How soon is NOW ?

onsemi SiC solutions

June 2024

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So…….. How soon is NOW ?

Often, we hear the question:

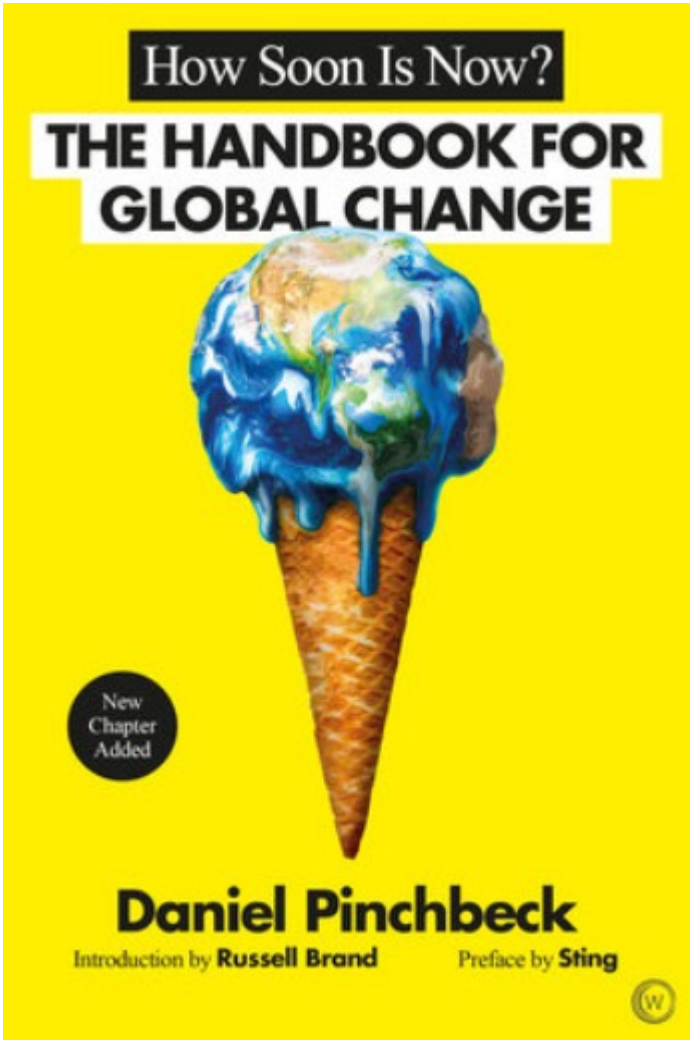
- When is SiC Mature & is there really a market for this ?
- When have SiC reached the right quality levels ?
- When will SiC be competitive over traditional technologies such as IGBT ?
- When will SiC be available in high volume ?
- When is market taking off ?

In 2023 SiC was forecasted to reach revenue of ~$3.8B and GaN ~$250M

***Market data for 2023 not yet published, expected in June 2024**

In this 30-minute webinar you will learn:

- **Why** SiC will dominate the Power Semiconductor market from now onwards
- **Why** SiC brings a high degree of efficiency to designs vs traditional Silicon (Si) solutions
- **Why** onsemi is a key player in the SiC space and the advantages customers will realise by choosing their solutions
- **When** SiC will be commercially competitive over traditional Si-Technologies applied in MOSFETs/IGBTs



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onsemi at a glance

($20M in 2020)
($75M in 2021)

$200M SIC in 2022 – $800M in 2023

HQ
Scottsdale
Arizona, USA

Revenue

$8.3 Billion Total

> $0.8 Billion SiC

- 25% Market Share
- Growing 2x Market

#1 Solar & Energy Storage
#1 Auto Image Sensors
#2 Silicon Power Revenue
#2 SiC Power Revenue

500
S&P 500® index
Fortune 500®

100
NASDAQ 100®
Company

~50 Billion
Units Shipped

37K+
Portfolio SKUs

19
Manufacturing Sites in
9 countries

8
Solution Engineering Centers in
5 countries

~30,000
Employees Worldwide

26% minority
minority workforce

45% female
Global workforce

30% female
Board of Directors

6 employee resource groups

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2022 & 2023 – SiC Related Press Announcements

