Mitsubishi Electric Press Conference
PCIM Europe 2023

May 9, 2023, PCIM site, Nuremberg

Dr. Masayoshi Takemi, Executive Officer,
Group President, Semiconductor & Device
Mitsubishi Electric Corp.

Dr. Gourab Majumdar (**Dr. Gourab Suzuki**), IEEE Fellow
Senior Fellow, Power Device Works
Mitsubishi Electric Corp.

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Contents:
- **Corporate Financial results, Vision**
- **Power Device Investment Plan**

● Corporate Financial results, Vision

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Financial highlight
-FY2022 Results /FY2023 Forecast-

Billion Yen

Net Sales (Left)

Operating Income (Right)

Home Appliances

Electronic Devices

Information & Communication Systems

Industrial Automation Systems

Energy & Electric Systems

6,000
5,000
4,000
3,000
2,000
1,000
0

400.00
300.00
200.00
100.00
0.00

FY2015 FY2016 FY2017 FY2018 FY2019 FY2020 FY2021 FY2022 FY2023

	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	FY2022	FY2023
	Actual	Actual	Actual	Actual	Actual	Actual	Actual	Actual	Forecast
Net sales	4,394	4,239	4,444	4,520	4,463	4,191	4,477	5,004	5,200
Operating income	301	270	327	290	260	230	252	262	330
(ratio)	6.9%	6.4%	7.4%	6.4%	5.8%	5.5%	5.6%	5.2%	6.3%
IBT	318.5	296.0	353.2	316.0	282	259	280	292	355
Net Income	228	210	256	227	222	193	203	214	260

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Financial highlight(Semiconductor & Device) -FY2022 Results /FY2023 Forecast-

Billion Yen

Net Sales

＊End of TFT business in FY22

300
250
200
150
100
50
0

FY15 FY16 FY17 FY18 FY19 FY20 FY21 FY22 FY23 Forecast

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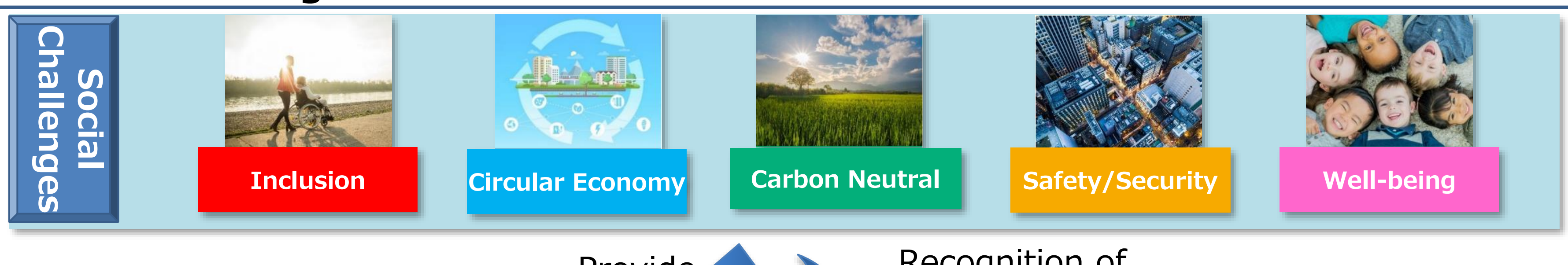
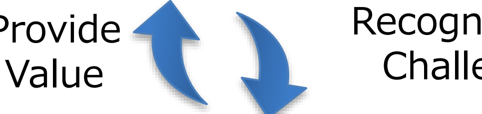
Social Challenges and MELCO Semiconductor`s Visions

■Social Challenges and Values our Business can Provide



Provide Value



Recognition of Challenges

Mitsubishi Electric Semiconductor and Device

【Power Semiconductors】
Pursue technical evolution by change of material and generation change
Power Supply, Motor Control(Energy saving,electrification)
・Consumer,EV, Renewable,Industrial,Traction,Grid

Realize a Carbon Neutral Society

【HF/OPTO Devices】
Create new value for changing feature/app.
Communication、Sensing (Connected、Detection)
・Comm. Network ・Data Center ・BTS ・Aircon ・Monitor

Realize a safe, secure and a comfortable society

Realize a sustainable society, increase corporate value

■Vision

Lead the change of society by "Evolution" and "Innovation" of Semiconductors

With continuous evolution and innovation on technology as our core, aim to be a leading company with top share products at each Product Group`s market segment

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●Power Device Investment Plan

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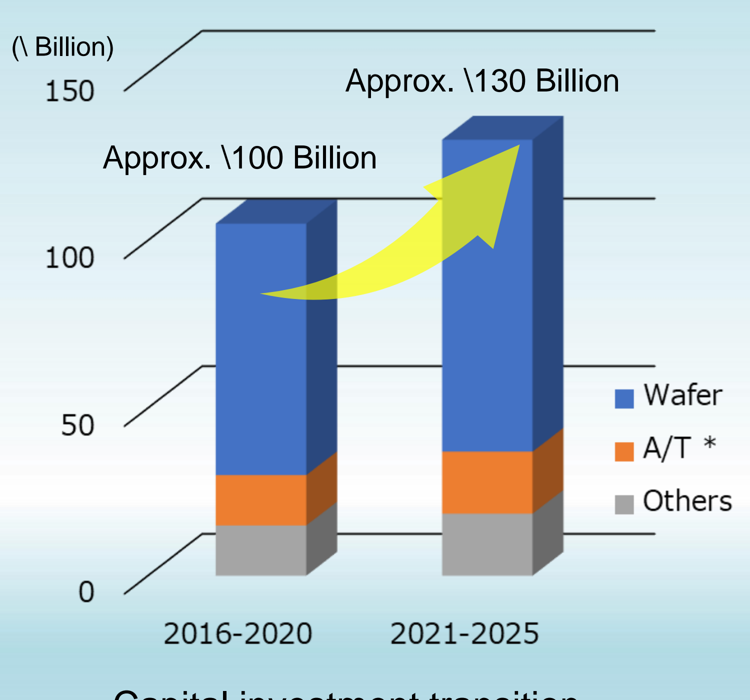
Investment Plan(Silicon) Nov.9th 2021 announcement

Capital Investment Plan

Wafer process capacity will be doubled by FY2025 compared to FY2020.

Also, invest on assembly and test process in a timely and appropriate manner to meet future demand.

Capital investment (actual, plan)



Capital investment transition

* A/T : Assembly and test

Manufacturing factory (example: wafer process)

- Constructed 200mm line with improved production efficiency at Fukuyama Factory.(***Silicon wafer***)

-Test run starts in November and production capacity will be gradually expanded.

<update> Production started at Apr./22 and capacity is expanding continuously.

-Started construction of 300mm line.(***Silicon wafer***)

<update>300mm wafer line will start from FY24.

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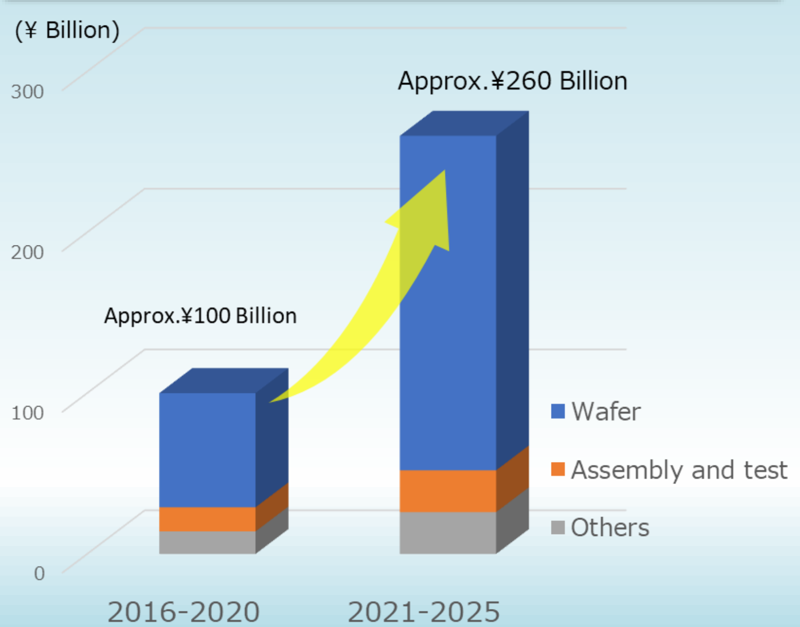
Investment Plan(SiC) March.14th 2023 announcement

- Cumulative Investment from FY2021 through 25 will be in the amount of approx. JPY260B (US$2B).
- The new wafer fab will be launched for SiC 8 inch on April 2026 at Kumamoto.
- The new additional factory for assembly and testing (AT) will be launched within FY2025 at Fukuoka.

Capital Investment (actual, plan)



Capital investment transition

The total amount of Capital investment from JFY2021 through 25 will be doubled as compared with the previous announcement made in November of 2021.

New Factories (Image:SiC Wafer Fab)

<Additional Capital Investment>
Wafer Fab: Shisui, Kumamoto Approx. JPY100B.
AT Factory:Imajuku, Fukuoka Approx. JPY 10B.

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Summary of Capacity Increase based on Investment Plan

Revenue

(¥ billion)

400

300

200

100

0

FY2021

FY2022

FY2025

FY2030

Progressing as planned for the medium-term plan

Accelerate growth with SiC

SiC sales ratio
＞ 30%

<SiC> FY2022 → FY2026
capacity approx 5 times

<Si >FY2020 → FY2025
capacity approx 2 times

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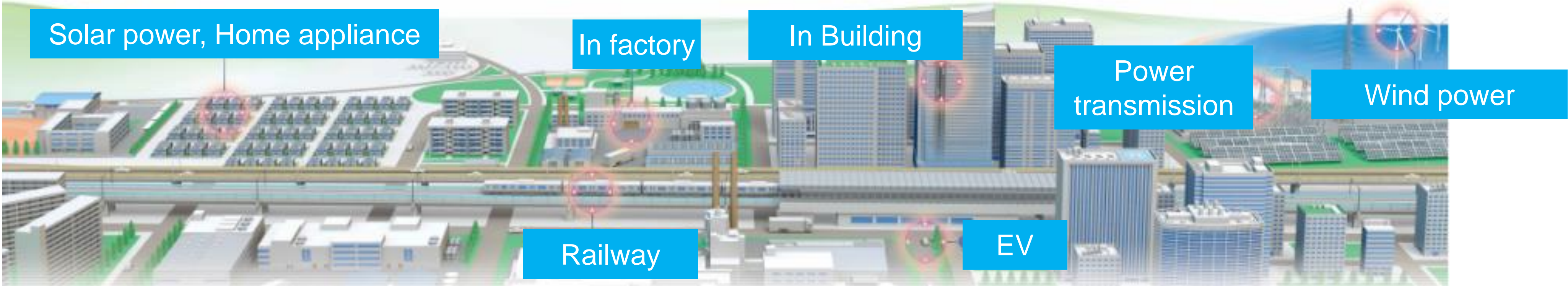
History of Silicon Carbide R&D and Products



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

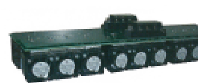
Application

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.

PV Power conditioner 2011/Jan.

