUDY: HIGH POWER INVERTER

Basic single-phase inverter
Basic three-phase inverter
SECTION 6 — CASE STUDY: HIGH POWER INVERTER

Three-phase inverter waveforms
SECTION 6 — CASE STUDY: HIGH POWER INVERTER

Wolfspeed three-phase inverter with inductive load
Wolfspeed three-phase inverter current output waveforms
SECTION 6 – CASE STUDY: HIGH POWER INVERTER

System block diagram: Wolfspeed 300 kW three-phase inverter reference design
Size comparison of XM3 power module with existing designs
SECTION 6 — CASE STUDY: HIGH POWER INVERTER

Wolfspeed 300 kW three-phase inverter
SECTION 6 – CASE STUDY: HIGH POWER INVERTER

Inverter cutaway
IF YOU ARE INTERESTED IN REVIEWING THIS MODULE, PLEASE CONTACT ME

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