ROHM’s Power Devices Technology Update

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ROHM Semiconductor GmbH
Product Marketing
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1. Introduction
2. SiC SBD
3. SiC MOSFET
4. Hybrid MOS (Si)
ROHM’s Accelerating Growth in Four Areas

Synergy of ICs Strategy
Cultivating new markets by assimilating ROHM’s analog technology with the digital technology of LAPIS Semiconductor

Example: Dedicated Chipset for Intel® Atom™ Processor

Chip Set

Currently broadening our lineup for automobile, FA, and more!

Reference Board

Sensor Strategy
Introducing variety of sensors for smartphones and digital health and fitness market

LED Strategy
Since our entry into the LED industry in 1973, we have been developing diverse technologies of LEDs and their related devices

Power Device Strategy
We will contribute to energy saving by the collaboration of the three technologies.

Device Technology + Control Technology + Module Technology

The Latest Power Device SiC (Silicon Carbide)

Power Transistors
Power Diodes
Power ICs/Control ICs

HEV/EV

“Full SiC” Power Modules

Power Modules

Packages
LED Driver ICs
Regulator Modules
LED Lighting
ROHM’s Power Devices

ROHM’s power item lineup covers wafers/bare dies, discrete packages, module, ICs and Intelligent Power Modules.

Device
- SiC (SBD/MOSFET)
- IGBT
- Hybrid MOS
- Super Junction MOSFET
- FRD
- SBD
- Shunt Resistor

PKG
- TO220
- TO247/3PF
- D-Pak / D2-Pak etc...

ICs
- Gate Driver
- Temperature/High Voltage monitor
- ACDC etc...

Power Module
- Case type (Full SiC Module)
- Mold type
- IPM etc...

ROHM’s power item lineup covers wafers/bare dies, discrete packages, module, ICs and Intelligent Power Modules.
Applications for Power Devices

- Solar
- Air Conditioner
- EV/HEV
- Power supply
- BEMS/HEMS
- Industry
  - Induction Heating
  - Medical
  - Pulse power
  - Auxiliary power supply
  - Drive
  - Accelerator (Collider)
- Train
- Others
Advantage of SiC Power Devices

Characteristics of SiC Devices

- A large safe operating range
- Operation at High Temp.
- High Breakdown Voltage
- Large Current
- Low Switching Loss

Physical properties (SiC / Si)

- Melting point: $x^2$
- Bandgap: $x^3$
- Breakdown electric field: $x^{10}$
- Thermal conductivity: $x^3$

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Si</th>
<th>SiC(4H)</th>
<th>GaN</th>
</tr>
</thead>
<tbody>
<tr>
<td>bandgap (eV)</td>
<td>1.12</td>
<td>3.26</td>
<td>3.39</td>
</tr>
<tr>
<td>electron mobility (cm²/Vs)</td>
<td>1350</td>
<td>1000</td>
<td>1500</td>
</tr>
<tr>
<td>breakdown field (MV/cm)</td>
<td>0.3</td>
<td>3.0</td>
<td>3.3</td>
</tr>
<tr>
<td>saturation electron mobility (cm/s)</td>
<td>1.0E+07</td>
<td>2.7E+07</td>
<td>2.2E+07</td>
</tr>
<tr>
<td>thermal conductivity (W/cmK)</td>
<td>1.5</td>
<td>4.9</td>
<td>1.3</td>
</tr>
</tbody>
</table>
Supply Chain of ROHM SiC Power Devices

**SiC epitaxial substrate**
- SiCrystal AG
  - 2 inch
  - 3 inch
  - 4 inch

**SiC discrete devices**
- DMOSFET SBD
- SiC-SBD 2010.4 MP.

**SiC power modules**
- SiC-DMOS 2010.12 MP.
- Power Module 2012.3 MP.

*Consistent Production System*

The production system of the consistent SiC power semiconductor

- 2007: ROHM kyoto Univ. and Tokyo Electron Establishment of SiC epitaxial equipment
- 2009: SiCrystal AG. is purchased.
- 2011: 4 inch Mass production start
- 2013: 6 inch Mass production start