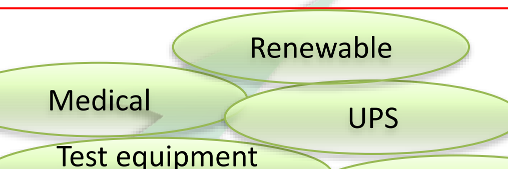
CNC Drive unit 2012/Dec.

APS for Railway 2013/Mar.

PV 2015/Jan.

Inverter for Railway 2013/Dec.

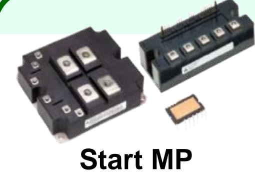
Improve productivity and performance of SiC device.

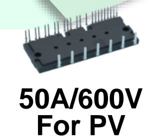


SiC Power modules

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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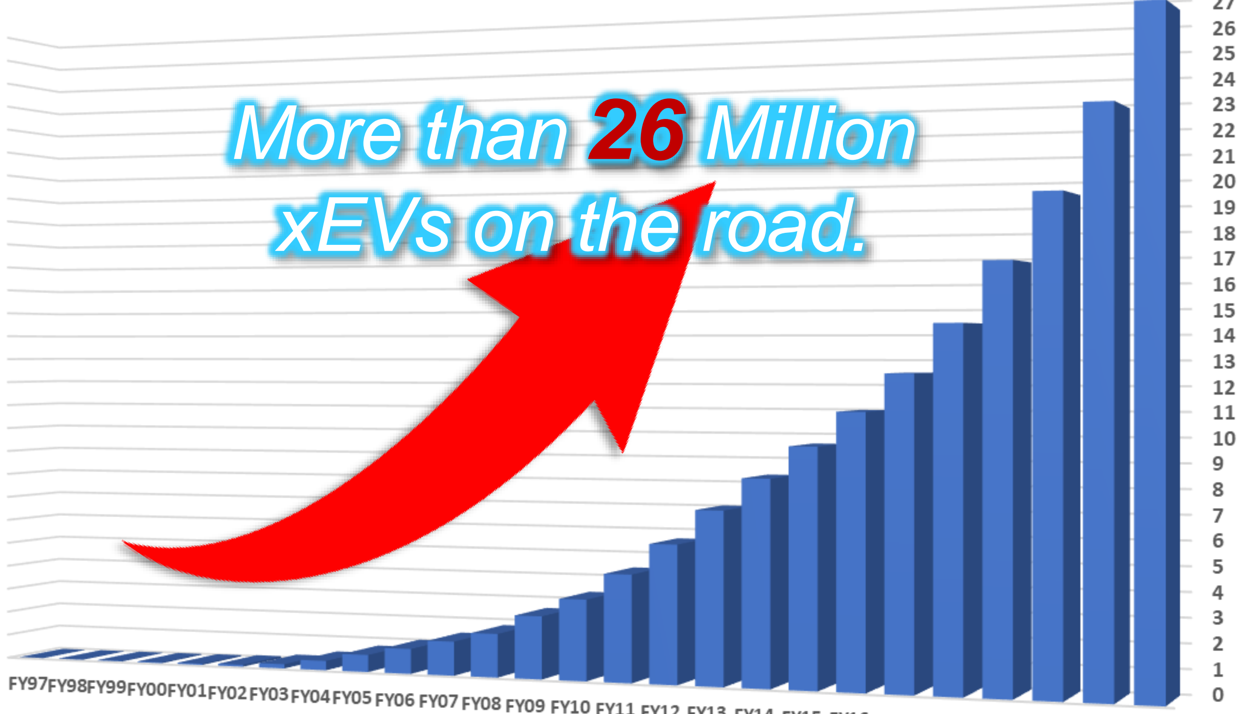
History of Automotive power devices

- ***Since 1997, Mitsubishi Electric has pioneered the mass production of power modules for hybrid and electric vehicles.***
- ***High-Quality track-record with more than <u>26 Million xEVs</u> on the road worldwide utilizing Mitsubishi Electric's power devices for Drivetrain.***

xEV power Device Shipment Record

-Accumulate Veihcle Number Base-



xEVs (Million Units) (Cumulative)

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

1997: MP of the world's first IPM for automotive
2015: MP of a power module integrated with a cooling fin
2016: Developed a power module implementing SiC
2020: MP of SiC for automotive

Our strength

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

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Dr. Gourab Majumdar (Dr. Gourab Suzuki), IEEE Fellow

Senior Fellow, Power Device Works
Mitsubishi Electric Corp.

Contents:

- **Background**
- **Advanced device technologies**
- **Advanced module products**

- **Background**
  - √ Power electronics and its new era
  - √ Chronology of our power device techs

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Power electronics application goes into new era

- Generation: Renewable energy generators are increasing
- Transmission & Distribution: AC&DC systems are expanding
- Carbon neutrality goals are demanding expansion and evolution of power electronics applications

→ Heavy impact on Power Electronics applications

Generation | **Transmission & Distribution** | **Electric Application**

Fossil fuel Power Plant
Hydroelectric Power Plant
Nuclear Power Plant
Photovoltaic Plant
Wind Power Plant (on/off shore)

AC Transmission
HVAC
Substation
Static Var Generator
Traction
AC Distribution
FACTS (SVG, STATCOM)
Renewable Energy
Energy Storage System
AC Distribution
Substation
HVDC
DC Transmission
HVDC
Substation
SVG (Middle,Small)
DC Distribution
Power Electronics Transformer(SST)
DC Distribution factory
Carbon dioxide Capture and Storage

Home appliance
Factory Automation (Servo, LV Drive) (Converter app.)
Crane, Mining (MV Drive)
Electric Construction Mobility
Air Conditioner
Escalator
Elevator
Factory, Building
xEV (Drive train)
UPS, Data Center
EV Charge Station
EV Bus
Hydrogen Electrolyzer
Hydrogen Charge Station

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 HEVs/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

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Historical Highlights of Mitsubishi Power Devices

Diodes

GTO thyristors (4,5kV/3,0kA) with world's largest capacity

Transistor Power modules (Insulated module)

GCTs (6,0kV/6,0kA) with world's largest capacity

Hybrid EV IPMs
DIPIPMs
(Transfer molded modules)

Hybrid EV T-PMs

SiC MOSFET modules

Integrated pin-fin module for xEV

7th gen. SLC modules for industries

Trench SiC MOSFET

1950s · 1960s · 1970s · 1980s · 1990s · 2000s · 2010s · 2020s · 2030s

Thyristors
JFET s

RC thyristors (2,5kV) with world's highest withstand voltage

TRIACs (300A) with world's largest capacity

Light Triggered Thyristors (8,0kV/3,5kA) in DC power transmission

IGBT modules
Industry IPMs

Installed HVIPMs (3,3kV/1,2kA) in Shinkansen

CSTBT™ IGBT

Expand IGBTs, IPMs (600V up to 6,5kV)

World first installed HVIGBTs (4,5kV/900A) in HVDC with MMC

Expand SiC modules (600V up to 3,3kV)

3.3kV Full SiC modules installed in trains

12' IGBT and 8' SiC
Wafer enhancement to meet booming demand

Thyristors & Bipolar Transistors

IGBTs and IPMs

SiC SBD and MOSFET

HV*** : High Voltage *** (≥ 1,7kV)
TRIAC : Triode for Alternating Current
GTO : Gate Turn-Off thyristor
GCT : Gate Commutated Thyristor
IPM : Intelligent Power Module
IGBT : Insulated Gate Bipolar Transistor
SiC : Silicon Carbide
MOSFET : Metal-Oxide-Semiconductor Field-Effect Transistor
MMC : Modular Multi-level Converter
SLC: Solid Cover Technology

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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

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Power loss 50%reduction

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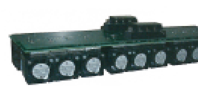
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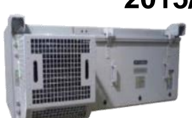
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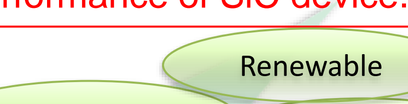
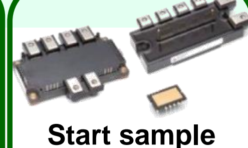


Improve productivity and performance of SiC device.

Renewable
Medical
UPS
Test equipment for automotive
xEV
High speed charger

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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- **Advanced device technologies**
  - √ **Silicon-based**
  - √ **SiC-based**

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- Advanced device technologies
  - √ Silicon-based
  - √ SiC-based

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Roadmap of Silicon IGBT technology

Meeting increasing demand

Smaller chip size

Larger wafer diameter

3rd Gen. IGBT

4th Gen. IGBT

5th Gen. IGBT

6th Gen. IGBT

7th Gen. IGBT

☛ RC-IGBT

Trench IGBT

CSTBT™

Finer pitch

Ultra thin process

	3rd Gen. IGBT	4th Gen. IGBT	5th Gen. IGBT	6th Gen. IGBT	7th Gen. IGBT
Relative chip size	~1,38	1,0	~0,6	~0,43	~0,33

Y-axis: 0,0 – 1,6

Chip size evolution (600V/10A)

Next Gen. 300mm

☛ RC-IGBT

5th-7th Gen. 200mm

4th Gen. 150mm

3rd Gen. 125mm

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Roadmap of Silicon Device technology

Ultra-Thin & Optimized Buffer

Legacy | '05 | '10 | '15 | '20 | '25 — Time scale: Chip development-based

IGBT

- 4th gen — Trench IGBT PT (p+, n+, p, n- 層（エピ）, n+ バッファ層(エピ), p+ 基板)
- 5th gen — CSTBT™ LPT (p, n, CS 層, n- 層)
- 6th gen — CSTBT™ LPT
- 7th gen — CSTBT™ LPT Thin
- 8th gen — CSTBT™ LPT

RC-IGBT

- 1st gen — IGBT+Diode In 1 chip
- 2nd gen — IGBT / Diode (p, n, n-, p+, n)
- 3rd gen — (p, n, n-, p+, n)

Diode

- 3rd gen — P, N- drift, N+
- 6th gen — 1200V級 IGBT; P, N- drift, N+
- 7th gen — RFC; P, N- drift, N+, P+
- 8th gen — RFC; P, N- drift, N+, P+

