



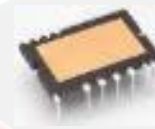
中国电源学会第二十五届学术年会 (CPSSC 2022)
The 25th China Power Supply Society Conference

Latest Advancement in Power Chip and Module Technologies

三菱电机株式会社

大中国区三菱电机半导体

Great China Mitsubishi Electric Semiconductor





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6. SiC power modules for power electronic transformer
7. Mid voltage IGBT for renewable energy power generation
8. High voltage power modules for rail traction
9. Power device solutions for electric vehicles
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 **01**

Outline

of Mitsubishi Electric Power Semiconductor

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Space Systems



Visual Information Systems



Energy Systems



Information & Communication



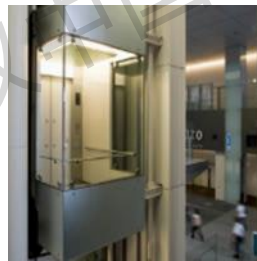
Factory Automation



Power Device



Transportation systems



Building Systems



Home Appliance



Automotive Equipment

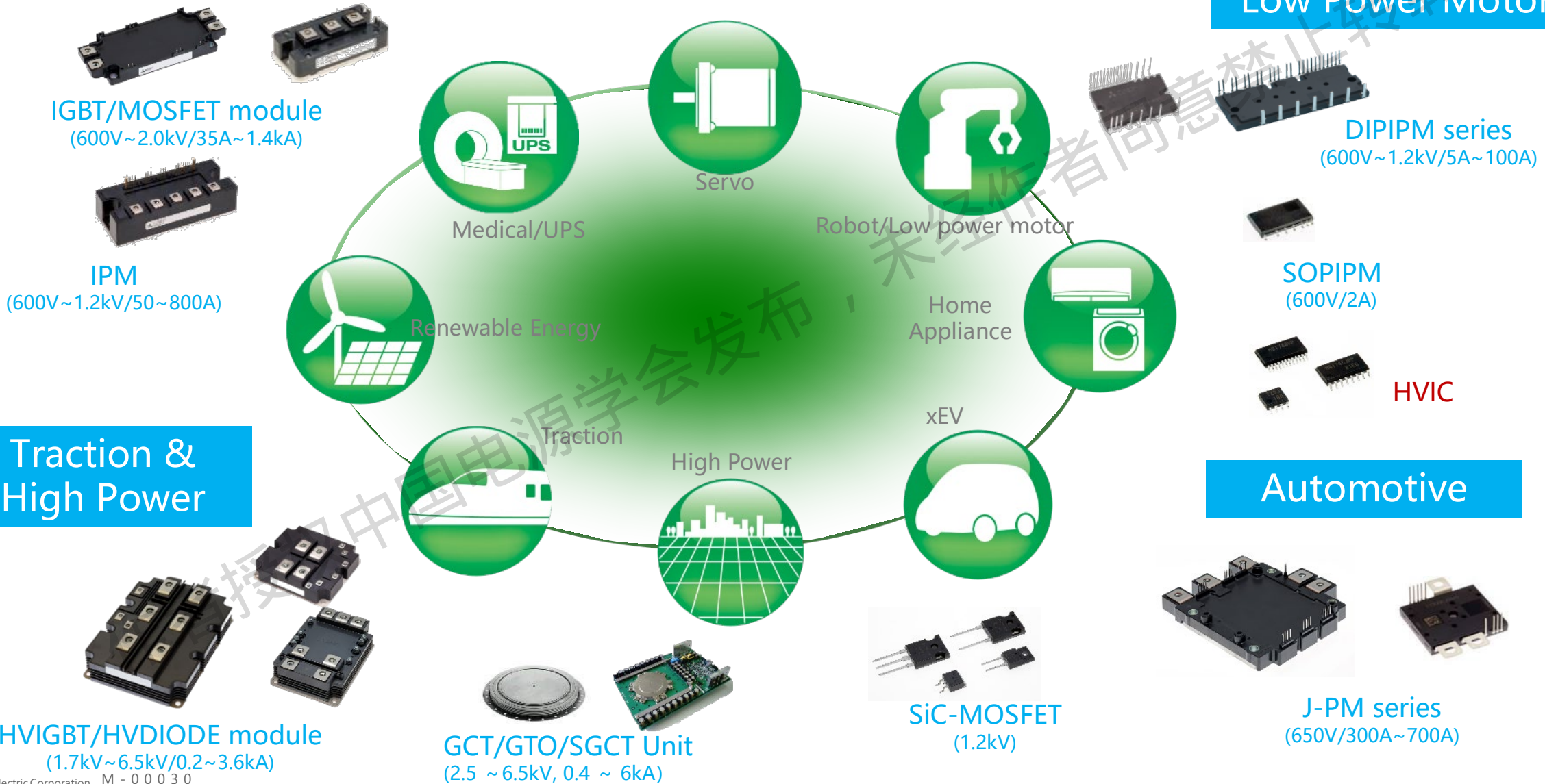
In addition to power device, the other 7 business lines shown in blue are closely related to power electronic technology.


Industry & Renewable Energy

Home Appliance & Low Power Motor

Traction & High Power

Automotive





02

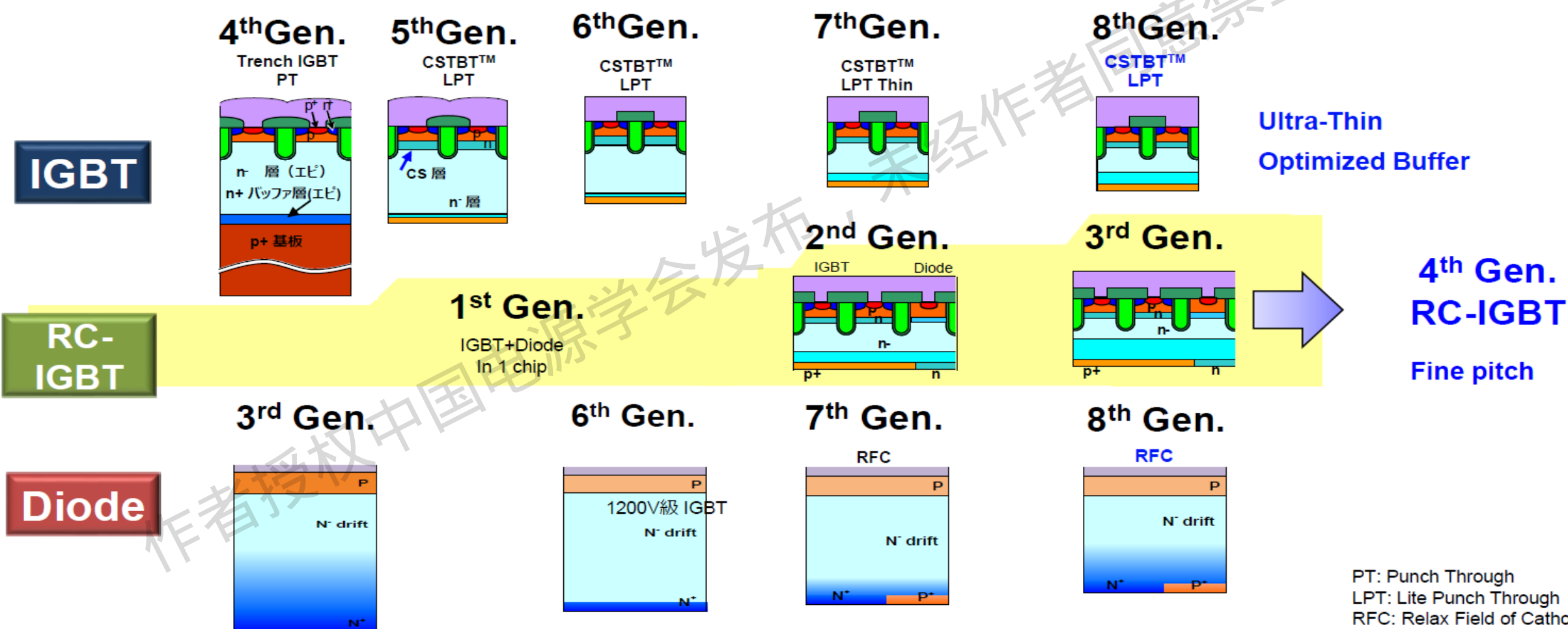
Roadmap

of Si & SiC power chips' technologies

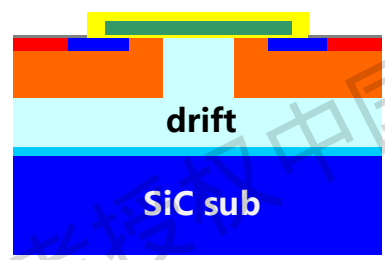
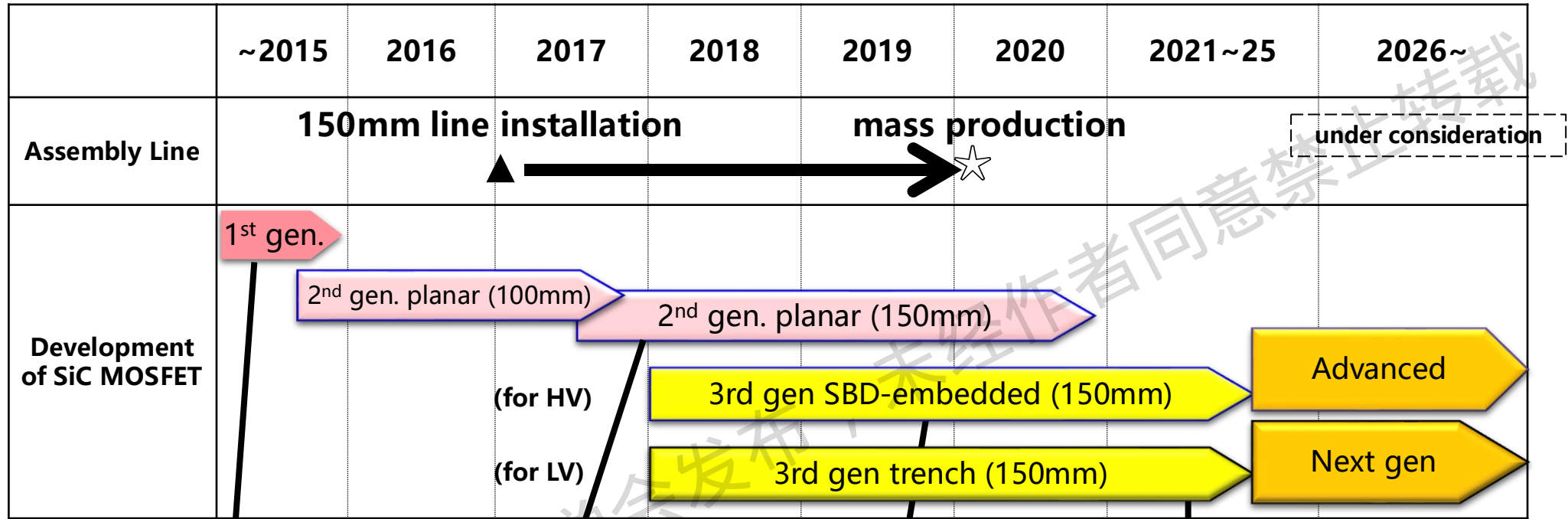
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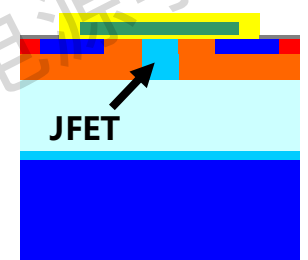
Chip Development Timing Base



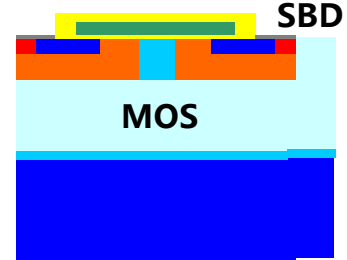
PT: Punch Through
LPT: Lite Punch Through
RFC: Relax Field of Cathode



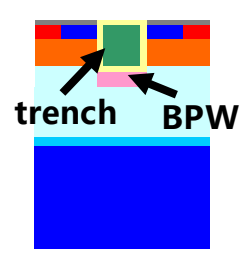
1st generation Planar MOS



2nd generation Planar MOS

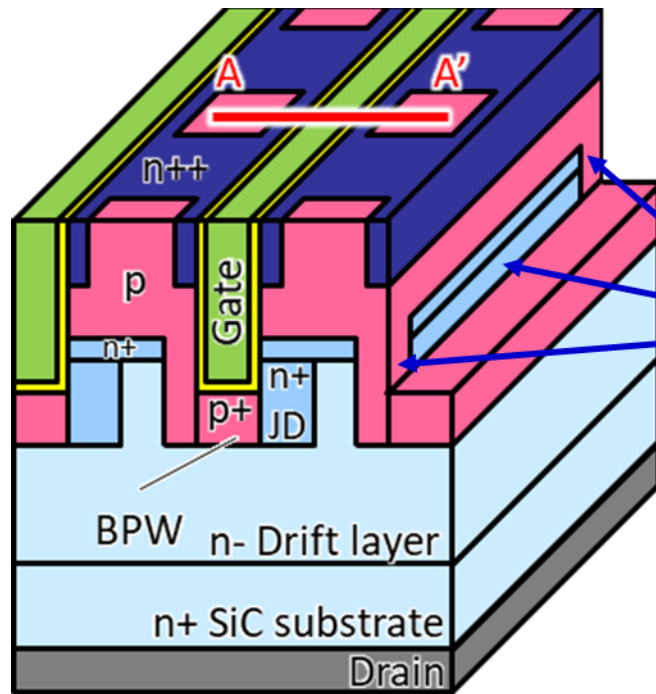


3rd generation SBD-embedded MOS

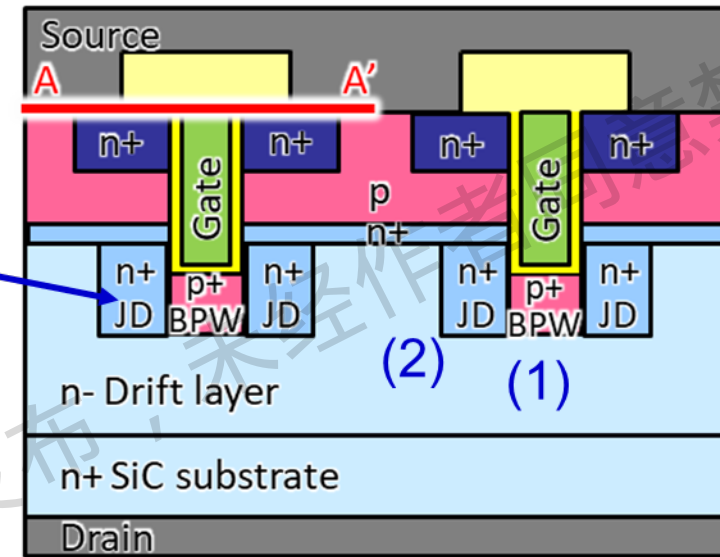


3rd generation Trench MOS

- ✓ The 3rd gen. low-voltage SiC MOSFET utilizes trench-gate structure;
- ✓ The 3rd gen. high-voltage SiC MOSFET utilizes SBD-embedded planar gate structure.



