For Reliable and Competitive SiC Power Converters

Dr. Nils Soltau
Deputy Manager Technical Marketing
Mitsubishi Electric Europe B.V.

Bodo's Wide Bandgap Event 2024

Making WBG Designs Happen

SiC

FOR RELIABLE AND COMPETITIVE SIC POWER CONVERTERS

Dr. Nils Soltau

Bodo's Wide Bandgap Event, Munich, Germany

December 4, 2024

Contributing to the realization of a low-carbon society and more affluent lifestyles

MITSUBISHI ELECTRIC
Changes for the Better

Early 1990s
Developed new material, silicon-carbide (SiC) power semiconductor, maintaining a lead over other companies

2000s
Developed various elemental technologies

2006
January 2006
Successfully developed SiC inverter for driving motor rated at 3.7kW

2009
February 2009
Verified 11kW SiC inverter, world's highest value*1 with approx. 70% reduction in power loss

November 2009
Verified 20kW SiC inverter, world's highest value*1 with approx. 90% reduction in power loss

2010
January 2010
Developed large-capacity power module equipped with SiC diode

October 2010
Launched "Kirigamine" inverter air conditioner

2011
January 2011
Verified highest power conversion efficiency*1 for solar power generation system power conditioner (domestic industry)*2

October 2011
Commercialized SiC inverter for use in railcars

2012
March 2012
Developed motor system with built-in SiC inverter

July 2012
Began shipping samples of hybrid SiC

September 2012
Verified built-in main circuit system for railcars

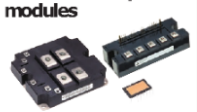
December 2012
Launched CNC drive unit equipped with SiC power module

2013
February 2013
Developed SiC for application in elevator control systems

February 2013
Developed technologies to increase capacities of SiC power modules

March 2013
Delivered auxiliary power supply systems for railcars

May 2013
Launched SiC power modules



December 2013
Launched railcar traction inverter with full SiC power module

2014
February 2014
Developed EV motor drive system with built-in SiC inverter

May 2014
Began shipping samples of hybrid SiC power modules for high-frequency switching applications

November 2014
Launched Large Hybrid SiC DIPIPM™ for PV Applications

2015
January 2015
Launched power conditioner for PV equipped with full SiC-IPM*2

June 2015
Railcar traction system with full SiC power modules installed in Shinkansen bullet trains

2016
April 2016
Launched Super mini Full SiC DIPIPM™

May 2016
Launched room air conditioners with full SiC DIPIPM™ in Japan

October 2016
Launched package air conditioners with full SiC DIPIPM™ in Japan

2017
March 2017
Launched SiC-SBD

March 2017
Develops World's smallest SiC Inverter for HEVs.

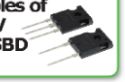
September 2017
Develops SiC Power Device with Record Power Efficiency

December 2017
Mitsubishi Electric and the University of Tokyo Quantify Factors for Reducing SiC Power Semiconductor Resistance by Two-Thirds

2018
January 2018
New 6.5kV Full-SiC Power Semiconductor Module Achieves World's Highest Power Density

December 2018
Mitsubishi Electric and the University of Tokyo Reveal New Mechanism for Enhancing Reliability of SiC Power Semiconductor Devices

2019
June 2019
Began shipping samples of 1200V SiC-SBD



February 2019
Develops Super Compact Power Unit for Hybrid Electric Vehicle

September 2019
Trench-type SiC-MOSFET with unique electric-field-limiting structure developed

2020
November 2020
Launched 4-terminal SiC-MOSFETs

July 2020
Launched SiC-MOSFET

July 2020
Develops Accurate Circuit Simulation Technology for SiC-MOSFETs

2021
January 2021
Launched Second-generation Full-SiC Power Modules

Development of these modules and applications has been partially supported by Japan's Ministry of Economy, Trade and Industry (METI) and New Energy and Industrial Technology Development Organization (NEDO).

* The year and month listed are based on press releases or information released during the product launch month in Japan.

*1 Researched in press releases by Mitsubishi Electric.

*2 Mitsubishi Electric solar-power generation system discontinued on March 31, 2020.

MITSUBISHI ELECTRIC
Changes for the Better

2010

October 2010
Launched "Kirigamine" inverter air conditioner

October 2011
Commercialized SiC inverter for use in railcars

2015

January 2015
Launched power conditioner for PV equipped with full SiC-IPM*2

June 2015
Railcar traction system with full SiC power modules installed in Shinkansen bullet trains