Date	Topic
August 23, 2023	onsemi Appoints Christina Lampe-Önnerud to the Board of Directors
July 27, 2023	onsemi and Magna Sign Strategic Agreements to Invest in Silicon Carbide for Growing Electric Vehicle Market
July 26, 2023	onsemi Secures $1.95B in Supply Agreements with Leading Solar Inverter Manufacturers
July 18, 2023	onsemi and BorgWarner Expand Strategic Collaboration for Silicon Carbide Worth Over $1 Billion in Lifetime Value
June 12, 2023	onsemi Selected by Nasdaq for 100 Index
May 31, 2023	Vitesco Technologies and onsemi Sign SiC Long-Term Supply Agreement and Agree to Invest in SiC Technology Capacity Expansion
May 16, 2023	Penn State and onsemi Sign MOU to Boost Silicon Carbide Research in the United States
May 16, 2023	onsemi and Kempower Enter Strategic Agreement for Electric Vehicle Chargers
May 15, 2023	onsemi and Sineng Electric Spearhead the Development of Sustainable Energy Applications
April 25, 2023	onsemi and ZEEKR Sign Long-Term Supply Agreement for Silicon Carbide Power Devices
March 21, 2023	onsemi Launches Simulation Tools to Bring Complex Power Electronics Applications to Market Faster
March 6, 2023	onsemi to Integrate its Silicon Carbide Technology in BMW Group's Next-Generation Electric Vehicles
February 10, 2023	onsemi Commemorates Transfer of Ownership of East Fishkill, New York Facility from GlobalFoundries with Ribbon Cutting Ceremony
January 25, 2023	onsemi and VW Group Cement Strategic Collaboration on Silicon Carbide Technology for Next-Generation Electric Vehicles with Strategic Agreement
January 24, 2023	onsemi to Host Financial Analyst Day
January 5, 2023	onsemi and Ampt Collaboration Increases Efficiency for Utility Solar Providers
January 4, 2023	onsemi Silicon Carbide Power Module for Traction Inverters Selected for Hyundai Motor Group's High Performance Electric Vehicles
January 3, 2023	onsemi's EliteSiC Silicon Carbide Family Solutions Deliver Industry-Leading Efficiency
November 14, 2022	onsemi Silicon Carbide Technology Enables All-Electric VISION EQXX to Go Further on a Single Charge
September 21, 2022	onsemi Expands its Silicon Carbide Fab in the Czech Republic
August 11, 2022	onsemi Celebrates Expansion of Silicon Carbide Production Facility in New Hampshire
May 11, 2022	NIO Selects High-Efficiency Silicon Carbide Traction Power Modules from onsemi

EliteSiC

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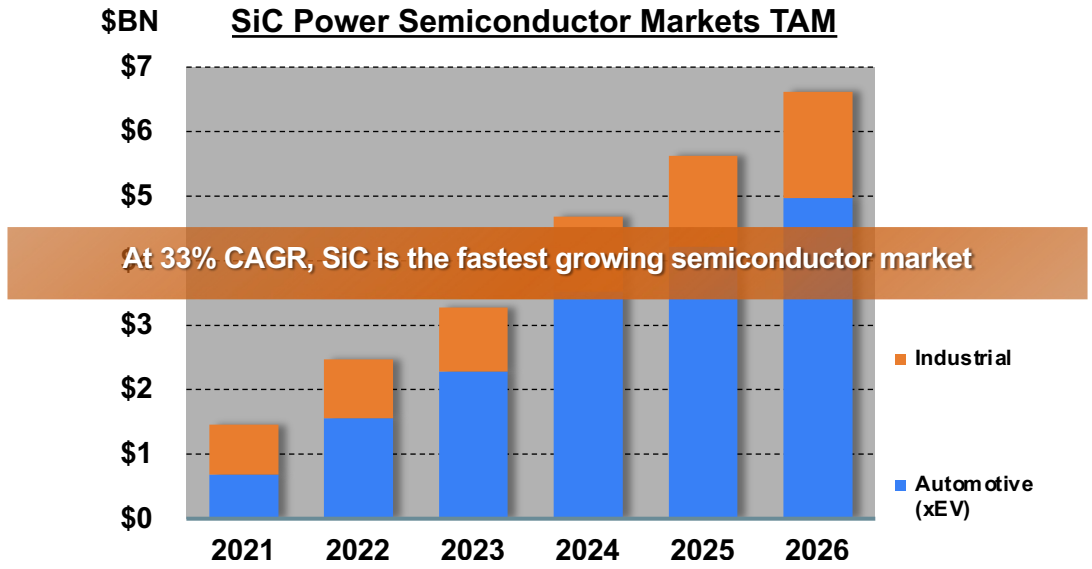
onsemi™
Selected for the Nasdaq-100 Index®
Recognized as a Fortune 500® company
Joined the S&P 500® index

The Power Semiconductor Market Outlook :

- **Power Semiconductor Market by 2028**
  - Total power marked forecasted to be $41B
  - SiC expected to be 23% or $9.4B
  - (Less than 20% is forecasted to be on 8inch..)
  - GaN is expected to be $2.2B
  - Parts of GaN market can be addressed with SiC Cascode
- **Automotive market ~70%**
  - eV Traction is KEY !
  - OBC, DCDC & BMS is significant
  - Adjacent such as Aircon
- **Industrial Market ~30%**
  - Renewables: Solar & Wind
  - Energy infrastructure ESS, UPS & EV Charging
  - + Servo Drives, Plasma cutting, Welding, Water Cookers, CT scanners +++



