Si and SiC Power Transistors in the Powertrain of Electric Vehicles (xEVs)

A Survey of Japanese Automotive and Semiconductor Manufacturers

An Independent Technical Report from LTEC Corporation

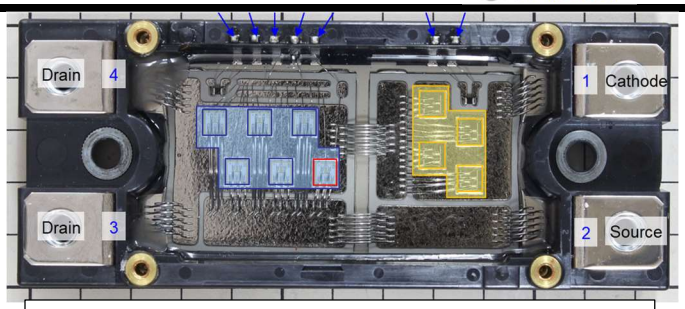
- **Some electric vehicle manufacturers already implemented Silicon Carbide (SiC) into their powertrains.**

  Find out who these manufacturers are.

  What advantages prompted them to adopt SiC despite identified disadvantages?

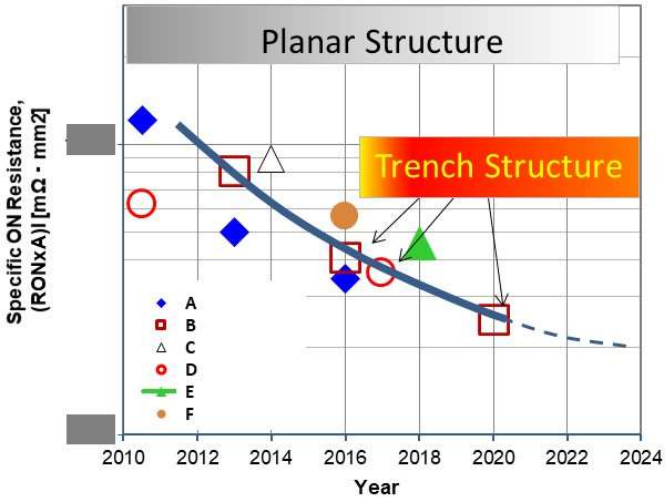
  Which SiC suppliers won these coveted spots?

- **What unsurmountable barriers are prompting EV manufacturers to remain with IGBT suppliers?**
- **Will SiC overtake Silicon IGBTs?**
- **How does the powertrain architecture for HEV, PHEV, BEV & FCEV differ?**
- **What are the different SiC & IGBT transistors?**
- **Is there another technology poised to overtake SiC**
- **How will SiC MOSFETs & IGBTs evolve?**
- **How do the 7th Generation silicon IGBTs compare with SiC MOSFETs in performance & price?**
- **What are the SiC growth inhibitors & unexploited advantages?**
- **Discusses thermals such as power module cooling system**
- **Breaks down the total power converter system cost by component**
- **Japanese power semiconductor manufacturers and their products for xEVs powertrains**



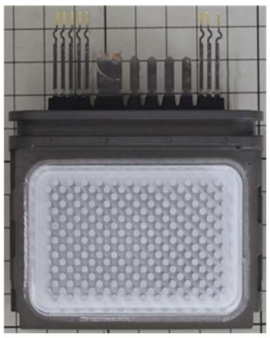
Power Module in Honda Clarity
(fuel cell electric vehicle)
ROHM SiC MOSFET Boost Converter

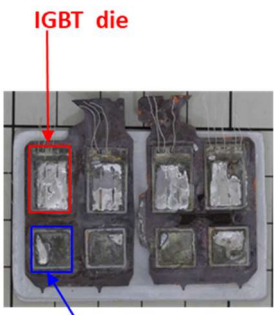
The evolution of 1200 V iC MOSFET structure