December 2012
Launched CNC drive unit equipped with SiC power module

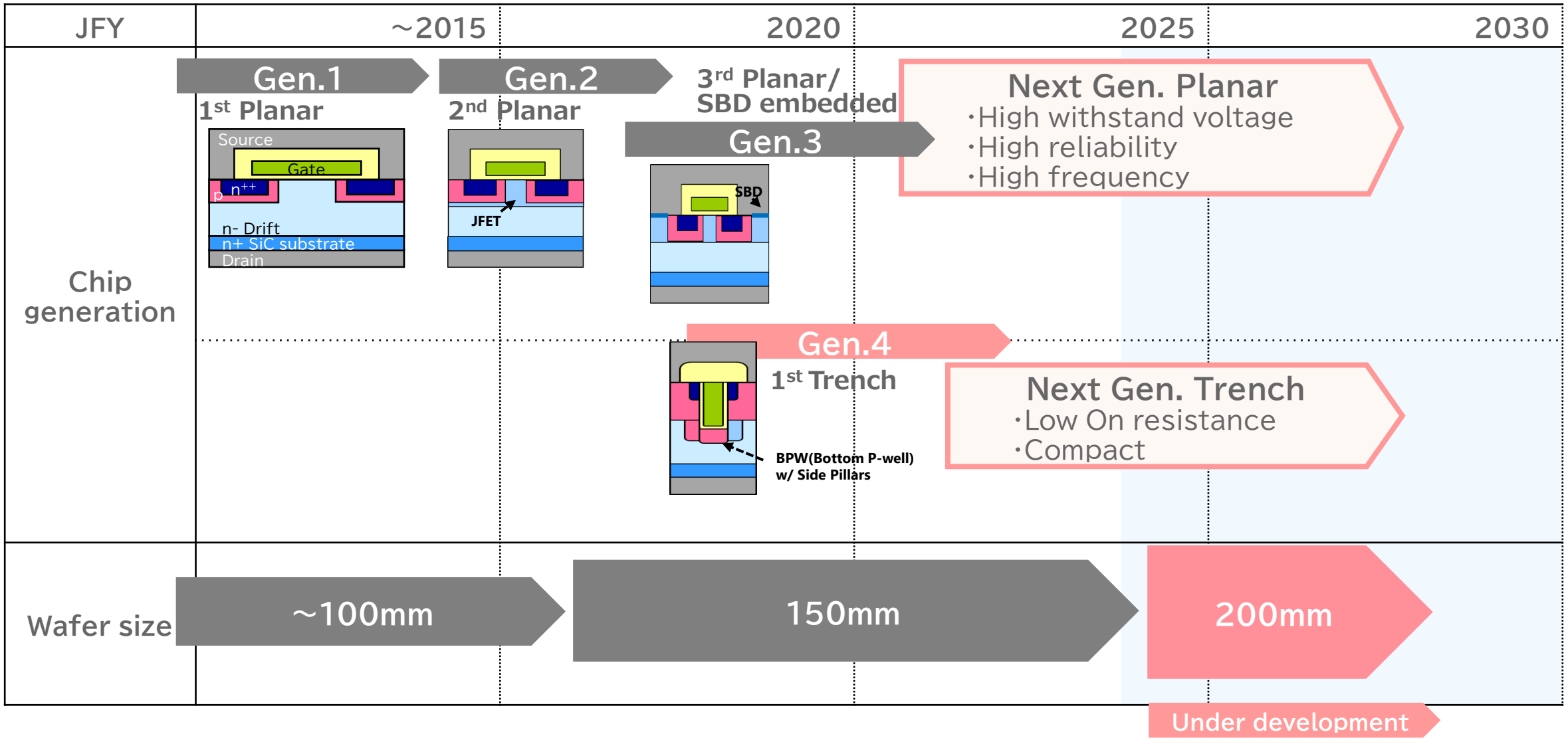
2016

April 2016
Launched Super mini Full SiC DIPIPM™

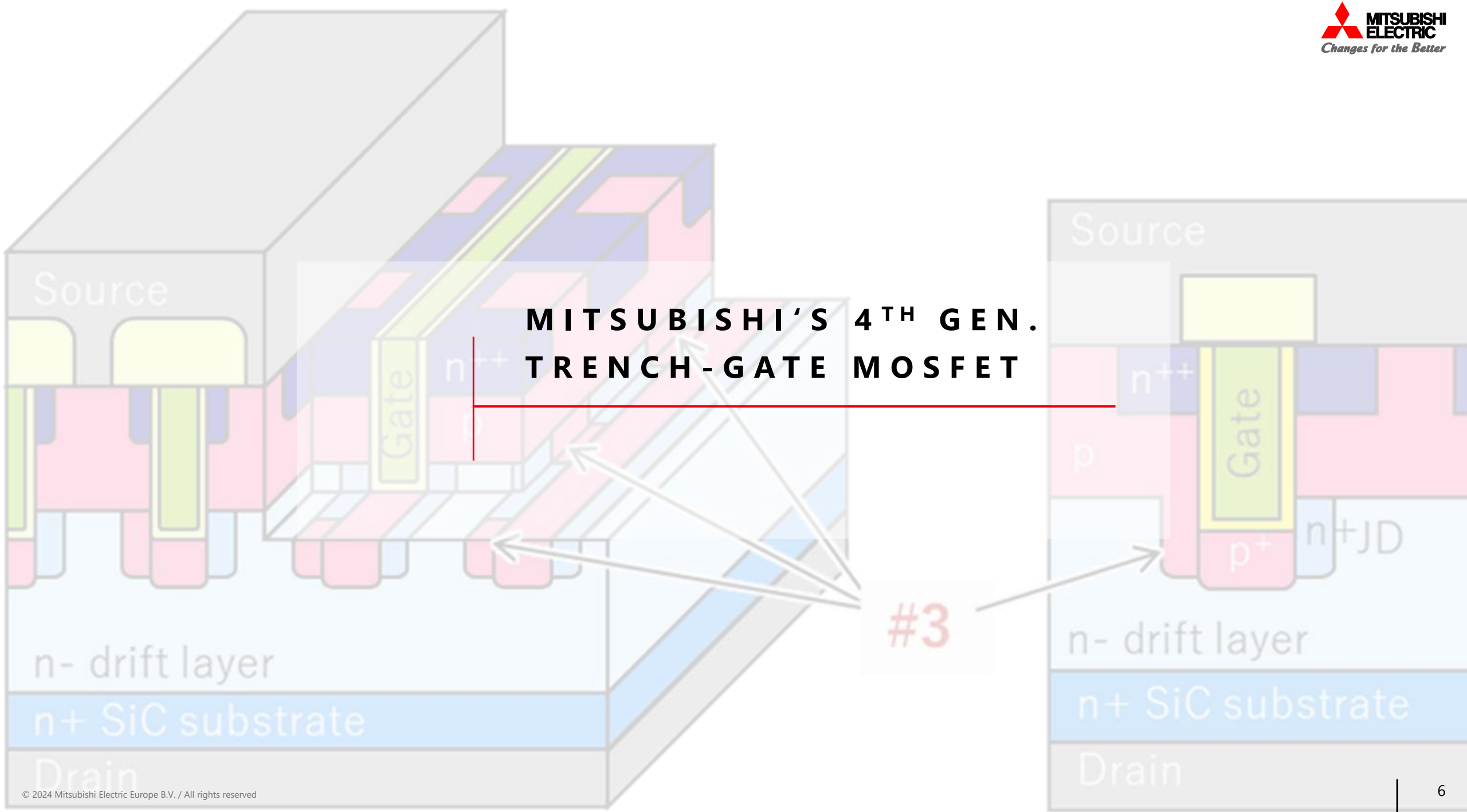
October 2016
Launched package air conditioners with full SiC DIPIPM™ in Japan

May 2016
Launched room air conditioners with full SiC DIPIPM™ in Japan

MOSFET DEVELOPMENT ROADMAP

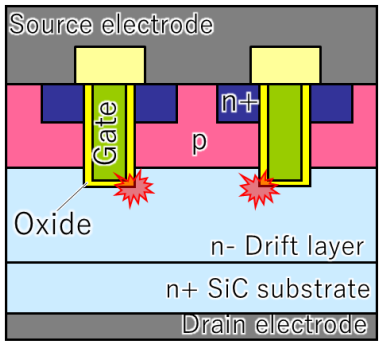


MITSUBISHI'S 4TH GEN. TRENCH-GATE MOSFET



DESIGN OF MITSUBISHI'S 4TH GEN. TRENCH-GATE MOSFET

Trench SiC MOSFET



✓ Advantage

Lower $R_{ds(on)}$
- Lower channel resistance
- Higher channel density

Higher cell density
- Smaller cell pitch
- Higher current density

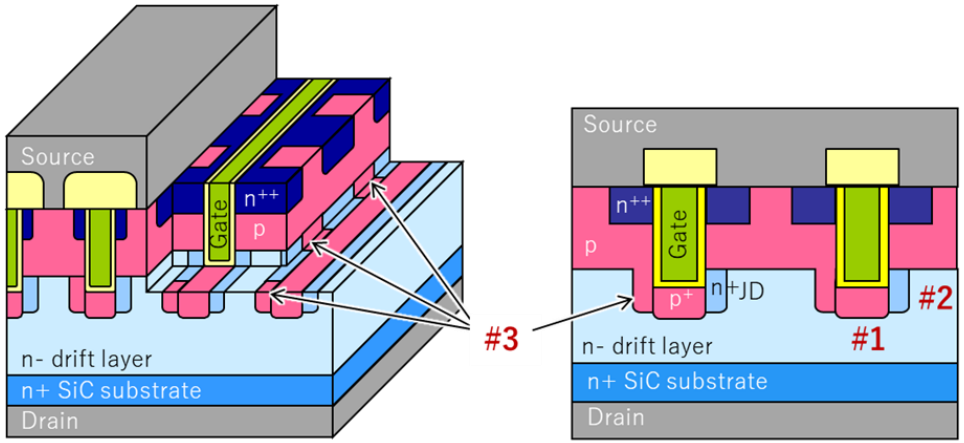
× Challenge

~~**Gate oxide reliability**~~
- Higher electric field @corner
- Higher stress @bottom
- Vth instability

~~**Electric field management**~~
- Field crowding @corner

~~**Parasitic capacitance**~~

Mitsubishi Trench SiC MOSFET (4th Gen.)