Source: Yole Power Intelligence Q1 2024

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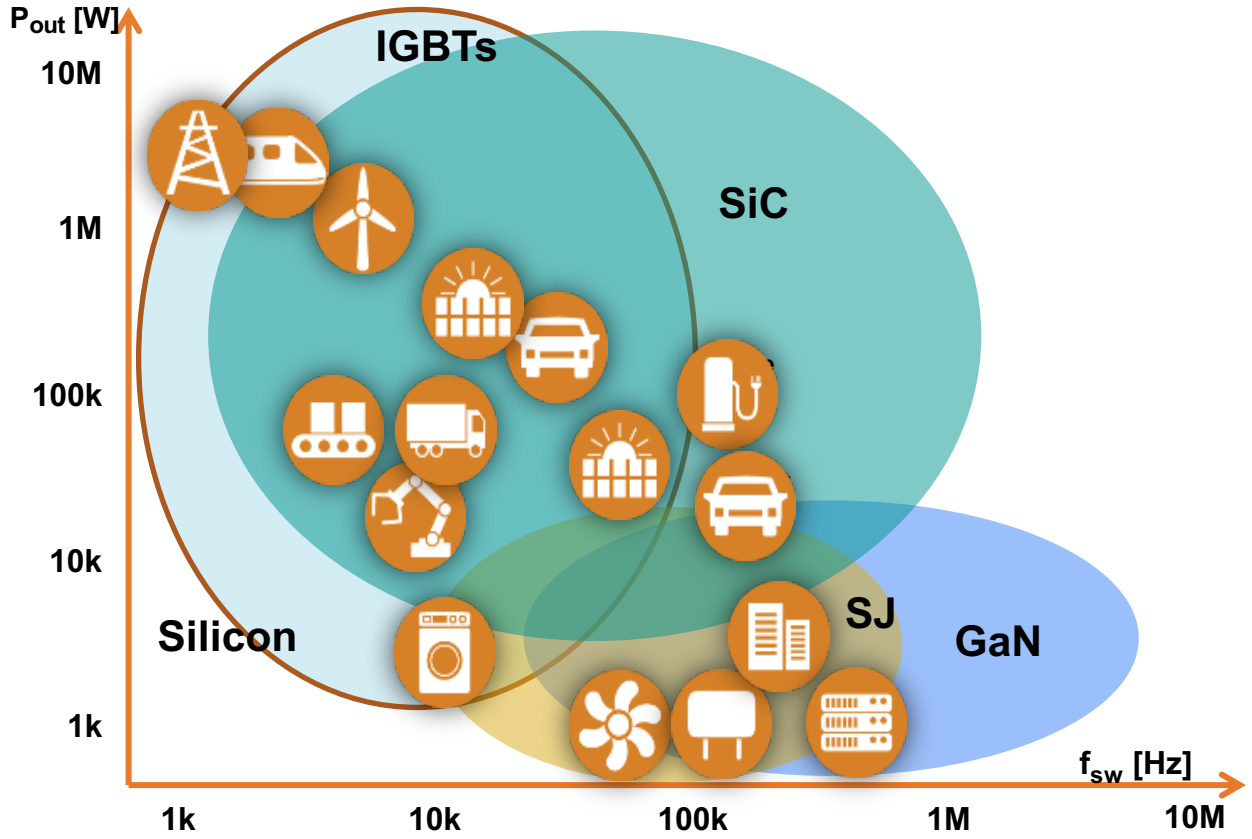
Application-Specific Power Switching Technologies



Innovation in switching technologies is key to driving power efficiency

Accelerating adoption of Wide band gap

- **Efficiency, speed and size**
- **Cost, packaging & supply**

GaN overlaps with SJ which also can be addressed by SiC Jfet Cascode in applications such as Server power, AC Adaptor, etc…

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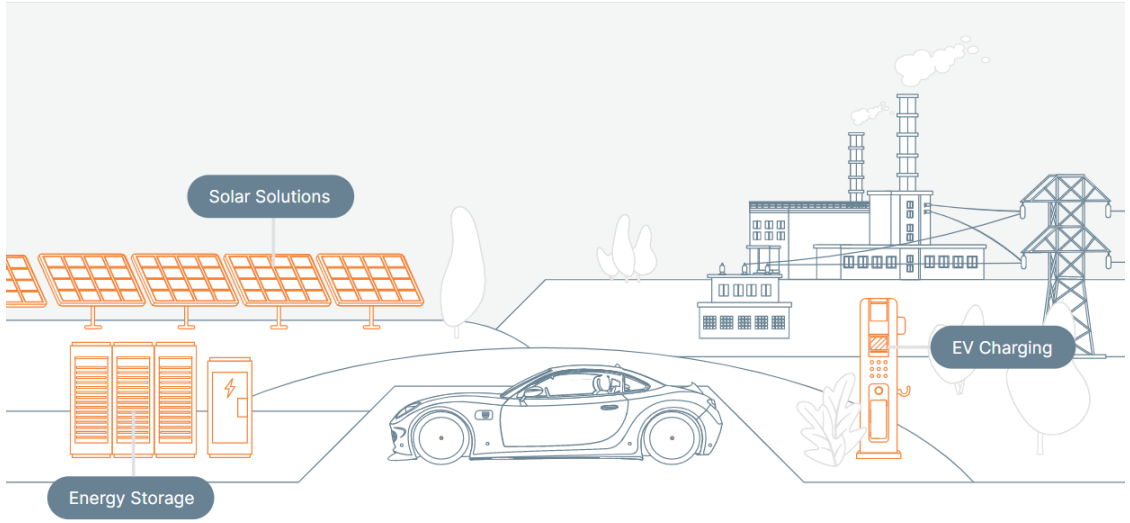
Applications Driving the SiC MOSFET & Diode Market