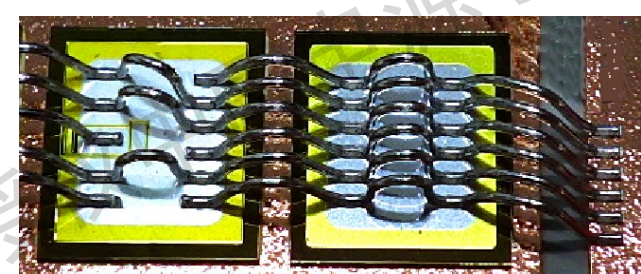
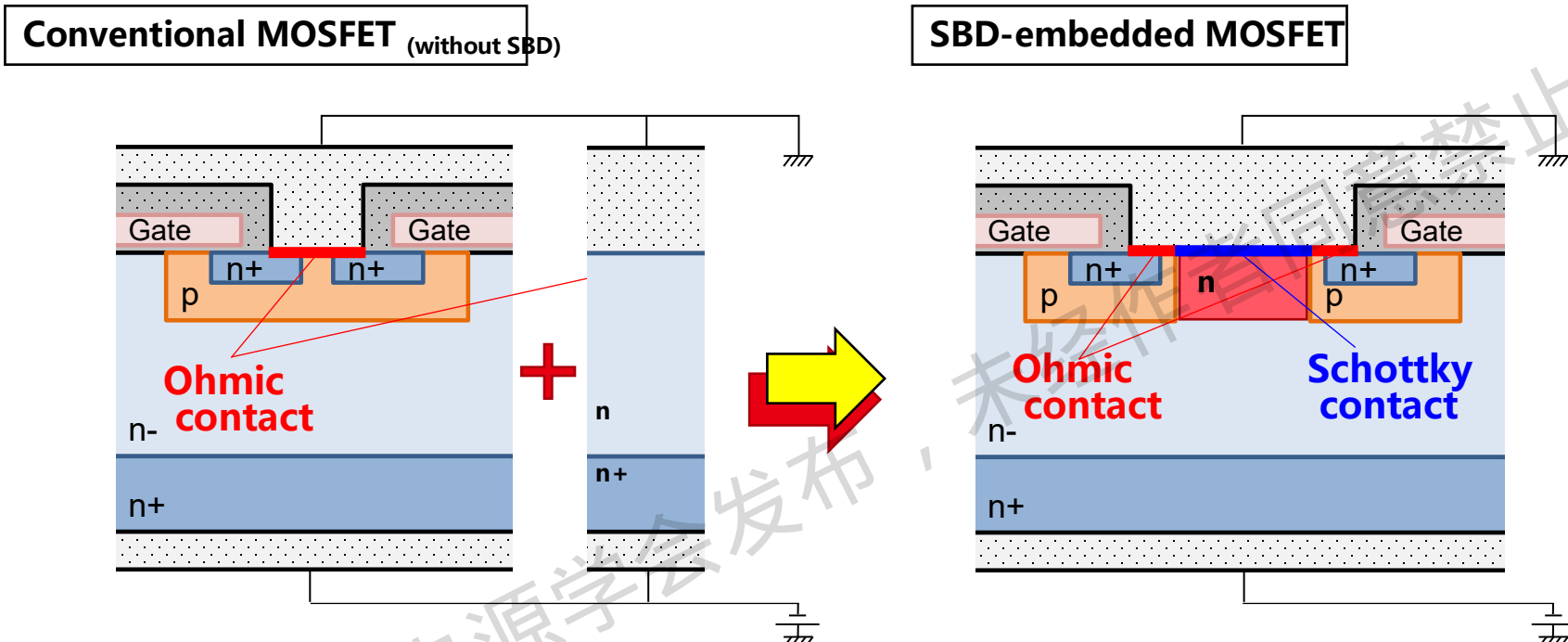
Tilted ion
implantation
through trench



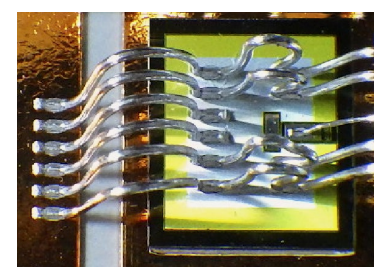
(1) Grounded p+ BPW
reduces gate oxide
electric field.

(2) n+ JD
reduces resistance
in current path.

- ✓ Utilizing tilted ion implantation technology, “low electric field on gate oxide” together with “low on resistance at current path” have been achieved.
- ✓ Requires no special process equipment, leading to superior productivity.



MOSFET SBD



SBD embedded MOSFET

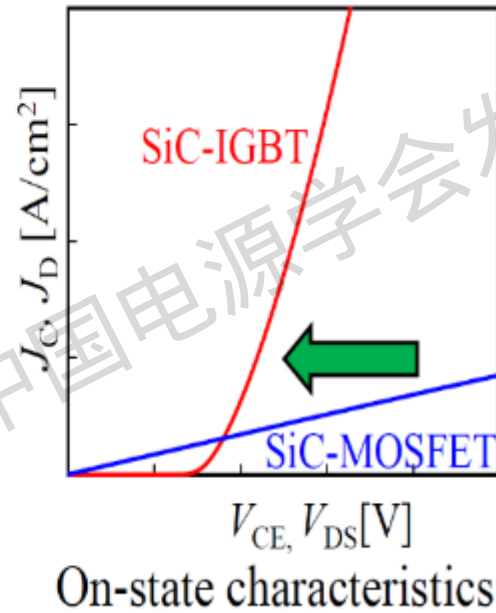
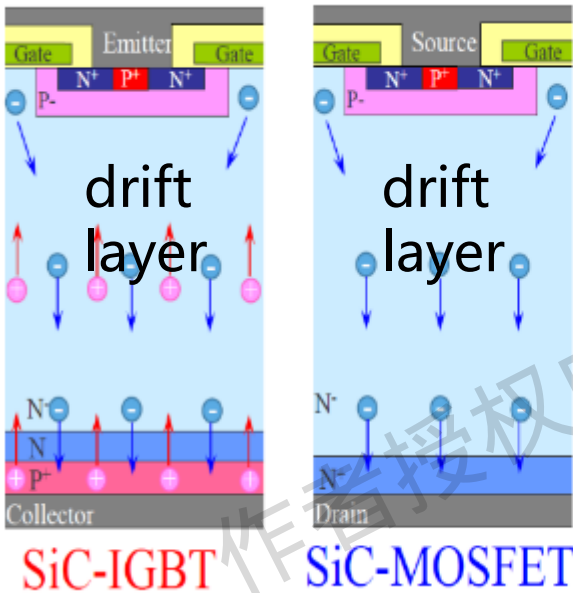
- ✓ Schottky and ohmic contacts in the same contact hole.
- ✓ No significant increase of process step

2-05 HV SiC-IGBT: 13kV chips under development

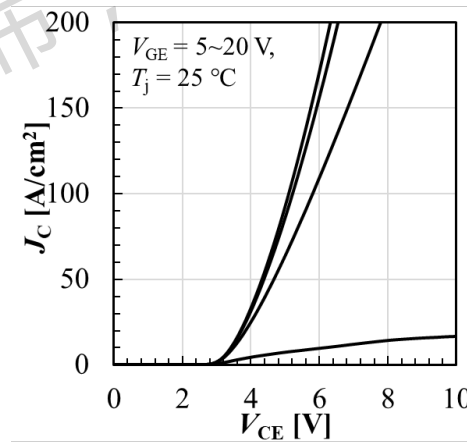
Thanks to conductivity modulation (bipolar current conduction), IGBTs markedly reduce resistance in drift layers. SiC-IGBTs with high voltage ratings (especially >6.5kV) has a great advantage in R_{on} .

These characteristics break the unipolar limit!

Differential on-resistance ($R_{on,diff}$) as low as $15\text{m}\Omega\text{cm}^2$.

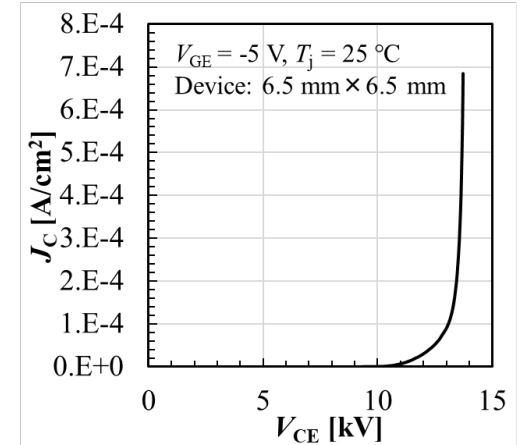


On-state characteristics



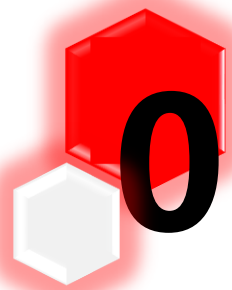
$V_{CEsat} = 5.2\text{ V}$, $R_{on,diff} = 15\text{ m}\Omega\text{cm}^2$

Breakdown characteristics



$V_{BD} = 13.7\text{ kV}$

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

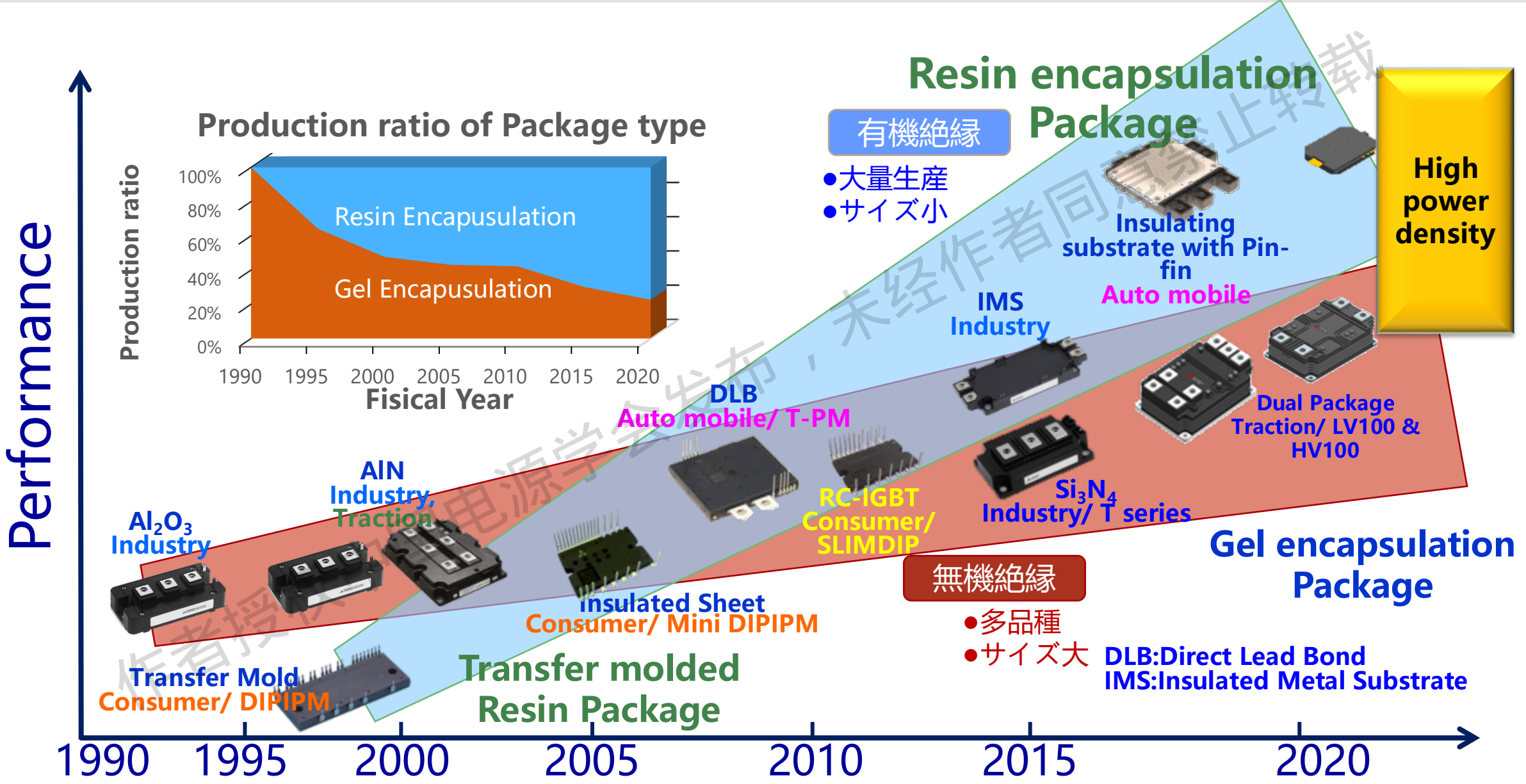
 **03**


Progression

of power module packaging technology

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 **04**

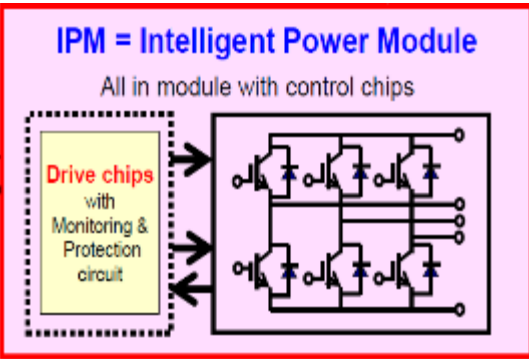
DIIPM™

for inverter household appliances

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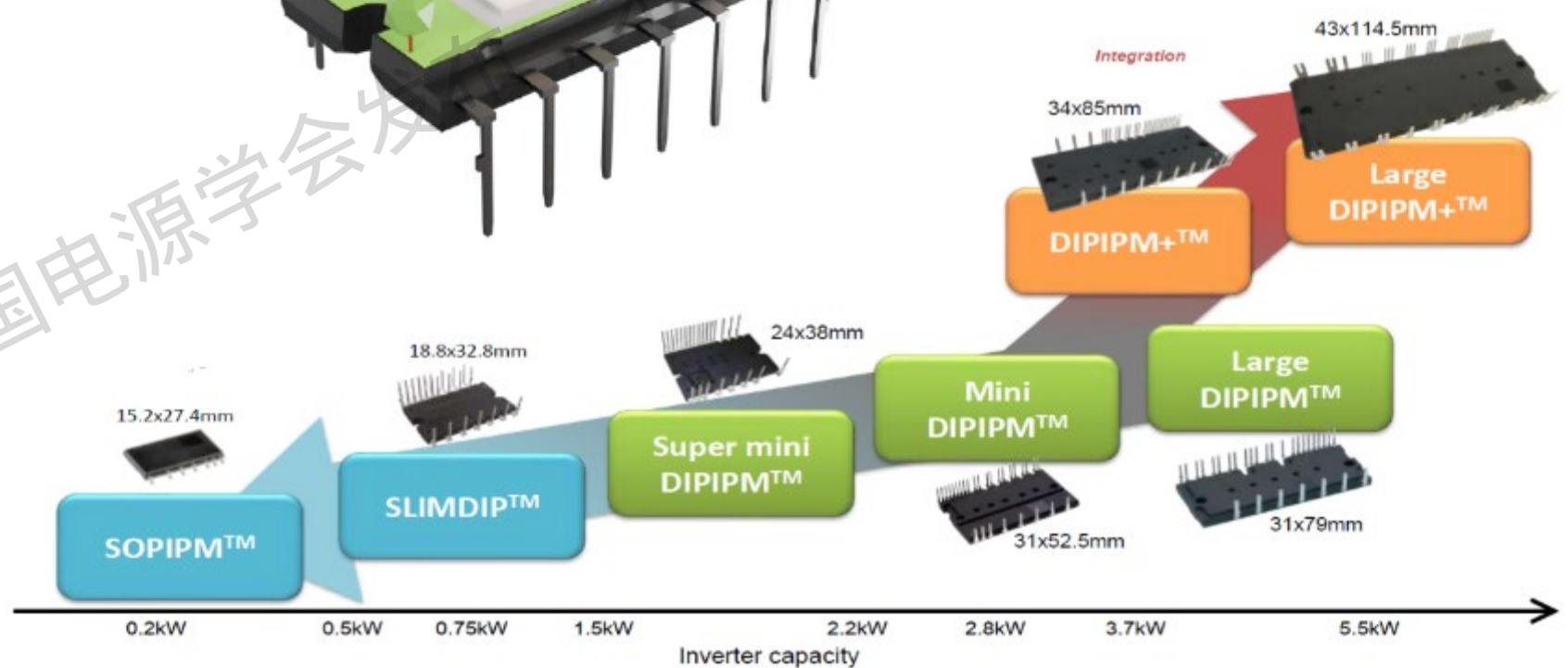
- ✓ Mitsubishi Electric invented and launched DIIPMTM in 1997. In the 25th anniversary year, its shipment has exceeded 1 billion units.