Next gen

Fine structure having novel features

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

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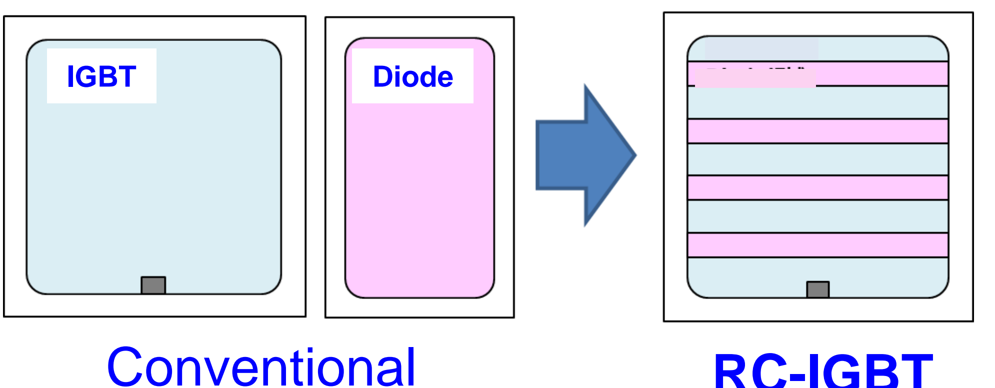
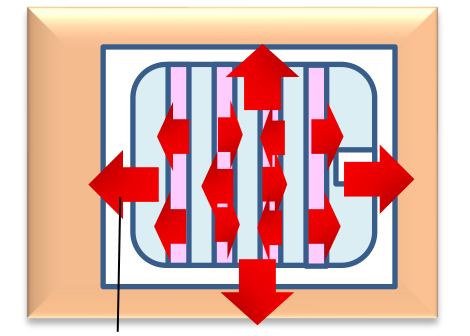
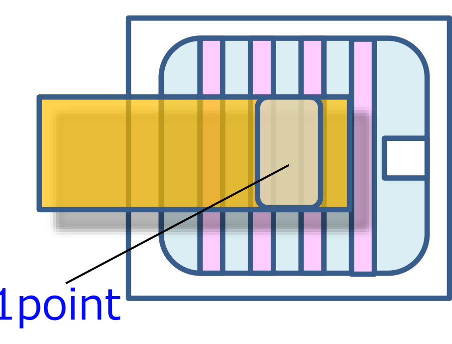
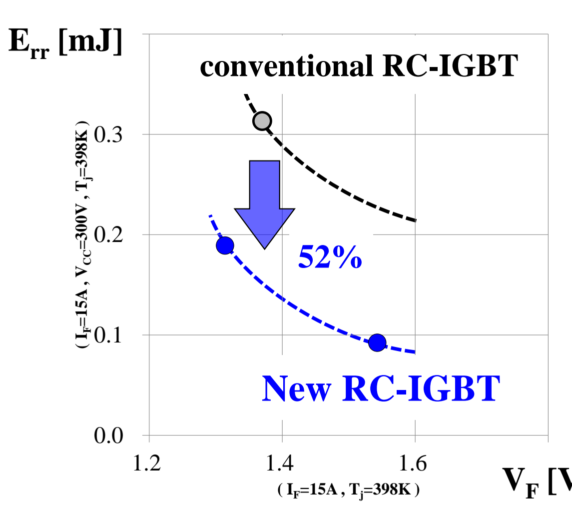
RC-IGBT, a two-way device integrating IGBT and Diode functions

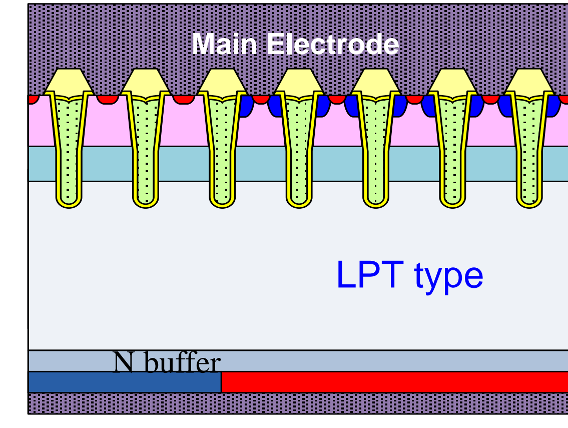




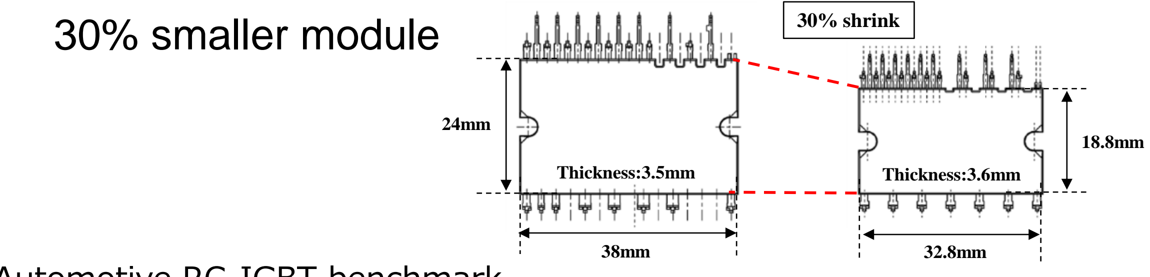


- RC-IGBT's downsizing merit for home appliance module

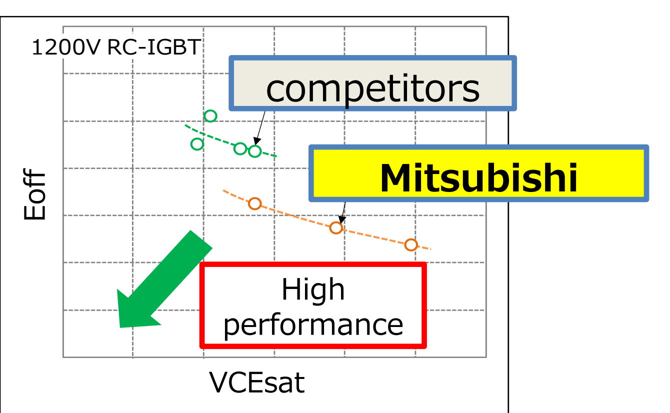




New RC-IGBT device cross-section



■ Automotive RC-IGBT benchmark



- Smaller chip size
- High current density
- Lower temp swing
  Better P/C performance

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

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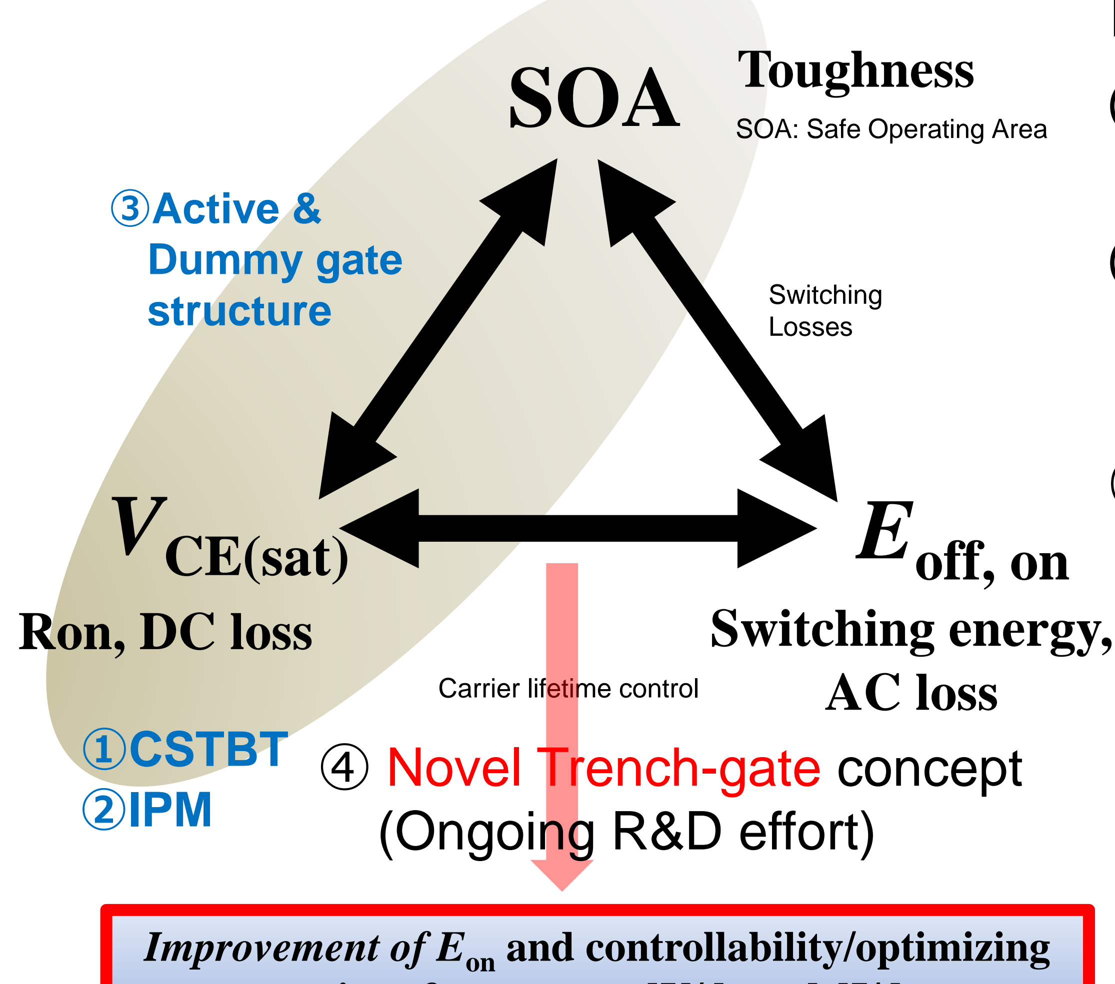
Further Improvement of IGBT performance (1/2)

Trade-off among IGBT performance indicators

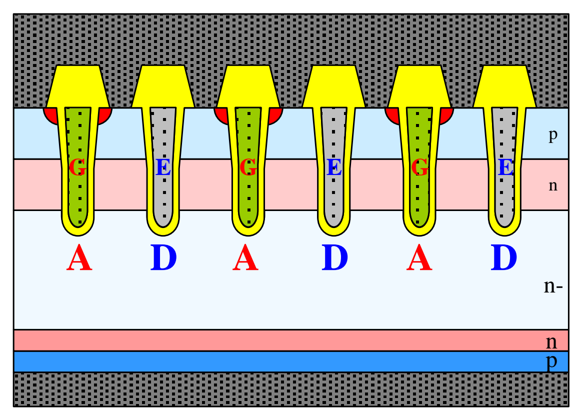


Mitsubishi Technology for better trade-off

① **CSTBT™** structure & **thinner wafer** for better Vce(sat)

② **IPM: Intelligent Power Module** with short-circuit detection ease the SOA criteria, enabling the use of low Vce(sat) IGBT

③ Trench IGBT with **active and dummy gate** for trade-off control



Ex.)
- Full Active for IPM
- ½ Active, ½ Dummy for industry application

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Further possibility of IGBT performance improvement (2/2)

Ongoing R&D effort to optimize performance by a novel split-gate structure.

7thGen.