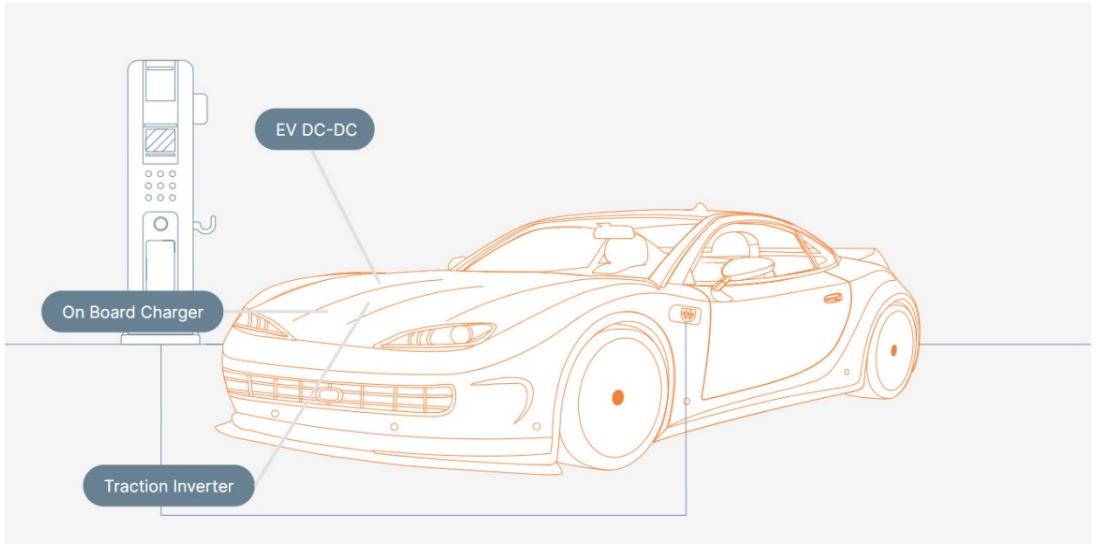
EliteSiC

Industrial
Energy Infrastructure



onsemi Industrial Qualified SiC
Solar Inverters: more power in same size
UPS/Energy Storage: lower cooling costs
EV Charging: faster charging with same cooling
Servo Drive: higher speed and more precision

Automotive
Electric Vehicles



onsemi Automotive Qualified SiC
Traction Inverters: increased vehicle range
On-board Charger: more compact solution

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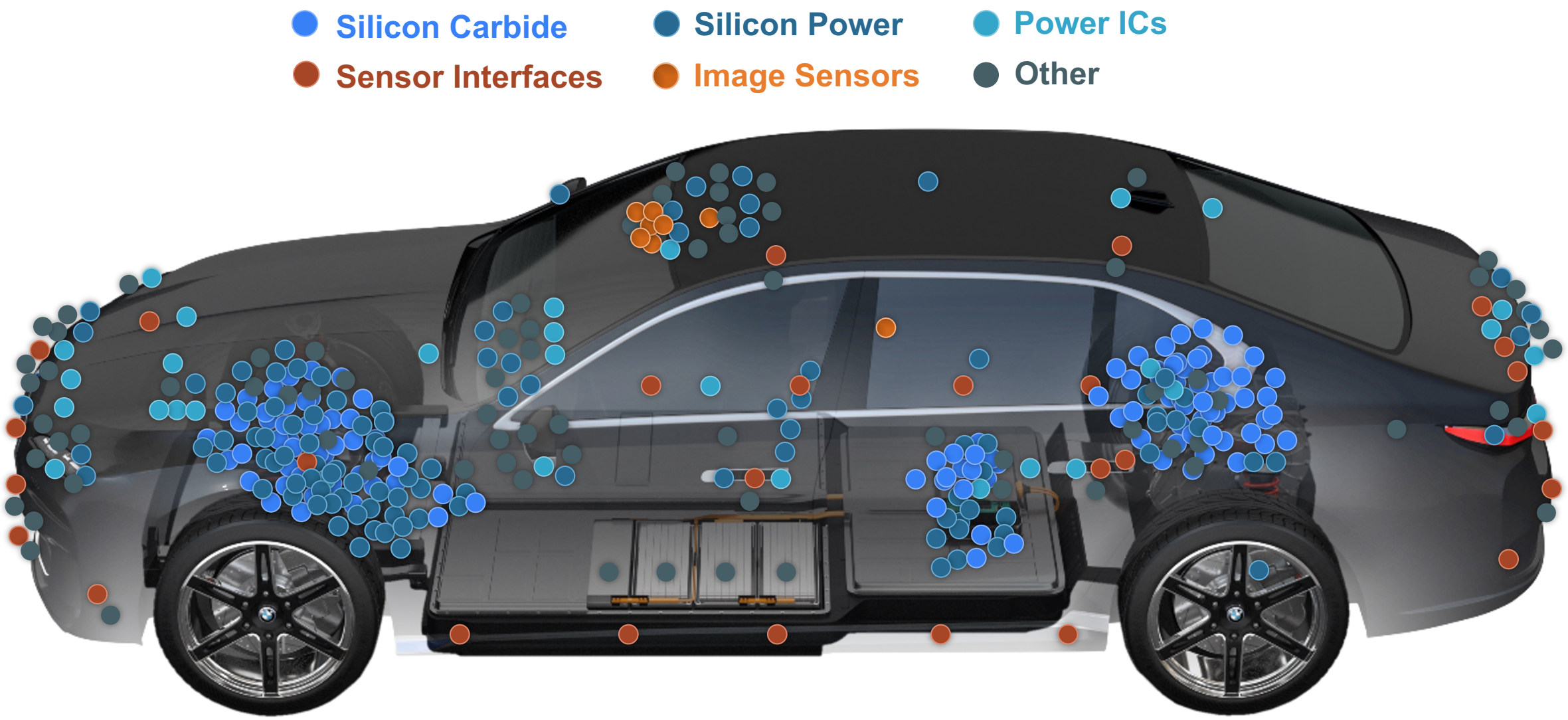
onsemi. Everywhere. Today.



