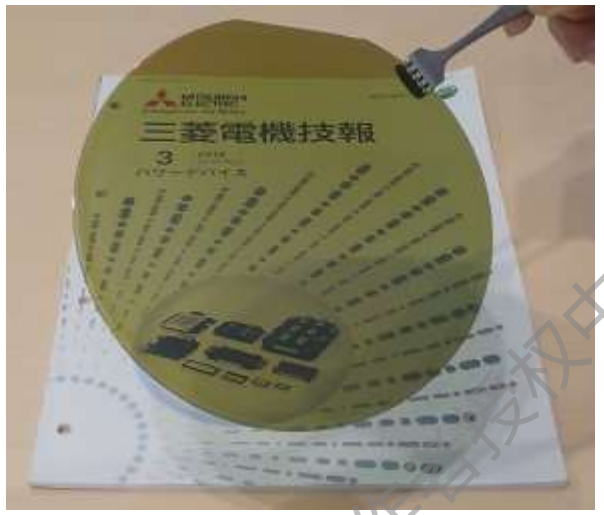
MITSUBISHI ELECTRIC
Changes for the Better

PEAS-2021

CPSSC-2021 Shanghai

Advancement of Power chips and Module Technology



Transparent SiC substrate

3300V / 750A
Full SiC 2in1
On sale

Nov. 2021
Mitsubishi Electric Corp.
Power Device Works
Senior Technical Advisor
Harufusa Kondo, PhD

Agenda

- Introduction:
  - Power electronics for Carbon Neutral
  - Mitsubishi Power Device Overview
- Power Chip technology advancement
  - Silicon IGBT
  - SiC MOSFET
- Power Modules with their application
- Conclusion

Agenda

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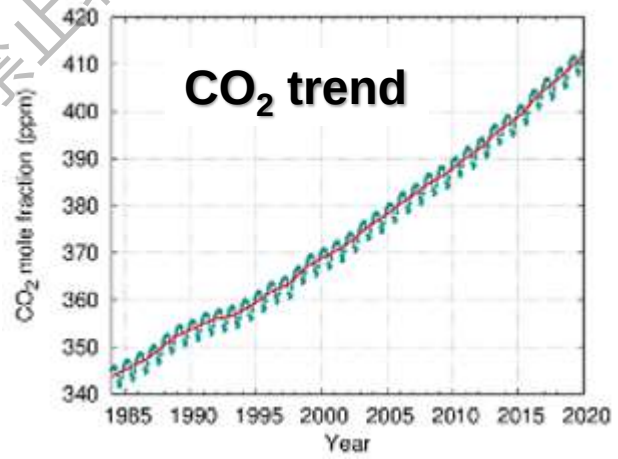
Carbon Neutral (1/2)

1. Environmental Requirement

→ Reduce Green House Gas and CO_2



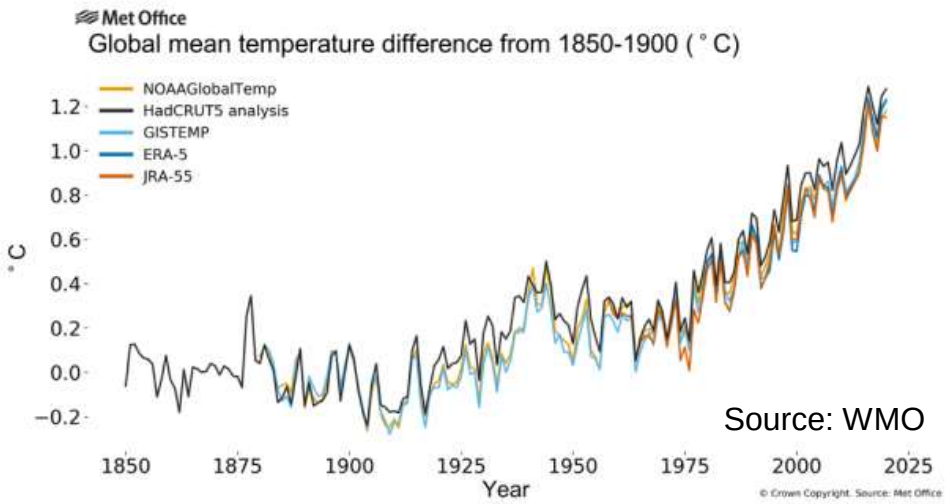
Source: WMO
(World Meteorological Organization)

2. Discussed at COP conferences

1997 COP3	Kyoto Protocol
2015 COP21	Paris, Follow-up Agreement
2021 COP26	Glasgow, 31Oct.-12Nov.

https://ukcop26.org/
COP: Conference on Parties

Temperature Trend



Source: WMO

Target is "below 2℃ increase, possibly 1.5℃" compared with pre-industrial era, Carbon Neutral after 2050.

Carbon Neutral (2/2) --- World Energy Outlook by IEA

1. Current Situation

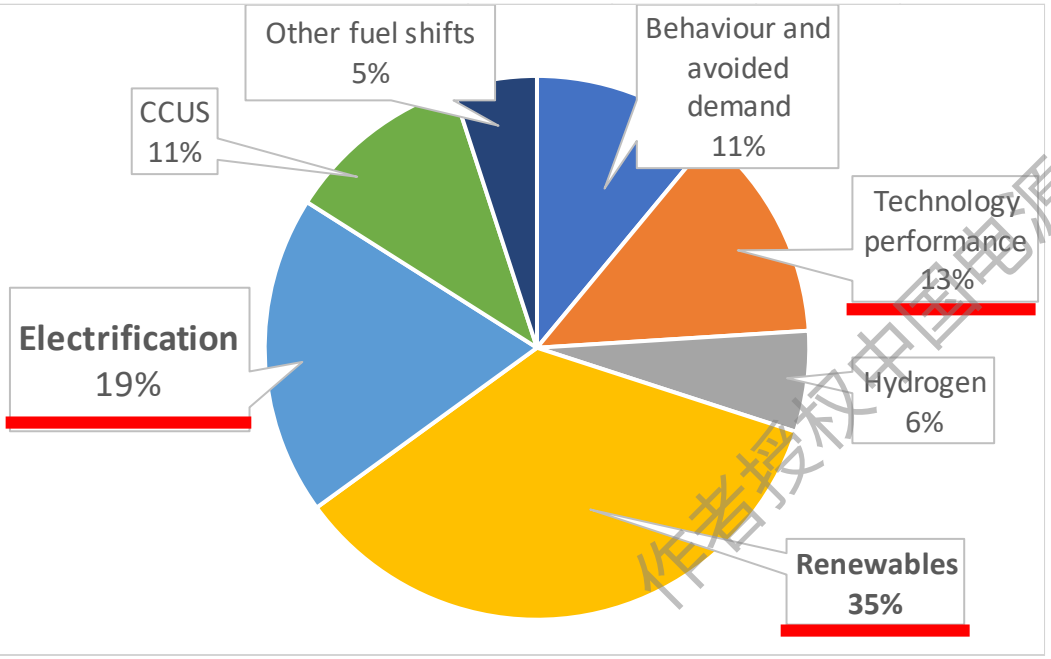
→ Need more effort for NZS

NZS: Net Zero Scenario

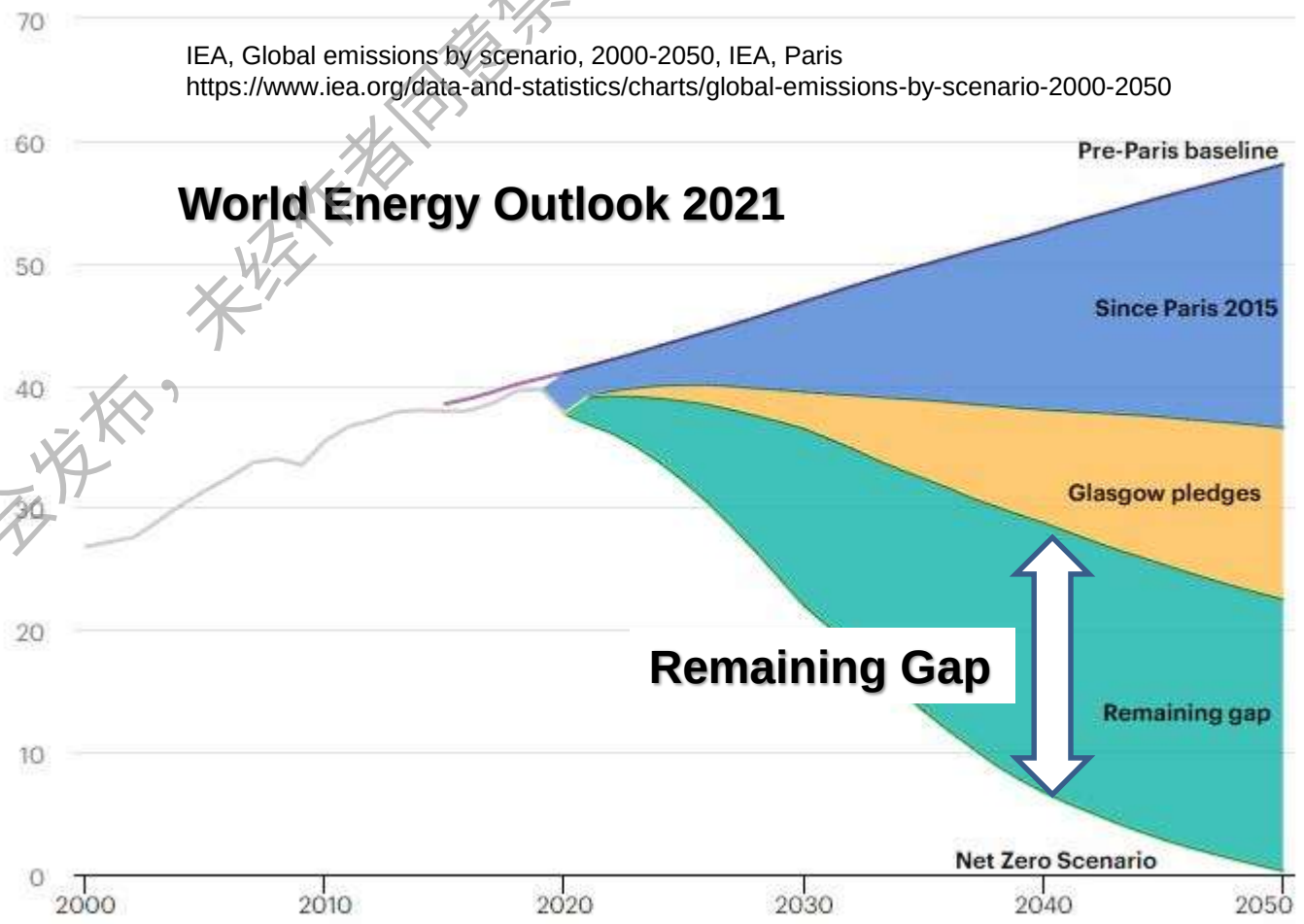
2. Measures to fill the Gap

→ Doubling PV and Wind

→ Higher energy efficiency



CO_2 –eq. Gt



IEA, Global emissions by scenario, 2000-2050, IEA, Paris
https://www.iea.org/data-and-statistics/charts/global-emissions-by-scenario-2000-2050

IEA, Cumulative emissions reduction by mitigation measure in the Net Zero Scenario, 2021-2050, IEA, Paris
https://www.iea.org/data-and-statistics/charts/cumulative-emissions-reduction-by-mitigation-measure-in-the-net-zero-scenario-2021-2050

CCUS = Carbon Capture, Utilization and Storage

Power Electronics for Carbon Neutral

1. Two aspects

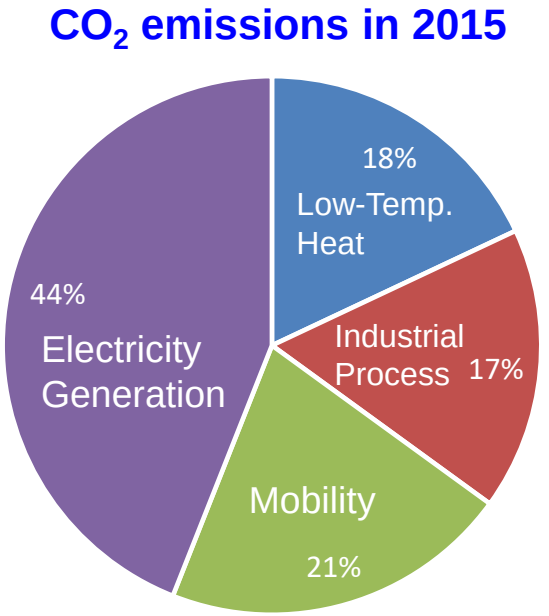
a) De-carbonization of Power Plant

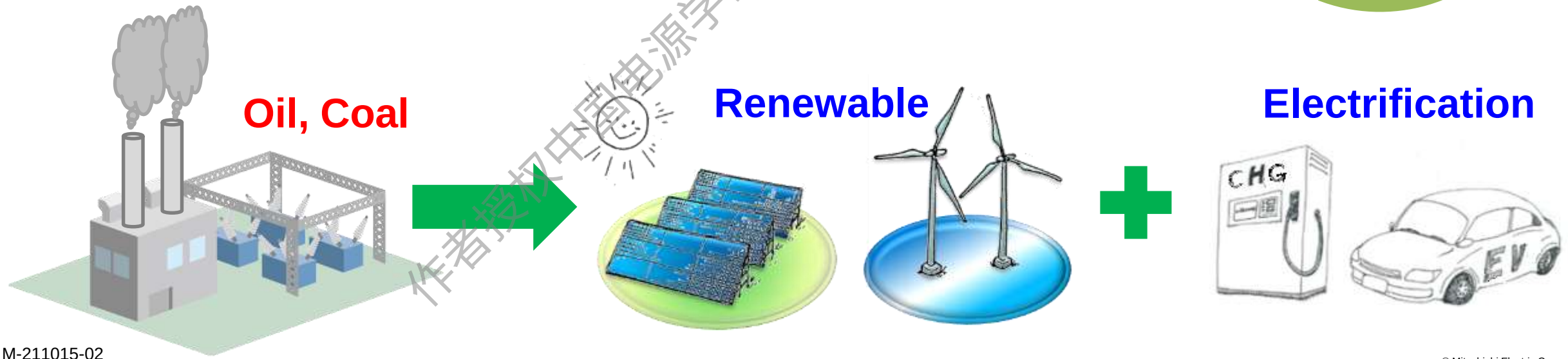
b) De-carbonization of User Side

2. Power Electronics application examples

a) Renewable power, Energy storage, Smart grid, Smart house

b) Inverterization and Electrification (mobility, industry, etc.)