1) Trench Bottom P-Well
- ✓ Reduction of E_{ox}
- × Increasing R_{JFET} (grounded p-well)

2) n-JFET Doping
- ✓ Reduction of R_{JFET}

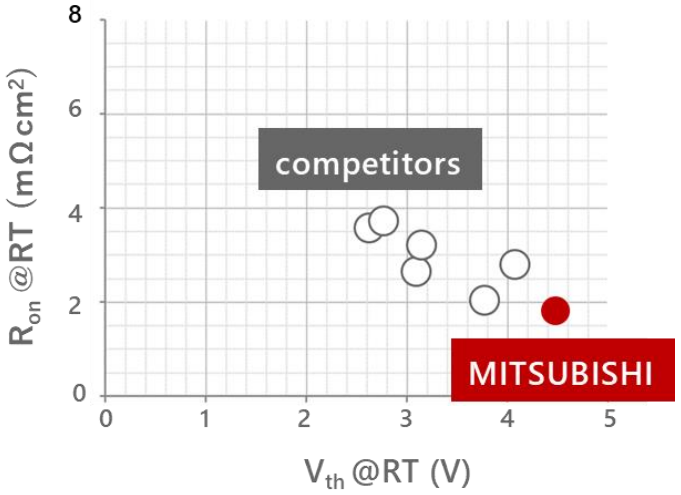
3) p-Sidewall Pillar
Grounding BPW
- ✓ → stabilizing the potential

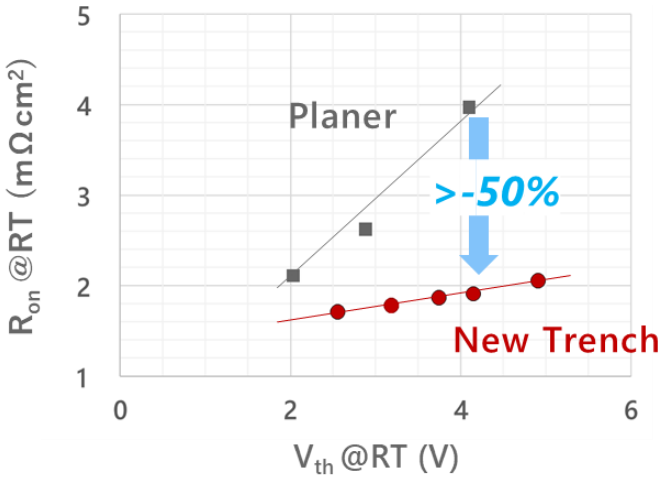
Achieved!

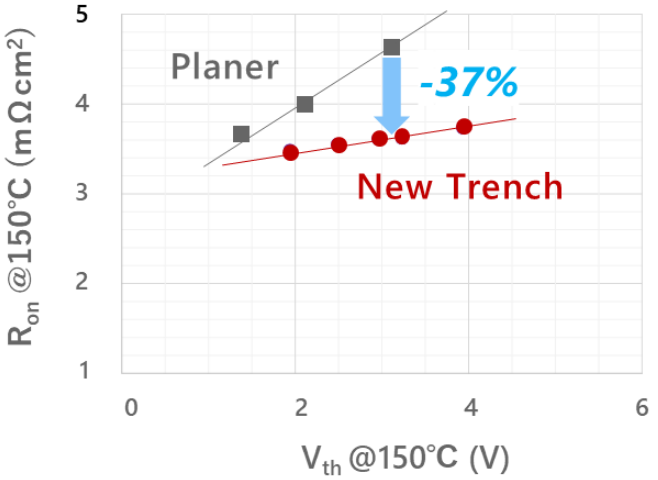
High Efficiency
High Performance
High Reliability