**Germany**
- SiCrystal AG

**Fukuoka**
- ROHM Apollo Co., Ltd.

**Kyoto**
- ROHM Co., Ltd. Kyoto HQ.
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Comparison of Forward Characteristics of SiC SBDs

2nd Gen SiC-SBDs realize lower Vf, which leads to better efficiency

※These data are provided to show a result of evaluation done by ROHM for your reference. ROHM does not guarantee any of the characteristics shown here.
Comparison between Si-FRD and SiC-SBD

High voltage is possible in SiC with “ultra fast” SBD structure
=> negligible recovery loss

Vf@10A (V)

Low recovery loss

Low conduction loss

600V/10A Devices
Ta=25°C
### ROHM’s Next Gen SiC SBD (Trench)

**Cross section**

<table>
<thead>
<tr>
<th>Conventional SBD</th>
<th>Trench SBD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schottky Metal</td>
<td>Schottky Metal</td>
</tr>
<tr>
<td>N-SiC (Drift layer)</td>
<td>P SiC</td>
</tr>
<tr>
<td>SiC sub.</td>
<td>N-SiC (Drift layer)</td>
</tr>
<tr>
<td>Metal</td>
<td>Metal</td>
</tr>
</tbody>
</table>

**Electric field distribution (reverse direction)**

Trench SBD structure reduces electric field at Schottky contact.

=> Trade-off between Vf and leakage current is improved.
Trench SBD structure allows for
1) implementation of low barrier height Schottky metal
2) thinner epi thickness and higher dopant concentration
results in lower Vf  (above graph is for case 1)
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RonA vs Blocking Voltage Characteristics

- Chip size can be halved for the same Ron, which leads to cost reduction
- Smaller package size for the same Ron

Chip size ratio for the same Ron at BVdss of 900V

- Si-MOSFET
- Si-SJMOS
- 2G SiC MOSFET
- 3G SiC MOSFET
- Latest Si-SJMOS
## Overview of ROHM SiC-MOSFET lineup

<table>
<thead>
<tr>
<th>Generation</th>
<th>2G SiC-MOSFET</th>
<th>3G SiC-MOSFET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>Planner gate (DMOS)</td>
<td>Trench gate (UMOS)</td>
</tr>
<tr>
<td>RonA 1200V</td>
<td>8.2mΩcm²</td>
<td>4.1mΩcm²</td>
</tr>
<tr>
<td>RonA 650V</td>
<td>6.5mΩcm²</td>
<td>3.1mΩcm²</td>
</tr>
</tbody>
</table>
Drain-source Bias Simulation Results

Condition: Same Vds supplied in both cases

Standard trench MOSFET

ROHM 3G SiC MOSFET

Suppression of the electric field concentration at the bottom of the gate trench is achieved by the double trench structure of ROHM 3G SiC MOSFET.

Eox: 35% lower
On-state Characteristics of 3G SiC Trench MOSFET

- Low Ron at recommended Vgs of 18V
- A positive temperature-coefficient of on-resistance over Vgs of 10.5V, thus lower risk of thermal runaway
Comparison of Temperature Dependency of Ron

- Compared to 2G planar MOSFET, Ron reduced by half throughout the entire temperature range.
Ciss vs Ron

The combination of Lower Ron & Ciss reduced both conduction and switching losses

Reduction from 2G DMOS
Ciss: by 35%
Ron: by 50%
with the same chip size

Ciss: by 70% at the same Ron

2G DMOS
80mΩ  1200V

3G UMOS
40mΩ  1200V

3G UMOS
80mΩ  1200V
Vgs vs Qg

35% Lower Qg compared to ROHM 2G SiC DMOS

Same chip size

3G UMOS
40mΩ 1200V

2G DMOS
80mΩ 1200V

Ta = 25°C
Vdd = 400V
Id = 10A
Pulsed
Total switching loss reduced by 30% compared to ROHM 2G SiC MOSFET
Reverse recovery characteristics of body-diode