Mitsubishi Electric Power Device Portfolio

Power Module Application Segments

Application segment	Application examples	IGBT and SiC - module: Case type: General	IGBT and SiC - module: Case type: HV	IGBT and SiC - IPM: Case type	IGBT and SiC - IPM: DIP type	SiC Discrete
Home appliances	Air conditioners; Washing machines; Refrigerators; Fan motors					
Industry including renewable energy	Inverters; AC motors; Robots; Photovoltaic power generation; Power conditioner; Wind power generation					
Traction/ Electric power	Traction; DC power transmission					
Automotive	xEV					

IPM: Intelligent Power Module

HV: High voltage

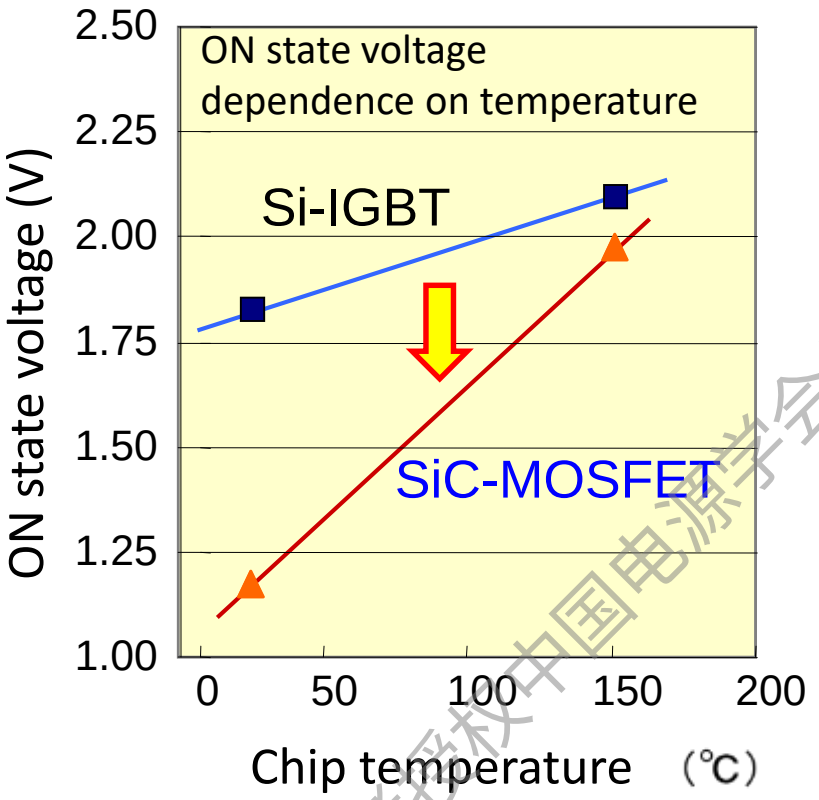
SiC diode and MOSFET

SiC diode and MOSFET

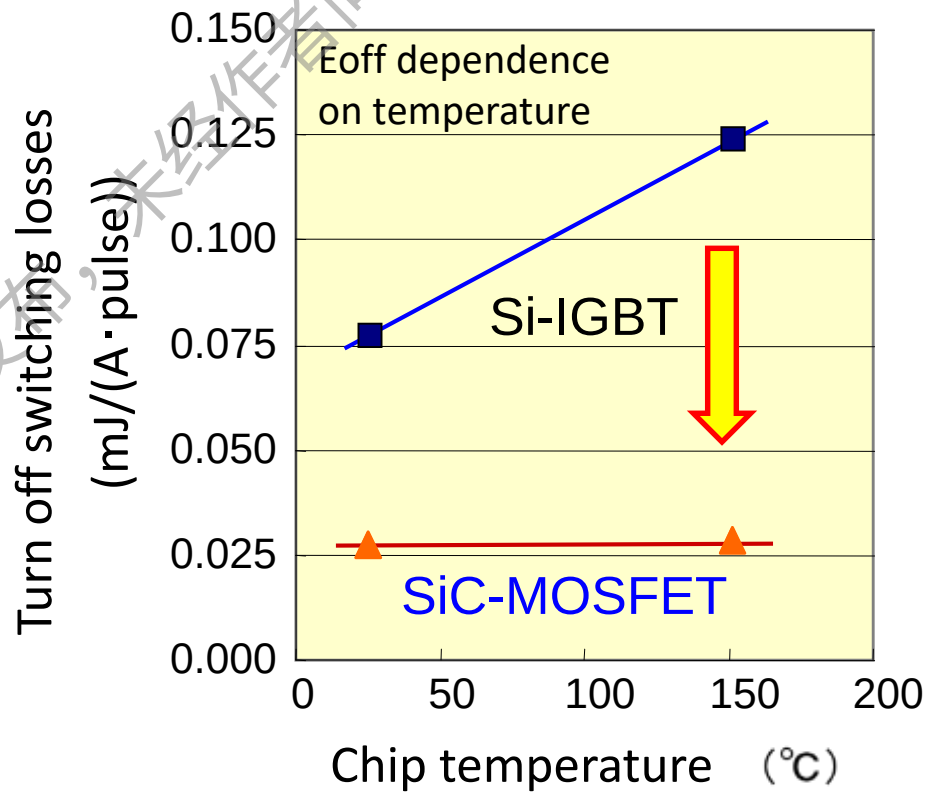
Technology of Silicon Carbide Power Chips

Benefit of SiC power device for Carbon Neutral

Better DC performance



Better AC performance



SiC power devices have strong loss advantages at higher frequency

History of Silicon Carbide R&D

1994~2004	2005~2009	2010~2014	2015~2018	2019~
Development	Practical test in research	System development & Field test	SiC users increase	Expand new application

Application

- Power loss 50%reduction — 3.7KW Inverter Top level 2006/Jan.
- Power loss 70%reduction — 11KW Inverter Top level 2009/Feb.
- Power loss 90%reduction — 20KW Inverter Top level 2009/Nov.
- Air conditioner 2010/Oct.
- CNC Drive unit 2012/Dec.
- PV 2015/Jan.
- PV Power conditioner 2011/Jan.
- APS for Railway 2013/Mar.
- Inverter for Railway 2013/Dec.

Improve productivity and performance of SiC device.

PV, Medical, UPS, Test equipment for automotive, xEV, High speed charger, Aviation

SiC Power modules

- 1.7kV/1.2kA Hybrid SiC 2010/Jan.
- Start sample 2012/Sep.
- Start MP 2013/May
- 50A/600V For PV DIPIPM™
- 1.2kV Full SiC

SiC device development

1st gen. planar gate → 2nd gen. Planar gate → Trench gate

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).

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  - Silicon IGBT
  - SiC MOSFET
- Power Modules with their application
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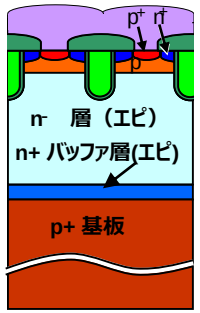
Silicon IGBT Roadmap

Chip Development Timing Base

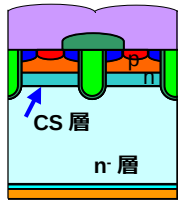
Legacy ’05 ’10 ’15 ’20 ’25

IGBT

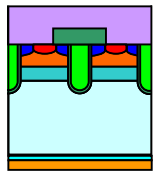
4thGen. Trench IGBT PT



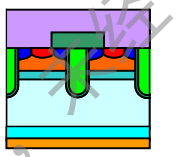
5thGen. CSTBT™ LPT



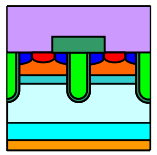
6thGen. CSTBT™ LPT



7thGen. CSTBT™ LPT Thin



8thGen. CSTBT™ LPT



Ultra-Thin

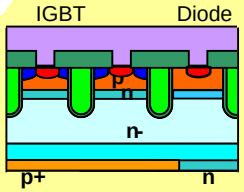
Optimized Buffer

RC-IGBT

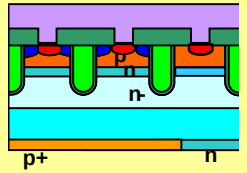
1st Gen.

IGBT+Diode
In 1 chip

2nd Gen.



3rd Gen.

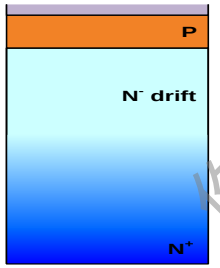


4th Gen. RC-IGBT

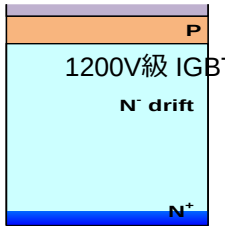
Fine pitch

Diode

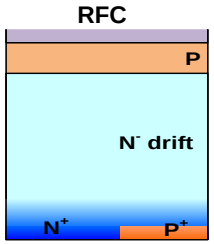
3rd Gen.



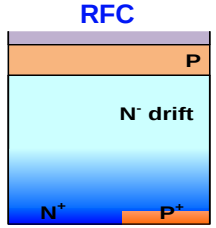
6th Gen.



7th Gen.

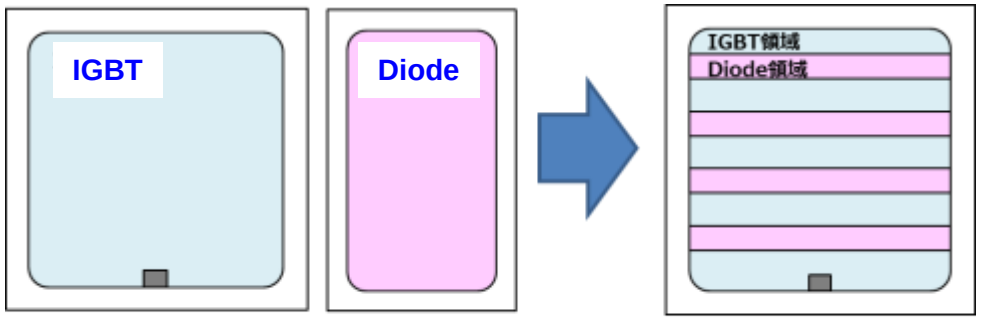


8th Gen.



PT: Punch Through
LPT: Lite Punch Through
RFC: Relax Field of Cathode

RC-IGBT, a combined device

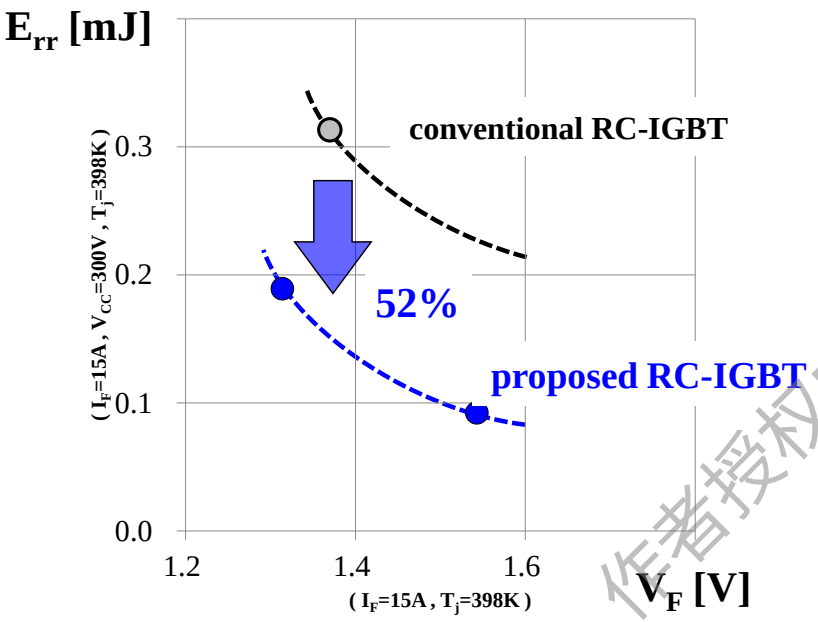


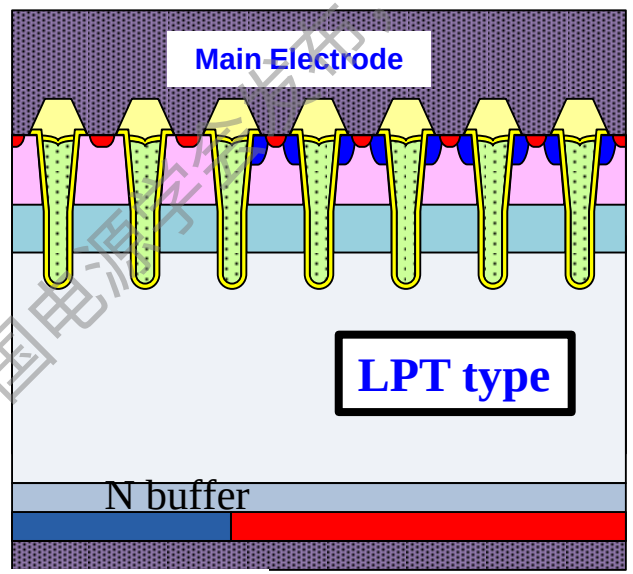
Conventional
IGBT + Diode

RC-IGBT

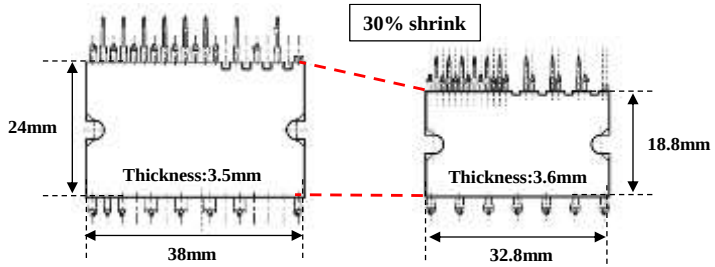
- Smaller chip size
- High current density
- Lower temp. swing