Dots represent onsemi devices designed in BMW's electric i7 vehicles

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Si vs. SiC – Silicon Carbide Drives Increased Power Density !!!

Higher Efficiency by Lower Power Losses

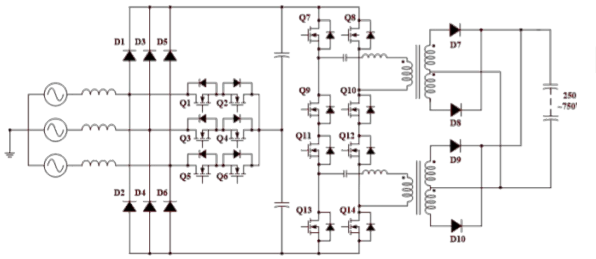
System
- Small Size
- Light Weight
- Cost benefits

Simpler topology : higher BVdss with lower Rds(on)

600 / 650V SJ MOSFET

3Φ Vienna PFC (~50kHz)

Series FB LLC (100~250kHz)



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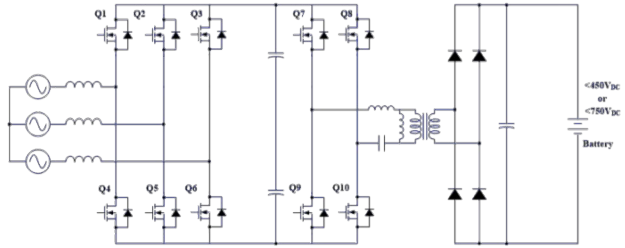
SiC MOSFET

Higher Switching Frequency

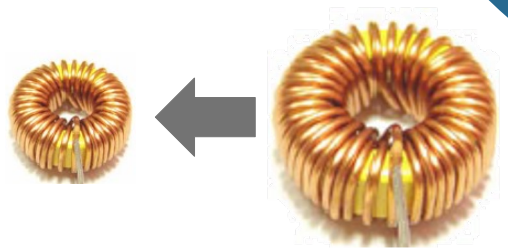
1200V SiC MOSFET

3Φ B6 Rectifier PFC (~70kHz)

FB LLC (150~400kHz)

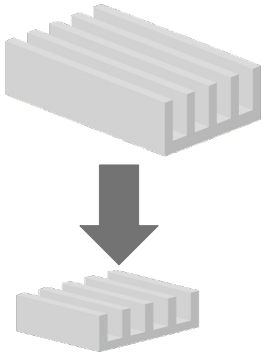


Smaller passives



Fewer Cooling

Smaller heatsink and packaging



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Move to SiC before your competitor !

Why SiC ?

Higher Efficiency / Lower Losses – Leads To:

- Longer Range or lower cost in case of car
- Less cooling requirements
- **Reduced Total Cost of ownership for your customer**
- **Contribution to CO2 Reduction Missions of your customers**
- **Improved Bottomline & New Business Cases for Your Company !**

Higher Switching Frequency Possible – Leads To

- Smaller Size & Lower Cost Passive Components..
- **Higher Power Density & Lower BoM Cost**
- **Less noise in case of motor drives**

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Advantages of onsemi SiC technology

Why onsemi SiC ?