Reverse recovery current of body-diode is extremely smaller than Si-MOSFETs

![Graph 1: Si-SJ MOS](image1)
- $t_{rr} \sim 600\text{nsec}$

![Graph 2: 3G SiC trench MOS](image2)
- $t_{rr} \sim 30\text{nsec}$

**Measurement Conditions**
- $E = 300\text{V}$
- $R_g = 100\Omega$
- $I_d = 36\text{A}$
## Reliability test

<table>
<thead>
<tr>
<th>TEST</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body-diode conduction</td>
<td>$I_{sd}=10,\text{A}$, $T_a=25,\degree\text{C}$ (1000h, n=20)</td>
</tr>
<tr>
<td>Vth stability (HTGB+)</td>
<td>$V_{gs}=+22,\text{V}$, $T_a=175,\degree\text{C}$ (1000h, n=80)</td>
</tr>
<tr>
<td>Vth stability (HTGB-)</td>
<td>$V_{gs}=-10,\text{V}$, $T_a=175,\degree\text{C}$ (1000h, n=30)</td>
</tr>
<tr>
<td>Robustness at non-weather protected locations (H3TRB)</td>
<td>$V_{ds}=960,\text{V}$ (V$<em>{ds</em>{\text{max}}}$*80%) $T_a=85,\degree\text{C}$ 85%RH (1000h, n=88)</td>
</tr>
</tbody>
</table>
Recombination induced stacking faults

Before stress

bipolar current

After stress

Defect Generation

4° off angle

Cross section

70 ~ 140um

Basal plane dislocation (Linear defect)

Forward Conduction

SiC MOSFET circuit diagram

Body diode (parasitic diode)

SiC MOSFET circuit diagram

Source

Gate

Drain

Forward Conduction

Defect Generation

Cross section

4° off angle

70 ~ 140um

Basal plane dislocation (Linear defect)

Device Degradation

Ron (Ω) @Id=2.5A, Vgs=18V

Ron (Ω) @Id=10A, Vgs=18V

Time (hrs)

0.00 0.50 1.00 1.50 2.00 2.50

Increase in Ron

ROHM SiC planar MOSFETs have already solved

Old process

Current process

ROHM SiC planar MOSFETs have already solved
Body-Diode Reliability

Condition

$\text{I}_F = 10 \text{A DC (body diode)}$

$\text{Ta} = 25^\circ \text{C}$

Number: 20

Ron increase rate of MOSFETs

$\text{Id} = 10 \text{A}$

$\text{Vsd} = 5 \text{V}$

$\text{N} = 20$

No degradation

V\text{F increase rate of body diode}

$\text{Id} = 10 \text{A}$

$\text{Vsd} = 5 \text{V}$

$\text{N} = 20$

No degradation

Applicable to inverters, converters, and any sort of topologies which have commutation current through the body-diode
Time Dependence of Vth Change Rate

HTGB(+22V)

- 100%
- 80%
- 60%
- 40%
- 20%
- 0%
20%
40%
60%
80%
100%

0 200 400 600 800 1000
Time (h)

No degradation

The change rate of Vth at Vd = 10V, Id = 10mA

HTGB (175℃)
Vgs = 22V
N = 80

HTGB(-10V)

- 100%
- 80%
- 60%
- 40%
- 20%
- 0%
20%
40%
60%
80%
100%

0 200 400 600 800 1000
Time (h)

No degradation

The change rate of Vth at Vd = 10V, Id = 10mA

HTGB (175℃)
Vgs = -10V
N = 30

▪ Vth were stable during the entire duration of both positive and negative gate bias test

▪ Rated Vgs(-) expanded from -6V (2G) to -10V (3G)
H3TRB test

For module applications in non-weather protected locations

Photovoltaic cell inverters   Industrial applications in humid tropical region

High Humidity  High Temperature  Reverse  Bias test

H3TRB test conditions

\[
V_{ds} = V_{ds\text{max}} \times 80\
T_a = 85^\circ C
85\%\text{RH}
1000\text{h}
\]