STABILITY OF MITSUBISHI'S 4TH GEN. TRENCH-GATE MOSFET

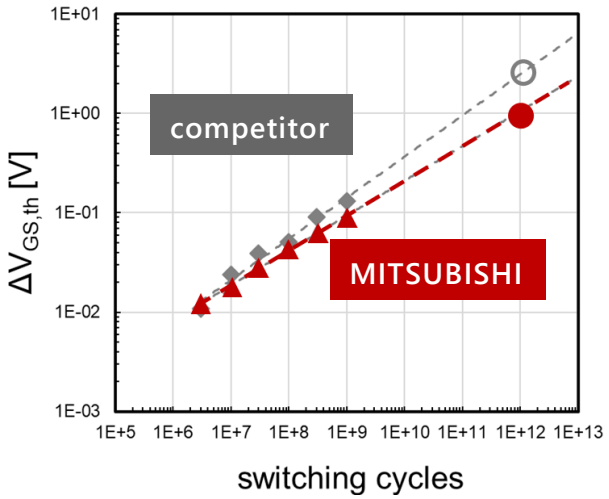
static characteristic

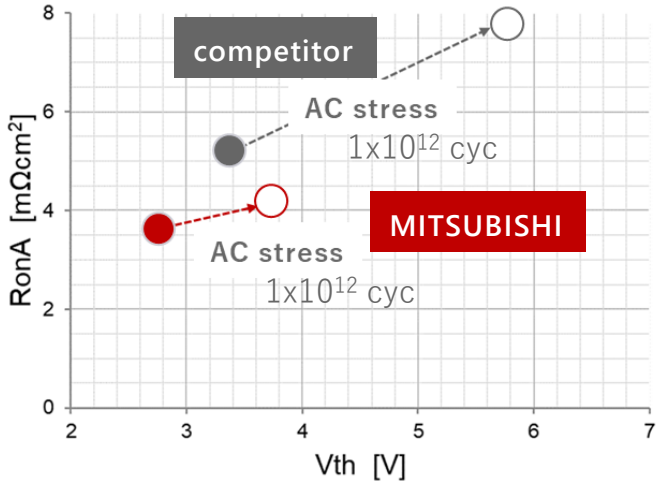






V_{th} stability under AC stress



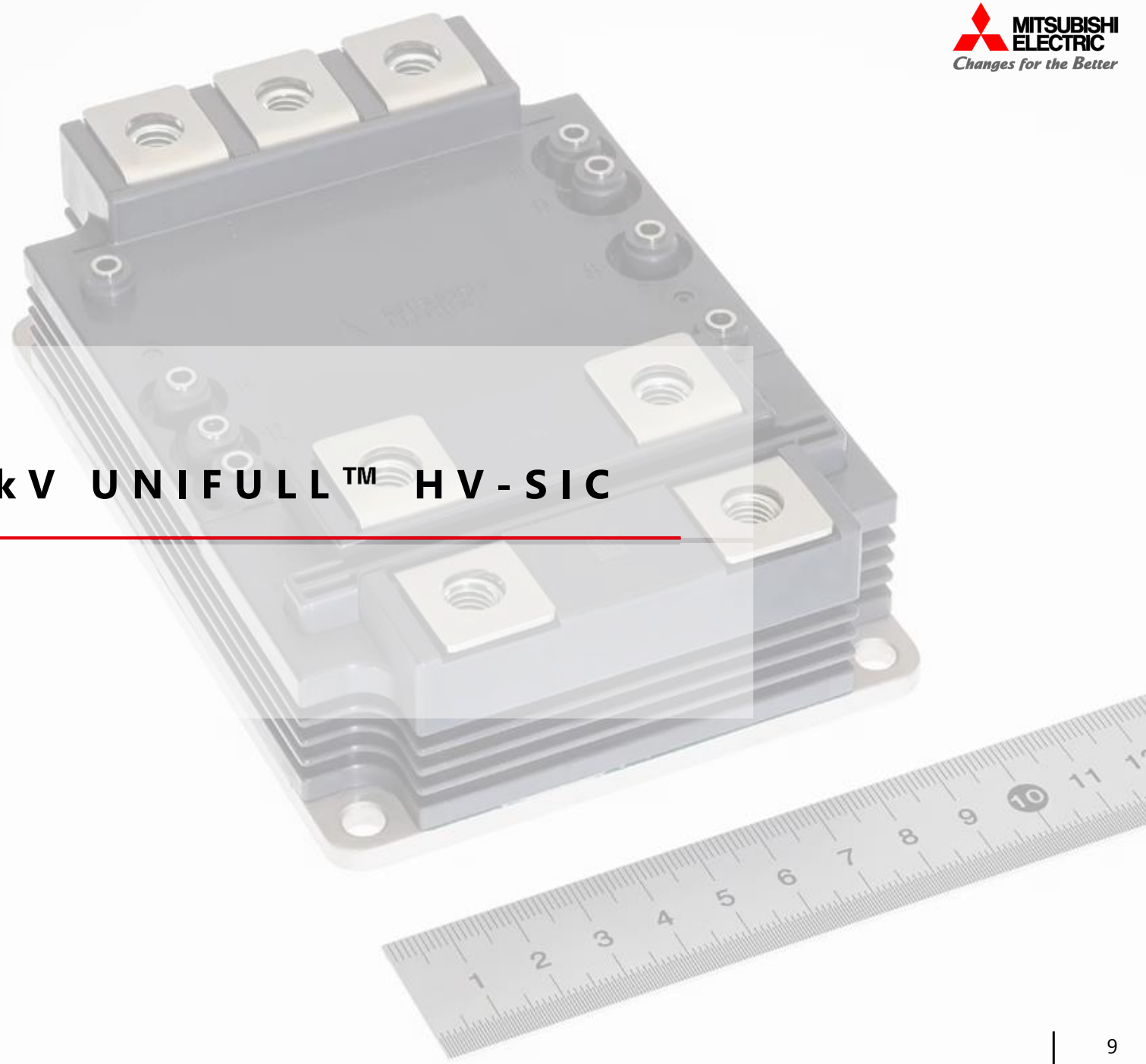


Achieved!

High Efficiency
High Performance
High Reliability

V_{GS}= +20V/-10V, V_{DS}=0V, T= 175°C,
f= 100kHz, duty= 50%

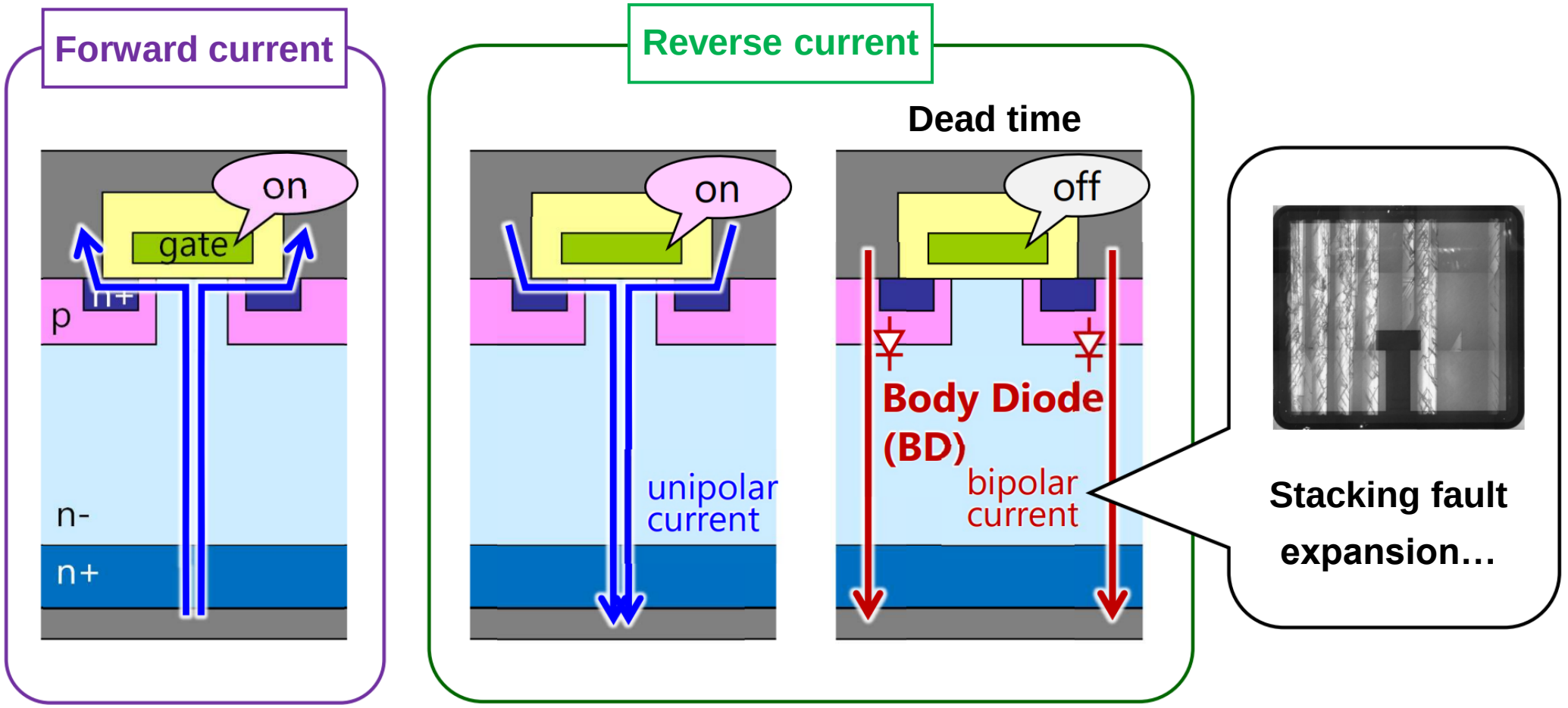
3.3kV UNIFULL™ HV-SIC



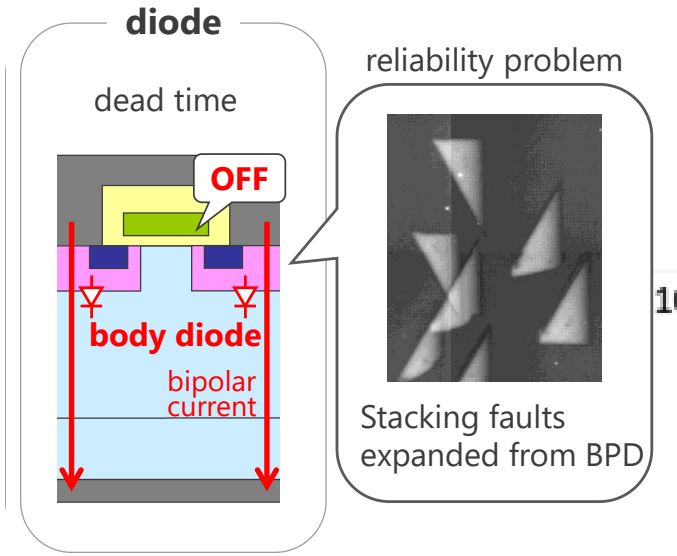
3 BIPOLAR DEGRADATION IN SIC SEMICONDUCTORS

✓ SiC-MOSFET has body diode, which causes bipolar degradation due to its conduction.