Excerpts from the report: Hitachi AMS: Audi e-tron Inverter Module

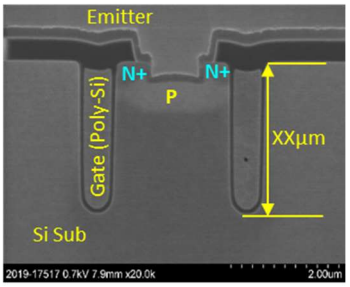
Water-cooled Dual-side Module





IGBT Die

IGBT Cross-Section



Integrated temperature sensor

Temperature sensor

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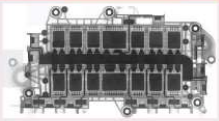
Table 8: Power Transistor Modules used in Automotive Motor Inverters and DC-DC Converter

		Fuji Electric	Hitachi AMS	Denso	Denso	Denso	Keihin
System	Product Identification	6MBI800XV-075V-01	Audi e-tron 55 Quattro	2020 Toyota Yaris PCU Traction Motor Inverter Power-Card	2016 Toyota Prius 4 PCU Traction Motor Inverter Power-Card	2021Toyota Mirai FC Boost Converter Power-Card	2020 Honda Fit PCU Traction Motor Inverter
	Configuration						
	VCC/IC						
	Motor Power Spec.						
Power Semiconductor Device	Half-Bridge arm Transistor Chip						
	Config. per Half-Bridge SW						
	Transistor chip size [mm²]						
	Trans. area per switch [mm²]						
	Free-wh. Diode (FWD) [mm²]						
	Tot. IGBT + FWD chip size [mm²]						
	VCE sat (pin) @Tj=25C IC/A=2A/mm sq., VGE=15V					@Id=100A	
	Power Semiconductor Supplier						
Module	Module assembly						
	Cross section						
	Module Size (x*y*z [mm])						
	Cooling						
	1-Ph Half-Br Packg Size (x*y [mm]) [mm²]						
	Trans. area per SW /Act. A. [mm²]						
	Therm. res per SW, Rth,jw @ G= 10L/m [°C/W]						
	Cooling Configuration						
	Cooling fluid						
	Cooling Structure						
	Pressure drop [kPa]						
	Specific Thermal Res.istance Per SW Rth,jw [°Cmm²/W]						

- Provides the reader with a comprehensive analysis of the leading IGBT and SiC devices including reliability and robustness concerns for operating life span of 10+ years
- Analyzes more than 55 power electronic systems such as motor inverters, on board chargers, and power supply systems in 2015-2021
- Focuses on:
  - Power Semiconductor Modules, and associated Car models and powertrain,
  - Plans for using SiC
- Semiconductor Supply chain, sourcing issues, trends
- Specific cases of SiC vs Si solution system level advantages, and disadvantages
- Analyzes and evaluates globally competitive IGBT and SiC power semiconductor devices

- Authored related articles:
  - "Addressing Short-Circuit Robustness of 1200 V SiC MOSFETs: Using Deep Structural and Physical Analysis," IEEE Power Electronics Magazine, June 2021
  - "The Current Status and Trends of 1,200-V Commercial Silicon-Carbide MOSFETs," IEEE Power Electronics Magazine, June 2019
  - "Benchmarking Power Transistors and Power Modules for High-Temperature Operation (Tj~200°C)," IEEE ITEC 2017, Chicago, IL, June 24, 2017
  - "Comparing Power Transistors Operating at High-Temperature (Tj~200°C)," Bodo's Power Systems, July 2017
- Targets Japanese automotive and several other manufacturers of EV systems (includes HEV, PHEV, BEV & FCEV)

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Table 9 : Structures of IGBTs used in 4th Gen PRIUS and 2020 Yaris Power Control Unit (PCU) cards