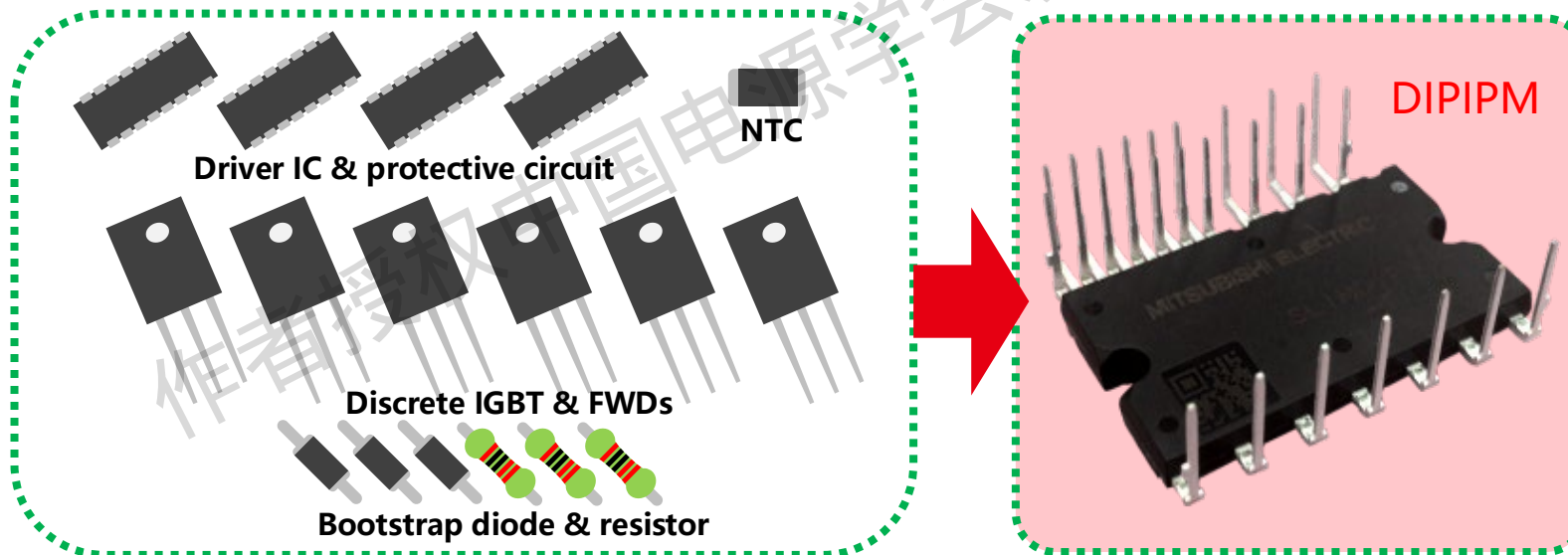
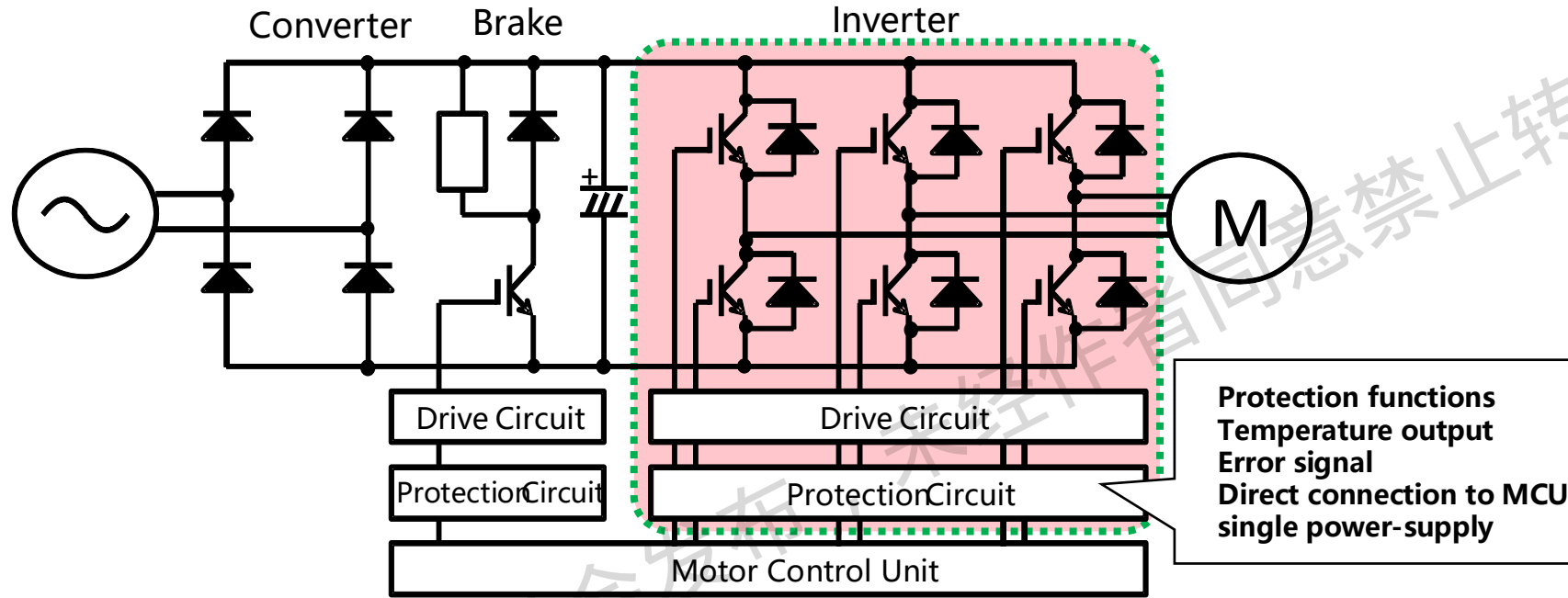


IPM Package

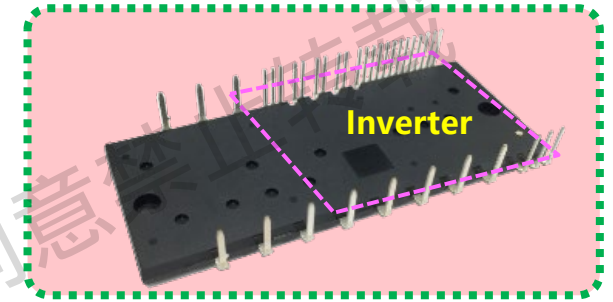
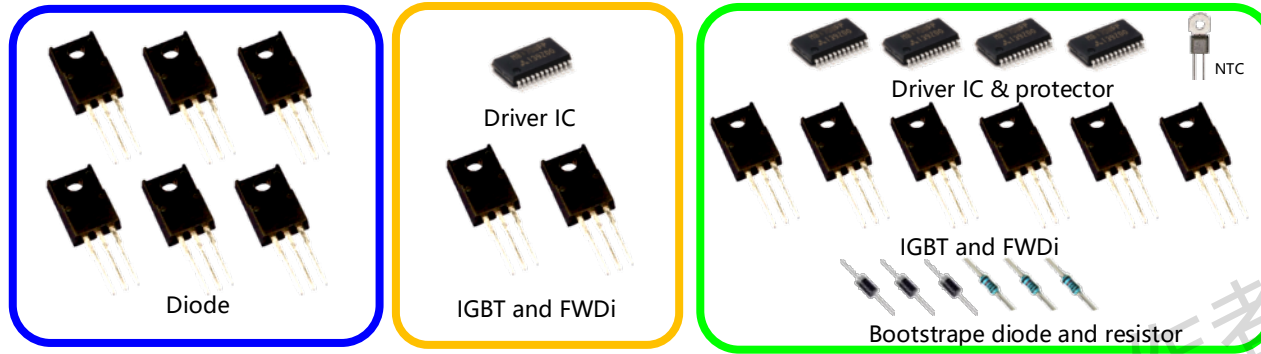


De facto standard package for white goods market

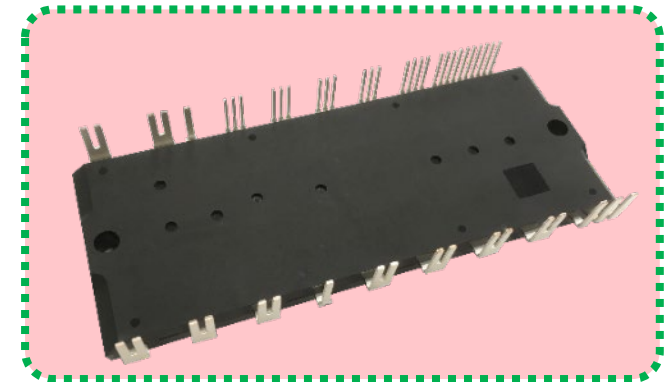
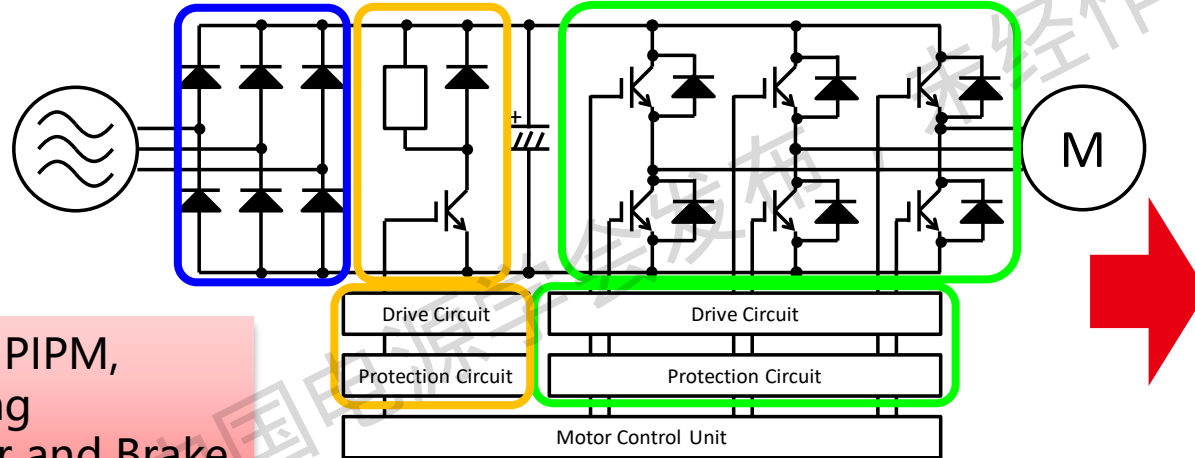




- ✓ Smaller package
- ✓ Less periphery parts
- ✓ Higher reliability



DIIPM+: 34x 85(mm)



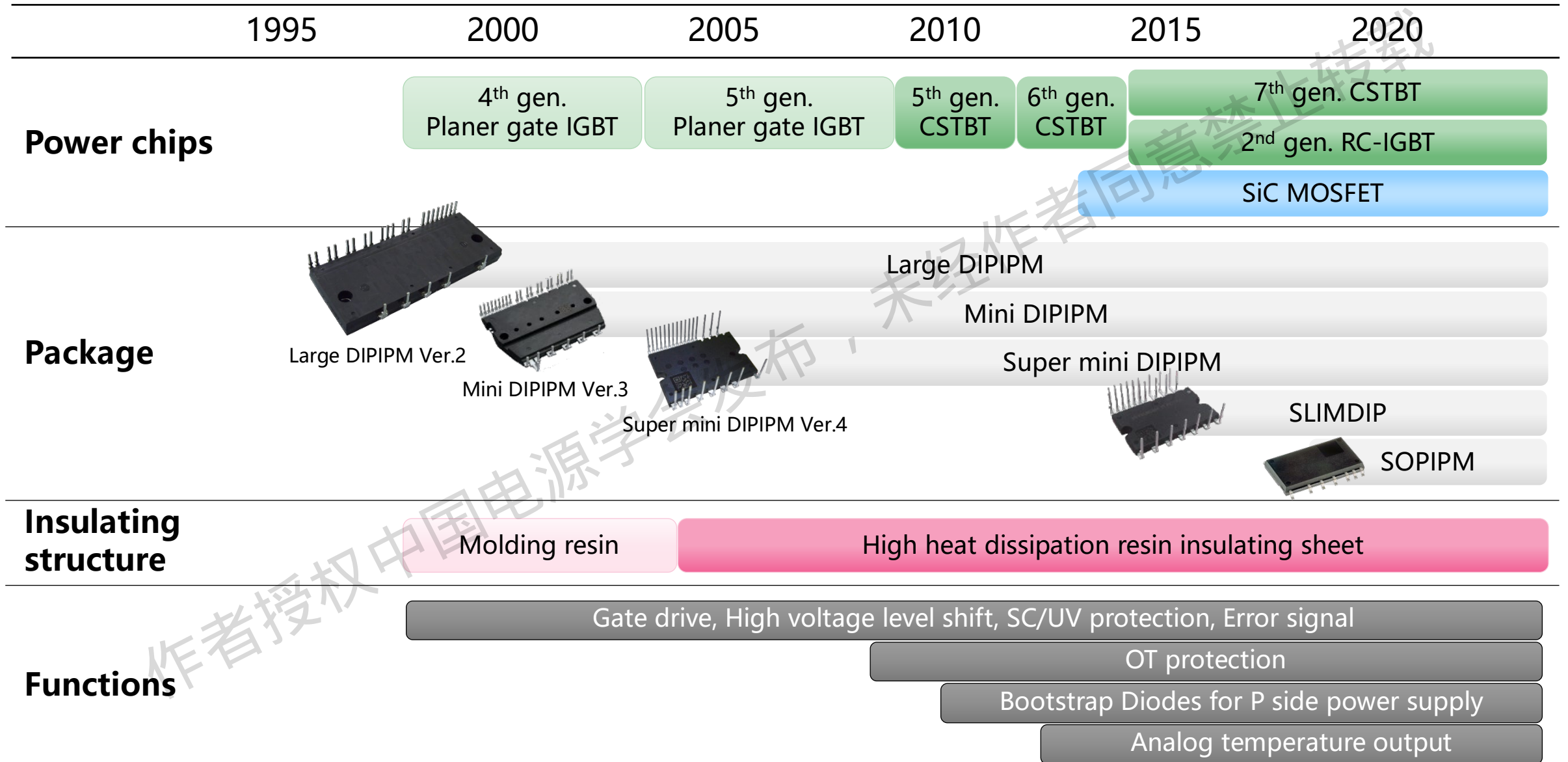
Large DIIPM+: 45 x 115(mm)