➡ **Serious reliability issue of SiC-MOSFETs.**

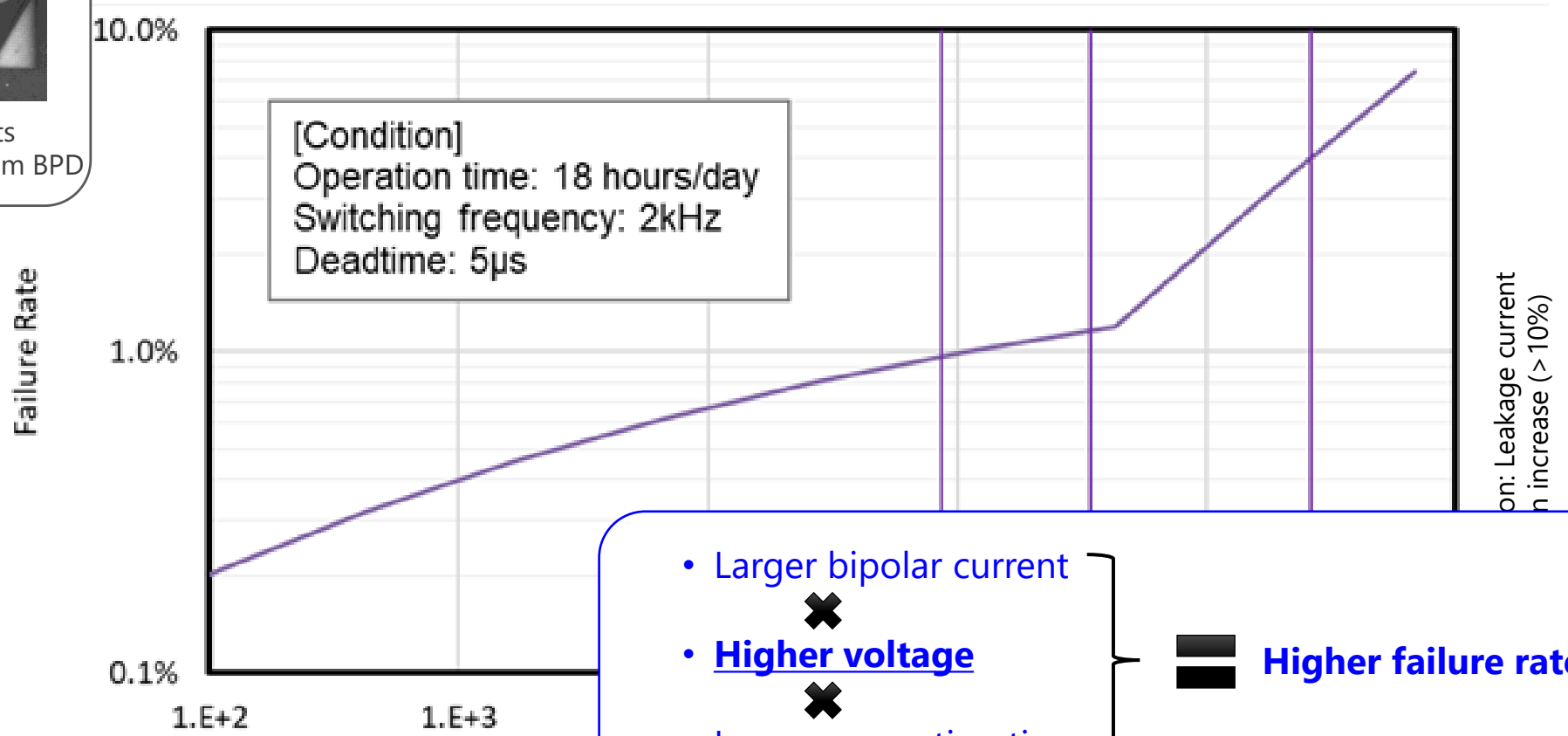


DEVICE FAILURES DUE TO BIPOLAR DEGRADATION



reliability problem

Stacking faults expanded from BPD



- Larger bipolar current
- ✖
- **Higher voltage**
- ✖
- Longer operation time

= **Higher failure rate**

RELIABILITY –ELIMINATE BIPOLAR DEGRADATION

[Conventional SiC module]

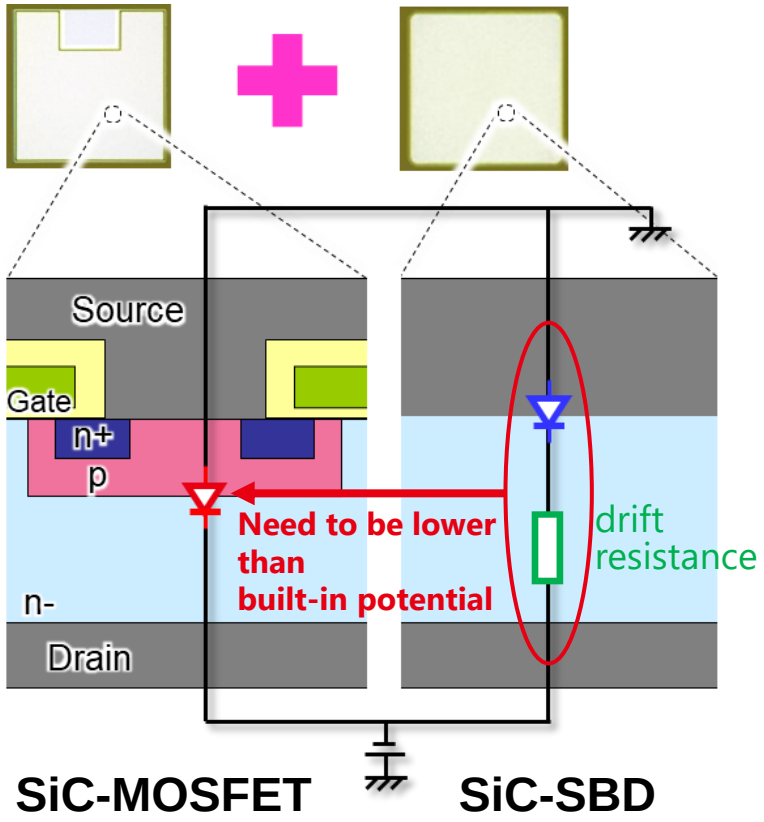
External SBD* chips are connected in **anti-parallel** to the SiC-MOSFET chips to **avoid bipolar degradation.**

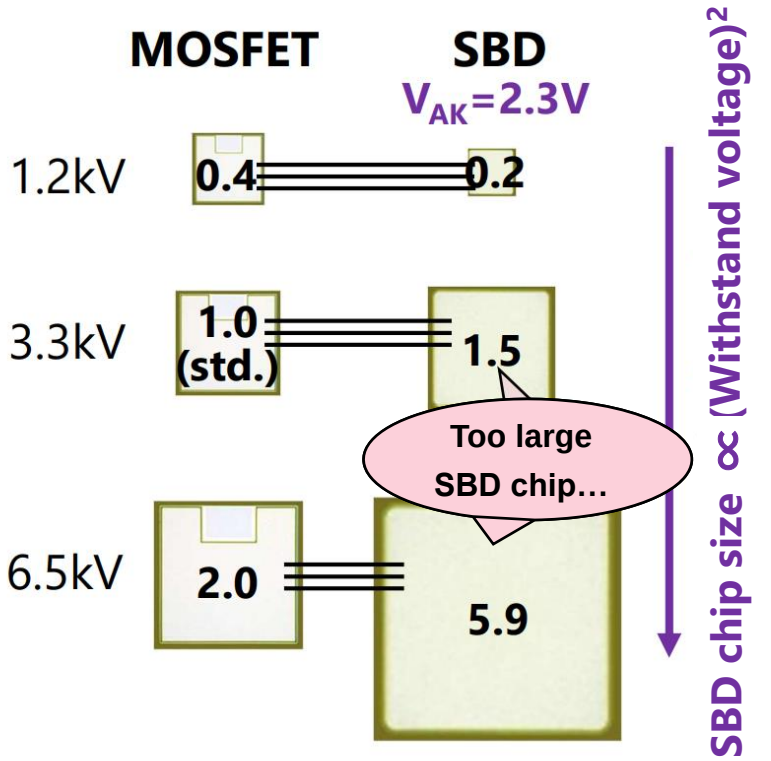
But…

✓ Cannot completely suppress bipolar conduction ➡ Special screening tests are necessary.

✓ The larger the withstand voltage, the larger the SBD chip size ➡ Increased manufacturing cost. Limited current density.