Better P/C performance





- RC-IGBT's downsizing merit for home appliance module



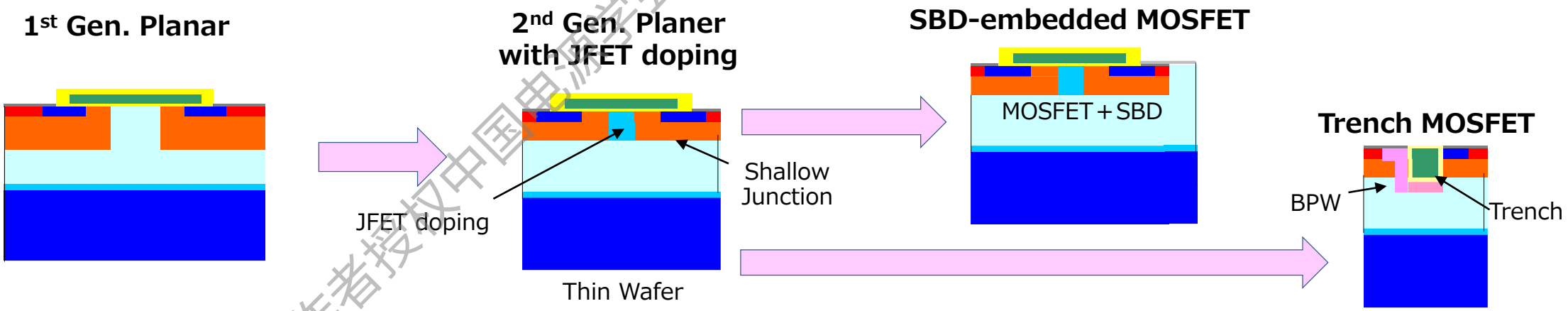
30% smaller module

T. Yoshida et al., ISPSD2016, Prague, 2016, pp. 159-162.

Silicon Carbide MOSFET Roadmap

Chip Development Timing Base

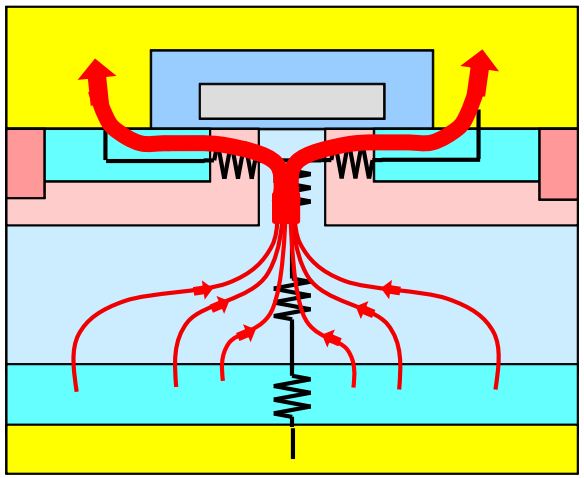
	FY	2015	2016	2017	2018	2019	2020	2021	2022～
Tech. Development	1st Gen.								
	2nd Gen. Planar				2nd Gen. Planer in 6inch		Production		
	High Vth, Low Voltage App.				Trench MOSFET			Production	
	High Voltage App.				SBD-embedded MOSFET			Production	



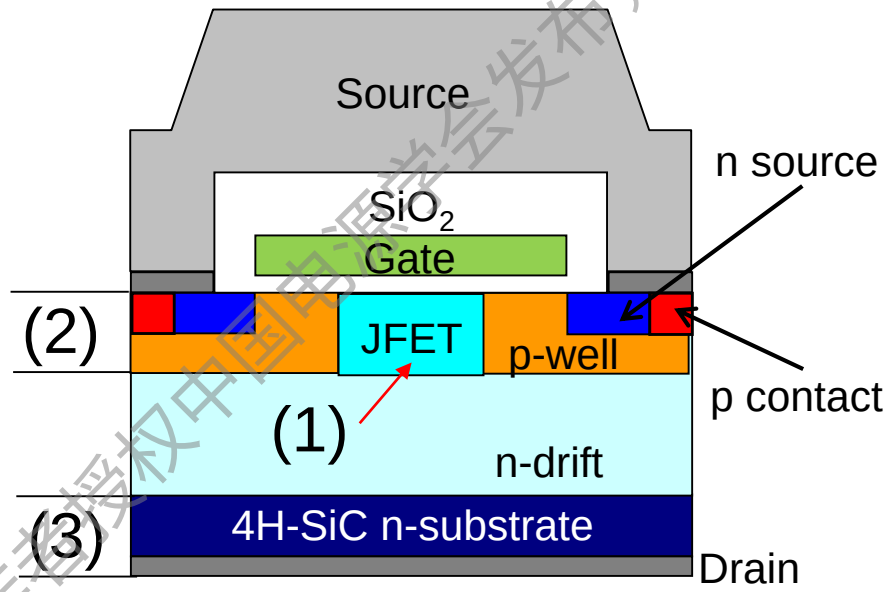
Second Gen. planar SiC MOSFET

Features of 2nd gen. MOSFETs

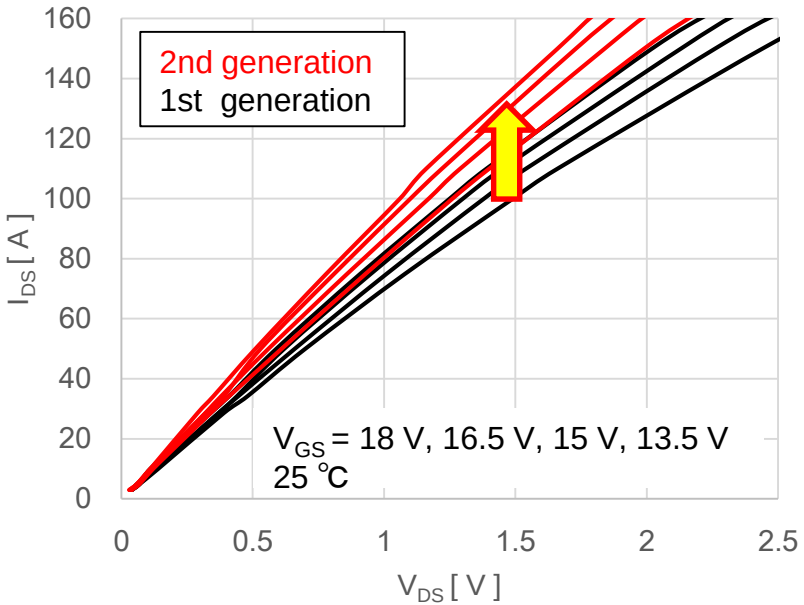
- ✔ Low on-resistance
  - (1) Adoption of JFET doping technology
  - (2) Shallow p-well doping
  - (3) Thin wafer process
- ✔ Low switching loss



Current concentration



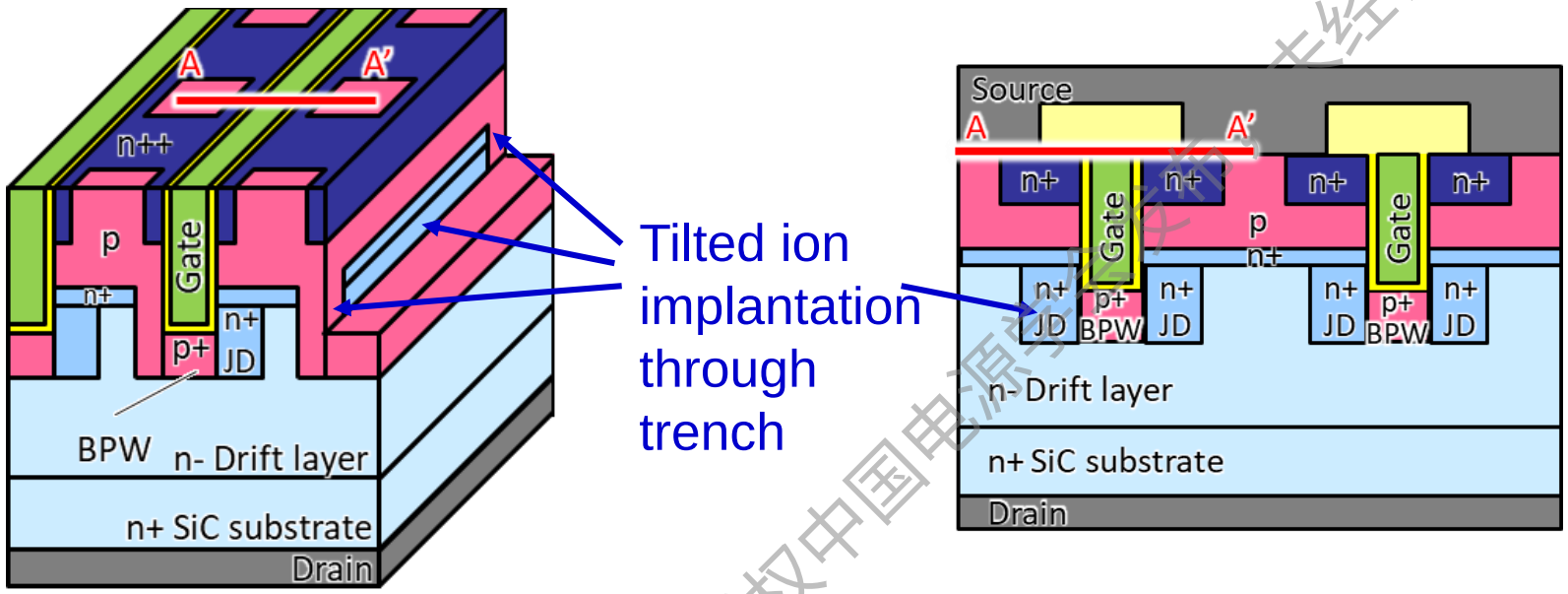
2nd Gen. MOS cell



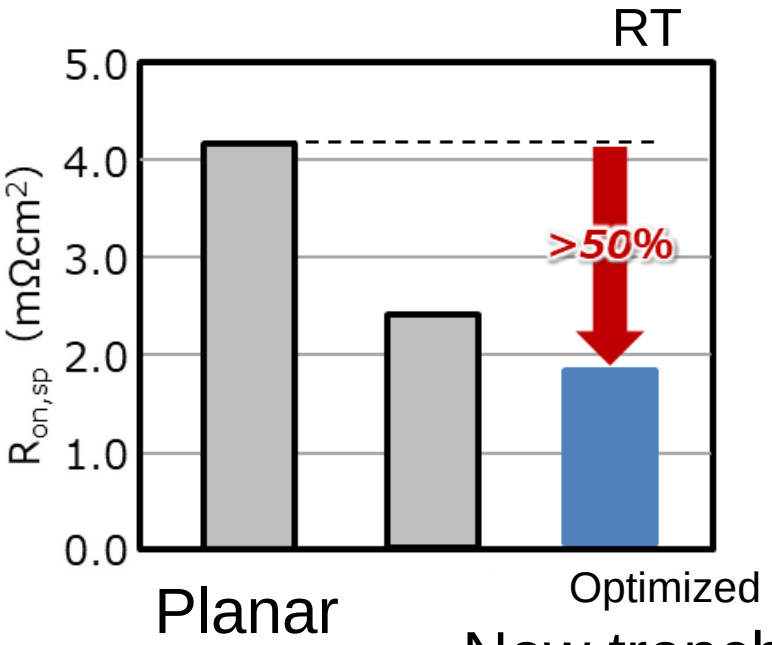
Forward characteristics of 1st/2nd gen.

New trench SiC MOSFET structure

✔Original trench MOSFET structure, with tilted ion implantation technology,
Requires no special process equipment, leading to superior productivity
✔Grounded p+ BPW reduces gate oxide electric field for good reliability
✔ n+ JFET Doping at current path for low on resistance, 50% better compared with planar MOSFET



Schematic structure of Mitsubishi's new trench SiC-MOSFET



$R_{on,sp}$ Comparison

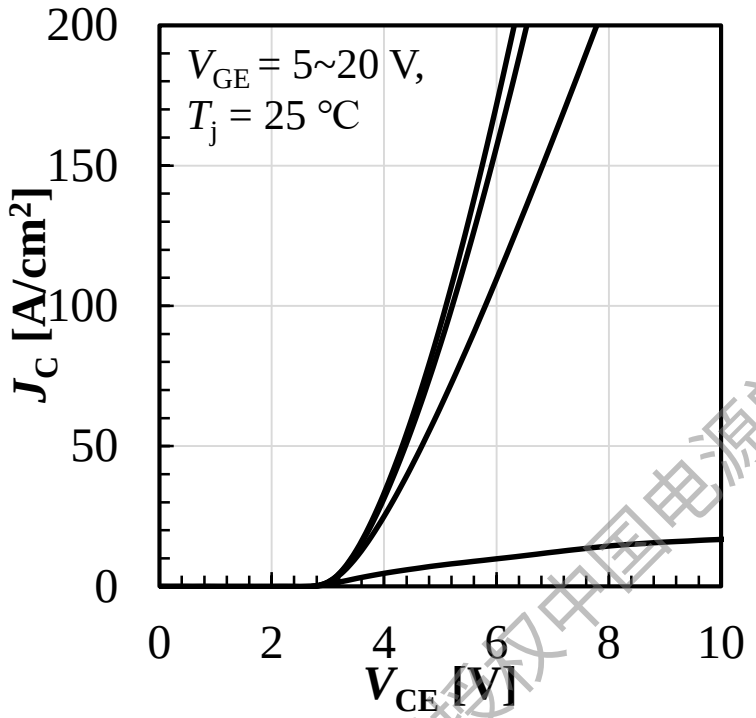
Y.Fukui et al., ICSCRM2019, Kyoto, 2019, Mo-1A-02. R.Tanaka et al., ICSCRM2019, Kyoto, 2019, Mo-1A-03.

