New Generation High Power Semiconductor Device Introduction

www.bruckewell-semi.com

ADRESS
6F.-9, NO.65, GAOTIE 7TH RD., JHUBEI CITY, HSINCHU COUNTY 302, TAIWAN

PHONE
TEL: +886-3-6673276  FAX: +886-3-6673226

ADRESS
1503-1504, 15F, BLOCK B, KECHUANG BUILDING NO.586
XIHUAN ROAD, QIXIAN STREET, KEQIAO DISTRICT,
SHAOXING CITY, ZHEJIANG PROVINCE, CHINA

PHONE
TEL: +86 575 85591861  FAX: +86 575 85591862
Company Description

Bruckewell technology corp is a discrete semiconductor design company that have the ability to offer KGD wafer-level products to provide silicon and wide bandgap (WBG) power semiconductor devices.

We pride ourselves in our expertise in all areas of power semiconductor technology and business operations, our technical team contribute over 20 years expertise in power semiconductor.

Our aim in becoming a technology innovator timely market partners for our customers.
Speaker

Henry Yeh
General Manager / Founder

Bruckewell technology, 2008-Now
Vishay Intertechnology Inc, 2005-2008
Fairchild Foundry, Taiwan, 2003-2005
Vishay Intertechnology Inc, 1998-2003
Our Products

- Bare Wafer
- Diode
- MOSFET
- TVS/Zener
- IGBT
- Standard/ Fast/ Schottky
- TVS/ Zener/ ESD
- Protector
- SiC Schottky Diode
- 20-900V N/P MOSFET
- SiC MOSFET
- GaN HEMT
- 650V-1350V
- Field Stop Series
## Classification High Power Devices

### UNIPOLAR

**MOSFETs, Schottky Diode**
- Conventional Devices (Silicon Limits)
- Novel Concepts, Super Junction and Floating islands
- Limits of Performance with these novel concepts

### BIPOLAR

**IGBTs**
- Low Losses, IGBT
- Bidirectional IGBT
- Integration of an IGBT transistor and a Diode
- Limits of Performance of IGBTs

### WIDE BAND GAP

**SiC, GaN Device**
- Properties of Wide Band Gap Semiconductors
- Comparison of Limits of performance
- SiC, GaN, Diamond, Current and Future Trends
Physical Properties of WBG Power Devices

<table>
<thead>
<tr>
<th>Material</th>
<th>Band gap energy $E_g$ (eV)</th>
<th>Thermal conductivity $\lambda$ (W/cm·°K)</th>
<th>Electron saturation velocity $V_{sat}$ ($\times 10^7$ cm/s)</th>
<th>Electric field breakdown $E_c$ (kV/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>1.12</td>
<td>1.5</td>
<td>1</td>
<td>300</td>
</tr>
<tr>
<td>GaN</td>
<td>3.39</td>
<td>1.3</td>
<td>2.2</td>
<td>3300</td>
</tr>
<tr>
<td>4H-SiC</td>
<td>3.26</td>
<td>4.9</td>
<td>2</td>
<td>2200 (7X of $E_c$ (Si))</td>
</tr>
<tr>
<td>Diamond</td>
<td>5.45</td>
<td>22</td>
<td>2.7</td>
<td>5600</td>
</tr>
</tbody>
</table>

- Wider Bandgap Energy
- Higher Thermal Conductivity
- Higher Electron Saturation Velocity
- Higher Electric Field Breakdown

- Higher operating temperatures
- Higher voltage operation
- Lower loss (lower Ron)
- Higher operating frequencies
Power Semiconductor on Different Frequency

Conversion Power (W)

MOSFET

IGBT

IGCT

PCT

Silicon

Frequency

$V_{BD} = W_D \left( E_{max,SiC} - W_D \frac{q N_D}{2 \epsilon_s} \right)$

War zone of Si, SiC, GaN
WBG share is small but increasing. WBG PE is a small segment of PE, PE is a very small share of total semiconductors. Growth of WBG devices is driven by smaller packaging, high power density and higher efficiency in Auto and industrial.
Power Semiconductor Application

Extend application
From Niche to New Application

Wind
PV
Home appliances
Rail
EV/HEV
Motor Driver

LiDAR
GaN Only
Charging Station
SiC
Battery
SiC
GaN Only
UPS
Global Power Semiconductor Patent Distribution