* Schottky Barrier Diode





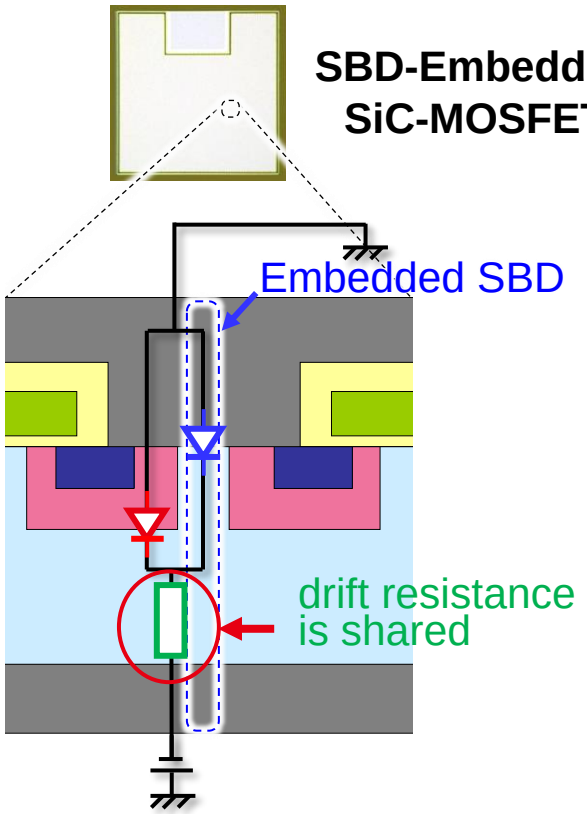
UNIFULL CELL DESIGN

[New module]

Bipolar degradation is prevented by embedding SBD into MOFET chip.

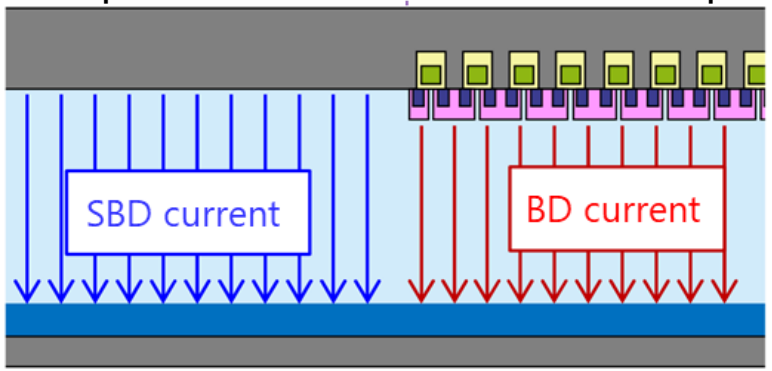
- ✓ Can completely suppress bipolar conduction in SOA*. ➡ Special screening tests are unnecessary.
- ✓ The external SBD chips are unnecessary. ➡ Reduced manufacturing cost. Increased current density.

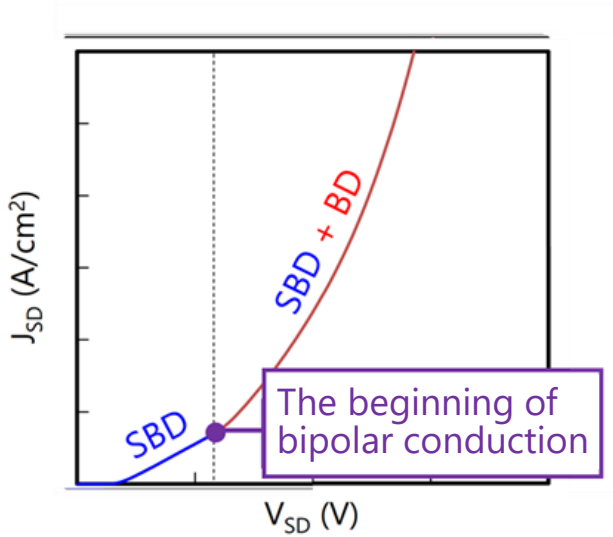
* Safe operating area



【Processes of inactivating the body diode】

Largely divided,
equivalent to the external SBD chip

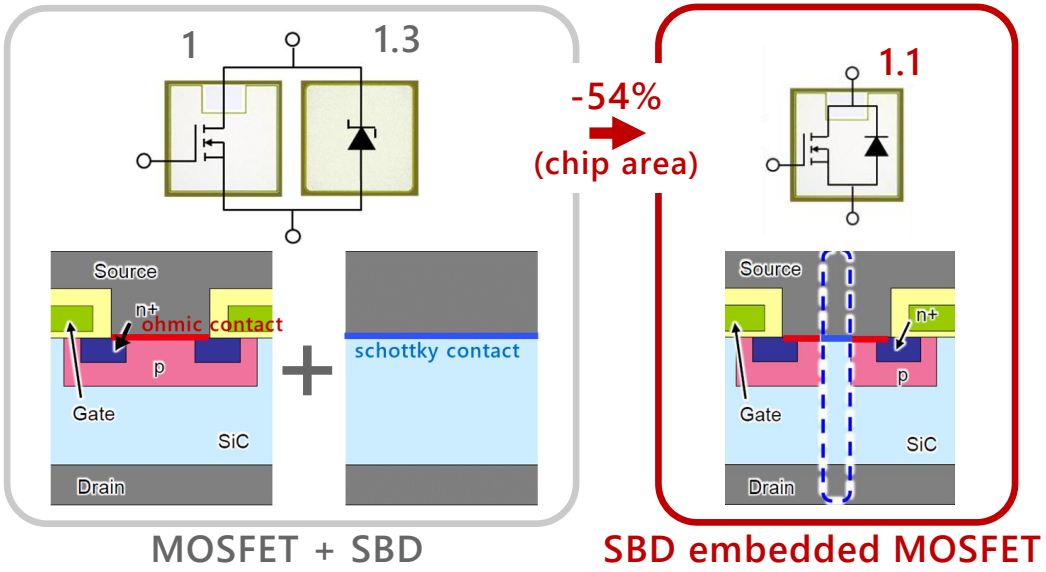




UNIFULL PERFORMANCE AND RELIABILITY INCREASE

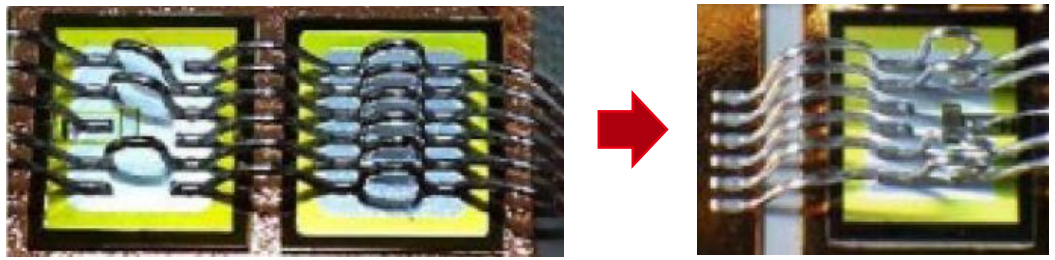
Design concept

✓ Chip area reduced by half or less



MOSFET + SBD

SBD embedded MOSFET



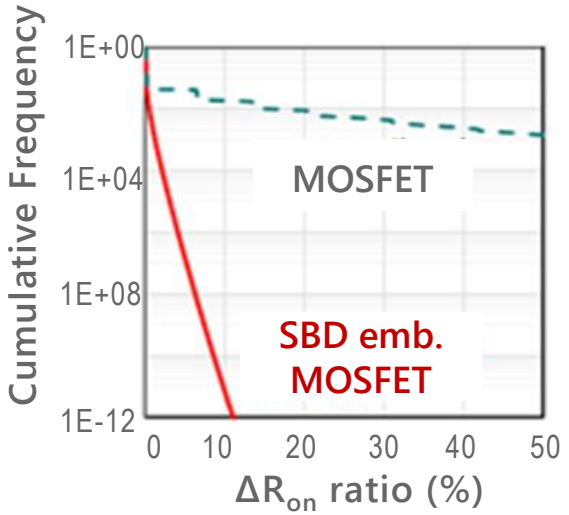
Bipolar Degradation

✓ Bipolar degradation of SBD embedded MOSFET is negligible

	Repetitive surge current 100 pulses	Normal operation (dead time) 10 kHz continuous
MOSFET	Active (BD, bipolar current)	Active (BD, bipolar current)
SBD emb. MOSFET	Active (BD, bipolar current)	Inactive (BD, unipolar current)