Future Technology of Silicon Carbide ～13kV IGBT

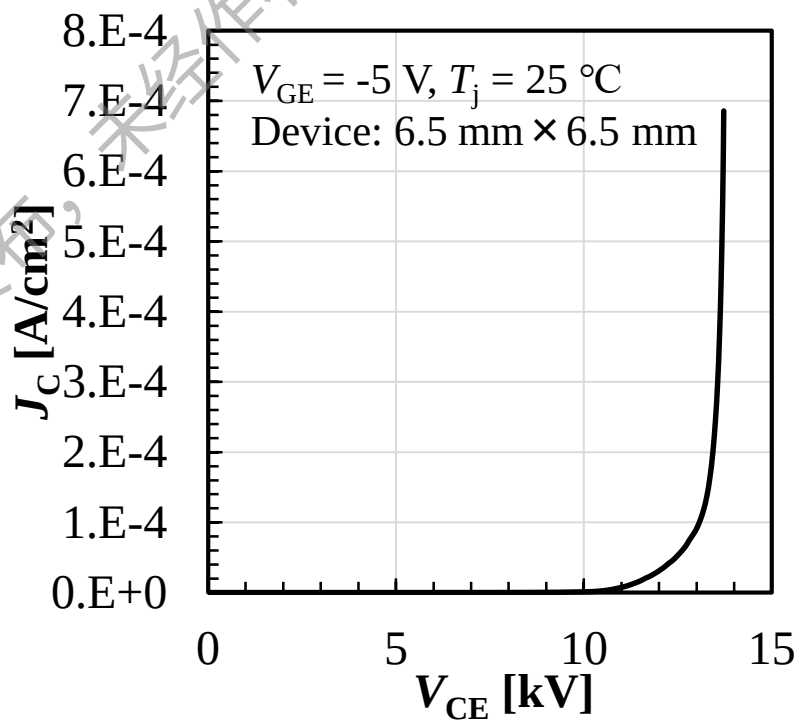
These characteristics break the unipolar limit

Differential on-resistance ($R_{on,diff}$) as low as 15mΩcm².

On-state characteristics



Breakdown characteristics



V_{CEsat} = 5.2 V, $R_{on,diff}$ =15 mΩcm²

V_{BD} = 13.7 kV

K.Konishi et al., ICSCRM2019, Kyoto, 2019, Fr-2A-04.

Agenda

- Introduction
- Power Chip technology advancement
- Power Modules with their application
  - Home Appliances
  - Automotive
  - Industry and Renewable
  - High Voltage Traction and Electricity
- Conclusion

Mitsubishi Power Devices

DIPIPM™
Modules realizing single-control power supply and photo-coupler-less system for household appliances and low-capacity inverters

Next topic

IPM
Modules with built-in control and protection circuits for AC servo robots and PV power generation

Power Modules for Vehicles
Modules realizing high performance and reliability for propulsion inverters in HVs/EVs

IGBT and SiC Modules
Modules for general-purpose inverters used in various applications

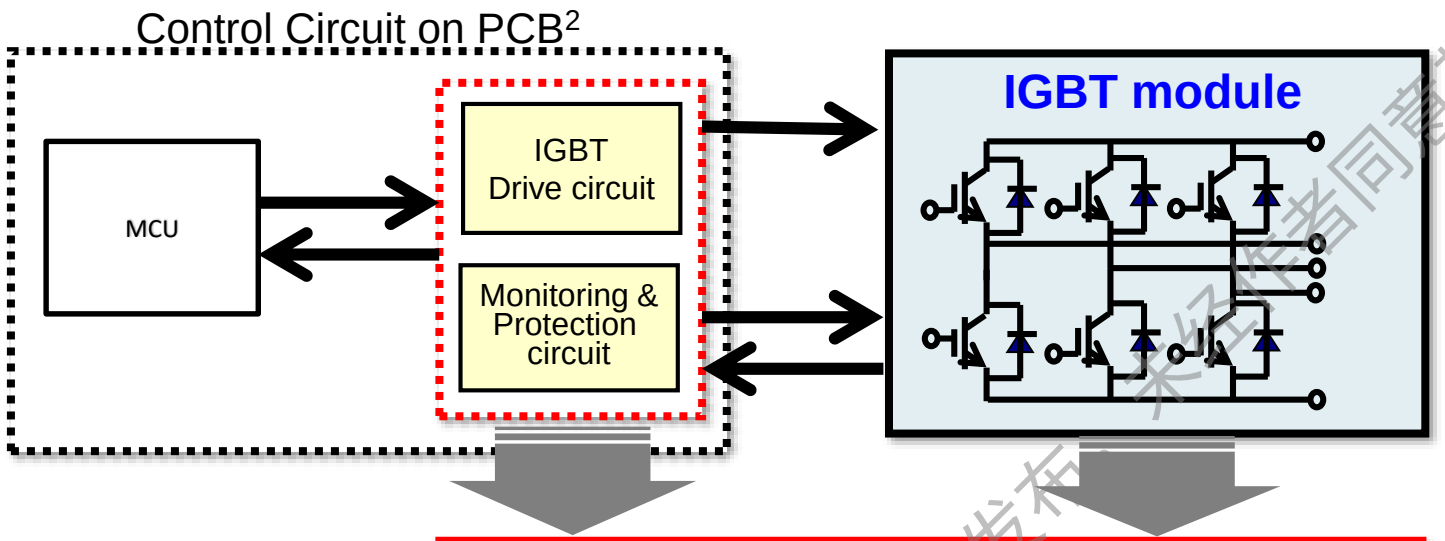
HVIGBT and SiC Modules
High voltage, large capacity and high reliability are realized for traction and power transmission application

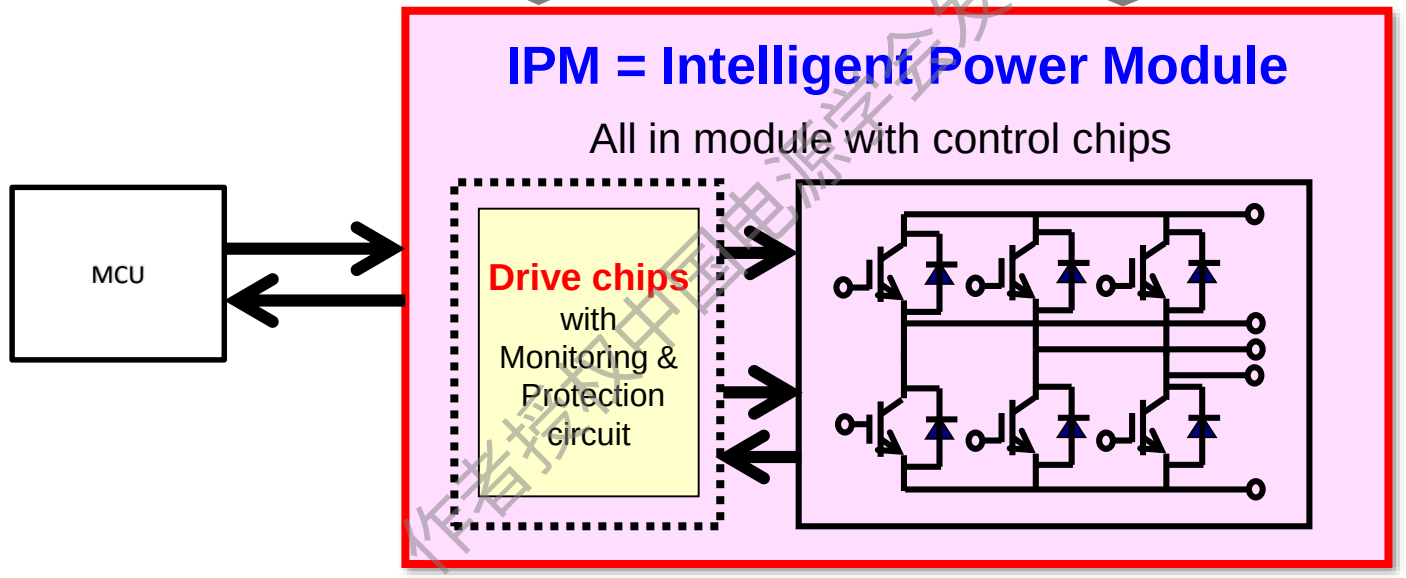
High Power Devices
Wide lineup including thyristor and stack from general purpose to high speed switching purpose

Transistor Array
Directly operation by output of 3V microcontroller, contribute to downsize or lighten each application machines

HVIC
HVIC, which can directly control gate drive by signal from microcontroller

IPM: Intelligent Power Module





IGBT Package

Case type

IPM Package

DIPIPM
(Dual In-line Package)

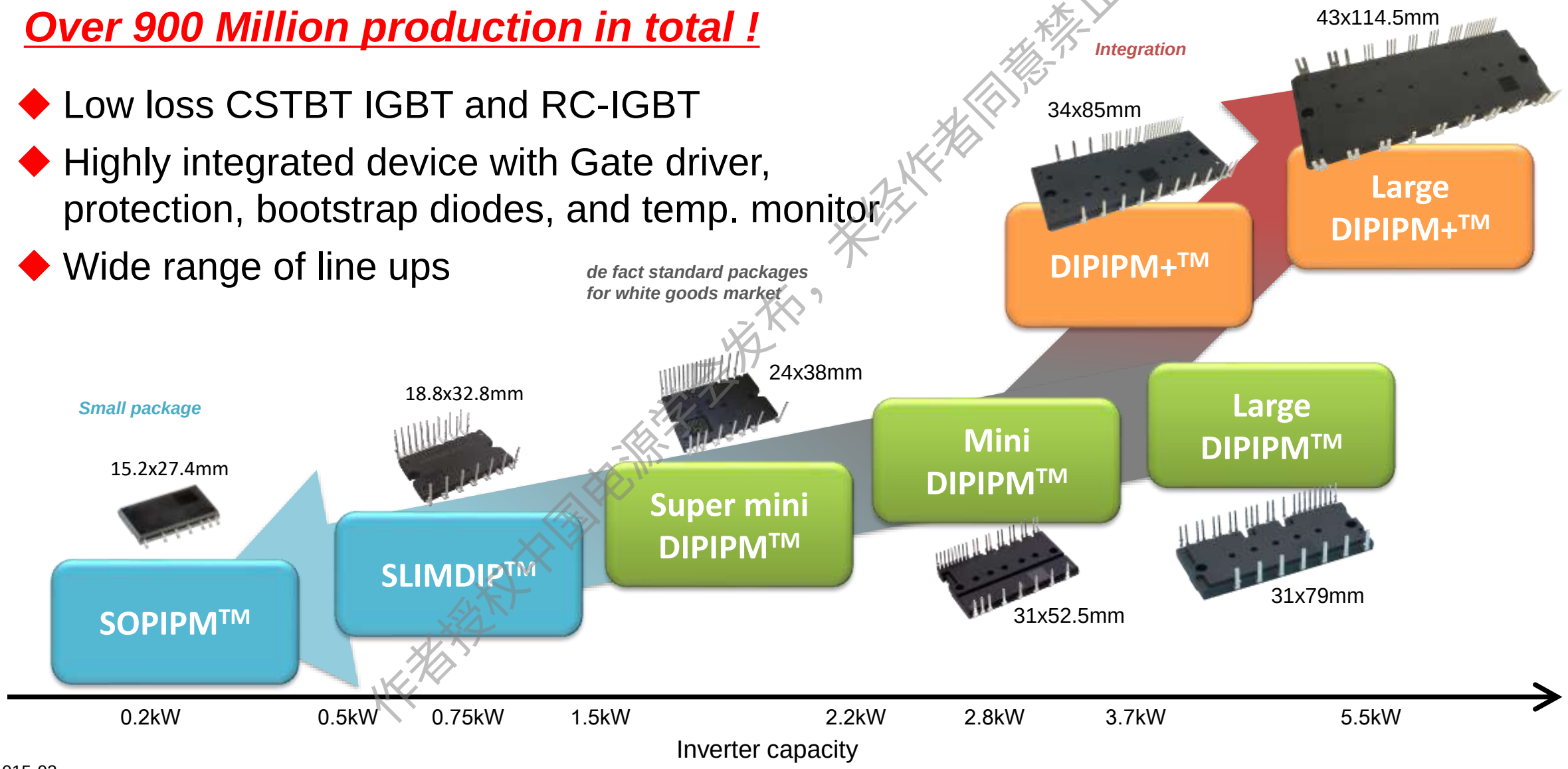
Case type

Mitsubishi DIPIPM family

Many thanks for your support as always!

Over 900 Million production in total !