All-in-one DIIPM, including Converter, Inverter and Brake

- ✓ Lower cost
- ✓ Smaller PCB size
- ✓ Better noise characteristics
- ✓ Shorten development cycle

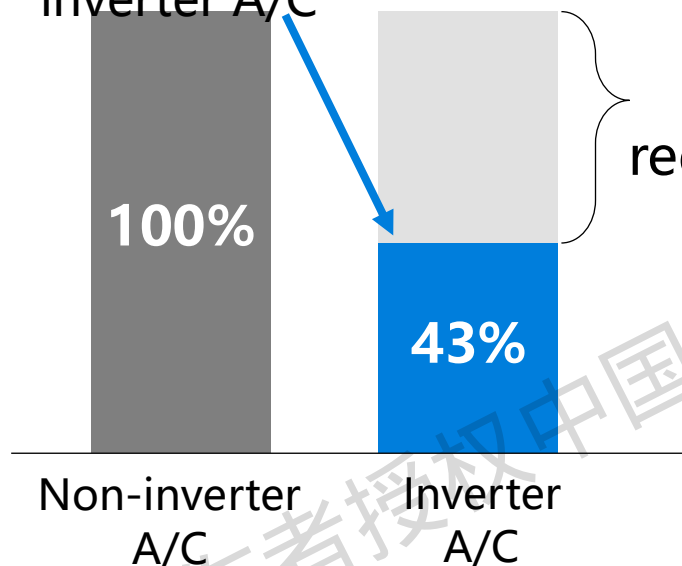
	5A	10A	15A	25A	35A	50A	75A	100A	150A
1200V	DIIPM+				Large DIIPM+				
600V									

Note: no brake inside Large DIIPM+



The power saved by DIPIPM is equivalent to 5.5 times of household power consumption in Tokyo

Example annual power consumptions by inverter/non-inverter A/C



Example annual power consumption of 1HP (2.8kW) unit
Non-Inverter type: 2124kWh / Inverter type: 913kWh
Calculated based on JIS C 9612:2013, wooden house in Tokyo



DIPIPM production in 2021

57% reduction \times

= **DIPIPM saved 147 TWh a year as inverter key parts!**

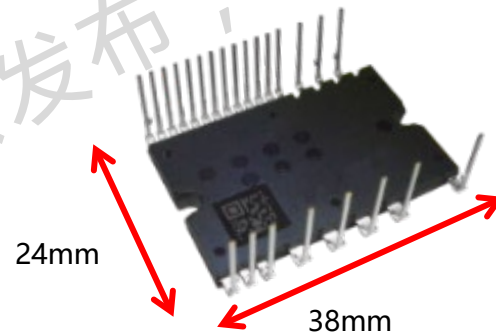
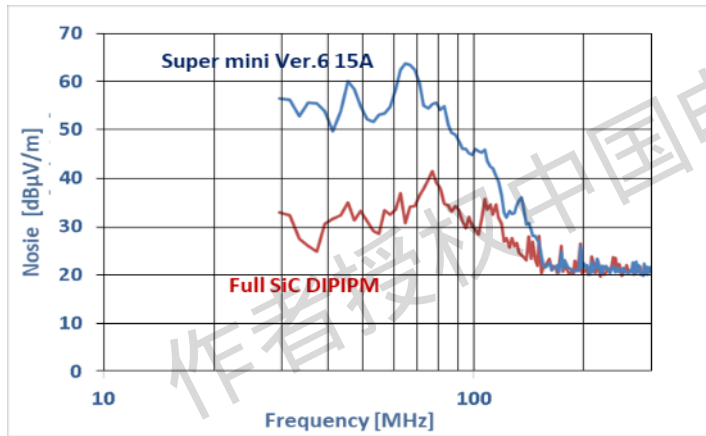


Japanese household power consumption: 3,708kWh/year
Number of household of Tokyo: 7219k household
All household power consumption in Tokyo: 27TWh

Features

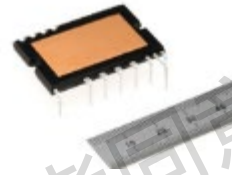
- ❑ Low ON voltage and Forward voltage by SiC MOSFET
→ Low loss
- ❑ Reduce recovery current and noise by applying body Di of SiC MOSFET
- ❑ Available to use common PCB with Super Mini DIP series

Radiation noise




Part No.	Application	Ratings
PSF15S92F6	A/C, small INV	15A/600V
PSF25S92F6	A/C, small INV	25A/600V


Air conditioner




launched in 2016



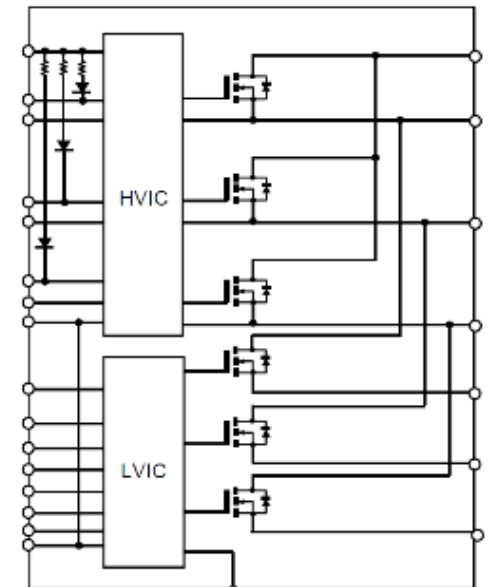
600V Full SiC DIPIPM™

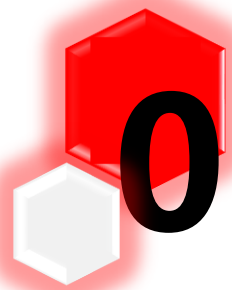


三菱ルームエアコン Zシリーズ



Block Diagram 框图



 **05**

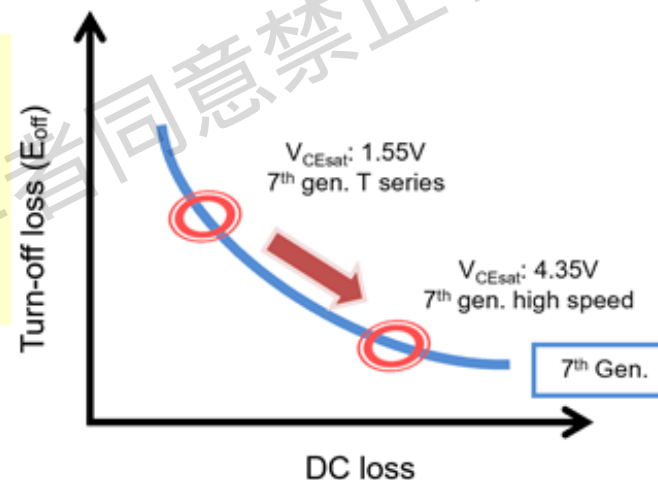
**High frequency power modules
for medical instruments**

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Module optimized for high speed switching applications

- ✓ Low power loss on high switching frequency operation (fc: 20~60kHz)
- ✓ Optimized for trade-off of IGBT and Di
- ✓ Target application: Medical, welding etc.
- ✓ Structure: 7th gen. high speed type chips + Cu base plate
- ✓ Other specs.: $V_{isol}=AC4.0kV$, $V_{CC}=850V$, $T_{vjop}=150^{\circ}C$, $T_{vjmax}=175^{\circ}C$



Package and line-up

※Only 1200V products

48 × 94mm



1200V / 200A

● CM200DY-24TH

62 × 108mm



1200V / 400A

● CM400DY-24TH

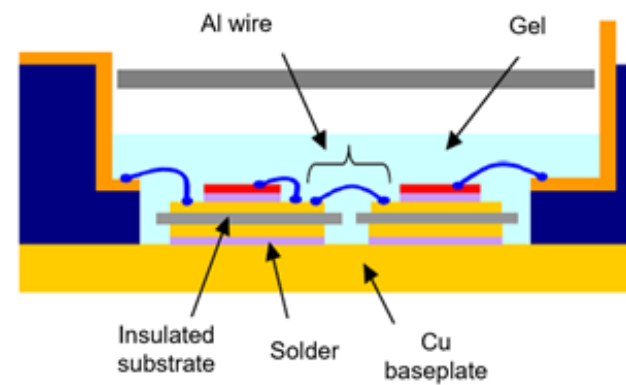
80 × 110mm



1200V / 400A, 600A

● CM400DU-24TH

● CM600DU-24TH

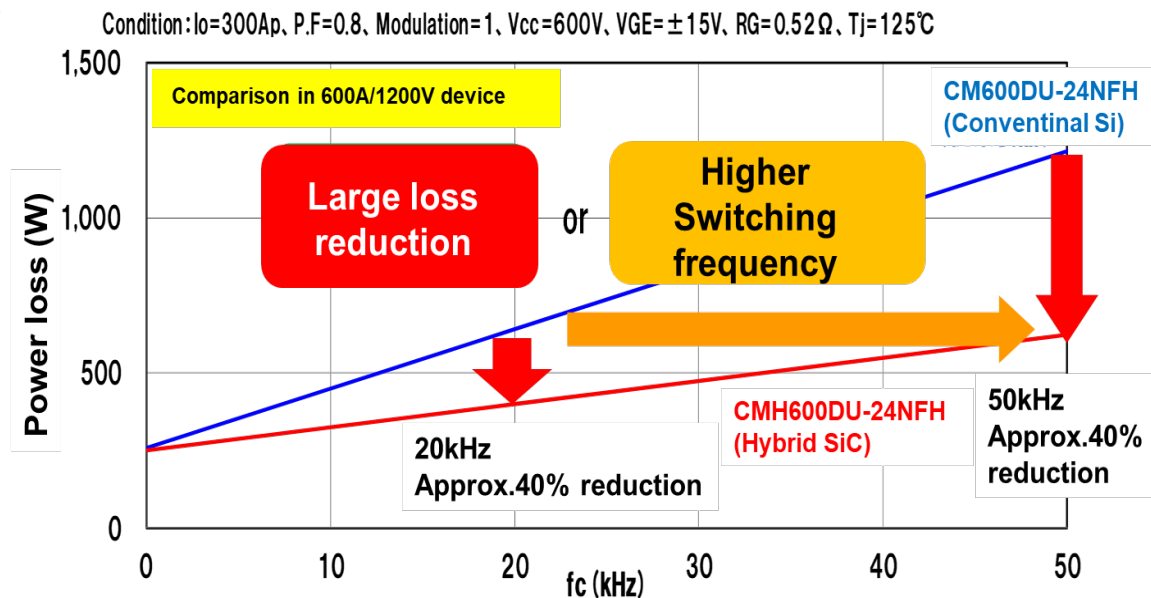
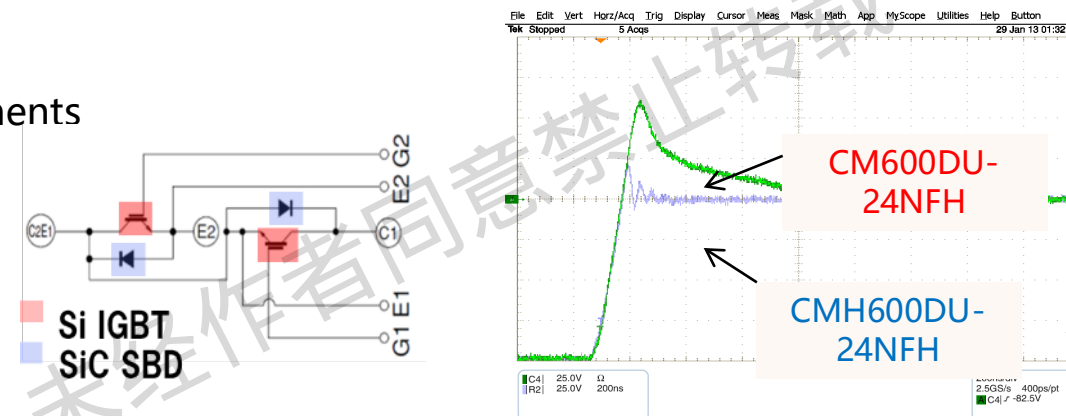


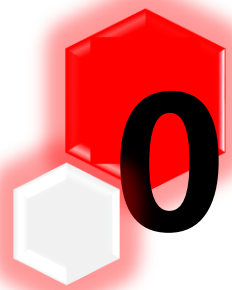
Internal cross section

- ✓ Low loss by SiC SBD chip ⇒ High efficiency, downsizing of heat sink
- ✓ High switching frequency ⇒ Miniaturization for peripheral components
- ✓ Compatible package with Si-NFH series ⇒ Easy replacement

Line up

Applications	Model	Rated voltage	Rated current	Circuit configuration	External size (D x W)
Industrial equipment	CMH100DY-24NFH	1200V	100A	2-in-1	48 x 94mm
	CMH150DY-24NFH		150A		48 x 94mm
	CMH200DU-24NFH		200A		62 x 108mm
	CMH300DU-24NFH		300A		62 x 108mm
	CMH400DU-24NFH		400A		80 x 110mm
	CMH600DU-24NFH		600A		80 x 110mm



 **06**

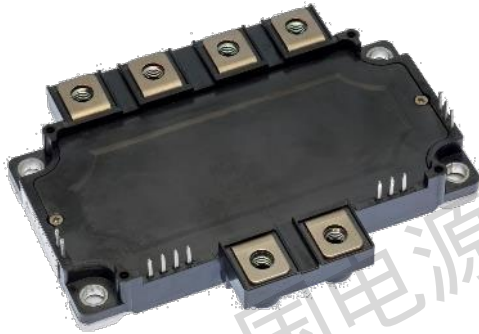
SiC power modules

for power electronic transformer

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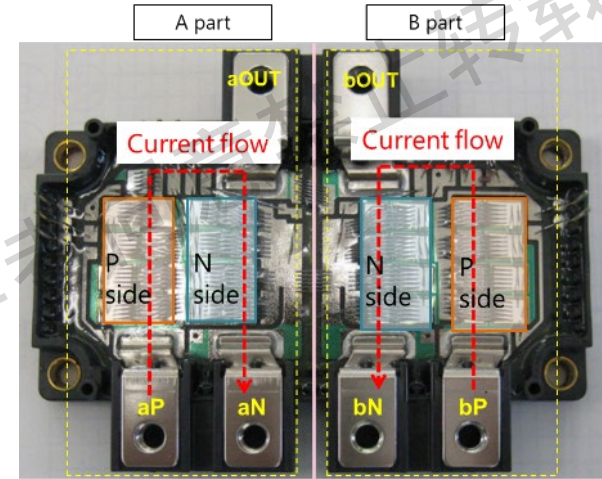
- Power loss reduced approx.70% compared with the conventional Si product*
 - Low internal inductance was achieved by symmetrical design
 - High switching frequency
- ⇒ **Miniaturization for peripheral components**