1000A/cm², 10ms

100A/cm² x 1 week @150°C deadtime 1 μs

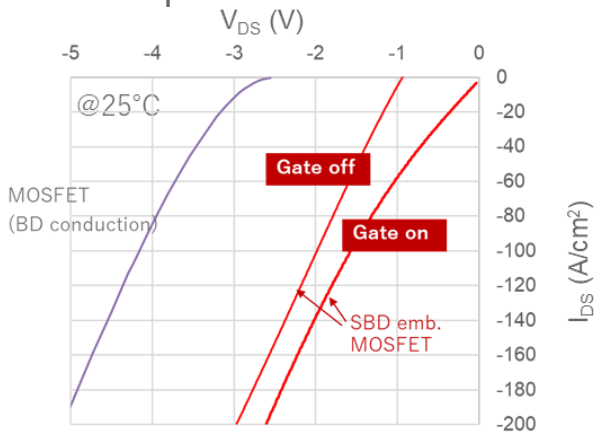


$$\Delta R_{ON}\ \text{ratio} = \frac{R_{ON}^{after} - R_{ON}^{before}}{R_{ON}^{before}}$$

Chip characteristics

Reverse characteristics (3rd quadrant)

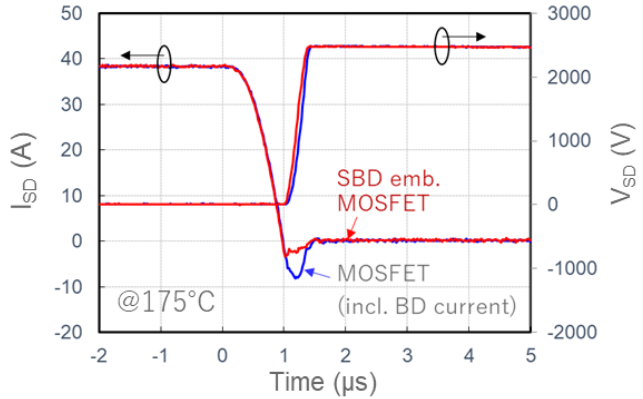
✓ Lower V_f



Reverse recovery

✓ smaller recovery current

(thanks to unipolar operation)

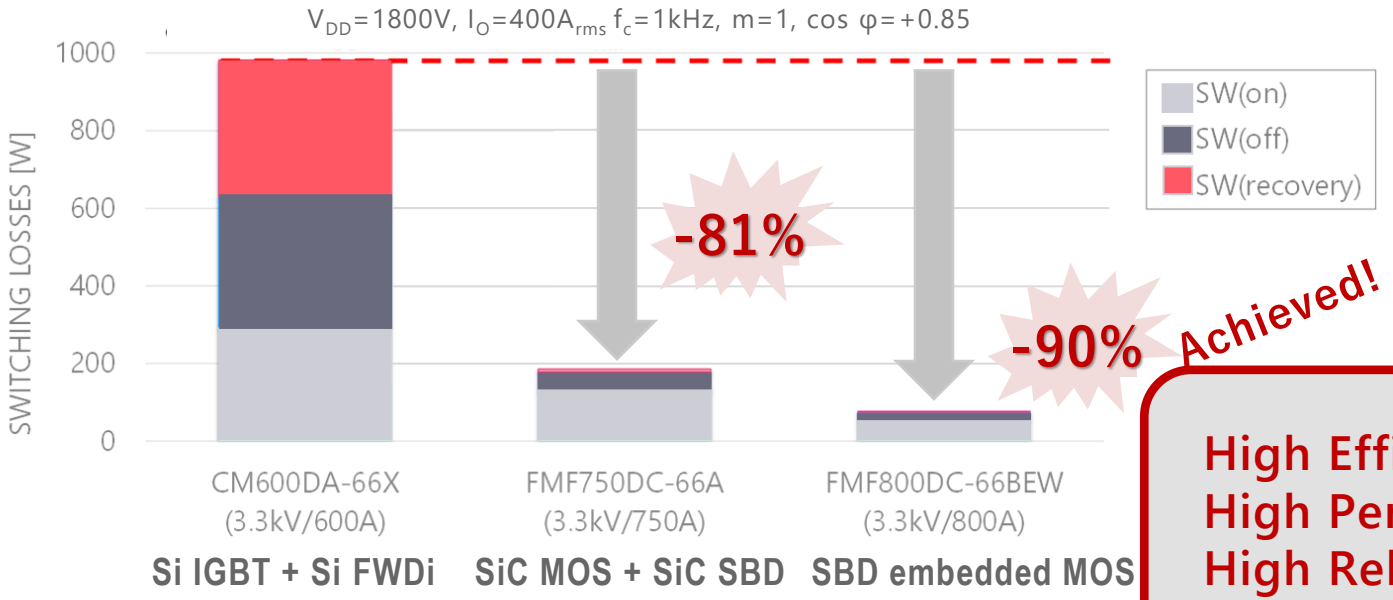


Power modules

Unifull

Unipolar device (MOSFET) ,
Uni-chip (SBD embedded),
and **Full**-SiC module

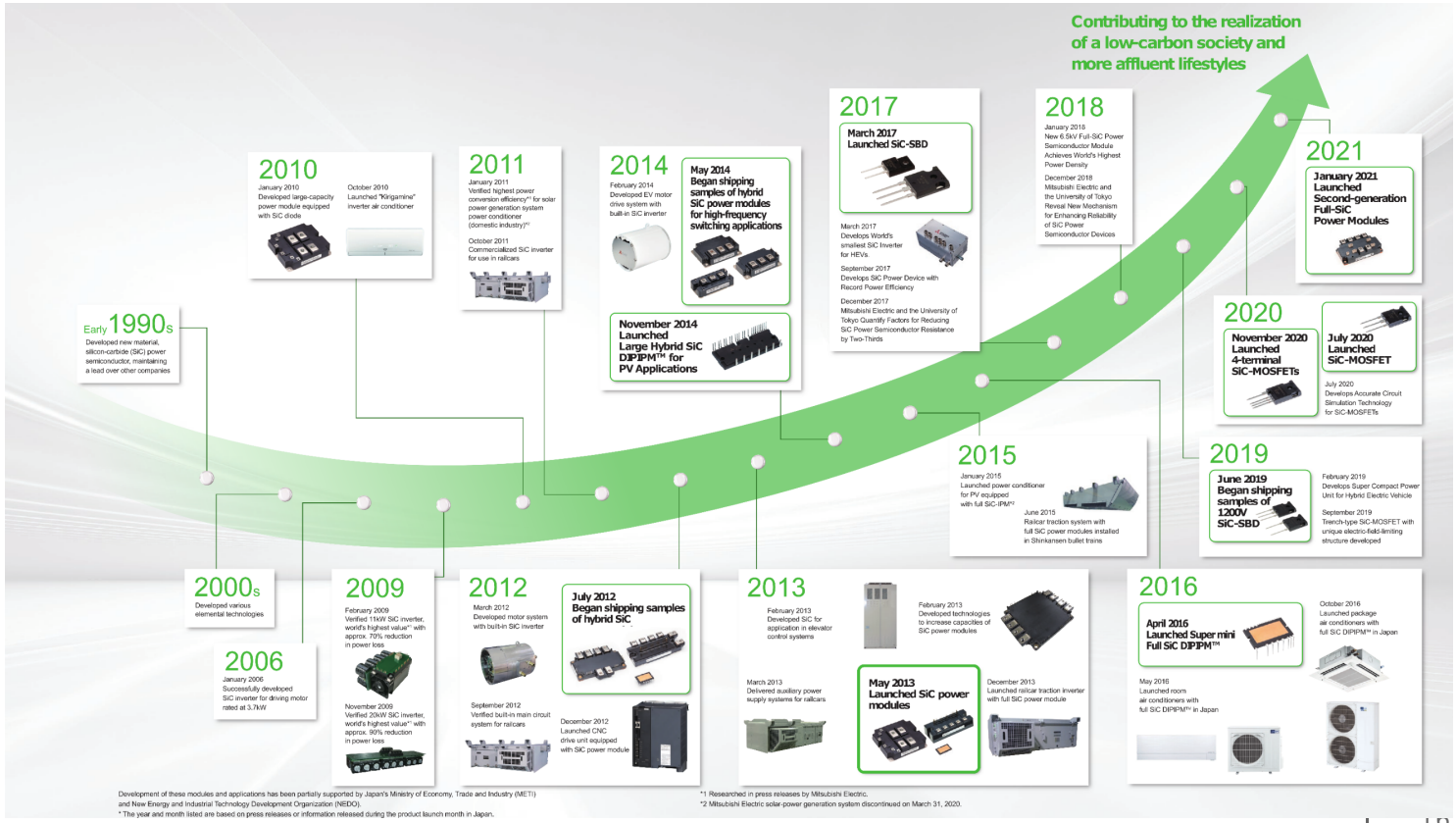
Type	FMF800DC-66BEW
Voltage rating	3.3kV
Current rating	800A
Isolation voltage	6.0kVrms
Connection	2in1
Dimensions (W × D × H)	100 × 140 × 40mm
Sample shipments	May 31 2023