- Low loss CSTBT IGBT and RC-IGBT
- Highly integrated device with Gate driver, protection, bootstrap diodes, and temp. monitor
- Wide range of line ups



DIPIPM family Line Ups

Rated current [A]

1 5 10 15 20 30 35 50 75 100

Rated voltage 600V

DIPIPM+

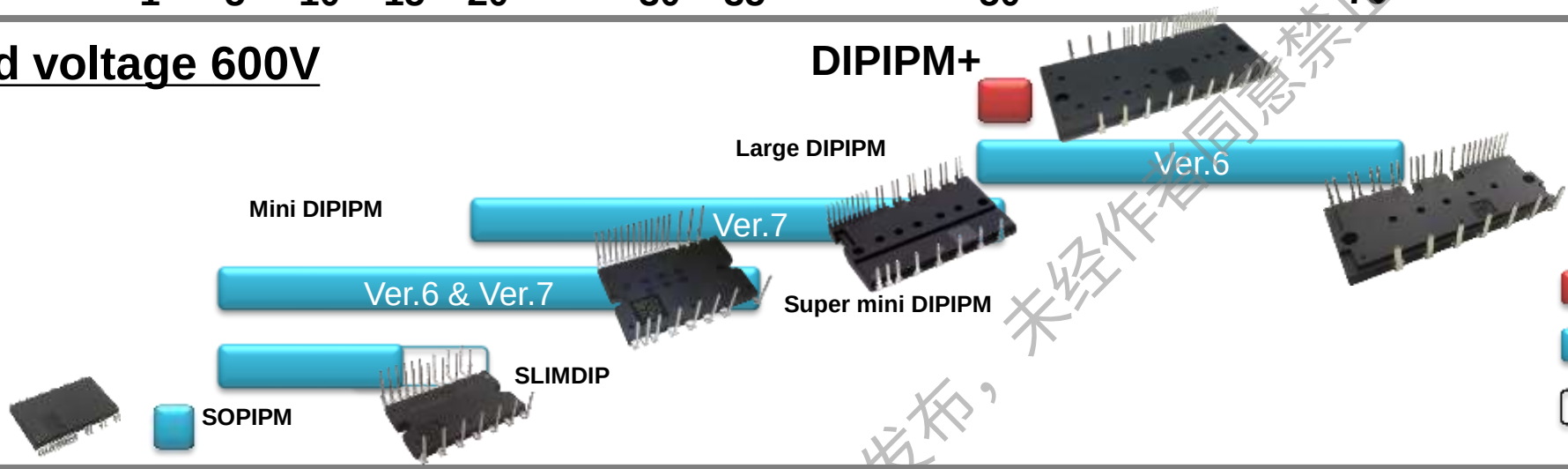
Large DIPIPM — Ver.6

Mini DIPIPM — Ver.7

Ver.6 & Ver.7 — Super mini DIPIPM

SLIMDIP

SOPIPM



CIB or CI

6 in 1

Under development

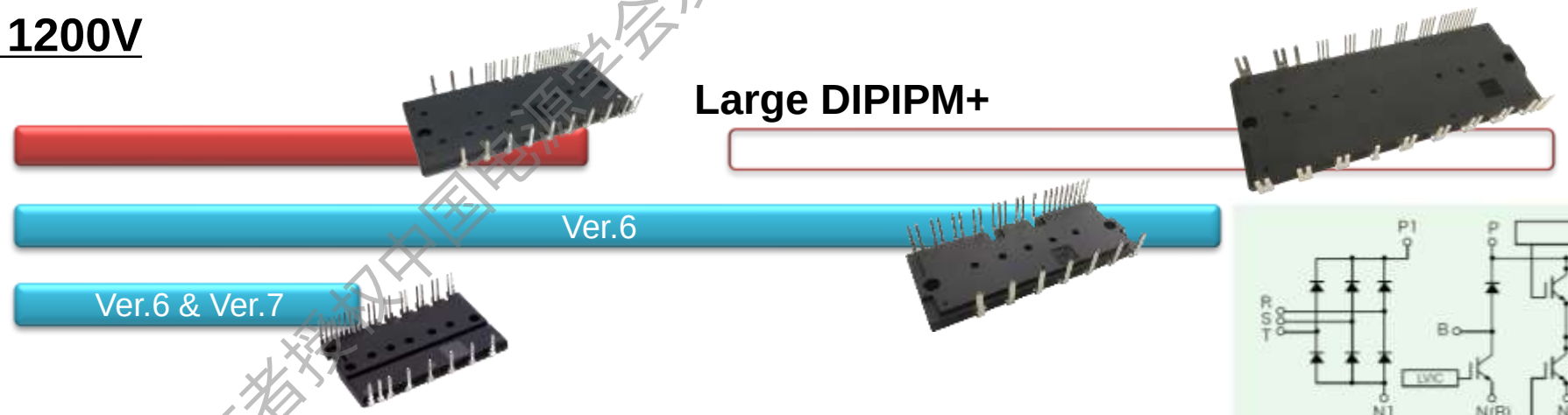
Rated voltage 1200V

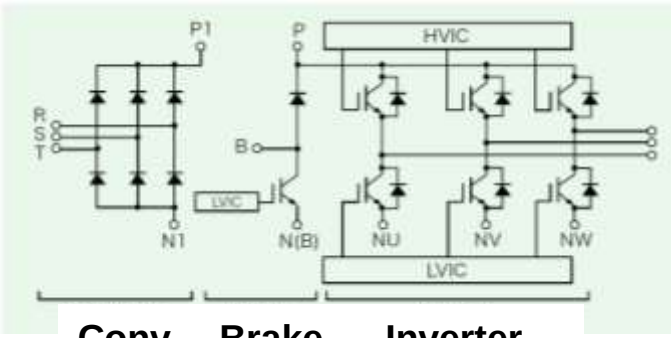
DIPIPM+

Large DIPIPM+

Large DIPIPM — Ver.6

Mini DIPIPM — Ver.6 & Ver.7



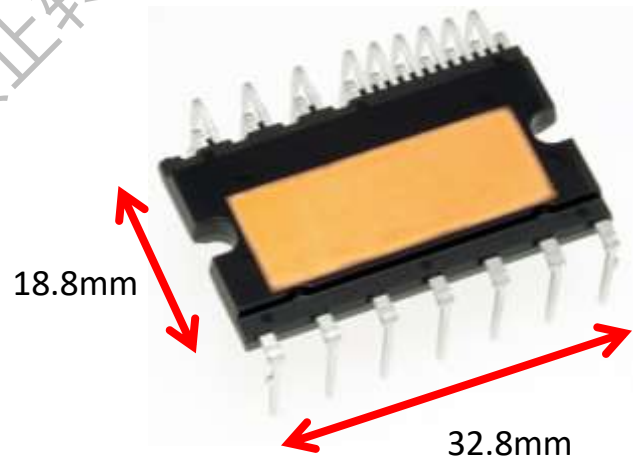


Conv. Brake Inverter

SLIMDIP Series

Why to use SLIMDIP?

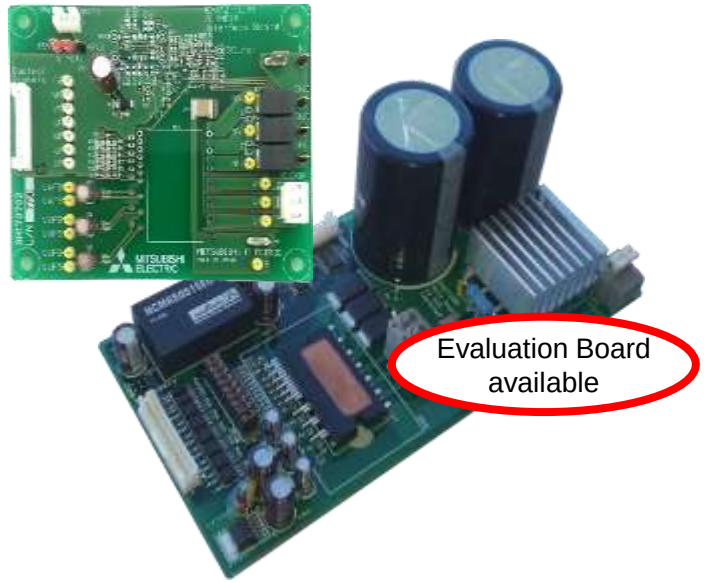
- 30% smaller package DIPIPM by employing RC-IGBT
- Easy PCB layout by additional GND terminal for bootstrap circuit
- Expanding operation temp. range Tc=115℃



Line up

Part No.	Application	Rating	SW speed
SLIMDIP-S	Fridge, Fan	5A/600V	Fast
NEW SLIMDIP-M	Fan, W/M	10A/600V	Fast
SLIMDIP-L	A/C	15A/600V	Regular
SLIMDIP-W	W/M, A/C	15A/600V	Fast
Under development SLIMDIP-X	A/C	20A/600V	Regular

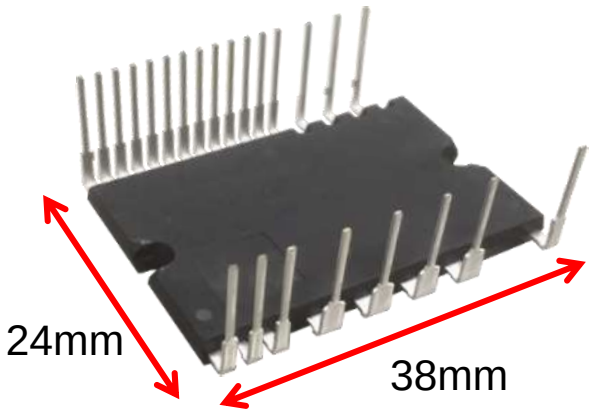
W/M: Washing machine, A/C: Air conditioner

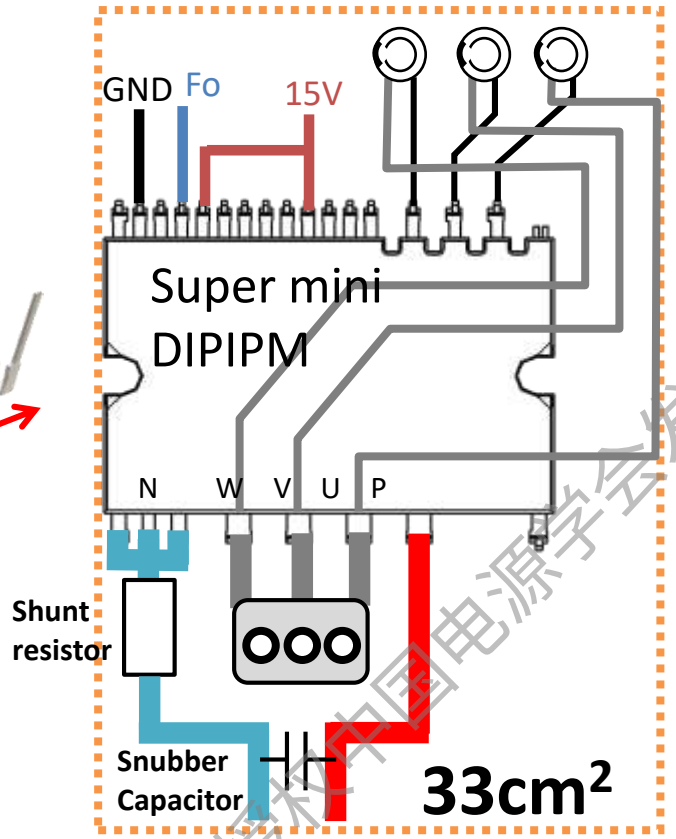


Optimized Terminal Layout of SLIMDIP

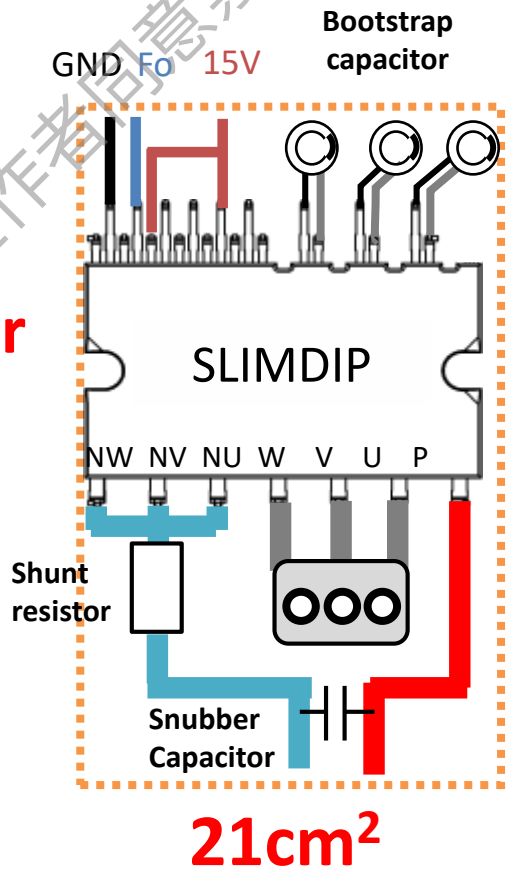
- Optimized Terminal Layout for Bootstrap Circuit:

Super Mini

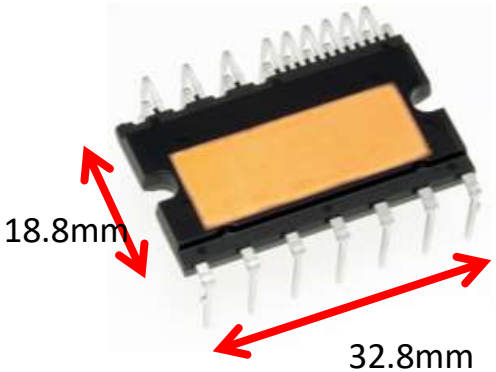




36% Smaller



SLIMDIP

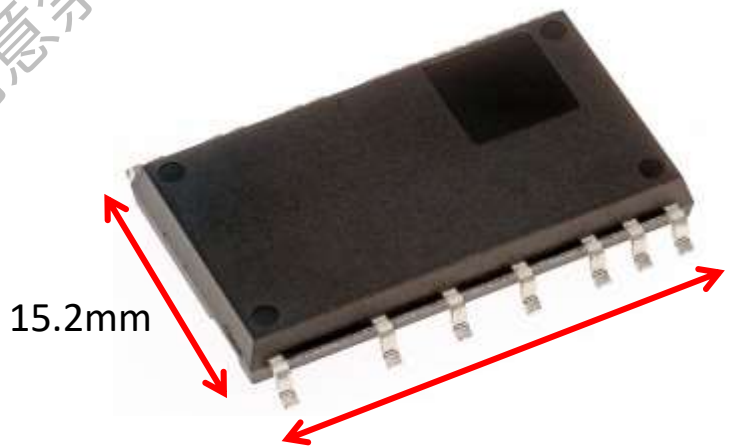


Easy and Simple PCB pattern design

SOPIPM

Bring system cost down by easy-to-use design

- Well-designed pin layout for shorter PCB design time
- Reduce additional parts and process for ensuring isolation by enough pin to pin distance
- Shrink PCB size by integration of abundant protection functions and also bootstrap diodes of control supply



27.4mm

Line up

Type name	Rating	Function
SP2SK	2A / 600V	UV, SC, OT, VOT, IL, Fo, BSD

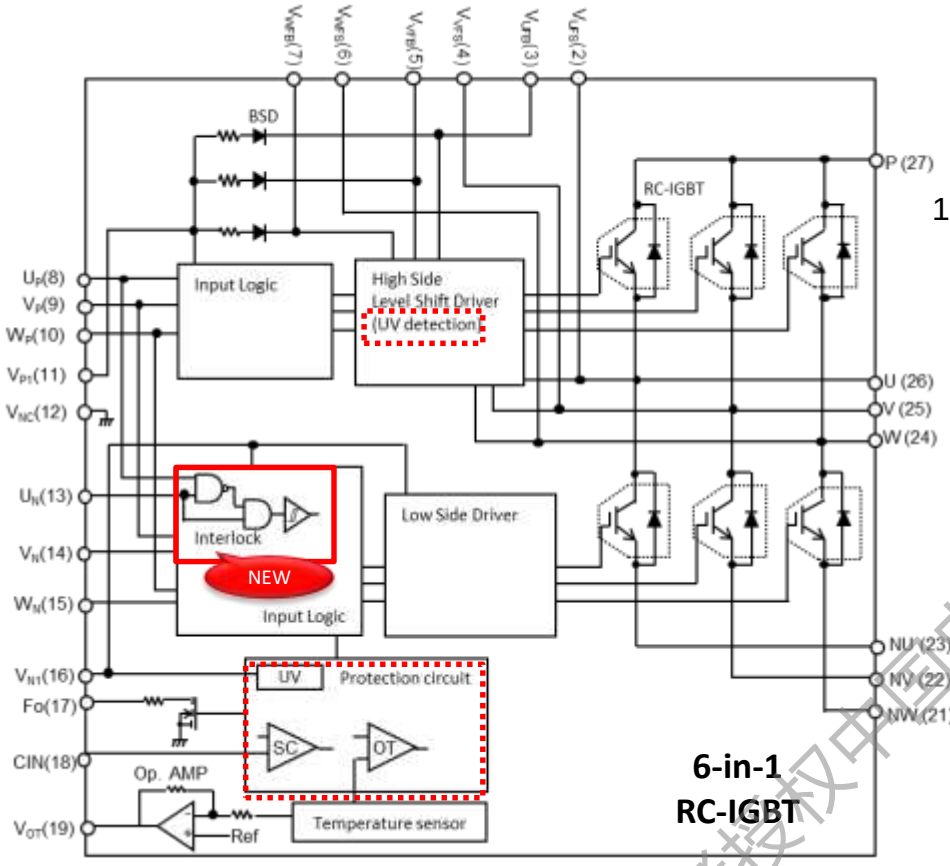
UV：Power supply Under Voltage protection
SC：Short Circuit protection
OT：Over Temperature protection
VOT：Analog Temperature Output
IL : Inter Lock
BSD : Bootstrap Diodes

IL prevents upper and lower IGBT to turn on simultaneously, by input noise or wrongly given control signals.