Required to prove the robustness in non-weather protected locations
H3TRB Test Result

Condition
Vds=960V (Vdsmax ×80%)
Ta=85°C
85%RH
Number : total 88 chips

Confirmed the robustness of 3G SiC MOSFET against H3TRB test, which proves the potential to be used under non-weather protected environment
<table>
<thead>
<tr>
<th>TEST</th>
<th>Condition</th>
<th>3G SiC-MOSFETs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body-diode conduction</td>
<td>Isd=10A, Ta=25°C (1000h, n=20)</td>
<td>〇 no degradation</td>
</tr>
<tr>
<td>Vth stability (HTGB+)</td>
<td>Vgs= +22V, Ta=175°C (1000h, n=80)</td>
<td>〇 no degradation</td>
</tr>
<tr>
<td>Vth stability (HTGB-)</td>
<td>Vgs= -10V, Ta=175°C (1000h, n=30)</td>
<td>〇 no degradation</td>
</tr>
<tr>
<td>Robustness at non-weather protected locations (H3TRB)</td>
<td>Vds=960V (Vdsmax*80%) Ta=85°C 85%RH (1000h, n=88)</td>
<td>〇 no degradation</td>
</tr>
</tbody>
</table>
## Lineup of 3G SiC MOSFET

<table>
<thead>
<tr>
<th>P/N</th>
<th>Package</th>
<th>BV\textsubscript{DSS}</th>
<th>Vgs</th>
<th>R\textsubscript{Dson}</th>
<th>ID max</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCT2080KE (2G DMOS)</td>
<td>TO247, Bare die</td>
<td>1200V</td>
<td>22V / -6V</td>
<td>45 ~ 450mΩ</td>
<td>10~ 68A</td>
</tr>
</tbody>
</table>

### SCT30XXKL

<table>
<thead>
<tr>
<th>P/N</th>
<th>Package</th>
<th>BV\textsubscript{DSS}</th>
<th>Vgs</th>
<th>R\textsubscript{Dson}</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCT30XXKL</td>
<td>TO247, Bare die</td>
<td>1200V</td>
<td>22V / -10V</td>
<td>22mΩ</td>
<td>Under development</td>
</tr>
<tr>
<td></td>
<td>TO247, Bare die</td>
<td></td>
<td>22V / -10V</td>
<td>30mΩ</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TO247, Bare die</td>
<td></td>
<td>22V / -10V</td>
<td>40mΩ</td>
<td></td>
</tr>
</tbody>
</table>

### SCT30XXAL

<table>
<thead>
<tr>
<th>P/N</th>
<th>Package</th>
<th>BV\textsubscript{DSS}</th>
<th>Vgs</th>
<th>R\textsubscript{Dson}</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCT30XXAL</td>
<td>TO247, Bare die</td>
<td>650V</td>
<td>22V / -10V</td>
<td>17mΩ</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TO247, Bare die</td>
<td></td>
<td>22V / -10V</td>
<td>22mΩ</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TO247, Bare die</td>
<td></td>
<td>22V / -10V</td>
<td>30mΩ</td>
<td></td>
</tr>
</tbody>
</table>

### Bare die

![Bare die image](image1)

### Package

![Package image](image2)
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ROHM Si HV-MOSFET


DMOS1  DMOS2  SJ-Multi epi-1st

40um cell  17um cell  16um cell

A*Ron  11.81mm²Ω  A*Ron  8.25mm²Ω  A*Ron  3.6mm²Ω
Ron*Qg  96Ω*nC  Ron*Qg  17.6Ω*nC  Ron*Qg  10.15Ω*nC
Planor Type  Planor type  Multi Epi type