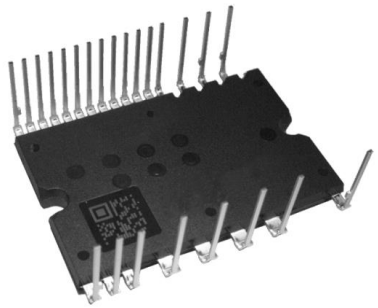


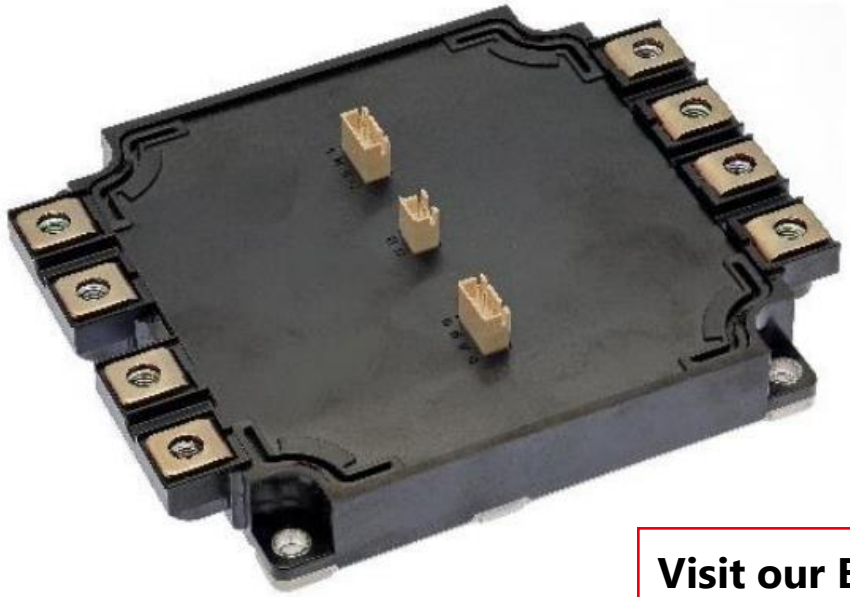
High Efficiency
High Performance
High Reliability

CONCLUSION

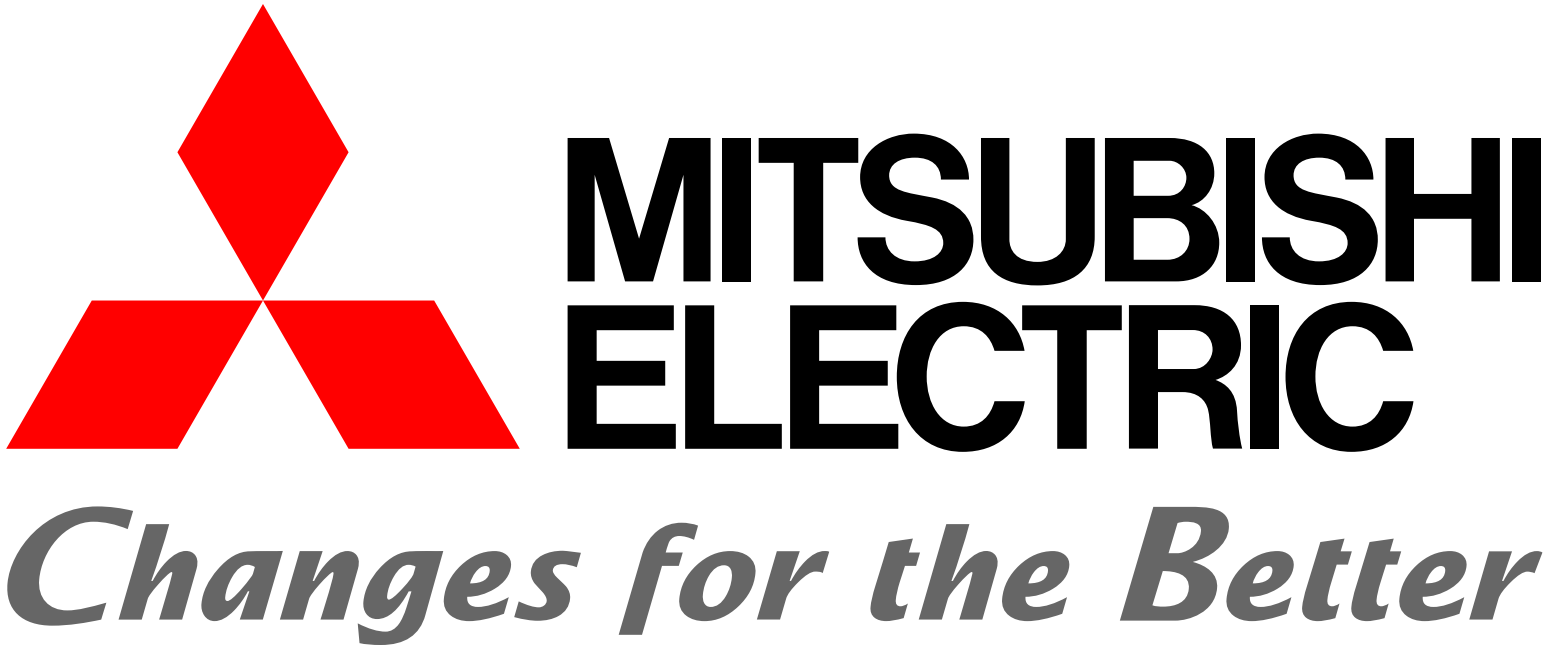
- Reliability of SiC devices and converters is most important point for user acceptance
- Quality of our power modules is always our highest priority
- Our customers' decades of field experience with their SiC power converters is the best proof





Visit our Booth and Choose from Various SiC Devices!


MITSUBISHI
ELECTRIC
Changes for the Better