Sophisticated Module Design of SOPIPM

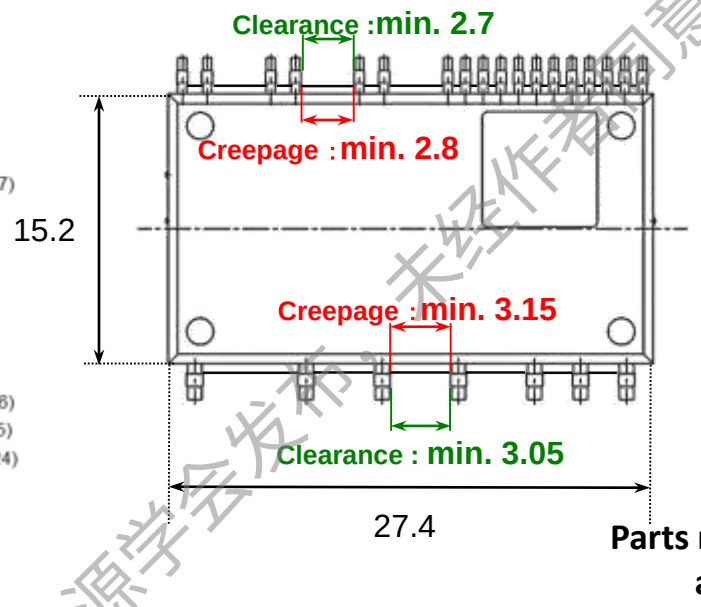
Dimension(mm)

Integrated Functions

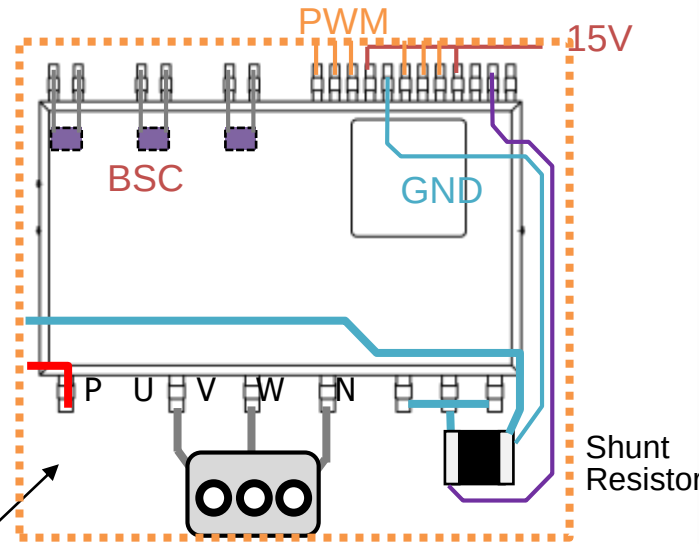


Integrated High Voltage Driver IC

Pin to pin isolation distance



Pinout for easy wiring



- **Integrated many protection functions**
  （UV, SC, OT, VOT, IL, Fo）
- **Wide insulation pin to pin distance**
- **Small PCB size and simple wiring**

Cost Reduction of PCB

Mitsubishi Power Devices

DIPIPM™
Modules realizing single-control power supply and photo-coupler-less system for household appliances and low-capacity inverters

IPM
Modules with built-in control and protection circuits for AC servo robots and PV power generation

Next topic

Power Modules for Vehicles
Modules realizing high performance and reliability for propulsion inverters in HVs/EVs

IGBT and SiC Modules
Modules for general-purpose inverters used in various applications

HVIGBT and SiC Modules
High voltage, large capacity and high reliability are realized for traction and power transmission application

High Power Devices
Wide lineup including thyristor and stack from general purpose to high speed switching purpose

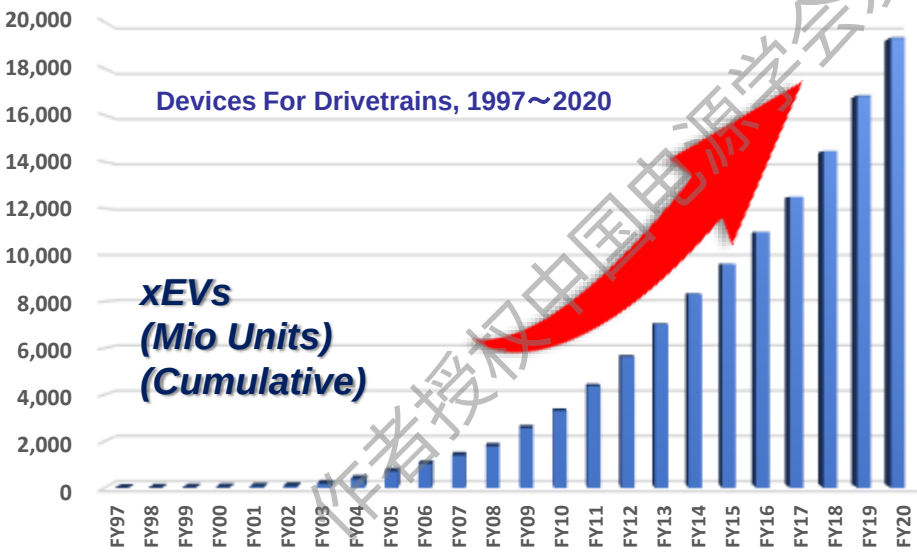
Transistor Array
Directly operation by output of 3V microcontroller, contribute to downsize or lighten each application machines

HVIC
HVIC, which can directly control gate drive by signal from microcontroller

xEV Business Experience

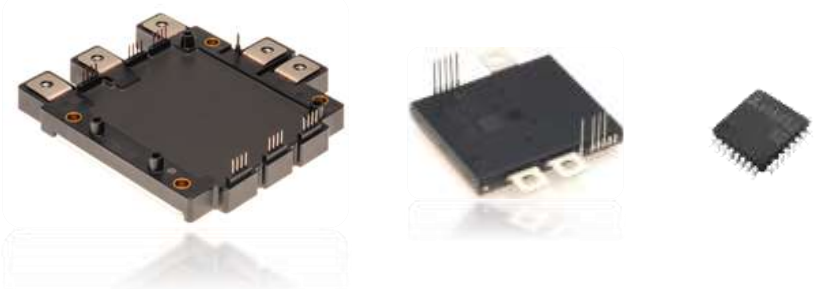
Why Mitsubishi Electric's Power Devices for xEV Drivetrain?

- Since 1997, Mitsubishi Electric has pioneered the mass production of power modules for hybrid and electric vehicles.
- More than 19 Million xEVs on the road worldwide utilizing Mitsubishi Electric's power devices for Drivetrain.
- With its wide-ranging product portfolio & distinctive technical support, Mitsubishi Electric is a solid partner in xEV projects for worldwide customers.



* An xEV drivetrain may include more than one power device.

World-Wide xEVs using Mitsubishi Electric Power

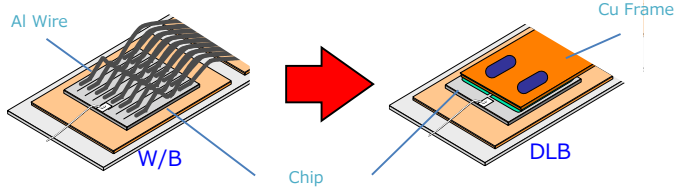


Progress of xEV Power Modules

Output / Function / Performance

* W/B(Wire bonding) vs. DLB(Direct lead boding

DLB contributes to high reliability because it can increase the bonding area between the chip and the frame.

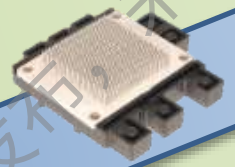


Next Generation
New Structure & High Heat Dissipation, Higher current density, Higher reliability, Higher operating temperature

High reliability
Long lifetime
Smaller size
Weight reduction
High Performance
High Heat Dissipation

※Next Gen. Device

J1 Series 6in1 module
DLB & Integrated Pin-Fin base plate type

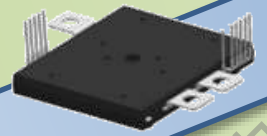


※7th Gen.
CSTBT IGBT

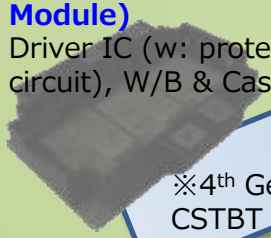
Next Gen. IGBT, RC-IGBT, SiC-MOSFET, etc.

Long lifetime
High reliability
Smaller size
Weight reduction

J Series (T-PM)
DLB & Transfer Mold



IPM (Intelligent Power Module)
Driver IC (w: protection circuit), W/B & Case type)



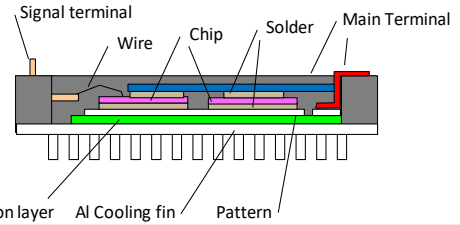
※4th Gen.
CSTBT IGBT

※6th Gen.
CSTBT IGBT

Smaller size
Weight reduction
High Performance
High Heat Dissipation

* Structure of J1 Series module

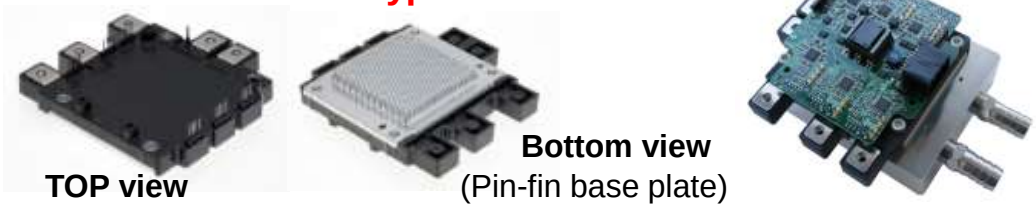
Direct cooling is possible by integrating the cooling fins and the module, and thermal resistance can be reduced.



1997 2009 2015 2020 ～2030

J1A series and T-PM series for Drive Train

J1 Series "J1A" Type



TOP view

Bottom view
(Pin-fin base plate)

■ Features

- Extra-Compact direct-cooling 6in1 package with cooling fin
- Highly reliable DLB* package for automotive inverters
- Low power loss 7th-generation CSTBT™ chip technology
- Drivetrain inverter solution based on 700A/650V J1A module
- Pb-free, compliant with RoHS directive (2011/65/EU)

■Line-up

Item	CT600CJ1A060-A	CT700CJ1A060-A
Specification	600A / 650V	700A / 650V
Saturation Voltage (Tj=25℃, Ic=Ratings, VGE=15V) ※ chip	1.25V	1.25V
IGBT Chip	CSTBT™, On-chip temperature sensor, On-chip current sensor	
Package	6-in-1 package with cooling fin (Pin-fin base plate)	

Note *DLB : Direct Lead Bonding (wire bond less)

T-PM Series (Transfer Mold Type)

■ Features

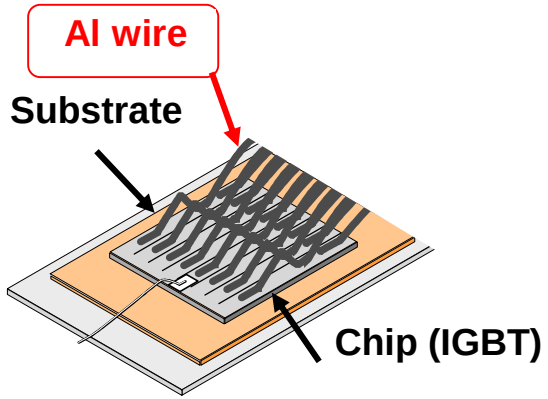
- Compact high-reliability transfer-molded package
- Highly reliable DLB for automotive inverters
- Low power loss CSTBT™ chip technology
- On-chip temperature and current sense emitter output
- Pb-free, compliant with RoHS directive (2011/65/EU)