Gate
R_G
Emitter
C_{GE}
G
E
C_{GC}
Active trench (A)
Dummy trench (D)
Collector

Thinner wafer

④ New Trench-gate structural concept under R&D investigation

(Under development)

High dV/dt option	Standard	High di/dt option
G, E	G, E	G, G / E, G
Vce, Ic, Kept as is, Improved, Time	Vce, Ic, $\frac{di}{dt}$, $\frac{dv}{dt}$, Time	Vce, Ic, Kept as is, Improved, Time

Optimized N buffer for thin wafer

Lower Loss + Controllable SW Speed

© Mitsubishi Electric Corporation

- Advanced device technologies
  - √ Silicon-based
  - √ SiC-based

© Mitsubishi Electric Corporation

Status Quo and Roadmap of SiC-MOSFET tech

Wafer

4” wafer → 6” wafer → *Adopt a unique wafer sizing & processing scheme for high volume production*

SiC MOSFET structure

- **Low Conduction / Switching Loss by unique structure**
- **High Reliability and Long-term stability**

Trench MOS (~1200V)

MOS SBD

SBD-embedded MOS (3.3kV≦)

Source
SiO_2
Gate
JFET
n source
p-well
n-drift
p contact
4H-SiC n-substrate
Drain

Start of product development

Cell structure

2nd generation planar MOS (600~3.3kV)

1st generation planar MOS

Features

First product

Low on-resistance and Low switching loss

(1) Adoption of JFET doping technology (2) Shallow p-well doping
(3) Thin wafer process (4) Faster switching by optimizing Ciss/Crss

~2010 ~2015 ~2020 ~2025

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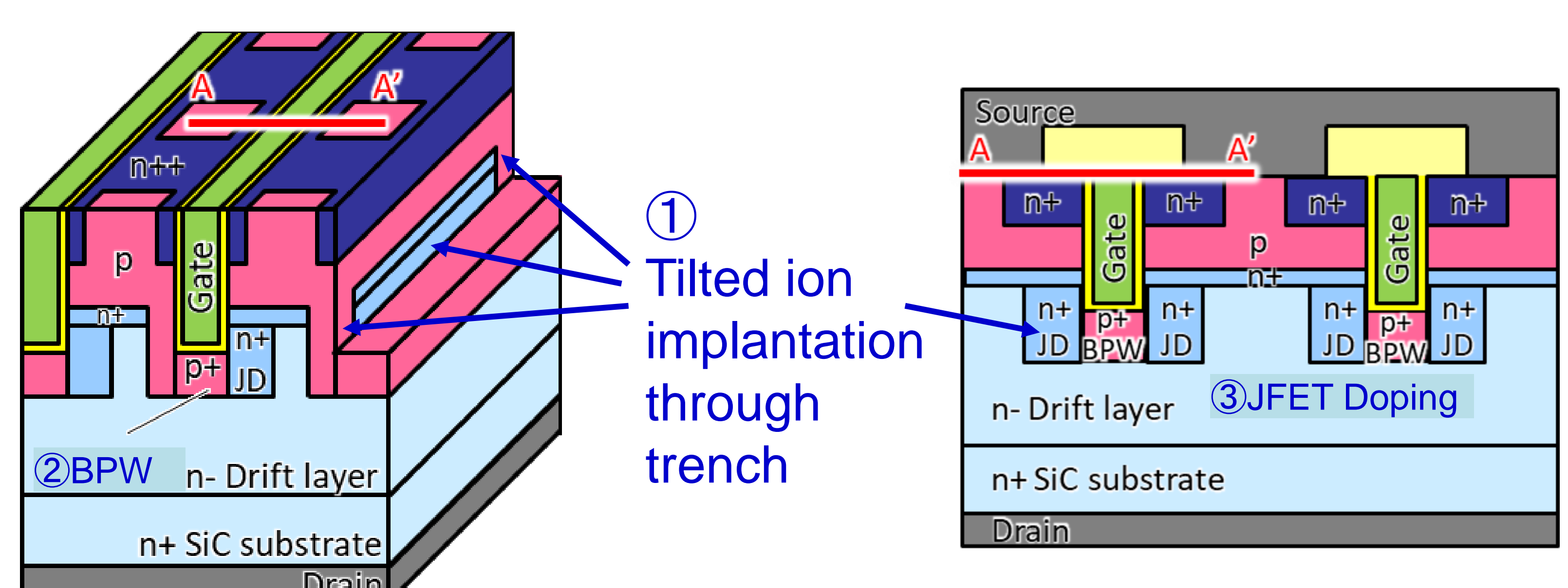
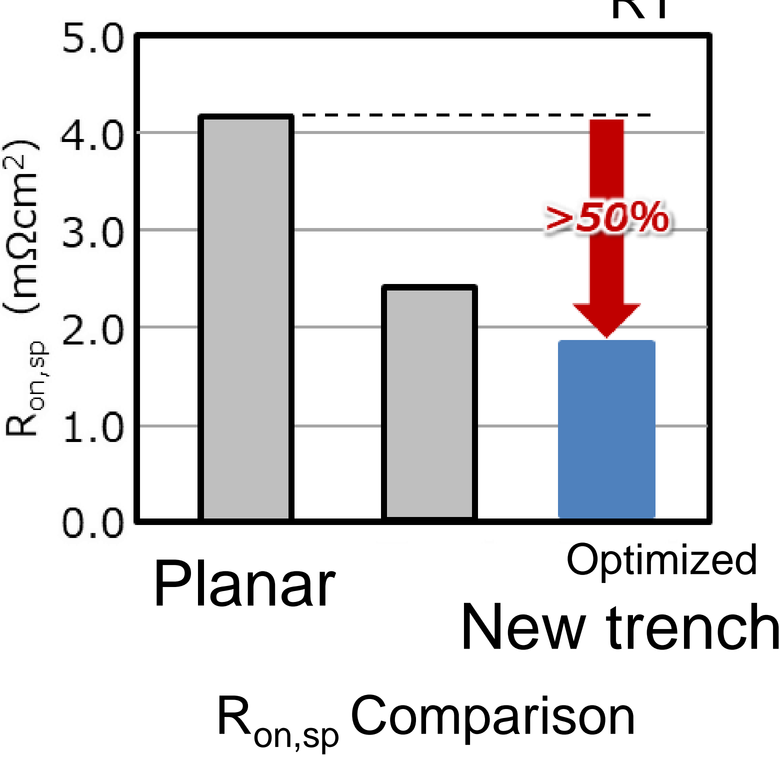
Trench SiC MOSFET for Low on resistance

- ✔Original trench MOSFET structure, with ① tilted ion implantation technology, Requires no special process equipment, leading to superior productivity
- ✔②Grounded p+ BPW reduces gate oxide electric field for good reliability
- ✔③n+ JFET Doping at current path for low on resistance, 50% better than 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.

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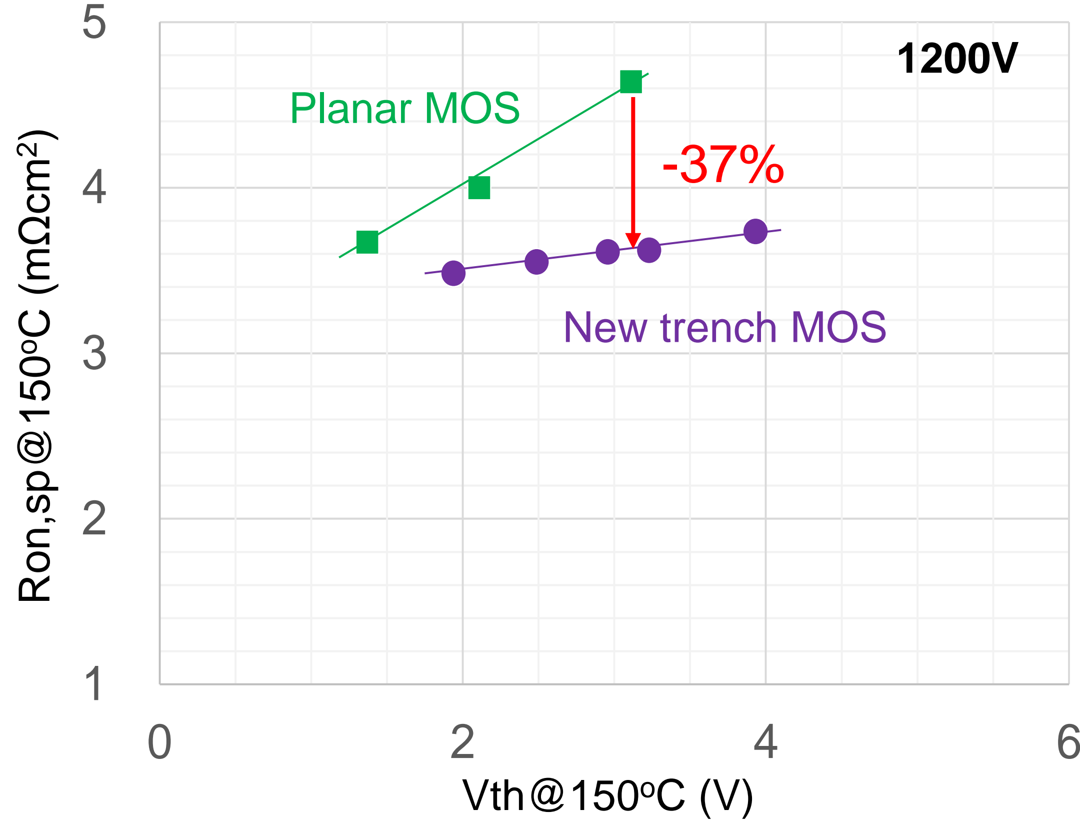
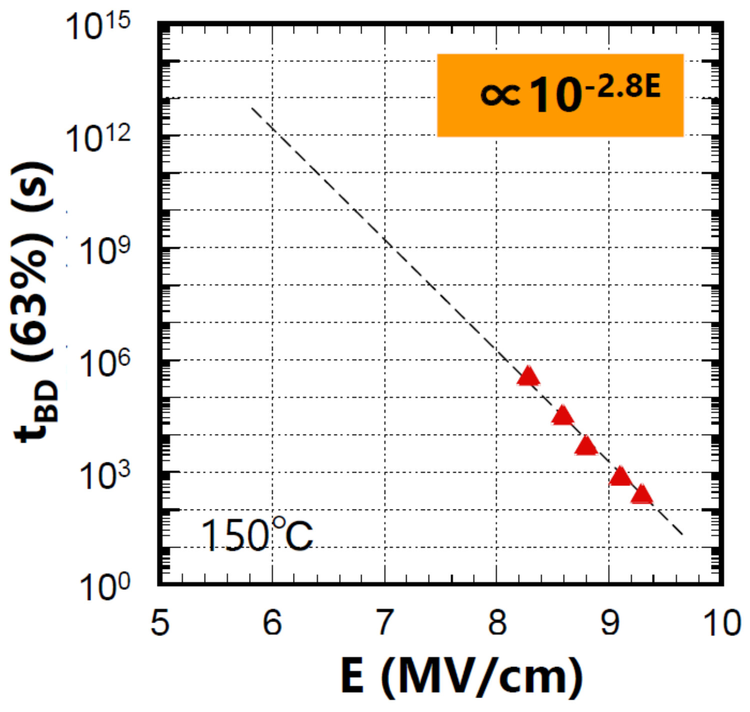
Ron vs. Vth of SiC-MOSFET



Gate oxide lifetime of SiC-MOSFET



Electric field dependence of t_{BD}

√ World-class low on-resistance trench-gate SiC-MOSFETs have been realized.

√ On-resistance is remarkably reduced especially in higher Vth range.