Proven Quality / Robust Planar Design

- In-process Control and Burn-in
- Defect Scanning during Manufacturing
- 100% Avalanche testing of All Dies
- No Drift in Threshold or Parameters
- High Reliability Gate Oxide
- Automotive Qualification AECQ-100

Best in class design tools

- Physical & Scalable accurate Simulation Models
- New online Plecs System design tool
- Application notes and Design guides

Fully Integrated Manufacturing

- Form Sand to Products

Industry's Broadest Portfolio

- Automotive & Industrial grade for All Parts and Packages
- Wide offering in Standard and Custom Power Integrated Modules (PIM)
- Large portfolio discrete packages including top cool

New 3rd generation SiC offering

- Optimized for High temperature operation
  - Diodes : Low series-resistance temperature dependency
  - MOSFETs : Stable reverse recovery over temperature
- Improved parasitic capacitances for High Frequency & High Efficiency application
- Large die with low $R_{DS(on)}$ available

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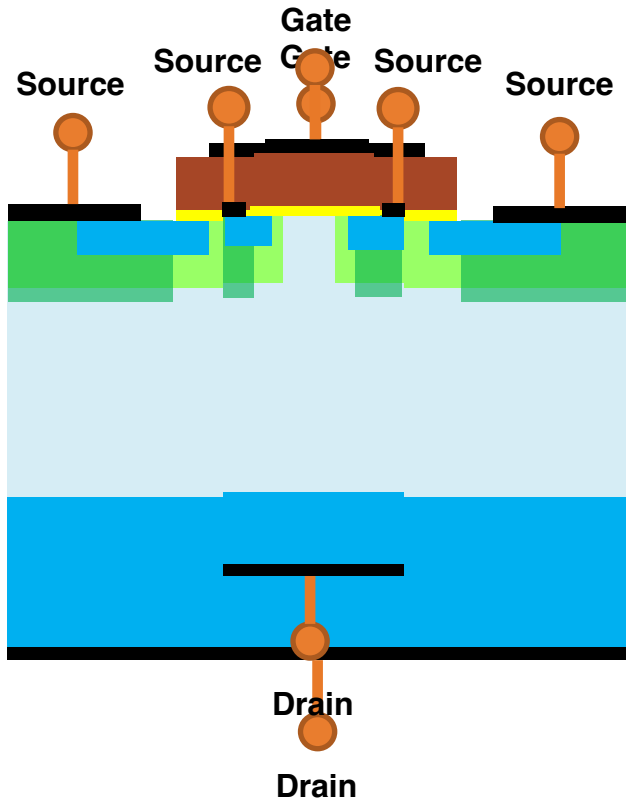
1200V EliteSiC Outperforms the Competition

Supplier	Technology	Conduction 175°C R_{SP} (Normalized)	Switching 175°C $E_{SW,SP}$ (Normalized)
Supplier A	Planar	1.05	1.95
Supplier B	Planar	1.38	1.68
Supplier C	Trench	1.07	1.35
Supplier D	Trench	1.31	1.70
onsemi	**Planar**	**1.0**	**1.0**