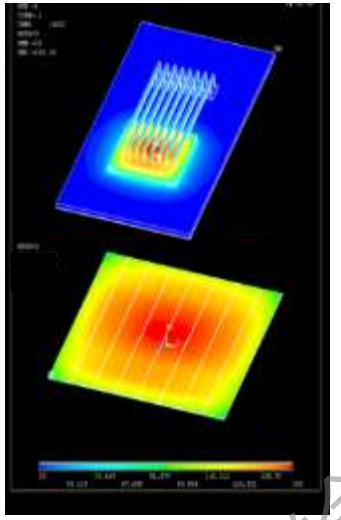
■Line-up

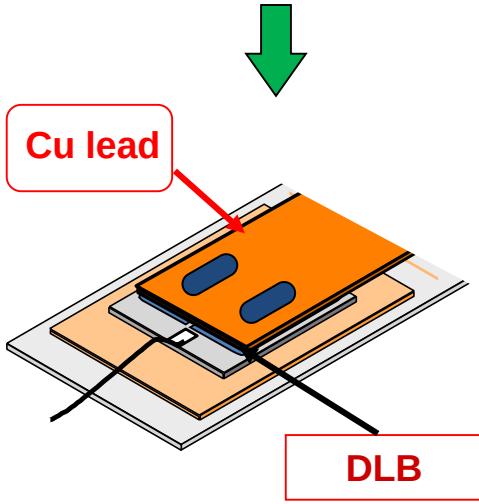
Item	CT300DJG060
Specification	300A / 650V
Saturation voltage (Tj=25℃, IC=Ratings, VGE=15V)	1.4V
IGBT Chip	CSTBT™, on-chip temperature sensor, on-chip current sensor
Package	2-in-1

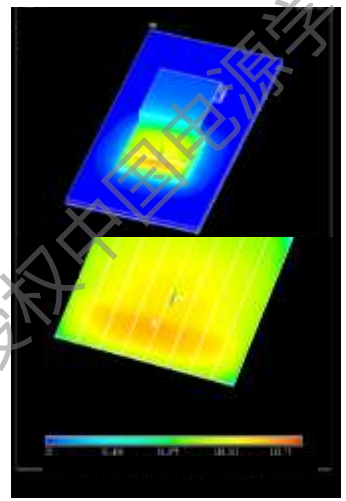
DLB technology for long lifetime

Direct Lead Bond (DLB)









DLB technology advantages:

- Enable enlarging the bonding area, uniform temperature distribution
- Improved lifetime of inner connection
- Reduced wiring resistance and inductance

High P/C & T/C = Long lifetime

SiC MOSFET N Series for OBC

Discrete（N-series SiC MOSFET）AEC-Q101

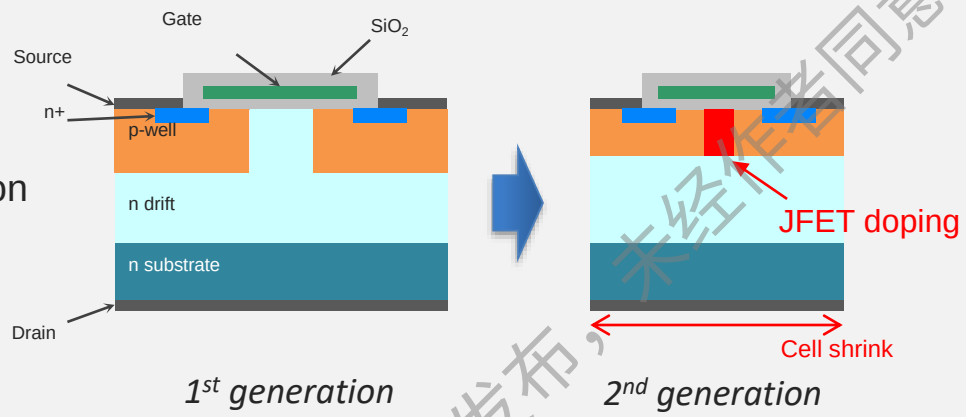
Features

- **Good performance**

  2nd Gen. MOSFET w JFET doping
  Low switching loss
  High robustness against self turn-on

- **High reliability**

  Allow body diode conduction
  Allow negative gate bias



Line-up

1200V

80mΩ
40mΩ
20mΩ

AEC-Q101

TO-247-3

TO-247-4

+ Kelvin terminal

TO-263-7

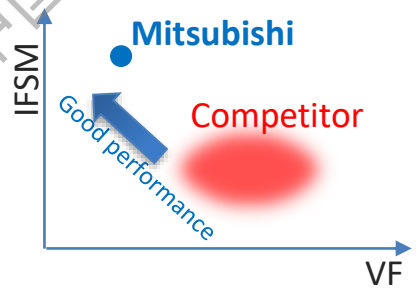
+ Kelvin terminal

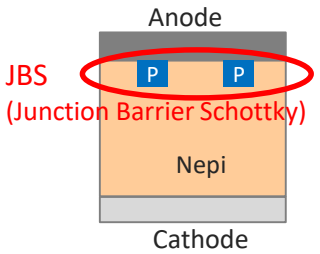
Discrete（SiC Diode）AEC-Q101

Features

- **Low VF & High IFSM**

  Original JBS (Junction Barrier Schottky) structure allows Low VF and high forward surge capability.





Line-up

1200V
10A
20A

AEC-Q101

TO-247-3

Mitsubishi Power Devices

DIPIPM™
Modules realizing single-control power supply and photo-coupler-less system for household appliances and low-capacity inverters

IPM
Modules with built-in control and protection circuits for AC servo robots and PV power generation

Power Modules for Vehicles
Modules realizing high performance and reliability for propulsion inverters in HVs/EVs

Next topic

IGBT and SiC Modules
Modules for general-purpose inverters used in various applications

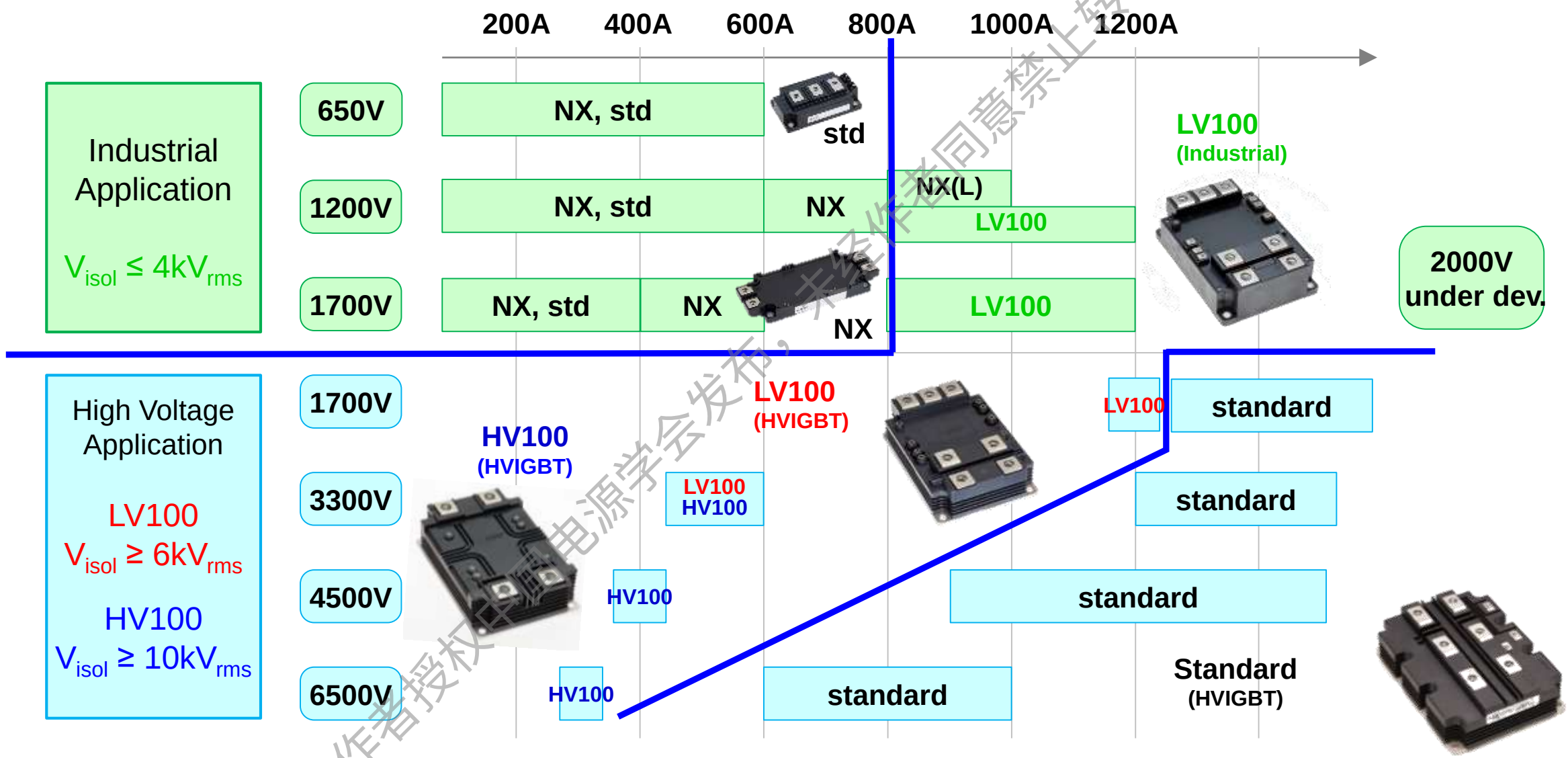
HVIGBT and SiC Modules
High voltage, large capacity and high reliability are realized for traction and power transmission application

High Power Devices
Wide lineup including thyristor and stack from general purpose to high speed switching purpose

Transistor Array
Directly operation by output of 3V microcontroller, contribute to downsize or lighten each application machines

HVIC
HVIC, which can directly control gate drive by signal from microcontroller

Modules for Industry and High Voltage application



"LV100" is available both in Industrial and High voltage application modules.

LV100 and HV100 Series

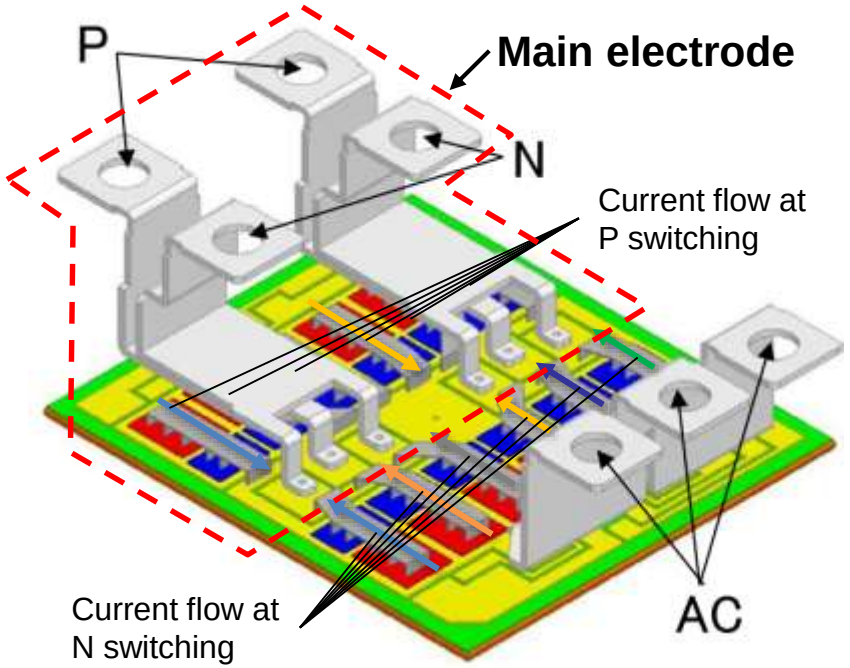
Both LV100 and HV100 will be a new market standard pkg. for high power IGBT modules

Main target	Renewable			High Voltage Application				
Line-up	 LV100 (industrial)			 LV100 (HVIGBT)		 HV100 (HVIGBT)		
Application	renewable, industrial, others			Traction, power transmission		Traction, power transmission		
Footprint	100mm × 140mm × 40mm							
V_{isol}	4kVrms			6kVrms		10kVrms		
Rated Voltage	1.2 kV	1.7 kV	2.0 kV	1.7 kV	3.3 kV	3.3 kV	4.5kV	6.5kV
Rated Current Si-IGBT	800A 1200A	800A 1200A	1200A	1200A	Si IGBT 450A 600A	450A 600A	450A under dev.	300 A under con.
Hybrid SiC	-	-	under dev. Suitable for 1500V PV	-	Hyb.SiC 600A	-	-	-
Full SiC	-	-	-	-	Full SiC 185A 375A 750A	-	-	-

* Customer can utilize their design resources by compatible footprint mounting holes. Ex) cooler, gate driver, etc.