√ Gate oxide lifetime more than 10^7 year (@ 5MV/cm, 150℃)

√ Stability confirmed by 1000hrs HTGB (@ V_G +20V and -20V (DC)

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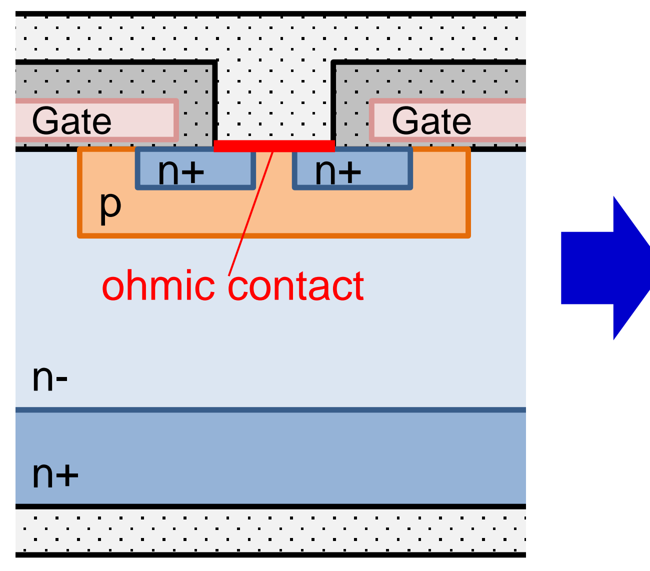
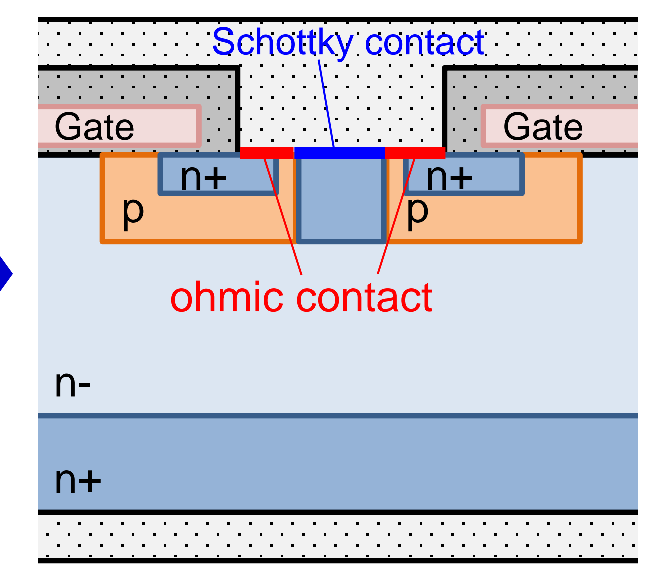
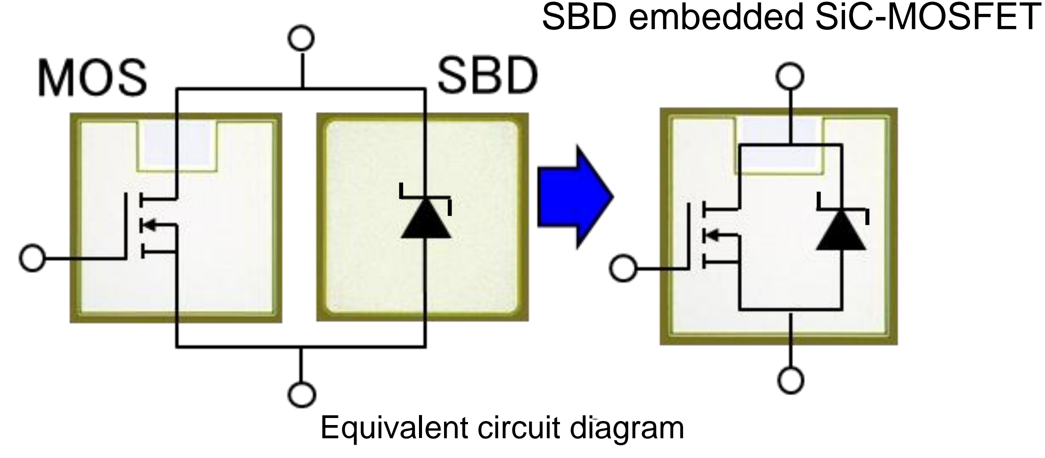
SBD embedded SiC-MOSFET





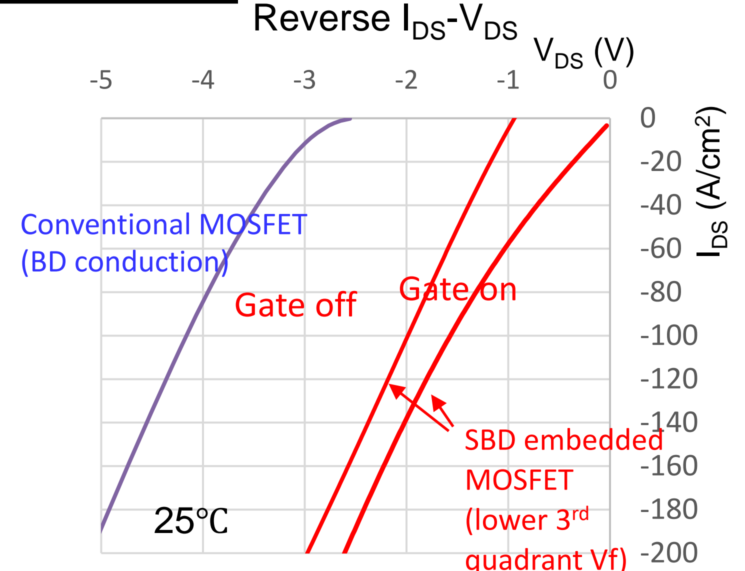
Cross sectional view of MOS cell

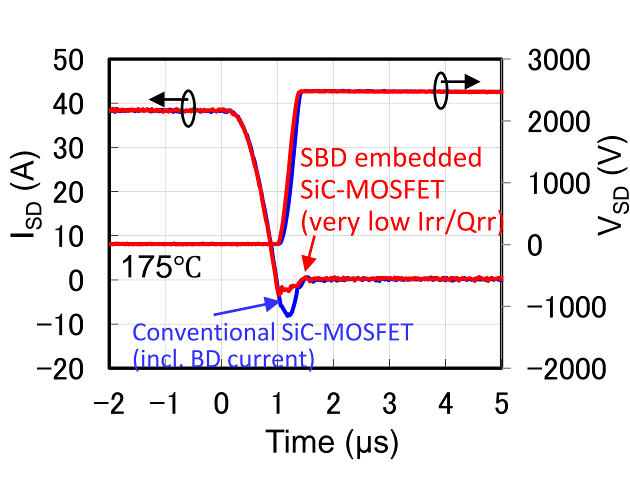


Equivalent circuit diagram

3.3kV class

SBD-embedded SiC-MOSFET vs. Conventional SiC-MOSFET





- ✔ Suppressing bipolar current flowing in reverse direction, hence free from bipolar-current-induced degradation
- ✔ No anti-parallel SBD required, reducing total chip area and cost

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- **Advanced module products**
  - √ DIPIPMs for consumer and home appliances
  - √ J-series for automotive
  - √ High power for industry
  - √ Cutting-edge packaging techs for various apps

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Mitsubishi DIPIPM™ family

Many thanks for your support as always!

Over 1 Billion 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

de facto standard packages for white goods market

Integration

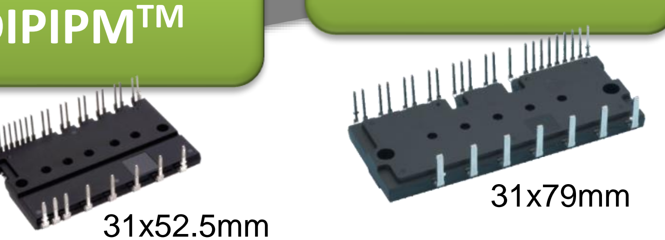
43x114.5mm

Large DIPIPM+™

34x85mm

DIPIPM+™

24x38mm



0.2kW 0.5kW 0.75kW 1.5kW 2.2kW 2.8kW 3.7kW 5.5kW

Inverter capacity

M-00091

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Silicon IGBT DIPIPM™ family Line up

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
- Super mini DIPIPM™ — Ver.6 & Ver.7
- SLIMDIP™
- SOPIPM™

Rated voltage 1200V

- Large DIPIPM+™
- DIPIPM+™
- Large DIPIPM™ — Ver.6
- Mini DIPIPM™ — Ver.7

Legend: CIB or CI / 6 in 1 / Under development

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Reasonable DIPIPM^{TM} for low-cost inverter

Features

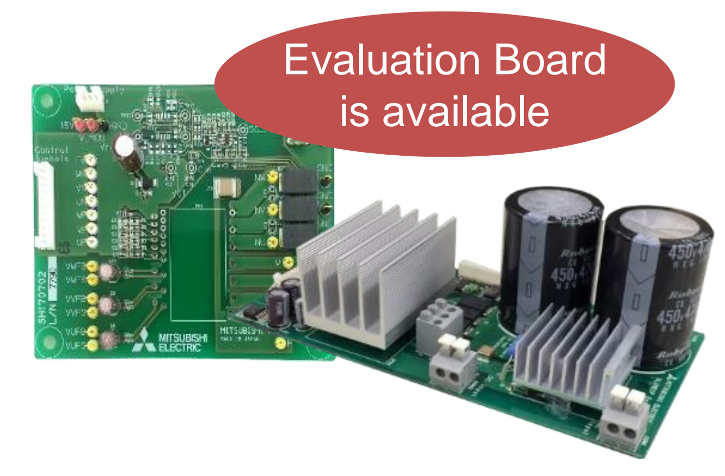
- *30% smaller* package DIPIPM^{TM} by integrating *RC-IGBT*
- *Easy PCB layout* by additional GND terminal for bootstrap circuit
- Expanding operable *case-temp* range T_{case} =115℃

18.8 x 32.8 mm

Line up

Part No.	Application	Rating	Suitable fc
SLIMDIP-S	Fridge, Fan	5A/600V	High
SLIMDIP-M	Fan, W/M	10A/600V	High
SLIMDIP-L	A/C	15A/600V	Low
SLIMDIP-W	W/M, A/C	15A/600V	High
SLIMDIP-X	A/C	20A/600V	Medium
New SLIMDIP-Z	A/C	30A/600V	Medium

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



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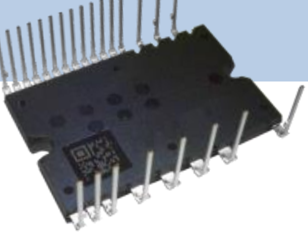
Full SiC Super mini DIPIPM^{TM} and its merits

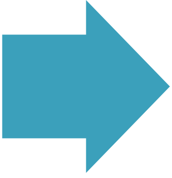
For not only feasibility study but also commercial use!