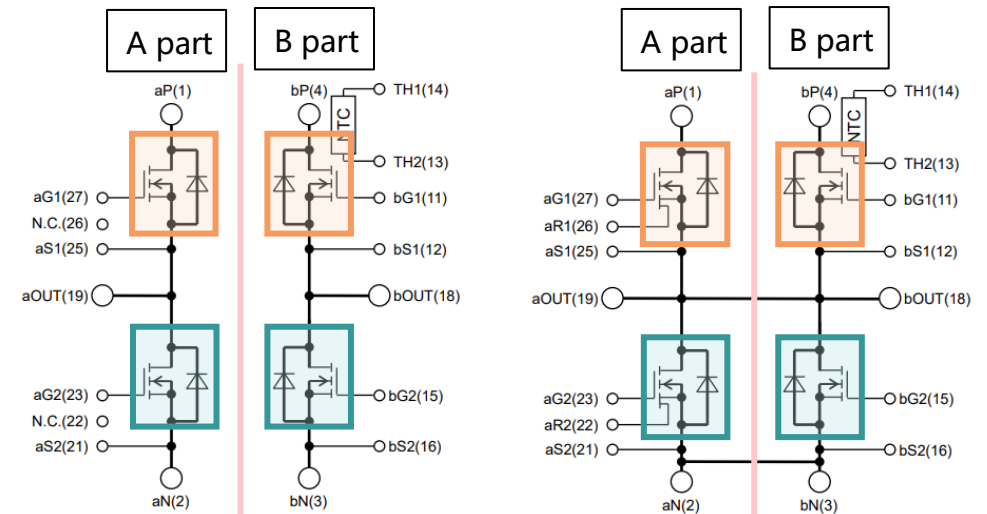
In production

Rated voltage	Type name	Rated current	Configuration
1200 V	FMF400BX-24B	400 A	4 in 1
	FMF800DX-24B	800 A	2 in 1

Internal layout



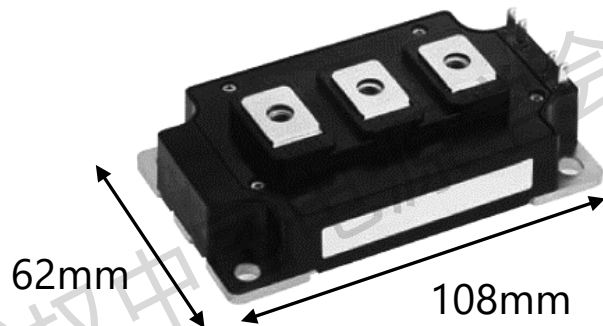
Internal Circuit



FMF400BX-24B

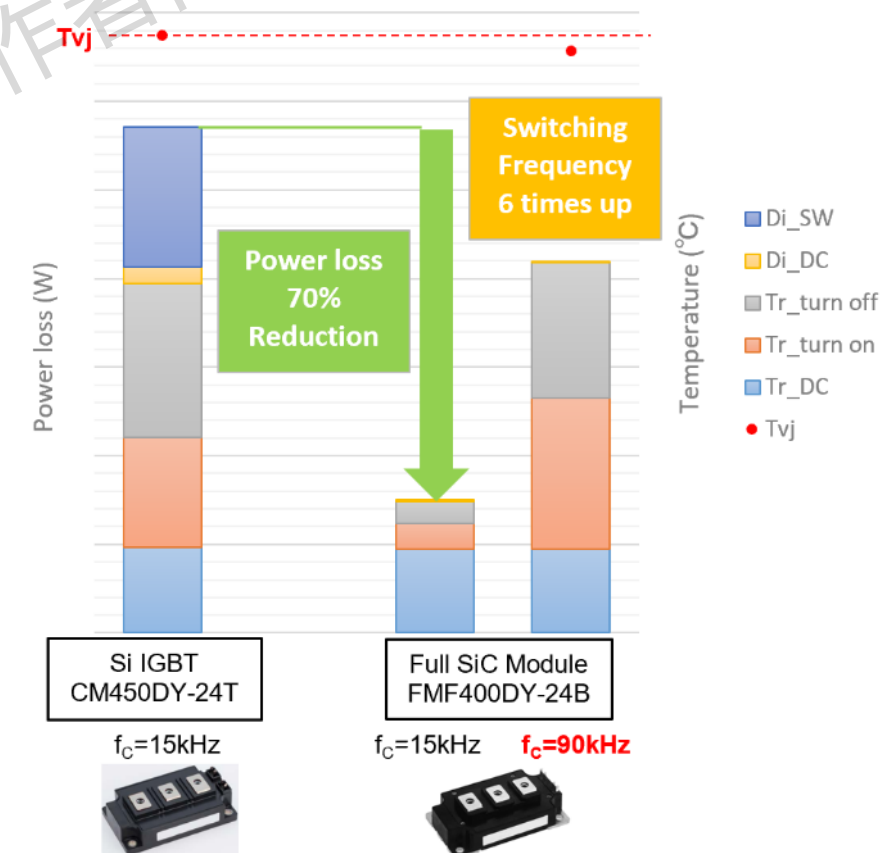
FMF800DX-24B

- ❑ Power loss reduced approx.70% compared with the conventional Si product*
- ❑ High switching frequency
 - ⇒ **Miniaturization for peripheral components**
- ❑ Compatible package with Si product
 - ⇒ **Easy to switch from Si device to SiC device**



Rated voltage	Type name	Rated current	Configuration	Package size
1200 V	FMF400DY-24B	400 A	2 in 1	62 x 108

Condition: $V_{cc}=600V$, $I_o=200Arms$, $PF=0.8$, Modulation=1, Sinusoidal



In production

6-03 2nd gen. Full SiC Power Modules(RTC)

- ❑ Power loss reduced approx. 70% compared to the conventional Si product
- ❑ Low-inductance package adopted to deliver full SiC performance
- ❑ RTC circuit is included for short circuit detection

In production

Rated voltage	Type name	Rated current	Configuration	#	Package size (mm)
1200 V	FMF300BXZ-24B	300 A	4 in 1	A	80 x 122
	FMF400BXZ-24B	400 A	4 in 1		
	FMF600DXZ-24B	600 A	2 in 1	B	
	FMF800DXZ-24B	800 A	2 in 1		
	FMF1200DXZ-24B	1200 A*	2 in 1		
1700 V	FMF300DXZ-34B	300 A	2 in 1	B	80 x 122
	FMF300E3XZ-34B	300 A	2 in 1 (Chopper)		

* Under development

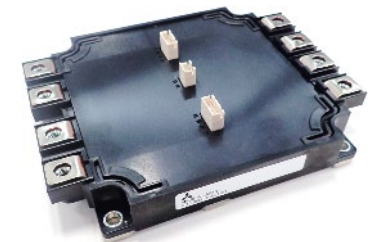
(A)



(B)

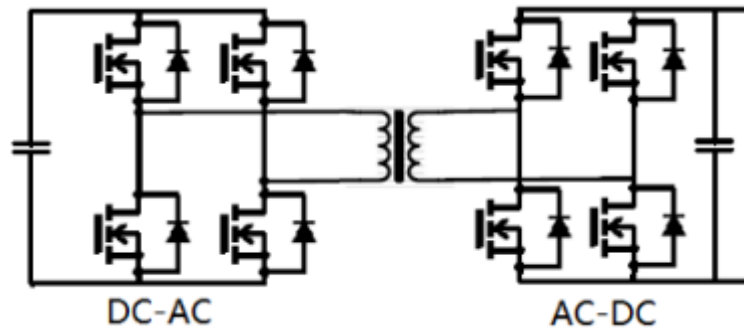


(C)



6-04 Dual Active Bridge based on full SiC module

Dual Active Bridge (DAB) converter is used in DC microgrid, new energy system and power electronic transformer. Power from thousands of watts to hundreds of kilowatts. Due to the excellent characteristics of low on-state loss and low switching loss of SiC devices, the performance and efficiency of DAB converter can be further improved.



Isolated DC/DC converter

500kW DAB test equipment based on FMF1200DX1-24A

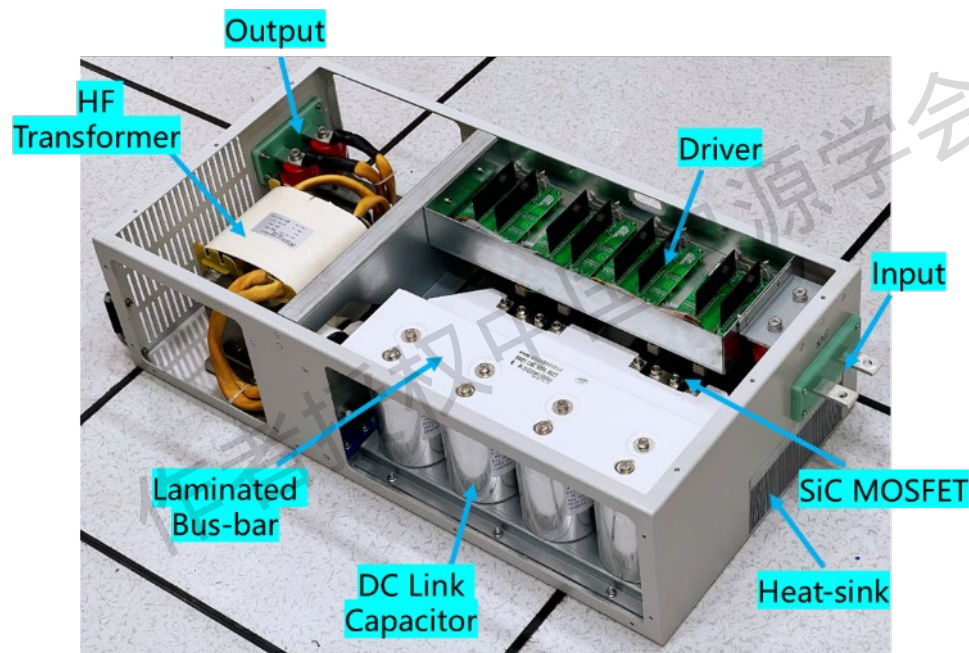
Application	Power capacity	Type name	Built-in topology
DAB converter	100kW	FMF300BXZ-24B	H-bridge
	135kW	FMF400BXZ-24B	H-bridge
	200kW	FMF600DXZ-24B	Half-bridge
	270kW	FMF800DXZ-24B	Half-bridge

*Fabian Sommer, Mirror Source based Overcurrent and Short Circuit Protection Method for High Power SiC MOSFETs

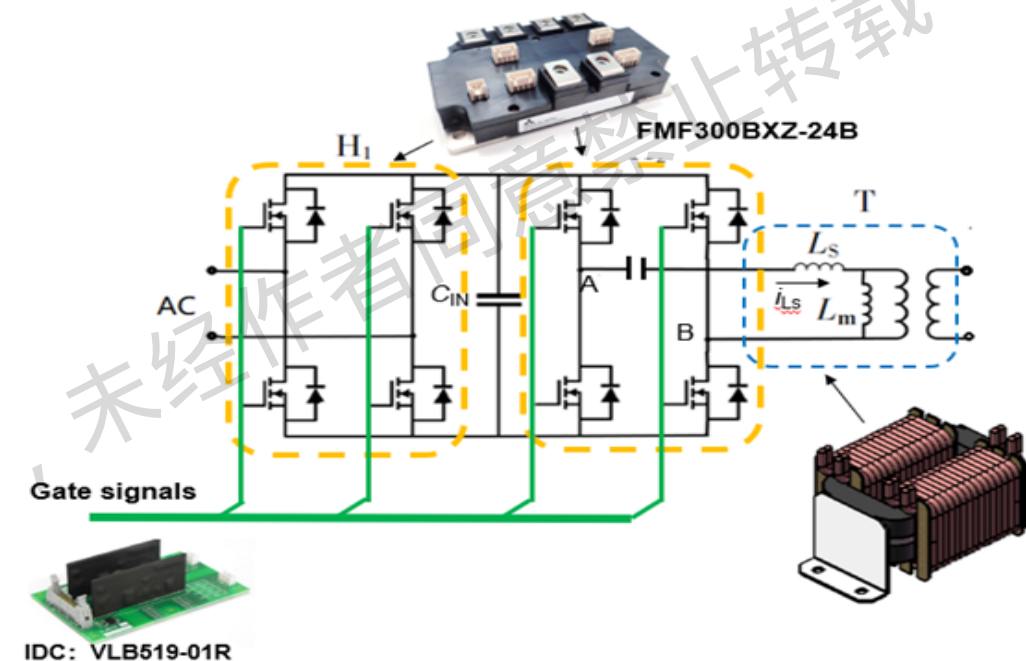
□ Spec. of PET stack

Rated capacity:	80kVA
DC Link voltage:	DC750V
Switcing Freq. :	20kHz
Topology:	DAB
Modulation:	Single phase-shift

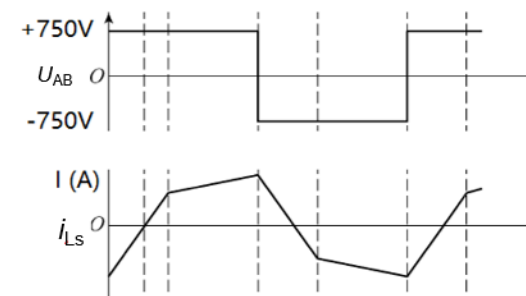
□ Photo of PET stack



□ Spec. of PET stack



□ Output voltage & current



 **07**

Mid voltage IGBT

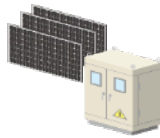
for renewable energy power generation

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□ PV Inverter

For central high power PV inverters 1500V_{DC} is common standard



□ BESS

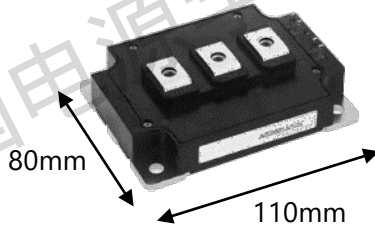
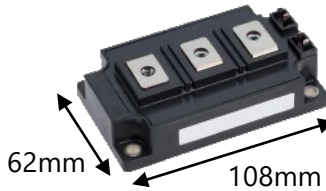
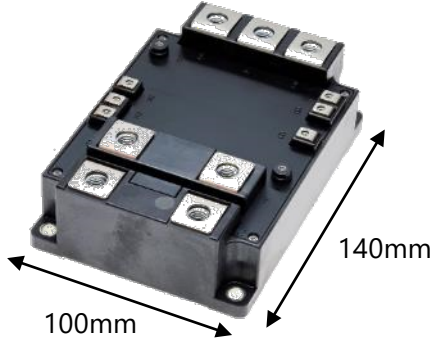
Many battery storage systems are based 1500V_{DC} voltages