USA
- MOSFET: 43%
- Bipolar: 13%
- IGBT: 15%
- Thyristor: 16%
- Diode: 13%

Germany
- MOSFET: 24%
- Bipolar: 17%
- IGBT: 23%
- Thyristor: 21%
- Diode: 12%

China
- MOSFET: 41%
- Bipolar: 12%
- IGBT: 19%
- Thyristor: 13%
- Diode: 9%

Japan
- MOSFET: 51%
- Bipolar: 25%
- IGBT: 7%
- Thyristor: 9%
- Diode: 8%

Korea
- MOSFET: 25%
- Bipolar: 8%
- IGBT: 7%
- Thyristor: 9%
- Diode: 9%
Shield Gate MOSFET Revolution – support 30V to 150V

Enhance RDS(ON)×QG (FOM)
Major Marketing are 40V, 60V, 100V
Decrement of Qg to Reach High Speed

Using \( BV_{dss} = \frac{2qN_dE_m^2}{\varepsilon_s} \)

\( N_d = 1e^{17} \rightarrow BV \sim 3V \)
Shield Gate MOSFET Benefits

Shielded Gate Technology benefits result in improved efficiency and better power density

• Reduced Qg
• Superior switching performance
• Low Ringing
• Intrinsic Shield Resistance and Capacitance
• No External snubbers required in most applications
• EPI Resistance is the major RDS(on) contributor

The lower specific drain-to-source resistance (RDS(ON).Area) translates into smaller chip size and consequently cheaper die cost for the customers.
Shield Gate MOSFET Package Challenges

Improve the thermal performance of package to support the high power density
Field Stop IGBT Revolution

**Planar**

- **PT (GEN3)**
  - Emitter
  - Gate
  - P-sub
  - Collector

- **NPT (GEN4)**
  - Emitter
  - Gate
  - P-base
  - Collector

- **FS Planar (GEN5)**
  - Emitter
  - Gate
  - P-base
  - Collector

**Trench**

- **FS Trench (GEN6)**
  - Emitter
  - Gate
  - P-base
  - Drift Region

- **FS Trench (SA)**
  - Emitter
  - Gate
  - P-base

**WF thickness**

- PT IGBT: 300um
- NPT IGBT: 200um
- FS IGBT: 100um
- N Buffer FS
## IGBT Technology Capability Summary

<table>
<thead>
<tr>
<th>Factor</th>
<th>PT</th>
<th>NPT</th>
<th>Field Stop</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Switching Loss</strong></td>
<td>Low (Short tail current)</td>
<td>Medium (Long, low amplitude tail current)</td>
<td>Low (Short tail current)</td>
</tr>
<tr>
<td></td>
<td>Significant increase in Eoff with temperature</td>
<td>Moderate increase in Eoff with temperature</td>
<td>Moderate increase in Eoff with temperature</td>
</tr>
<tr>
<td><strong>Conduction Loss</strong></td>
<td>Low (Flat to slight decrease with temperature)</td>
<td>Medium (Increases with temperature)</td>
<td>Low (Increases with temperature)</td>
</tr>
<tr>
<td><strong>Paralleling</strong></td>
<td>Difficult (Must sort on VCE(on))</td>
<td>Easy (Optional sorting)</td>
<td>Easy (Optional sorting)</td>
</tr>
<tr>
<td></td>
<td>Must share heat</td>
<td>Recommend share heat</td>
<td>Recommend share heat</td>
</tr>
<tr>
<td><strong>Short Circuit Rated</strong></td>
<td>Limited (High gain)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
**Trench SiC MOSFET Patent Assignees**

- **Full SiC power modules**
- Other power modules, including hybrid Si/SiC modules, modules with SiC devices not specified (MOSFET, SBD) and modules with Si, GaN or SiC as possible power devices.

**Innovation triggers**
- First SiC Diode commercially available (Infineon)
- First Si/SiC hybrid module in production (Infineon)
- First SiC MOSFET commercially available (CREE, Rohm)

**Full SiC modules related patenting activity increases**

**Number of publications**
- 1995
- 1996
- 1997
- 1998
- 1999
- 2000
- 2001
- 2002
- 2003
- 2004
- 2005
- 2006
- 2007
- 2008
- 2009
- 2010
- 2011
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017
- 2018
Trench SiC MOSFET Patent Assignees

The chart illustrates the patenting activity of various companies in the Trench SiC MOSFET technology. The x-axis represents the number of pending patent applications, while the y-axis shows the number of granted patents. Companies are positioned based on their patenting activity, with a focus on patenting right reinforcement and IP leadership.
SiC Schottky Diode Structure