Concerns of SiC discrete

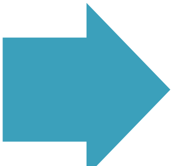
Mitsubishi SiC DIPIPM^{TM}, DIPPFC

Higher destruction risk
by smaller SOA



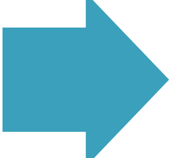
Safe operation
by integrated protection function

Higher noise
by faster switching

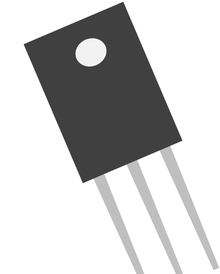


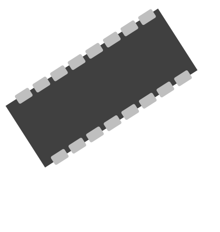
Low noise with adjusted
characteristics

Long design time



Short term evaluation
by compatible package





Part No.	Application	Ratings
PSF15S92F6-A6	A/C, small INV	15A/600V
PSF25S92F6-A6		25A/600V

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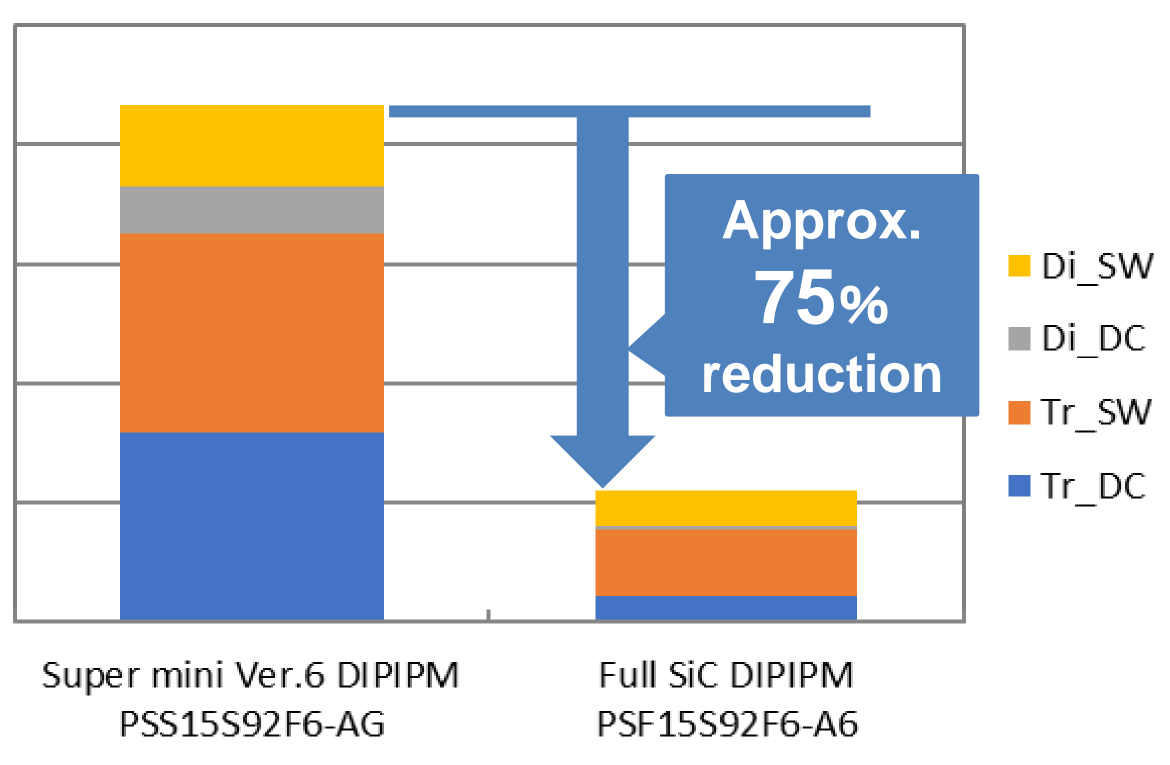
Benefits of Full SiC Super mini DIPIPM™

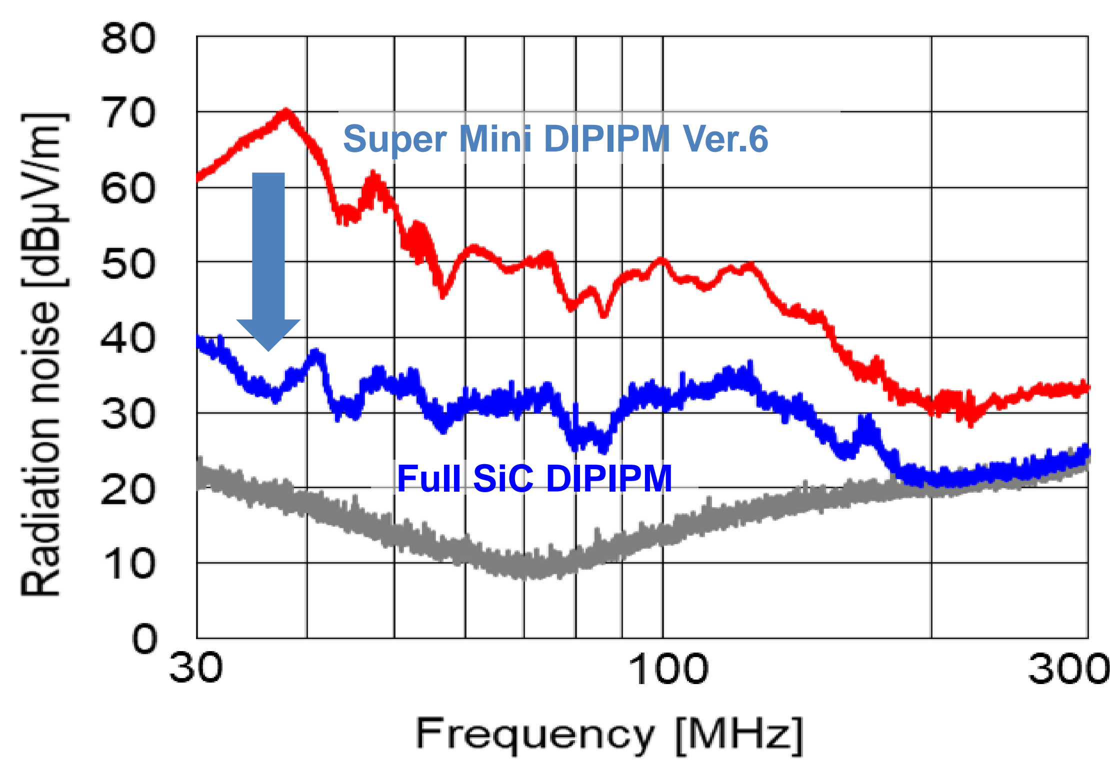
Loss Reduction with Noise Reduction enables High efficiency system

Total Loss



■Conditions: Vcc=300V, VD=18V(SiC) /15V(Si), fc=5kHz, Io=1Arms, PF=0.95, M=0.8, Sinusoidal, Tj=125°C

Low Noise due to low recovery loss



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- Advanced module products
  - √ DIPIPMs for consumer and home appliances
  - √ J-series for automotive
  - √ High power for industry
  - √ Cutting-edge packaging techs for various apps

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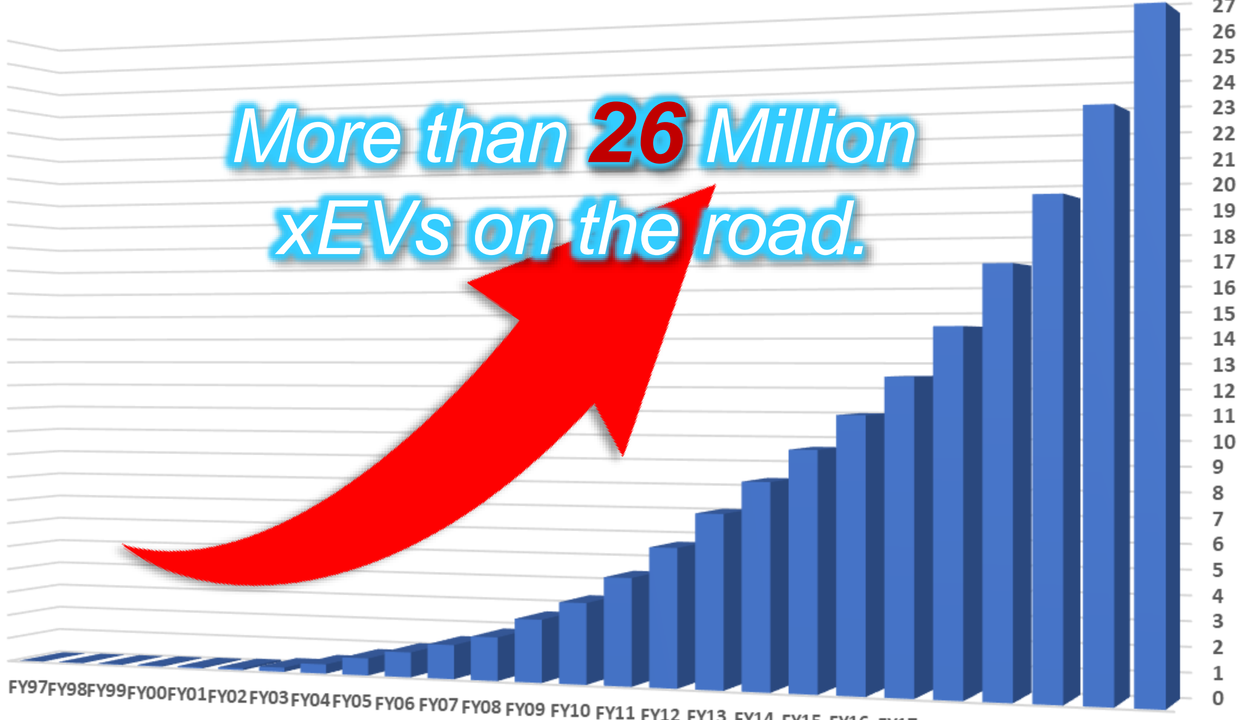
History of Automotive power devices

- ***Since 1997, Mitsubishi Electric has pioneered the mass production of power modules for hybrid and electric vehicles.***
- ***High-Quality track-record with more than <u>26 Million xEVs</u> on the road worldwide utilizing Mitsubishi Electric's power devices for Drivetrain.***

World-Wide xEVs using Mitsubishi Electric Power Devices

xEV power Device Shipment Record



xEVs (Million Units) (Cumulative)

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

1997: MP of the world's first IPM for automotive
2015: MP of a power module integrated with a cooling fin
2016: Developed a power module implementing SiC
2020: MP of SiC for automotive

Our strength

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

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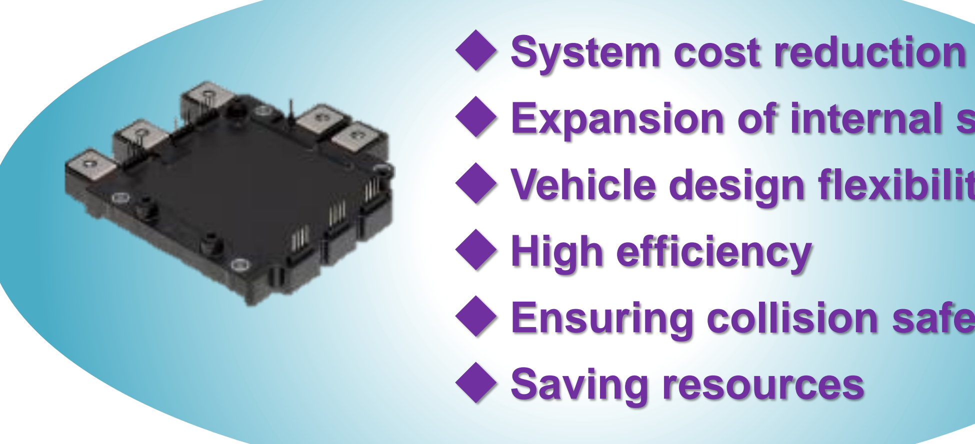
Inverter advantage using J1A

Inverter/E-Axle using J1A can be miniaturized and has many advantages.