□ Wind Power Converter

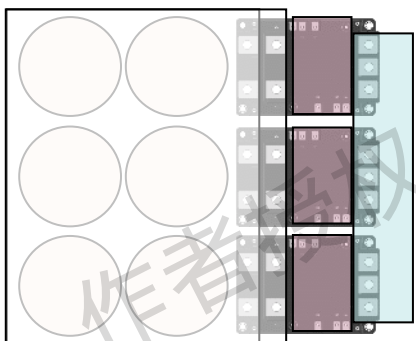
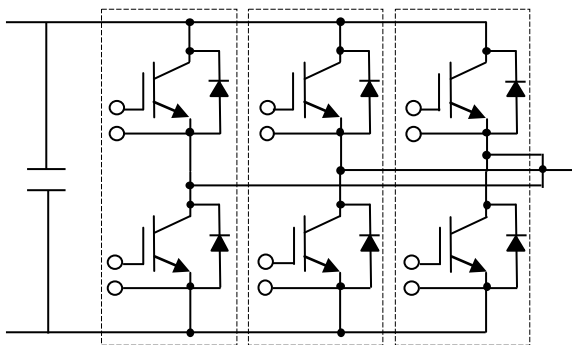
Increase of AC and DC-voltage so as to achieve cost reduction and system optimization



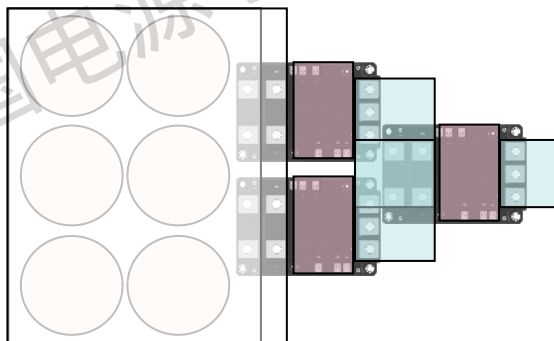
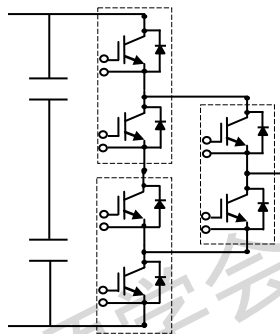
Blocking voltage	2000V		
Type name	CM400DY-40T	CM400DY-40TA	CM1200DW-40T
	std. package (80mm)	std. package (62mm)	Industrial LV100
Package			
Chip	7 th generation IGBT and FWD		
Maximum DC voltage	1500V		
Isolation voltage	4kV		

Simple and Scalable

- Simple 2-level topology **reducing complex mechanical design**
- High scalability by simple 2-level topology paralleling



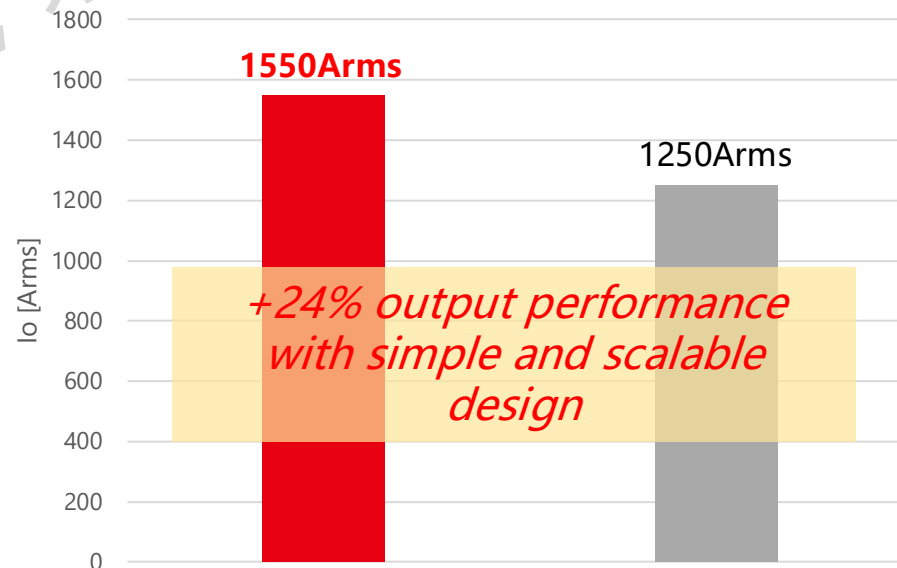
CM1200DW-40T
with 2-level / 3pcs paralleling



CM1200DW-24T
with 3-level ANPC (I-type)

Output current (calculated example)

SPWM, $V_{cc}=1400V$, $V_{out}=850V_{rms}$, $PF=1$, $M=1$, $R_{th}(\text{heatsink}) = \text{water cooler assumed}$
 $f_c(2\text{-level})=2.5\text{ kHz}$, $f_c(3\text{-level})=1.25\text{kHz}$ ($\frac{1}{2}$ of $f_c(2\text{-level})$)

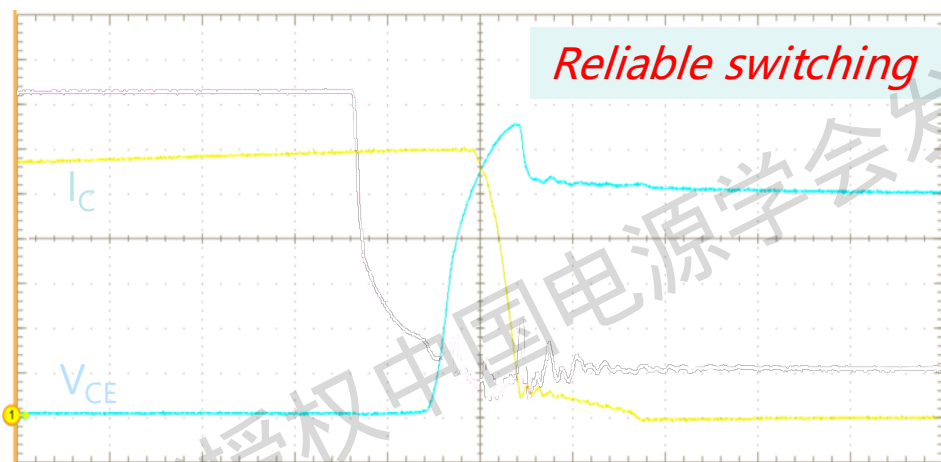


CM1200DW-40T 2-level / 3pcs paralleling
CM1200DW-24T 3-level ANPC (I-type)

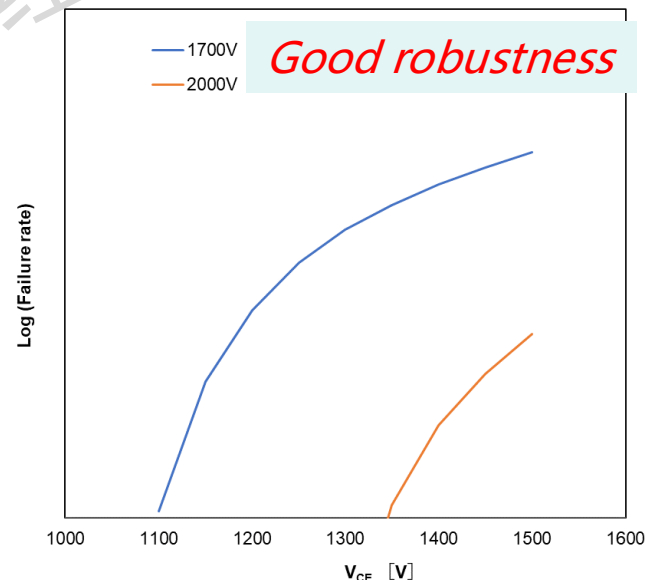
High Reliability

- 7th gen. 2.0kV IGBT / FWD has **reliable switching at 1500V_{DC}**
- High efficiency **by latest 7th gen. IGBT and FWD**
- **Lower LTDS failure rate** than 2-level topology with 1.7kV device

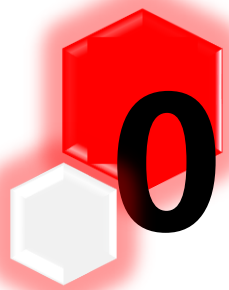
LTDS: Long Term DC Stability



IGBT Turn-off waveform
(CM1200DW-40T, V_{cc}=1500V, I_c=2400A, T_j=150°C)



LTDS curves of 1200 A IGBT modules



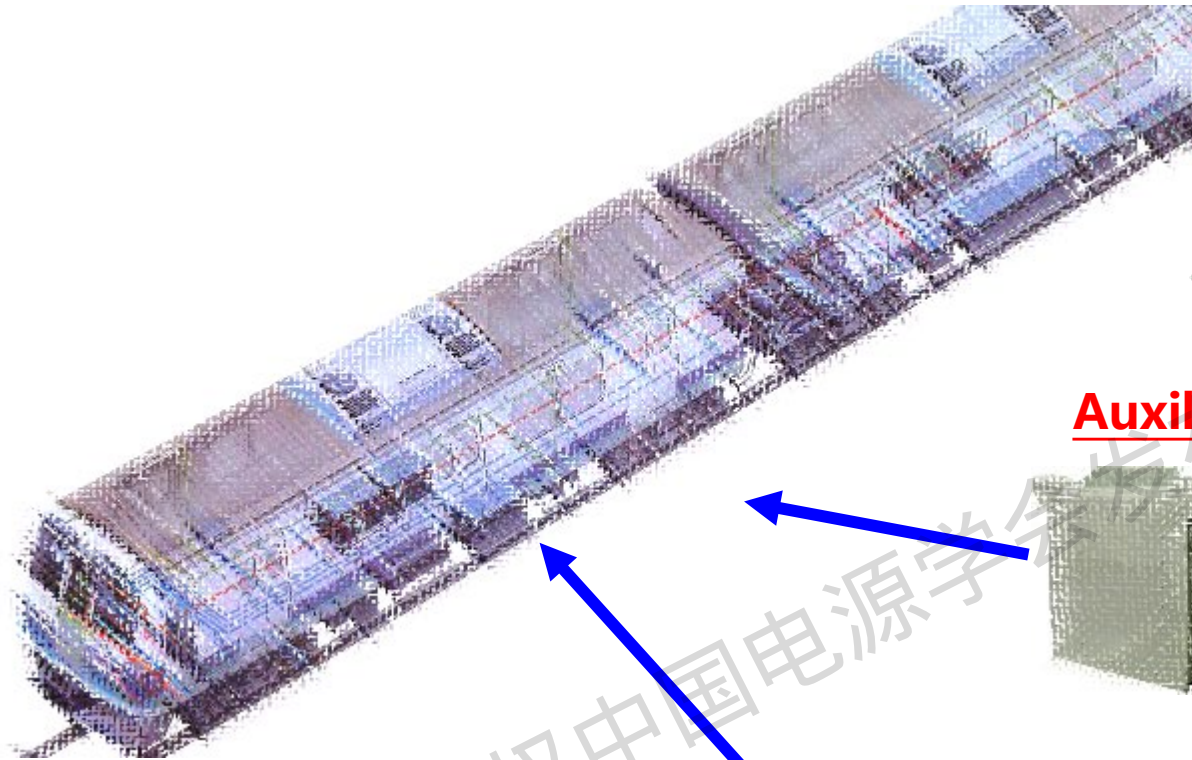
08

High voltage power modules

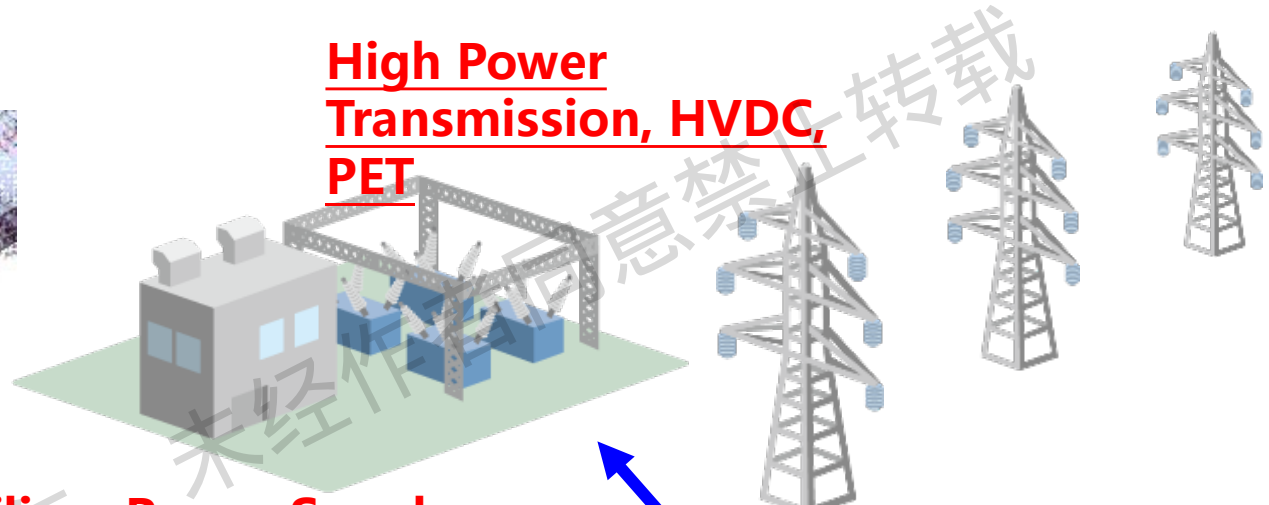
for rail traction

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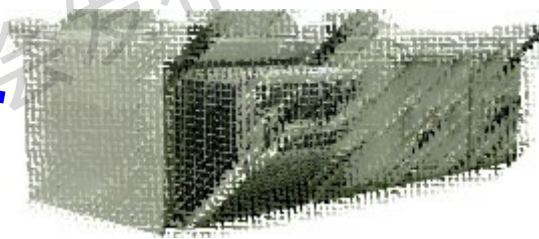




**High Power
Transmission, HVDC,
PET**



Auxiliary Power Supply



**X series, SiC
(LV100 / HV100 package)**

- High Voltage IGBT covers**
- 1,700V to 6,500V
 - 450A to 2,400A
 - Used in rail cars, and HVDC (High Voltage DC) electric power transmission

**Traction
Converter**



**X series
(Standard package)**

8-02 High Power Density Trend

3.3kV

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

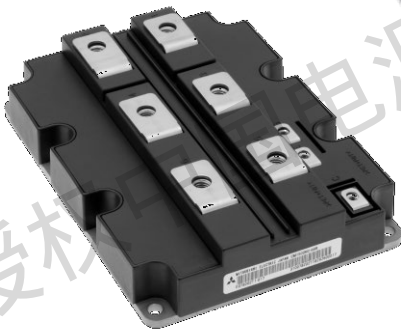
The same footprint size for H/R/X modules as below

H-series (1200A)



4.51 A/cm²

R-series (1500A)