- **N**⁻-Drift Layer: 40 μm/2x10¹⁵ cm⁻³
- **N**⁺-Substrate
- **CATHODE**: SBD, JBS, PiN
SiC Schottky Diode Structure

Structure of the JBS/MPS diode, consisting of interdigitated pin and Schottky diodes, electrically connected in parallel.
# SiC Device Cost Comparison

<table>
<thead>
<tr>
<th>Need to transfer 10kW</th>
<th>IGBT + Si Diode</th>
<th>SiC MOSFET + SiC Diode</th>
<th>SiC MOSFET + SiC Diode</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Switching Frequency</strong></td>
<td>20kHz</td>
<td>60kHz</td>
<td>100kHz</td>
</tr>
<tr>
<td>Inductors</td>
<td>$62</td>
<td>$35</td>
<td>$20</td>
</tr>
<tr>
<td>Capacitors</td>
<td>$65</td>
<td>$65</td>
<td>$65</td>
</tr>
<tr>
<td>Cooling</td>
<td>$45</td>
<td>$30</td>
<td>$38</td>
</tr>
<tr>
<td>Power Semiconductors</td>
<td>$10</td>
<td>$40</td>
<td>$40</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$182</td>
<td>$170</td>
<td>$163</td>
</tr>
</tbody>
</table>

**Comparison based on:**

- 10kW interleaved boost converter
- Output Power: 10kW
- Input Voltage Range: 300VDC - 450VDC
- Output/DC-Link Voltage: 640VDC

Use SiC products to restructure, not increase overall system cost.
SiC Technology Cross the Chasm

We are here

The Early Market

Tech Euthusiasts & Visionaries

Chasm

Pragmatists

Conservatives

Skeptics

PRODUCT EXTENSION
## Silicon Carbide (SiC) Timeline for EV/HEV

Almost Car suppliers announce the EV Car time schedule

<table>
<thead>
<tr>
<th>Car Supplier</th>
<th>Timeline Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GM</td>
<td>20 all electric cars by 2023</td>
</tr>
<tr>
<td>Ford</td>
<td>13 models by 2023</td>
</tr>
<tr>
<td>Toyota &amp; Mazda</td>
<td>U.S.-based plant by 2021</td>
</tr>
<tr>
<td>Daimler /Mercedes-Benz</td>
<td>Electrify entire portfolio by 2022</td>
</tr>
<tr>
<td>Jaguar Land Rover</td>
<td>Electrify (HEV/EV) all lineup by 2020</td>
</tr>
<tr>
<td>Renault/Nissan/Mitsubishi</td>
<td>12 All-Electric cars by 2022</td>
</tr>
<tr>
<td>Volvo</td>
<td>Electrify entire line by 2019</td>
</tr>
<tr>
<td>VW/Audi/Porsche</td>
<td>300 EV/HEV by 2030</td>
</tr>
</tbody>
</table>
In 2017, JEDEC a global leader in developing open standards for the microelectronics industry, formed the JC-70 committee on “Wide Band-gap Power Electronic Conversion Semiconductors.” creating universal standards to help advance the adoption of WBG power technologies.
SiC Products To Debut Automotive marketing

Industry news

- ROHM Semiconductor introduces SiC technology into Formula E on 2016’
- ON Semiconductor announces SiC Diodes for Automotive on Jun-18’
- Wolfspeed issued the first AEC-Q101 on Mar-18’
- Infineon announced to target automotive markets with SiC on Sep-18’
- Littelfuse introduced two auto grade of 650 V SiC Schottky diodes on Feb-19’
- ST-Micro issued the Automotive-grade Schottky diodes on Mar-19’

Automotive Key Technology:

1. Follow AEC-Q101 qualification, operation on -55C to 175C
2. MPS structure work for automotive
3. Thin wafer technology < 110um
Conclusions

• Si Based Power semiconductors are a key enabler for modern and future power electronics systems including grid systems
• High power semiconductors devices and new system topologies are continuously improving for achieving higher power, improved efficiency and reliability and better controllability
• The Diode, IGBT and MOSFET continue to evolve for achieving future system targets with the potential for improved power/performance through further losses reductions, higher operating temperatures and integration solutions
• Wide Band Gap Based Power Devices offer many performance advantages with strong potential for very high voltage applications
Thank you

Next-Generation Power Semiconductors
Global key Supplier

www.bruckewell-semi.com

By Henry Yeh
E-mail: henry@bruckewell.com
Phone: +886 935670828