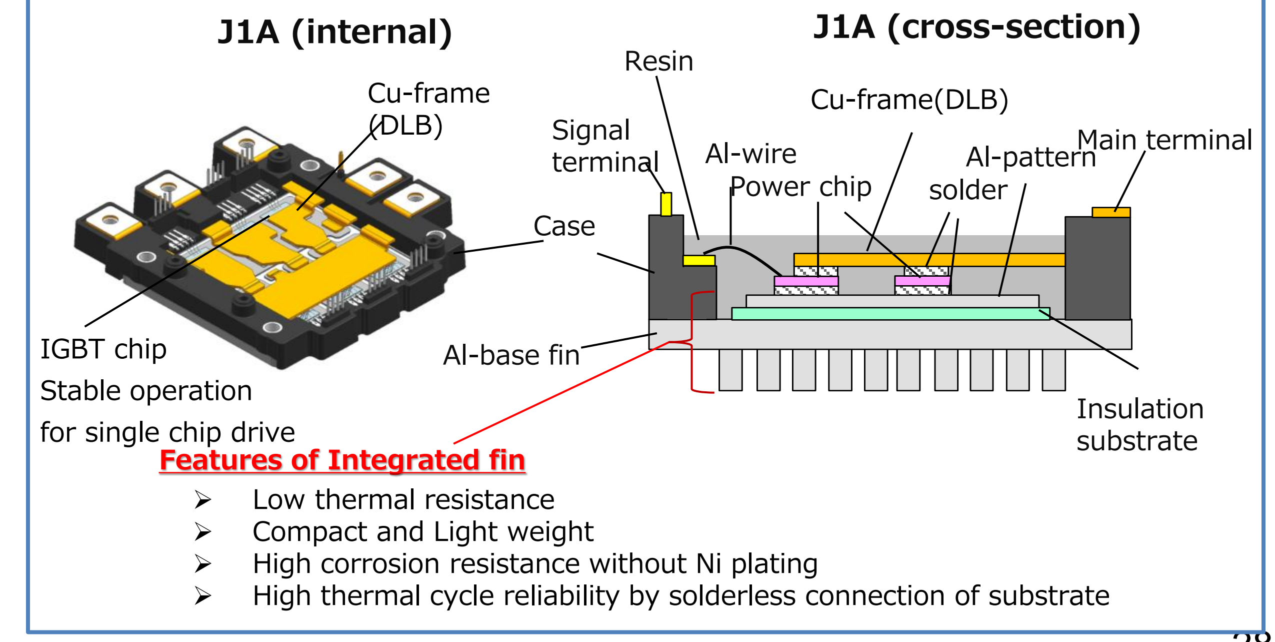
■ Comparison

	Mitsubishi	Competitor A		Competitor C
Series	J1A	Module 1	Module 2	
Size (including main terminal)	120 × 115.7mm S=13,844mm2 **(-29% !!)**	216 × 100mm S=21,600mm2 (+11%)	154.5 × 126.5mm S=19,544mm2 (REF)	162 × 116mm S=18,792mm2 (-4%)
Weight	340g **(-53% !!)**	1,340g (+86%)	720g (REF)	560g (-22%)

■ Inverter advantage using J1A



- ◆ **System cost reduction**
- ◆ **Expansion of internal space**
- ◆ **Vehicle design flexibility**
- ◆ **High efficiency**
- ◆ **Ensuring collision safety**
- ◆ **Saving resources**



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Evolution of Mitsubishi automotive power module

Wire bonding and DLB

DLB realizes high reliability by large bonding area of a chip and frame

Al Wire
Cu frame
Chip
W/B
DLB

Output / Function / Performance

IPM

Integrated PCB/ Wire bonding/ Case type

4th gen. IGBT

T-PM

Wire bonding/ Transfer mold type

5th gen. IGBT

High reliability

J series (T-PM)

DLB/ Transfer mold type

6th gen. IGBT

Light wight
Compact

J1 series

DLB/Integrated fin type

7th gen. IGBT

High power density
Low loss

under development

Next gen cutting-edge technologies for drivetrain

⇒Transfer-molded power core as building block

⇒Advanced RC-IGBT & SiC-MOSFET chip sets

J series T-PM structure

Cu-Heat spreader
chip
solder
Mold resin
Cu-frame (DLB)
Isolation sheet

J1 series structure

Integration of a cooling fin and module realizes low thermal resistance

Signal terminal
Wire
Chip
Solder
Main Terminal
Isolation layer
Al Cooling fin
Pattern

1997 | 2001 | 2009 | 2015 | 2020～

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  - √ High power for industry
  - √ Cutting-edge packaging techs for various apps

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Development roadmap for industrial applications

- To meet the various requirements from industry including renewables and emerging applications, our product covers from legacy modules to new dual modules using both Si and SiC advanced chip techs.

Gen

Next gen IGBT and SiC

7th gen IGBT

2nd SiC

Lineup expansion

Product family expansion

Lineup expansion

1.7kV, 2.0kV, etc

1st SiC

2015

2020

2025

Product family

LV100

NX

std

4in1 module

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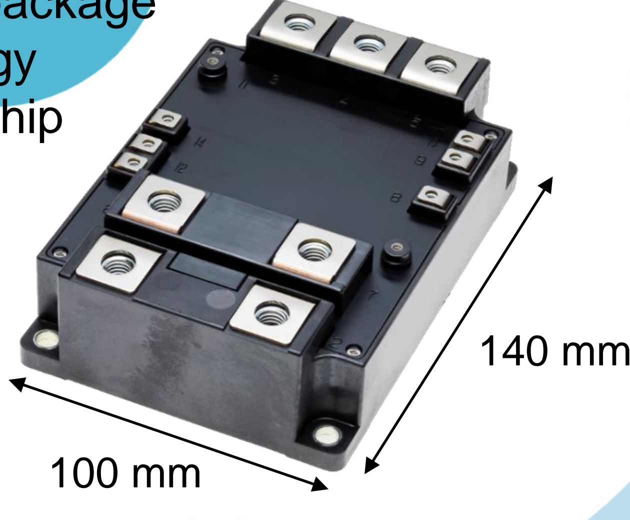
Industrial LV100 series

❑ Key benefits

High Power, Compact, Reliable

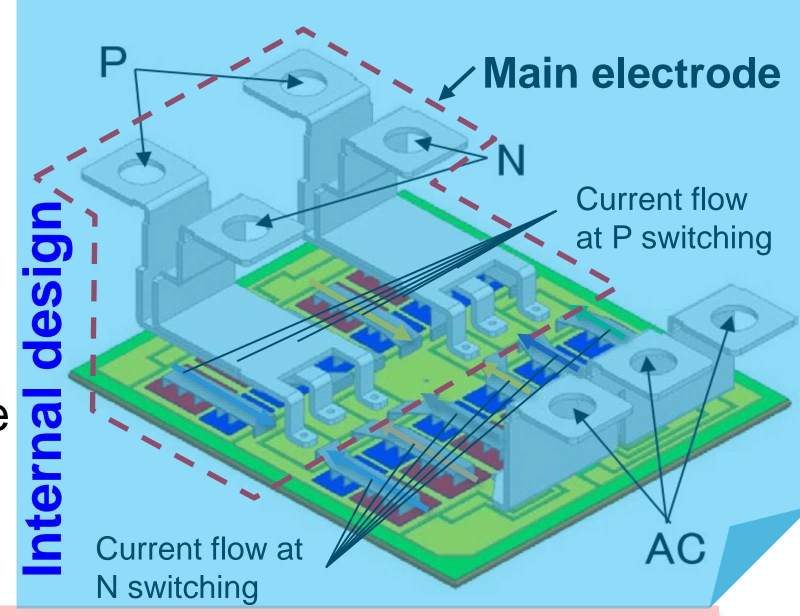
- High output power with compact package
- Reliable SLC packaging technology
- Low power loss by latest 7th gen chip



Scalable and Flexible

Hundreds kW ~ Multi MW

- Symmetric package design for paralleling
- 2-level and multi-level configurable



Extendable

- Up to 2.0kV, 1200A with one common package
- High power SiC suitable in future
- Wide LV100 family (Traction type up to 4.5kV)

- **Industrial LV100 is the next generation standard package for high power industrial applications**

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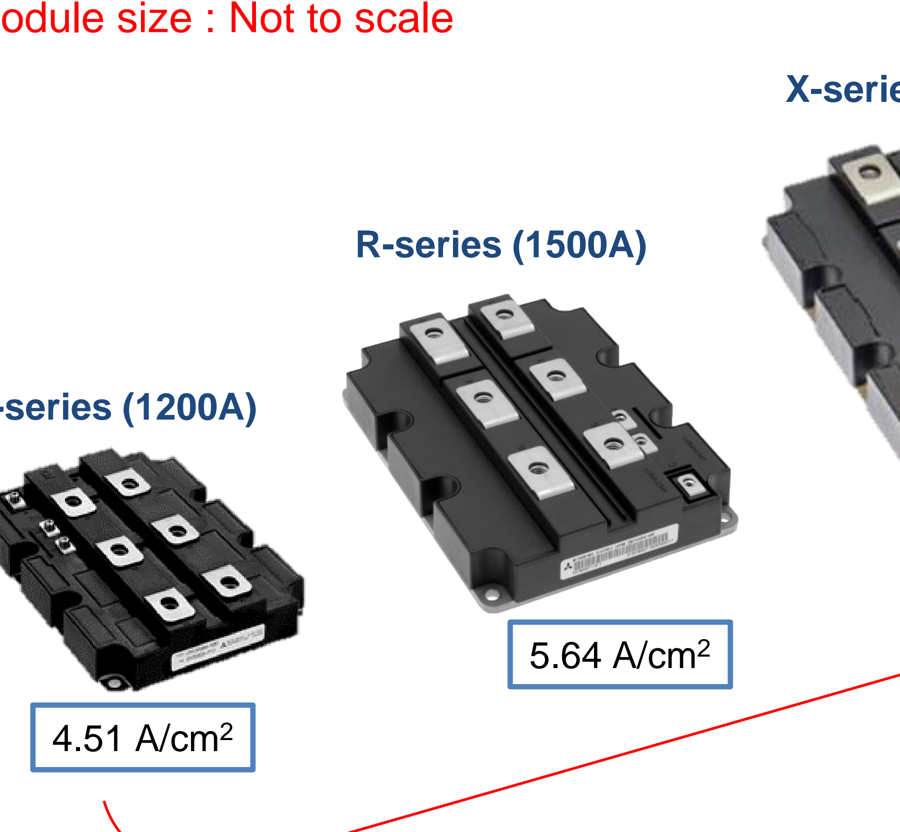
High Voltage Power Module Progress

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/cm²

R-series (1500A)

5.64 A/cm²

X-series (1800A)

6.77 A/cm²

IGBT LV100 (600A)