5.64 A/cm²

X-series (1800A)



6.77 A/cm²

Si-IGBT LV100 (600A)



8.57 A/cm²

Package improvement

Si-IGBT chip improvement

SiC LV100 (750A)

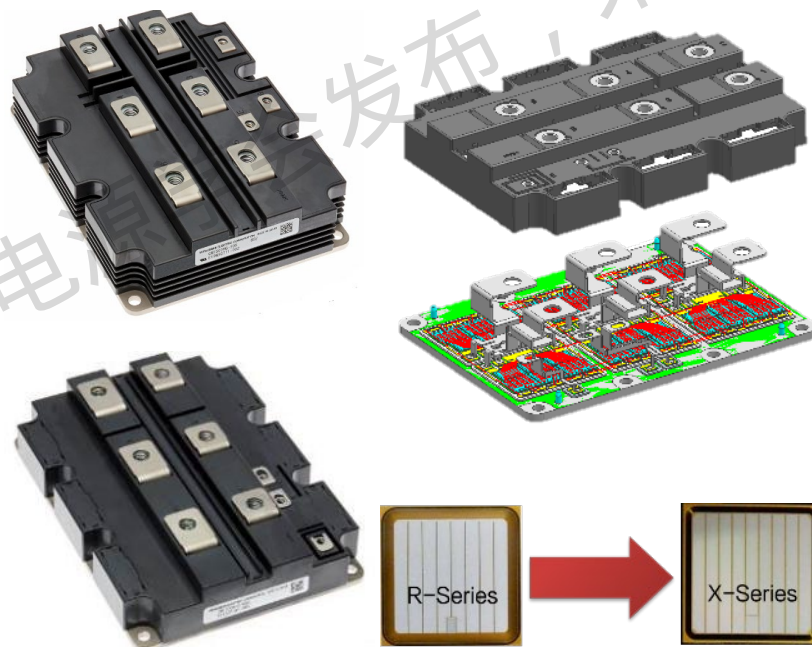
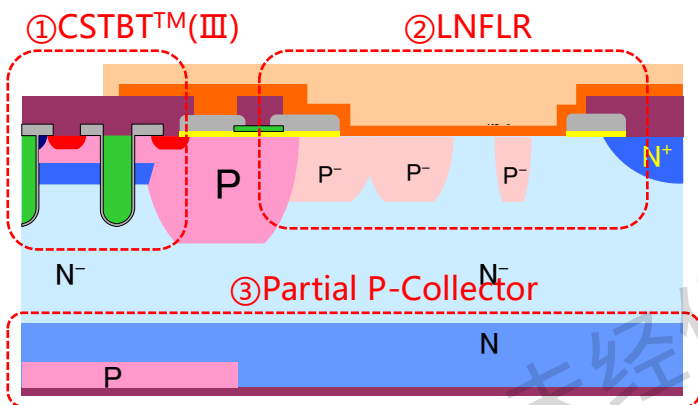


10.71 A/cm²

SiC-MOSFET introduction

The same footprint size for Si LV100 and SiC LV100 as above

- ❑ 7th gen. IGBT chip and RFC* diode chip reduce power loss
- ❑ Reduced package size (in the case of same voltage and current ratings) will lead to smaller inverters
- ❑ Package' s new internal structure achieves longer lifetime through improved heat dissipation, moisture resistance and flame retardancy



3.3kV IGBT

① Inverter losses reduction

New trench gate structure

→ CSTBT™ (III)

- Higher carrier concentration at emitter side under on-state
- Lower V_{CEsat}

② Improvement output current & R_{th}

New edge termination structure

→ LNFLR (Linearly-Narrowed Field Limiting Ring)

+SCC (Surface Charge Control)

- Active area is increased by shrinking edge termination area
- Robustness against humidity

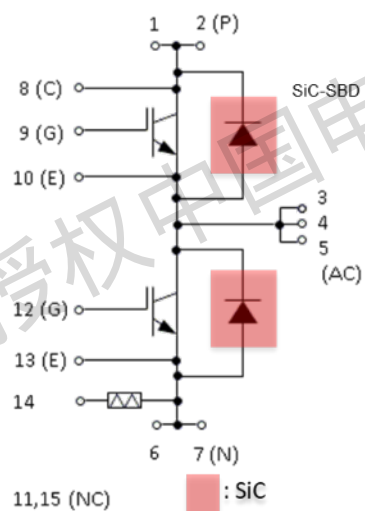
③ Wide SOA margin

→ Partial P collector

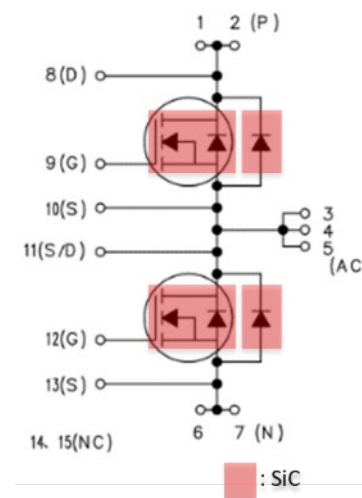
- Minimize hole injection efficiency in edge termination

*1: Relaxed Field of Cathode

Type	Series	P/N	Vce/Ic/Config	Feature	Common	Dimension	
LV100 (6kViso)	Hybrid SiC	CMH1200DC-34X	1.7kV/1200A/2in1	<ul style="list-style-type: none"> Low loss by SiC SBD NTC thermistor inside Reasonable cost 	<ul style="list-style-type: none"> Power unit can be standardized by using LV100 with Si and SiC chips 	100*140*40	
		CMH600DC-66X	3.3kV/ 600A/2in1				
	Full SiC	FMF750DC-66A	3.3kV/750A/2in1	<ul style="list-style-type: none"> Extremely low loss by SiC MOSFET & SiC SBD Higher current density 			<ul style="list-style-type: none"> Low inductive and symmetrical design for smooth switching
		FMF375DC-66A	3.3kV/375A/2in1				
		FMF185DC-66A	3.3kV/185A/2in1				

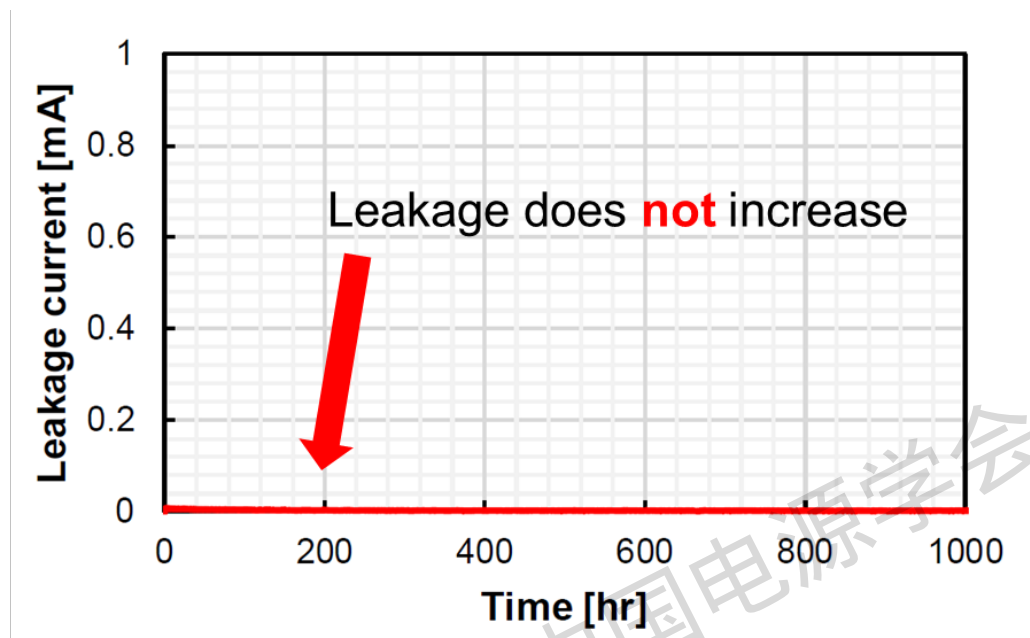


Hybrid SiC



Full SiC(FMF750DC-66A)

HV-H³TRB Reliability

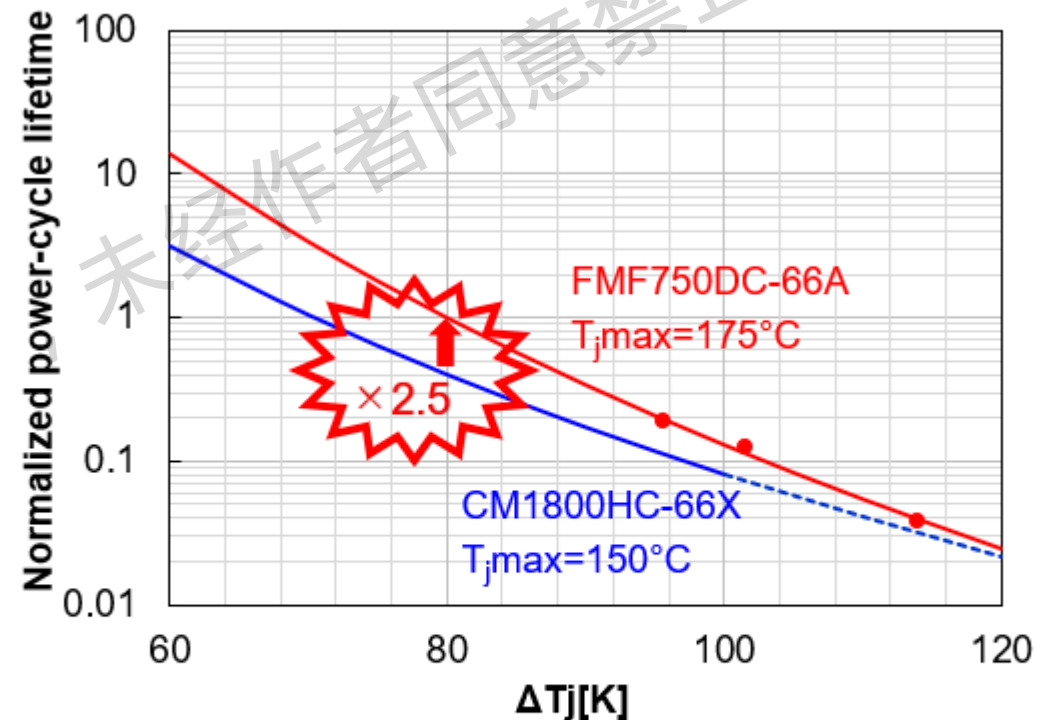


HV-H³TRB result

Condition: Ta=85 °C, RH=85 %, V_{GS}=-10 V, V_{DS}=2100 V

3.3 kV Full SiC shows excellent humidity resistance

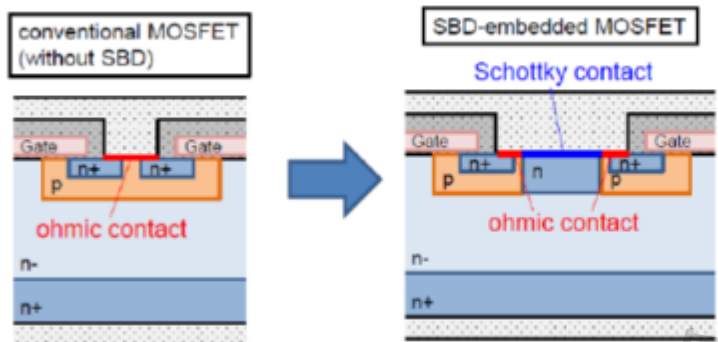
Power Cycle Reliability



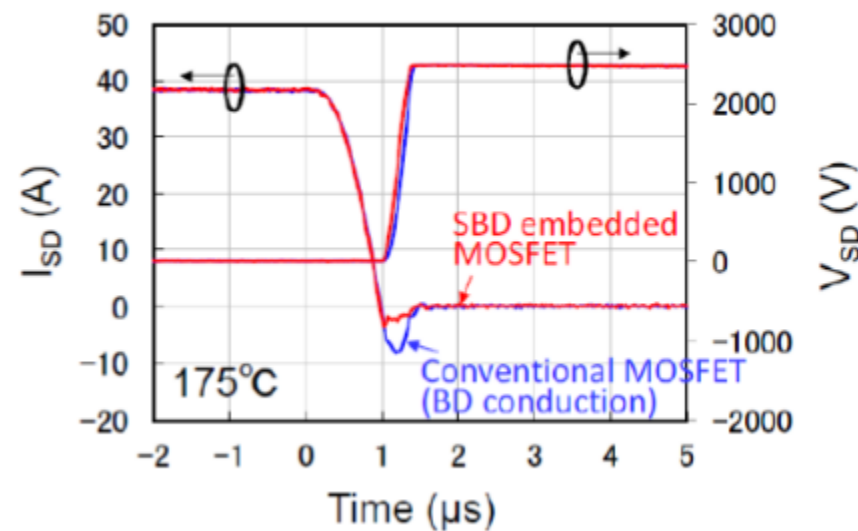
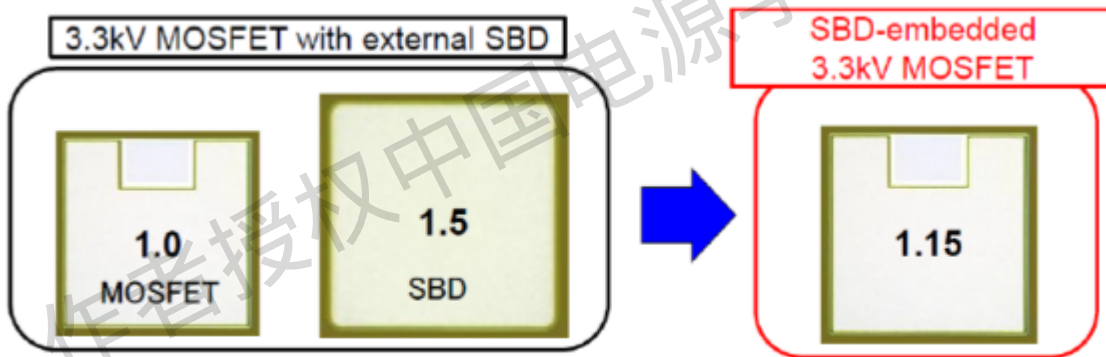
Power Cycle test result

3.3 kV Full SiC has excellent Power Cycle Capability

- ✓ SBD-embedded MOSFET module shows small recovery current thanks to unipolar operation;
- ✓ Development schedule: TS in 2023; ES in 2023; CS in 2024.



- ✓ Schottky and ohmic contacts in the same contact hole.
- ✓ No significant increase of process step.