Easy Paralleling of LV100

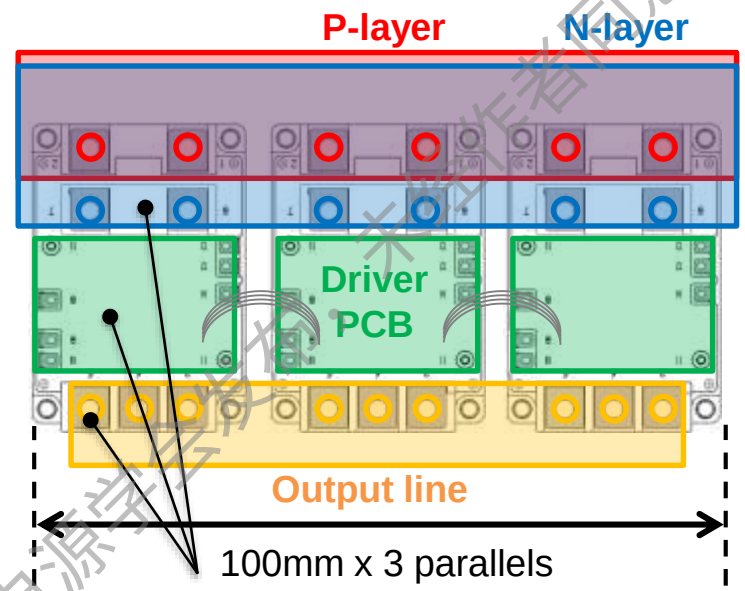
① Internal design



- **Symmetric layout**
- **Laminated electrode structure**
  - **→ Low impedance between P-N**
    (L=9nH @CM1200DW-34T)
  - **→ Less snubber capacitor**

② Easy Paralleling pinout

Ex) 3 parallel connecting



Simple layout

- **Simple connecting by electrode layout position**
  - **→ Simple current path**
  - **→ Good current balance**

Developed by TAMURA

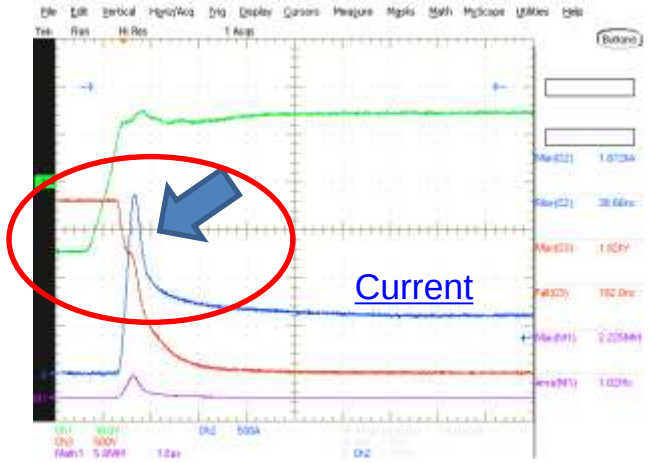
Home page: http://www.tamura-ss.co.jp/electronics/en/
Contact: soudan@tamura-ss.co.jp

High Power Products ～LV100 Hybrid, and Full SiC

Turn-on Switching Full-SiC & Hybrid-SiC & Si

Conditions: V_{CC}=1800V, I_C=600A, T_j=150°C, Ls=65nH

$d_{i(on)}/d_t$	50% - 90%	6177 A/µs
$d_{v(on)}/d_t$	70% - 50%	-
I_{C_peak}	-	1872 A
E_{on}	All range	1.02 J

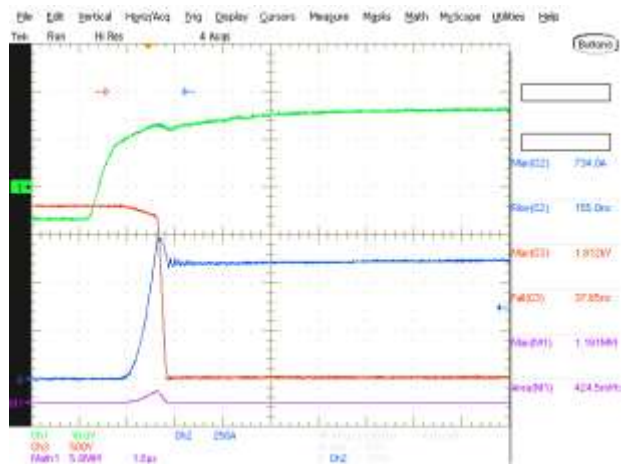


600A/3300V Si IGBT module

$d_{i(on)}/d_t$	50% - 90%	2204 A/µs
$d_{v(on)}/d_t$	70% - 50%	-
I_{C_peak}	-	668 A
E_{on}	All range	0.62 J

600A/3300V Hybrid SiC module

$d_{i(on)}/d_t$	50% - 90%	1549 A/µs
$d_{v(on)}/d_t$	70% - 50%	-
I_{C_peak}	-	734 A
E_{on}	All range	0.42 J



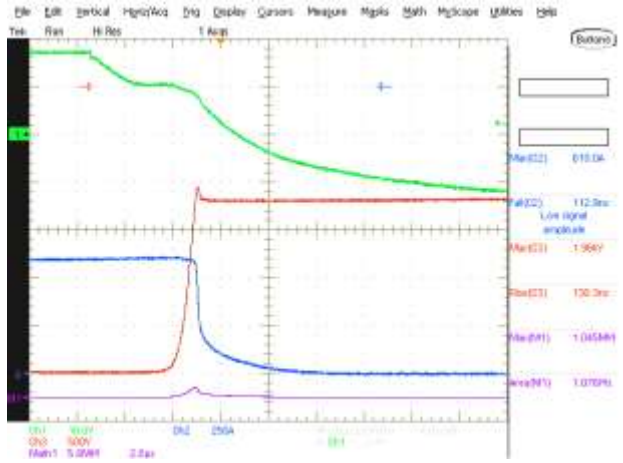
750A/3300V Full SiC module

High Power Products ～LV100 Hybrid, and Full SiC

Turn-off Switching Full-SiC & Hybrid-SiC

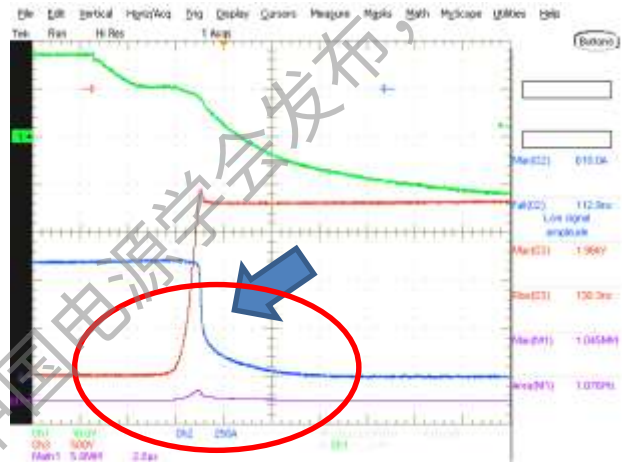
Conditions: V_{CC}=1800V, I_C=600A, T_j=150° C, Ls=65nH

$d_{i(on)}/d_t$	50% - 90%	2114 A/µs
$d_{v(on)}/d_t$	70% - 50%	2682 V/µs
V_{CE_peak}	-	1960 V
E_{on}	All range	1.05 J



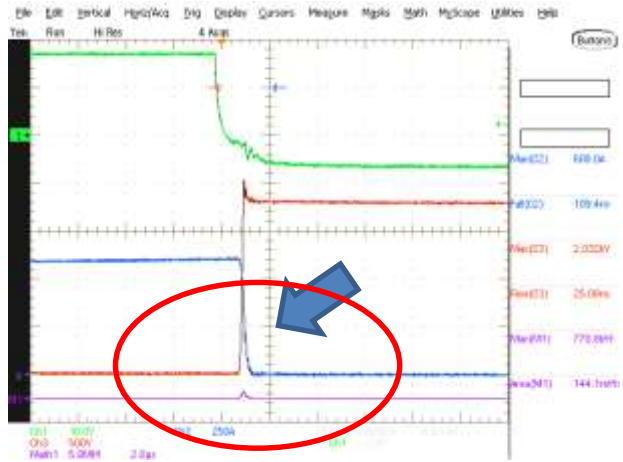
600A/3300V Si IGBT module

$d_{i(on)}/d_t$	50% - 90%	2114 A/µs
$d_{v(on)}/d_t$	70% - 50%	2682 V/µs
V_{CE_peak}	-	1960 V
E_{on}	All range	1.05 J



600A/3300V Hybrid SiC module

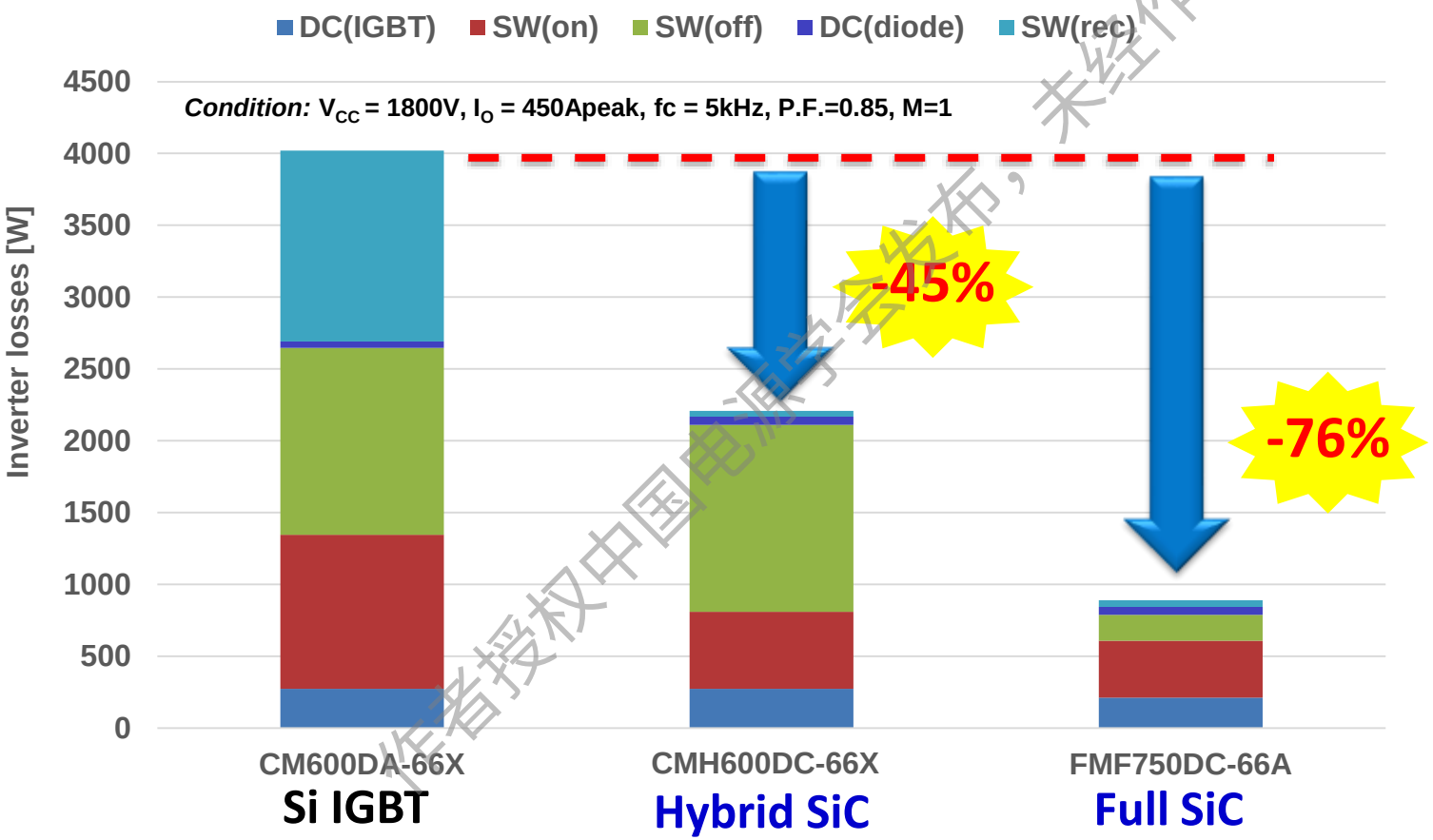
$d_{i(off)}/d_t$	50% - 90%	2239 A/µs
$d_{v(off)}/d_t$	50% - 70%	14629 V/µs
V_{CE_peak}	-	2032 V
E_{on}	All range	0.14 J

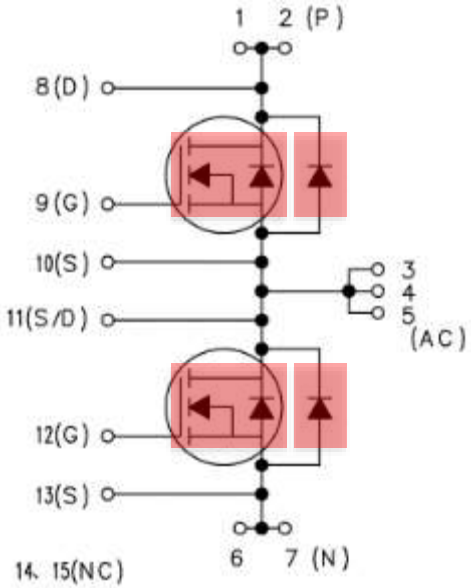


750A/3300V Full SiC module

LV100 Series High Voltage SiC Module

Type	Series	Type name	V_{CES}/ I_C /config.	Dimension
LV100 (6kViso)	Full SiC	FMF750DC-66A	3.3kV/750A/2in1	100×140×40mm³
LV100 (6kViso)	Full SiC	FMF375DC-66A	3.3kV/375A/2in1	100×140×40mm³





High Voltage Power Module Progress

3.3kV

The higher current density has been realized by chip improvement and package improvement

Module size : Not to scale

H-series (1200A)

4.51 A/cm^2

R-series (1500A)

5.64 A/cm^2

X-series (1800A)

6.77 A/cm^2

IGBT LV100 (600A)

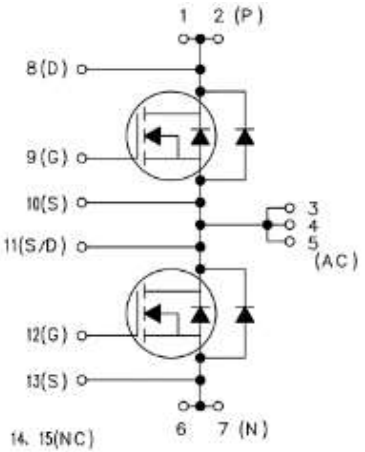
8.57 A/cm^2

SiC LV100 (750A)

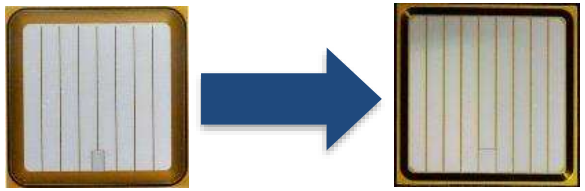
10.71 A/cm^2

Package Improvement (Dual transistor)

SiC Introduction



IGBT chip improvement



R-Series

X-Series

Agenda

- Introduction
- Power Chip technology advancement
- Power Modules with their application
  - Home Appliances
  - Automotive
  - Industry and Renewable
  - High Voltage Traction and Electricity
- Conclusion

Conclusions

01 Realization of the Carbon Neutral Society is the world-wide concern

02 Inverterization and Electrification would progress further more.
Power Device plays the key roll to support this trend.

03 Mitsubishi Electric provides a wide range of power semiconductor solutions including SiC, for four application segments
1) Home Appliance,
2) Industry and Renewable,
3) Railway and power transmission
4) Automotive

We strive to contribute for the further revolution of power devices, in order to achieve the low carbon society