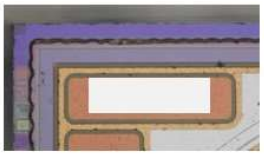
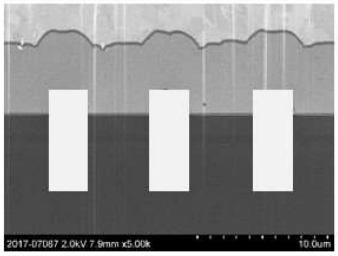
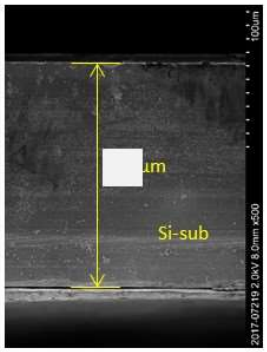
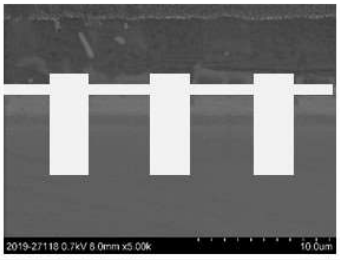
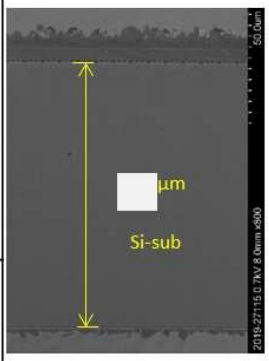
Traction	Die	Die Marking	Trench Structure	Die cross-section
4Gen Prius	 Size: xxx.xxmm^2		 Trench depth :xμm Trench pitch :xμm Top metal thickness:xμm	
2020 Yaris	 Size: xxx.xxmm^2		 Trench depth :xμm Trench pitch :xμm Top metal thickness:xμm	

Table 5 : Summary of Analyzed Automotive Power Electronic System

Japanese Automakers and SiC MOSFETs & Si IGBTs Manufacturers Status Survey 20H-0693-1

Table 5: Summary of Analyzed Automotive Power Electronic Systems

#	Analyzed Part/System	Manufacturer Tier 1	SiC or Si IGBT Semiconductor	Used in Car Model
1	PCU Traction Motor Inverter Driver	Denso		
2	PCU Traction Motor Inverter Driver	Denso		
3	Voltage Control Unit Boost Converter Power Module	Mitsubishi Elec		
4	Fuel Cell Voltage Control Unit Boost Converter Power Module	Denso		
5	Fuel Cell Voltage Control Unit Boost Converter Power Module	HONDA (In house)		
6	PCU Traction Motor Inverter Driver	HITACHI Astem (KEIHIN)		
7	Traction Motor Inverter Driver	HITACHI Astemo (HITACHI AMS)		
8	Traction Motor Inverter Driver	NISSAN (In house)		
9	Traction Motor Inverter Driver	Mitsubishi Elec		
10	IGBT Driver	Meidensya		
11	Traction Motor Inverter Driver	Nidec		
12	Traction Motor Inverter Driver	ZF		
13	Traction Motor Inverter Driver	Continental		
14	Traction Motor Inverter Driver	TESLA (In house)		
15	PCU Traction Motor Inverter Driver	Delphi		
16	Traction Motor Inverter Driver	LG Electric		
17	PCU Traction Motor Inverter Driver	Bosch		

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Table 4 : Japanese Power Semiconductor Device and Module Manufacturers

Table 4: Japanese Power Semiconductor Device and Module Manufacturers

Vendor	Device	Application			
		HEV/PHEV・EV		Others	
		Motor Inverter	Boost converter		
(1) Mitsubishi Electric	IGBT	TOYOTA: Prius (DENSO module) *rumor→Guangzhou Automobile, Geely Automobile New Model	TOYOTA: RAV4	High Voltage (>3.3 k V) ・750V RC-IGBT	・Estimated to be used in DENSO PCU
	SiC	✔		・ ・I ・I (C	es ~700V announced Railways
(2) Fuji Electric	IGBT	HC TO le)		・ ・I	ays ・Co-development with DENSO
	SiC	✔		・(FRENIC- M	
(3) ROHM	IGBT	HC)			
	SiC		H	・	
(4) RENESAS	IGBT	Au e)			
	SiC			E mor)	
(5) TOSHIBA	IGBT	TO			
	SiC				・2020, Oct., announced new 1200V SiC MOSFET
(6) HITACHI	IGBT	ec e- A *)		Hi ,Railways	
	SiC	✔		3. IR ya line)	
(7) DENSO	IGBT	T '4, A		・ ・ w	er module. outsourced oment *IGBT is supplied by Toshiba, Mitsubishi, Fuji electric
	SiC		ELL	・ ule	

The list of more than 55 LTEC Power Systems reports available here

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