Difference between conventional MOSFET and SBD-embedded MOSFET Reversed recovery waveforms



09

Power device solutions

for electric vehicles

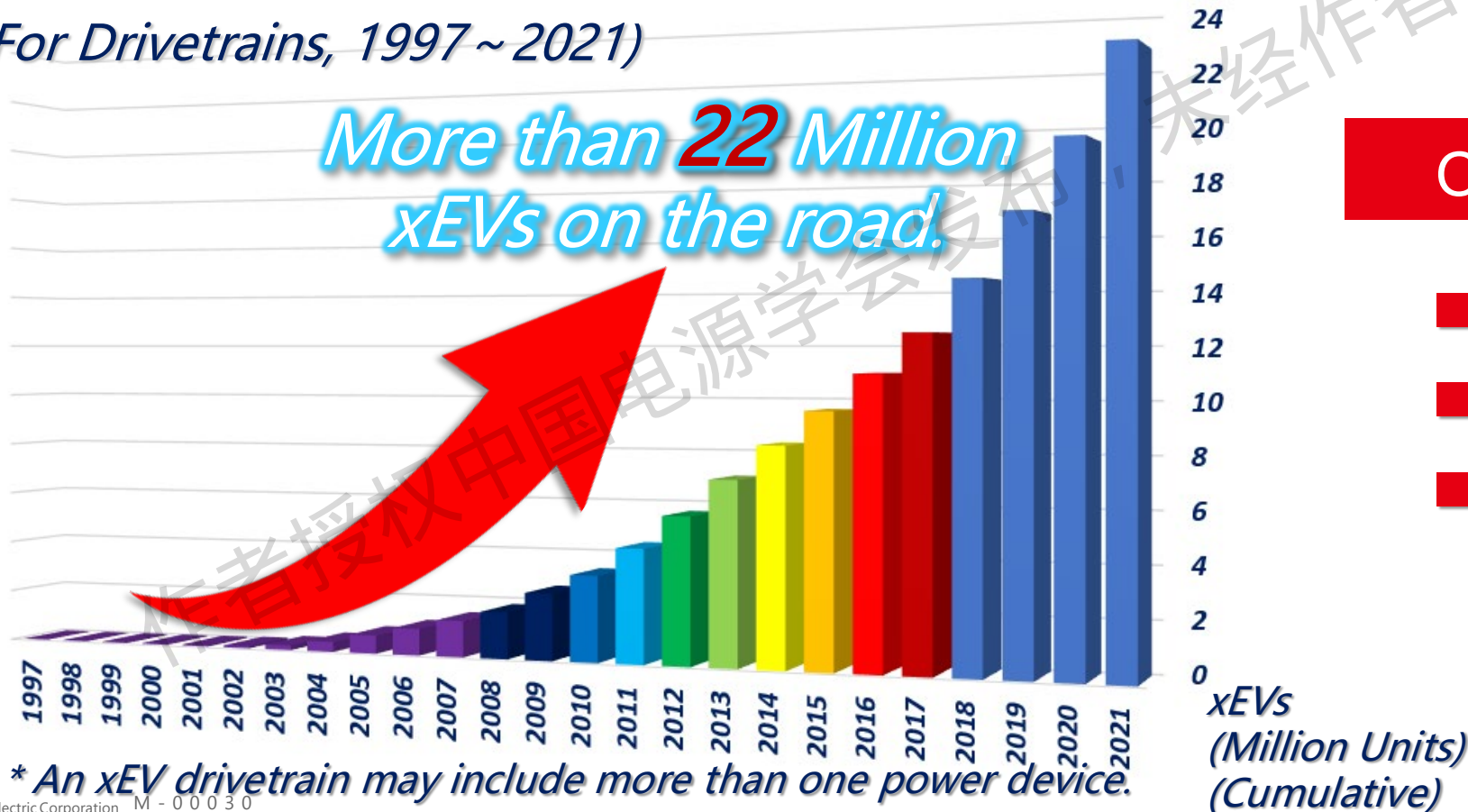
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- Since 1997, Mitsubishi Electric has pioneered the mass production of power modules for hybrid and electric vehicles.
- Proven High-Quality track-record with more than 22 Million xEVs on the road worldwide utilizing Mitsubishi Electric's power devices for Drivetrain.

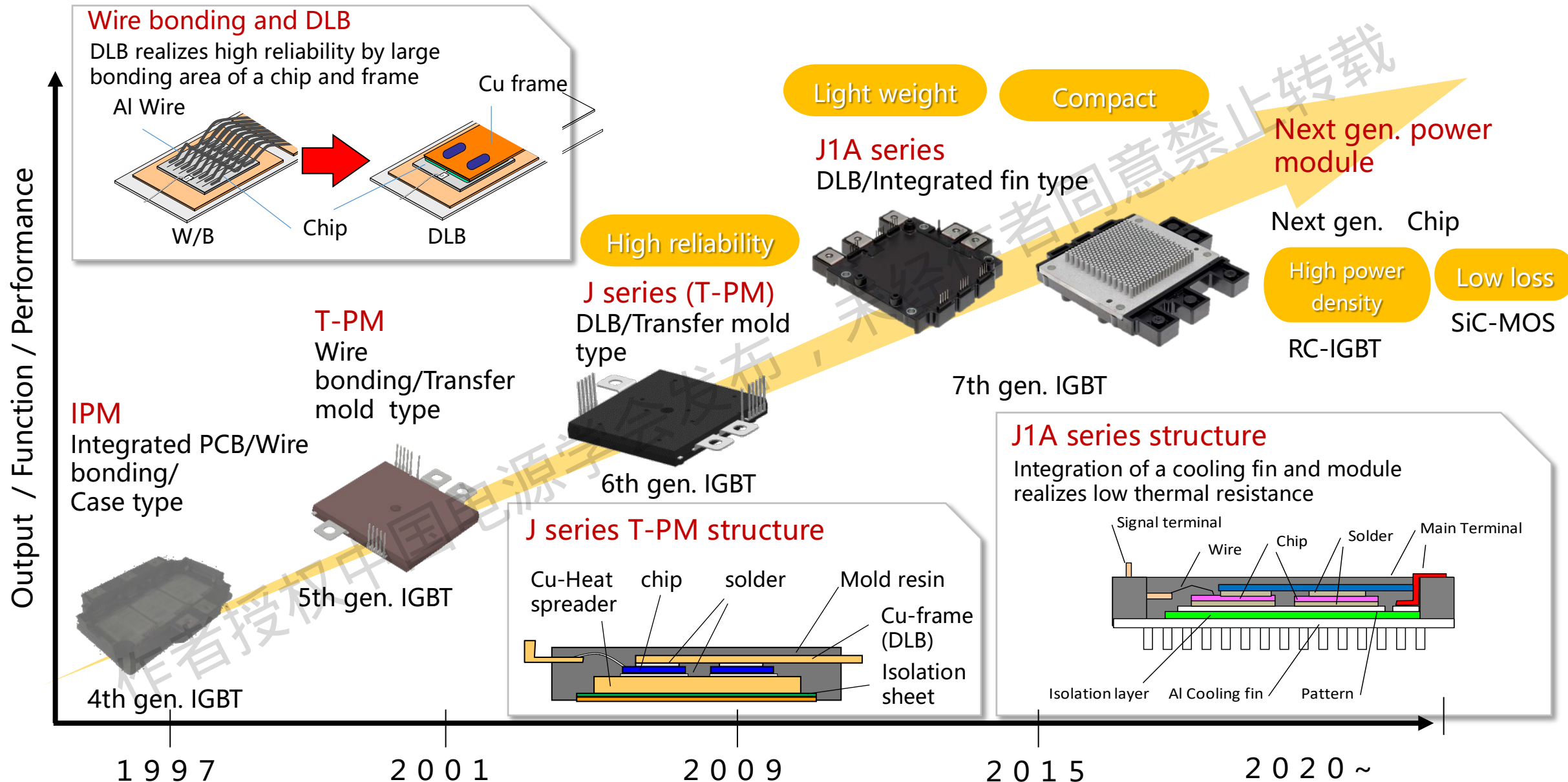
World-Wide xEVs using Mitsubishi Electric Power Devices

(For Drivetrains, 1997~2021)



Our strength

- *Miniaturization*
- *Low loss*
- *High reliability*



Ultra compact



CT700CJ1A060-A
120×115.7=12,884mm²; 350g

Small & Light



Competitor inside

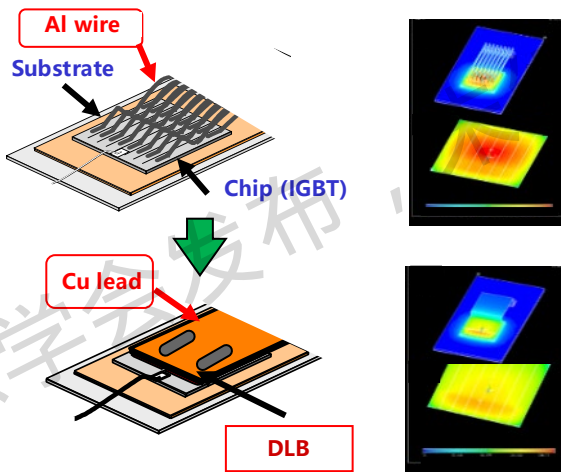
40~50 % smaller



J1A inside

Long life

Direct Lead Bonding (DLB)



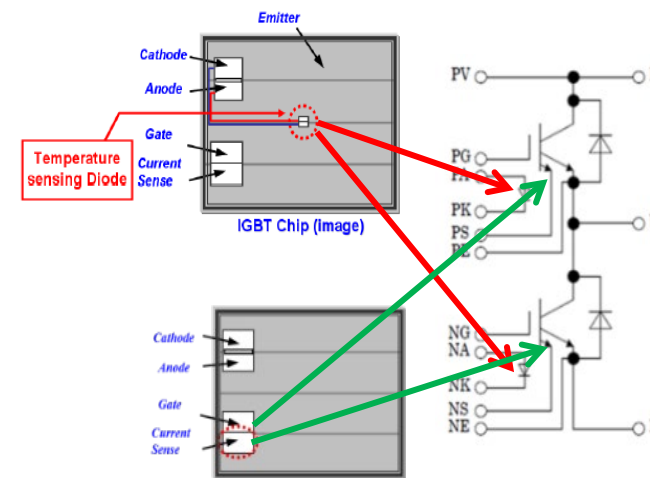
- DLB expands the binding area and makes the temperature distribution more uniform
- DLB improves the life of internal connections
- DLB reduces internal inductance (as low as 57%)



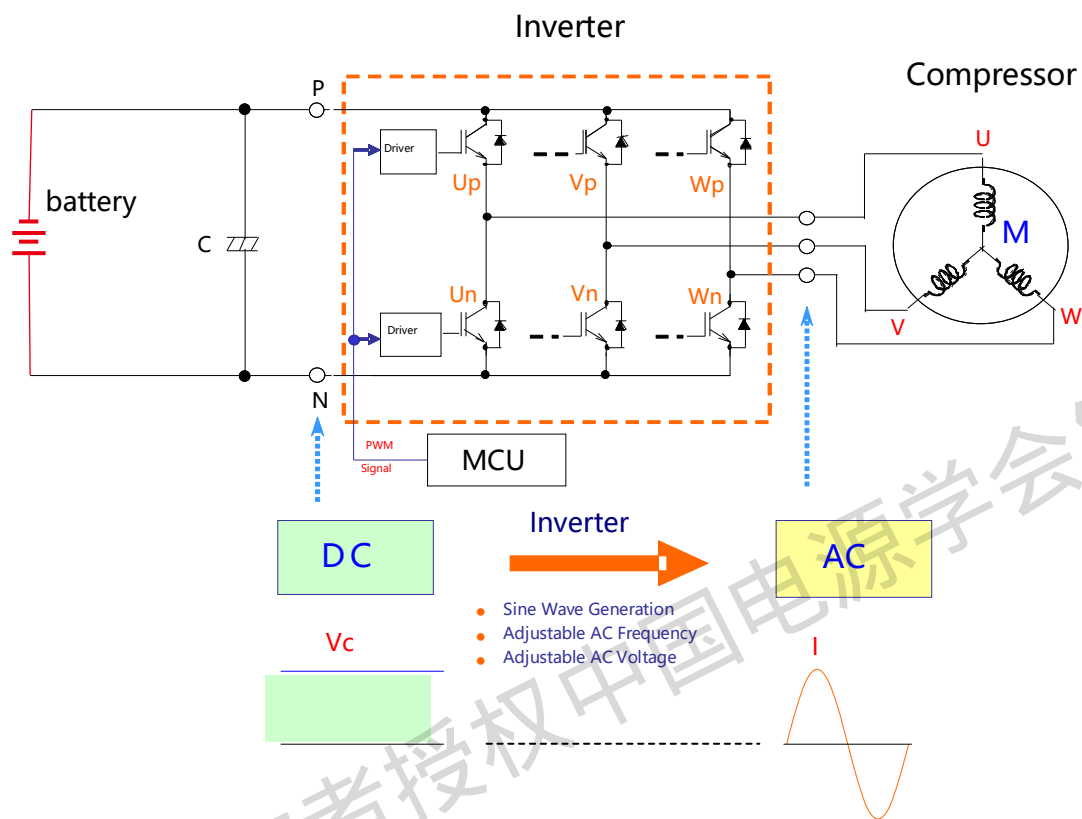
High P/C & T/C

Reliable protection

All Mitsubishi automotive IGBT modules have on-chip temperature/current sensor so as to achieve accurate and safe protection

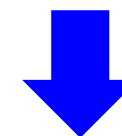


Topology of EV Air-conditioner

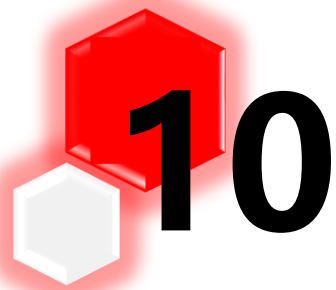


Power module solution for EV Air-conditioner

Battery Voltage	Capacity of Compressor	Mini DIIPM (600V)	Large DIIPM (1200V)
~DC400V	<26CC	PSS20S71F6	
	26CC	PSS30S71F6	
	34CC	PSS50S71F6	
~DC800V	36CC		PSS35SA2FT
	50CC		PSS50SA2FT
	63CC		PSS75SA2FT



Future: Higher voltage with new package;
AEC-Q certification



Summary

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□ Power chips

Mitsubishi Electric strategy for future WBG power semiconductor:

- MIT²-MOS™ trench-gate for LV SiC modules;
- SBD-embedded planar-gate for HV SiC modules;
- Planar SiC-IGBT for Ultra-HV SiC modules.

□ Packaging

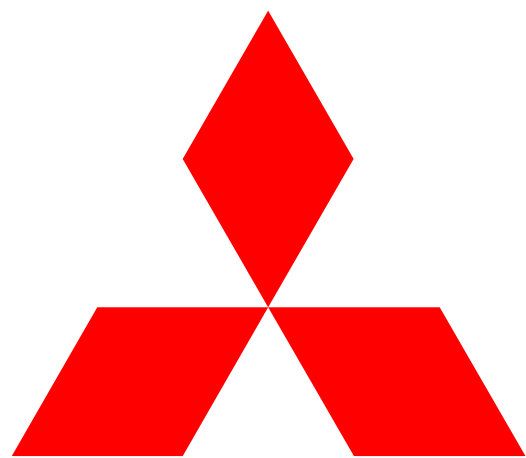
The number of resin encapsulated power modules shipped had increasingly exceeded that of gel encapsulated power modules.

□ Power modules

Mitsubishi Electric provide complete power device solutions for applications in household appliances, industry, new energy, railways and automobiles.



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ELECTRIC**

Changes for the Better

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