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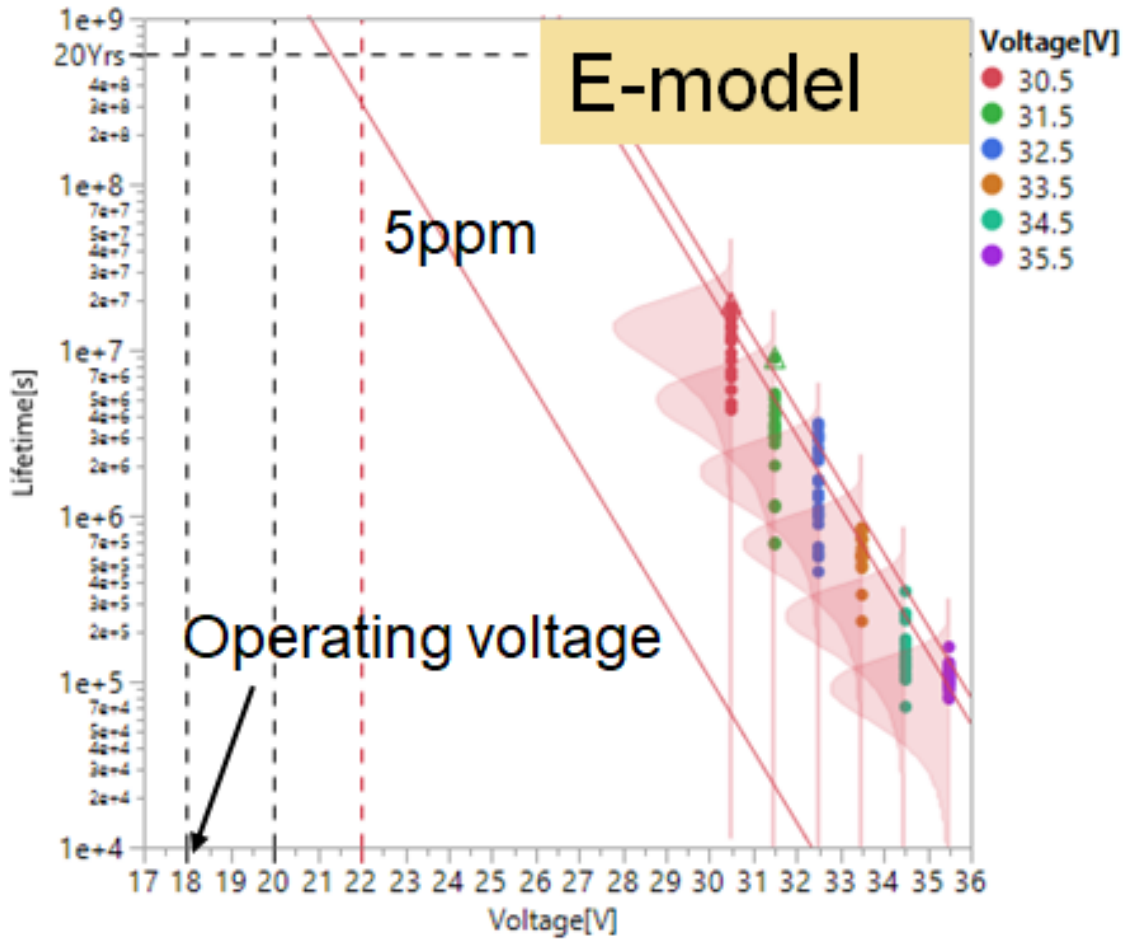
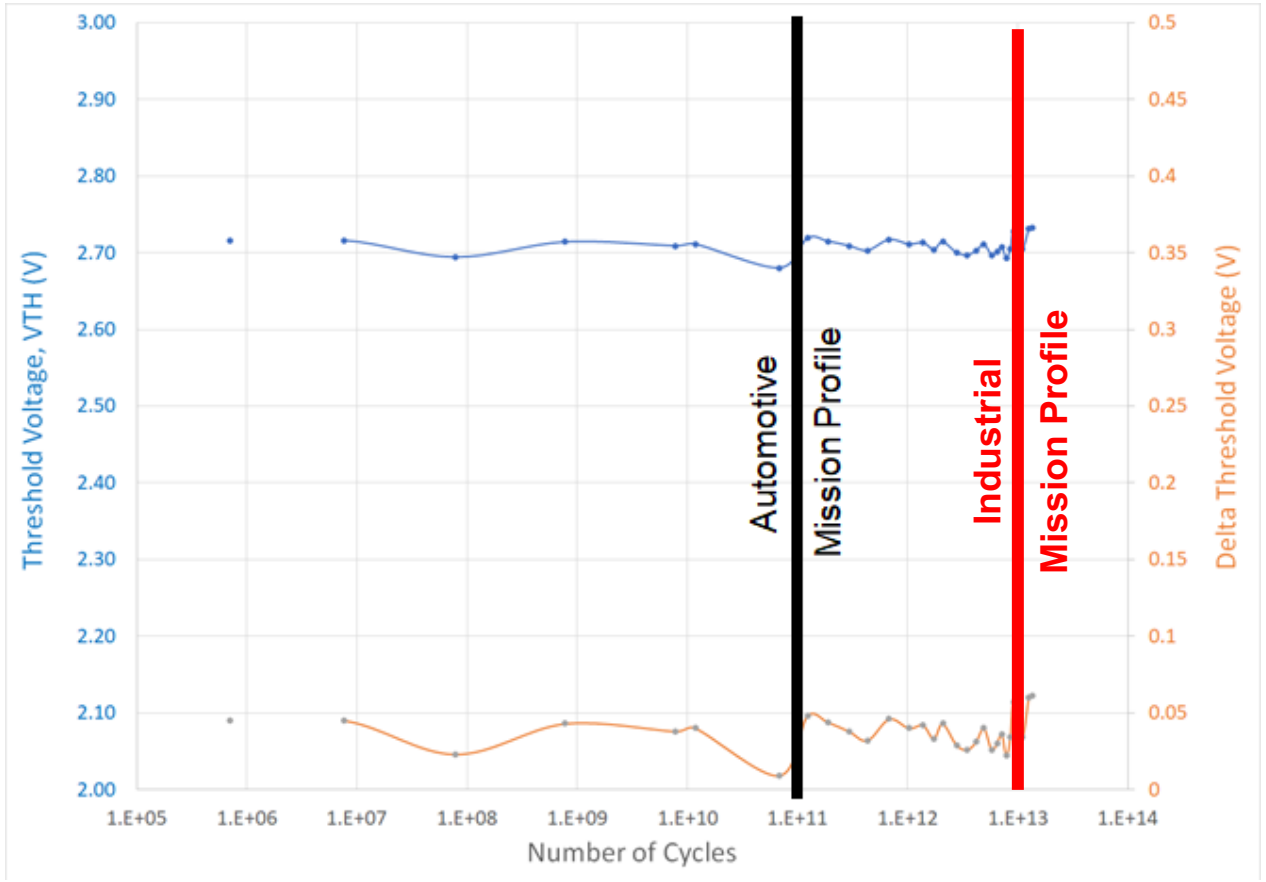
EliteSiC MOSFET Meets Demanding Reliability Standards