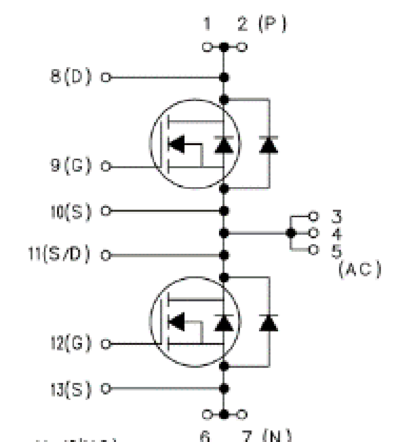
8.57 A/cm²

Package Improvement (Dual transistor)

SiC LV100 (750A)

10.71 A/cm²

SiC Introduction



IGBT chip improvement

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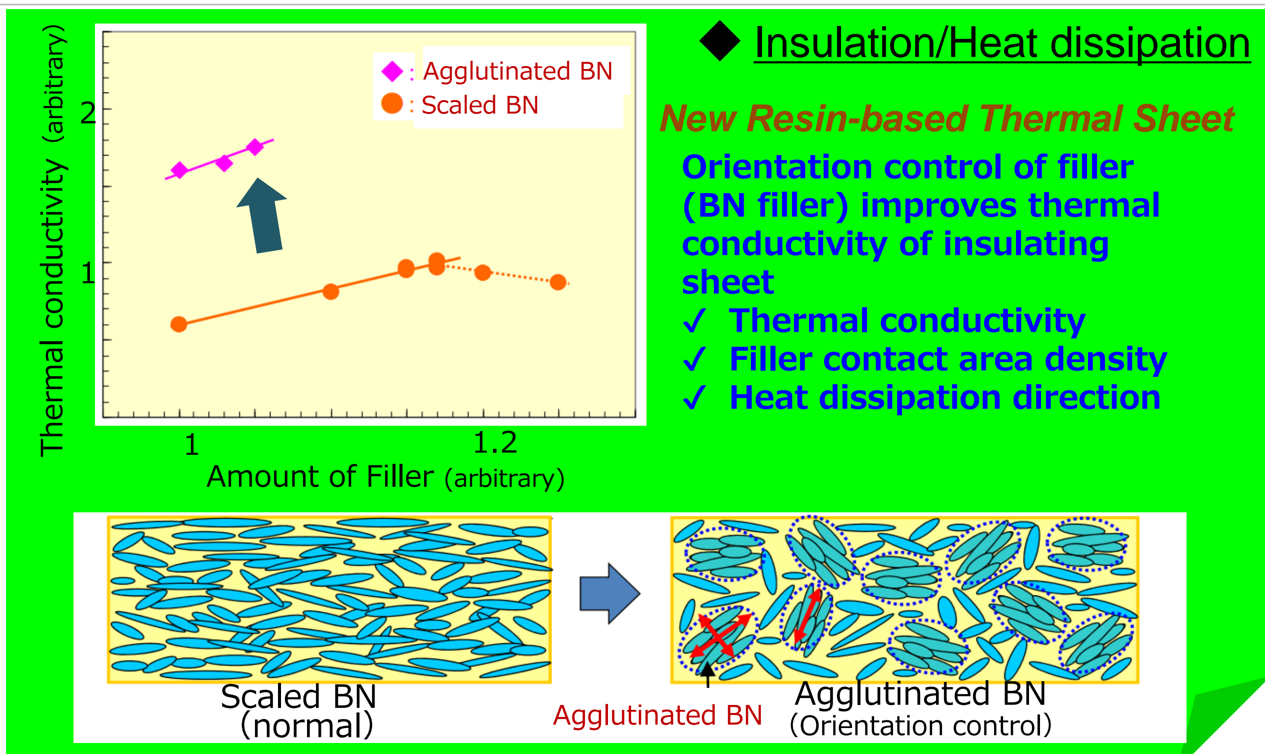
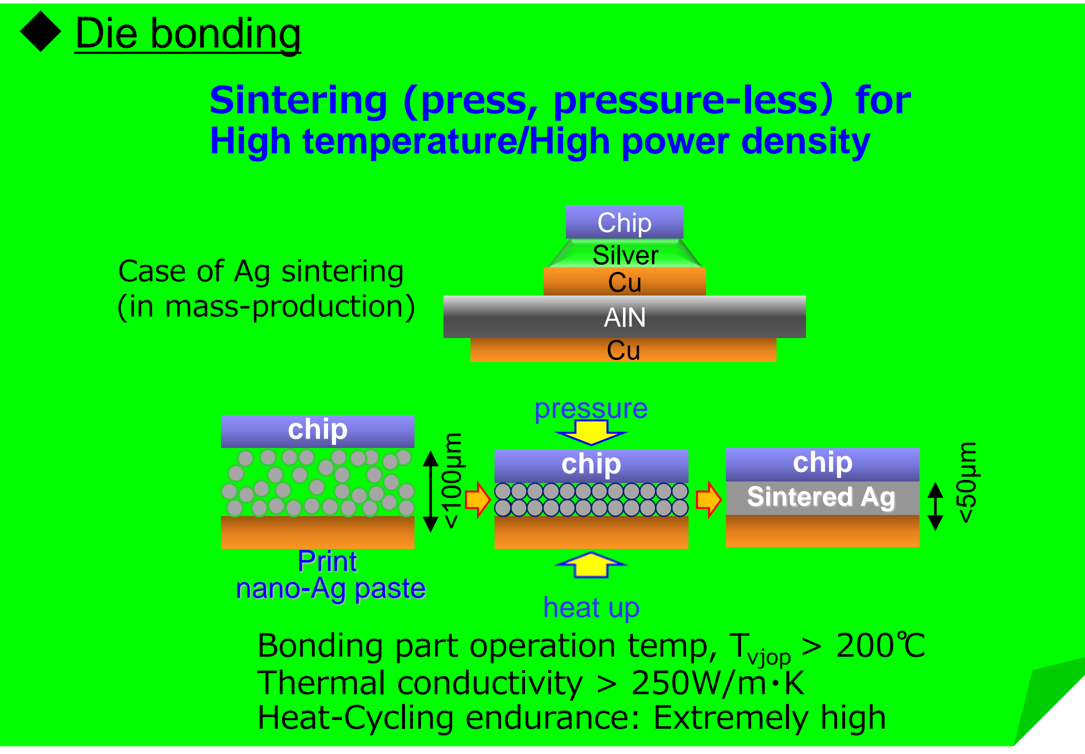
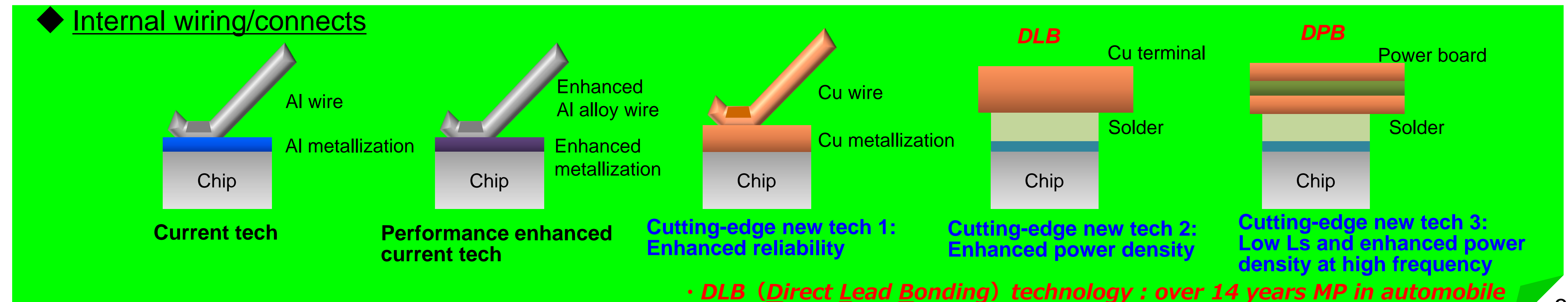
Cutting-edge Packaging Techs







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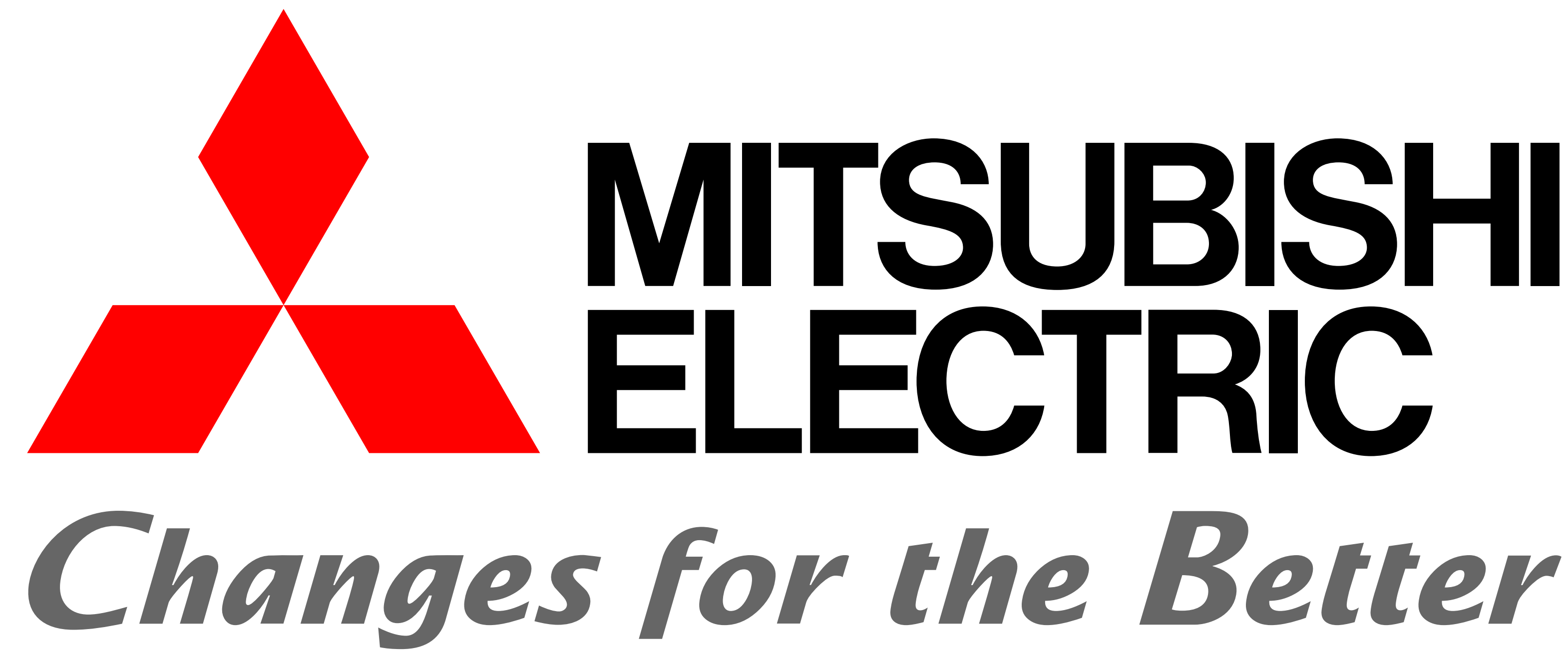
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