① PrestoMOS FN Series

② SJ-Multi epi-2nd EN Series

Shrink

A*Ron  2.3mm²Ω
Multi Epi type Super Junction

③ HybridMOS GN Series

New concept Super Junction

＜SJMOS Achievement＞

2007 ~ PDP sustain  2008 ~ PDP power supply  2010 ~ LED-TV
2007 ~ Power Supply  2008 ~ LED lighting  2011 ~ Refrigerator Inverter
2008 ~ LCD-TV  2010 ~ Solar Inverter  2012 ~ Automotive
## What is Hybrid MOS? - High Voltage SW Devices -

<table>
<thead>
<tr>
<th></th>
<th>SiC MOSFET</th>
<th>Si IGBT</th>
<th>Si Super-junction MOSFET</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structure</strong></td>
<td><img src="image1" alt="SiC MOSFET Structure" /></td>
<td><img src="image2" alt="Si IGBT Structure" /></td>
<td><img src="image3" alt="Si Super-junction MOSFET Structure" /></td>
</tr>
<tr>
<td><strong>Breakdown voltage</strong></td>
<td>High</td>
<td>High</td>
<td>Up to around 900V</td>
</tr>
<tr>
<td><strong>Ron</strong></td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>but has on-set voltage</td>
<td>but increasing at high temperature</td>
<td></td>
</tr>
<tr>
<td><strong>Switching speed</strong></td>
<td>Rapid</td>
<td>Limited switching frequency due to tail current at turn-off</td>
<td>Rapid</td>
</tr>
</tbody>
</table>

- **SiC MOSFET**: High breakdown voltage, low Ron, rapid switching speed.
- **Si IGBT**: High breakdown voltage, low Ron (but has on-set voltage at high temperature), limited switching speed.
- **Si Super-junction MOSFET**: Up to around 900V breakdown voltage, low Ron (but increasing at high temperature), rapid switching speed.
**Hybrid-MOS**  New structure SJ MOSFET  - GN series -

- **Fastest in the market !!** ROHM add IGBT function on Super Junction MOSFET.
- ROHM has achieved “Low Rdson at High Temperature condition” while using Super Junction MOSFET structure.

## Merit

### Comparison with Super Junction MOSFET

1. **About 62%** Ron reduction in High Current operation (Tj=125°C)
2. Smaller change rate of Ron in temperature increase.

### Comparison with IGBT,,,

- **IGBT Turn-off waveform**
- **Hybrid-MOS Turn-off waveform**

### Table: Characteristics

<table>
<thead>
<tr>
<th>Part.No</th>
<th>VDSS (V)</th>
<th>ID (A)</th>
<th>RDS(on) Typ. (Ω) Vgs=10V</th>
<th>Qg Typ. (nC) Vgs=10V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tj=25°C</td>
<td>Tj=125°C</td>
<td>ID=5A</td>
<td>ID=10A</td>
</tr>
<tr>
<td>R6020GNZ</td>
<td>600</td>
<td>20</td>
<td>0.37</td>
<td>0.24</td>
</tr>
<tr>
<td>R6035GNX</td>
<td>600</td>
<td>35</td>
<td>0.17</td>
<td>0.11</td>
</tr>
</tbody>
</table>
Application Example:
PFC circuit for the outdoor unit of the air conditioner

Driving System:
2 Phase Interleave Cont. Current Mode

- Improved Power Consumption in whole range

Conditions:
Pmax=7KW
Vin=200Vac 60Hz
Vout=340Vdc  Tj=100℃
Driving Frequency:  fsw=30kHz

Hybrid-MOS R6035GNX

Q1,Q2 Power Dissipation (power consumption per device)

Light loading 500W/50℃
81% Down

Heavy loading 4kW/100℃
56% Down

IGBT: 600V/40A

Hybrid-MOS R6035GNX

Switching
Conduction
Conclusion

Takes Highest Performance devices for you !!

(Technology Leadership)

SiC Device/Module
600V~1700V

IGBT
400~1200V

Si Super-Junction
(Hybrid-MOS)
500~800V