Long Gate oxide lifetime with low failure rate

Stable operation during mission profile

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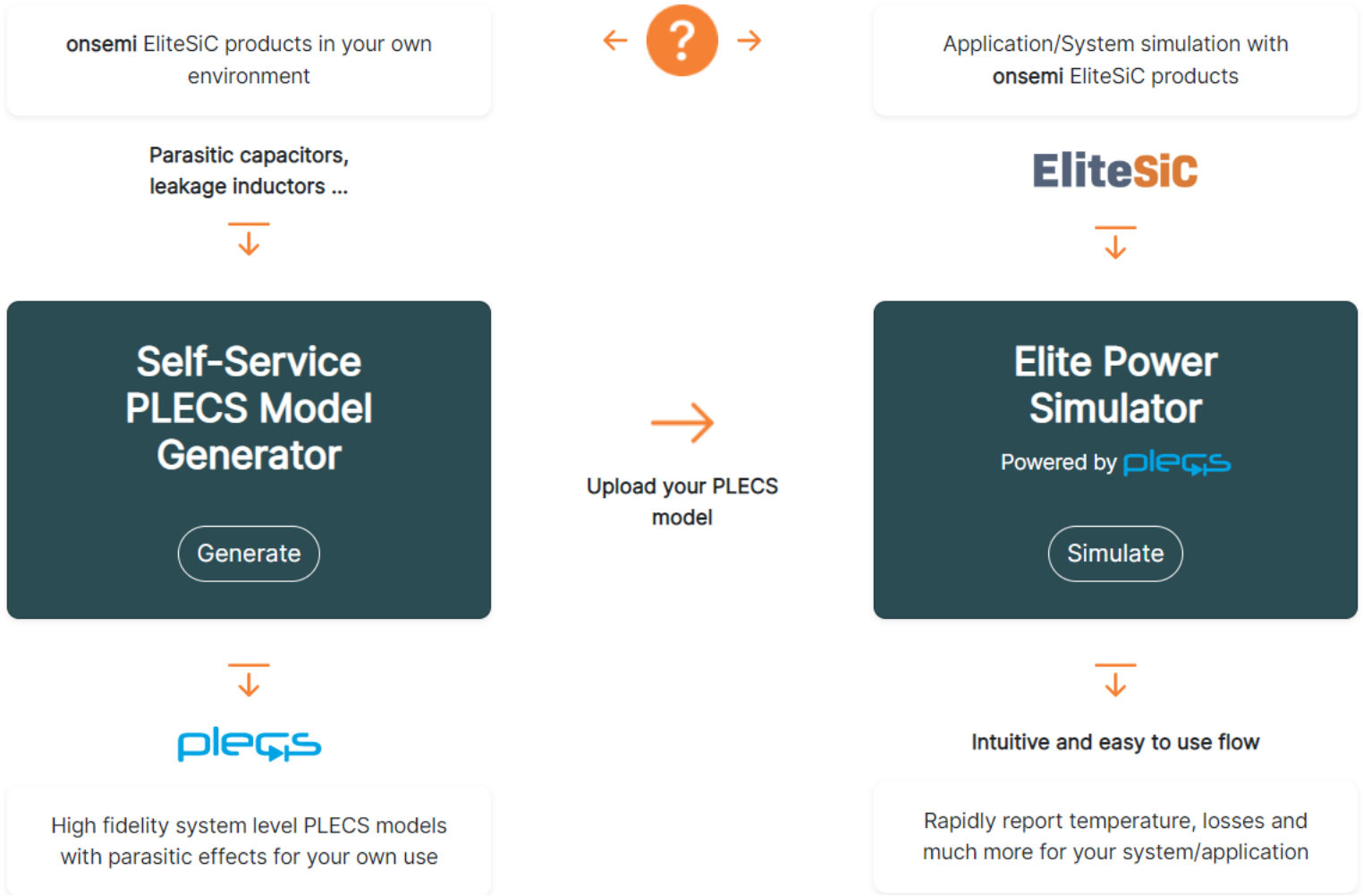
Accelerating New Solutions with Online Design Tools

- The **Elite Power Simulator**
  - System simulation of onsemi's EliteSiC products
  - *Powered by PLECS
  - Broad range of hard and soft switching circuits available
  - Simulation of semiconductor distribution corners
  - 3-Dimensional loss plotting
  - Interfaces with SSPMG
- The **Self-Service PLECS Model Generator (SSPMG)** creates customer-specific high fidelity PLECS model

Ultimate Power delivered when the Elite Power Simulator and SSPMG are deployed together



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Silicon Versus SiC – The Fundamental Challenge

EliteSiC

Czochralski process

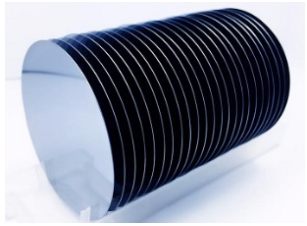
150 mm (SiC) single crystal

SiC boule

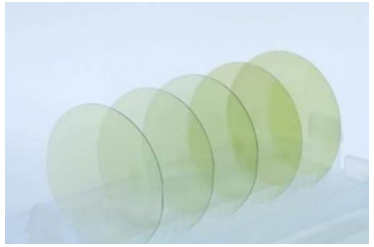
PVT process

onsemi manufactures silicon wafers and singulates SiC wafers

Silicon 200mm wafers



SiC 150mm wafers



Material Length in mm. (Ingot / Boule)	Temperature in Celcius	~Total Growing Time in Hours	mm. of Growth Pr. Hour
1500	~1450 C	15	100
40	~2500 C	336	0,119

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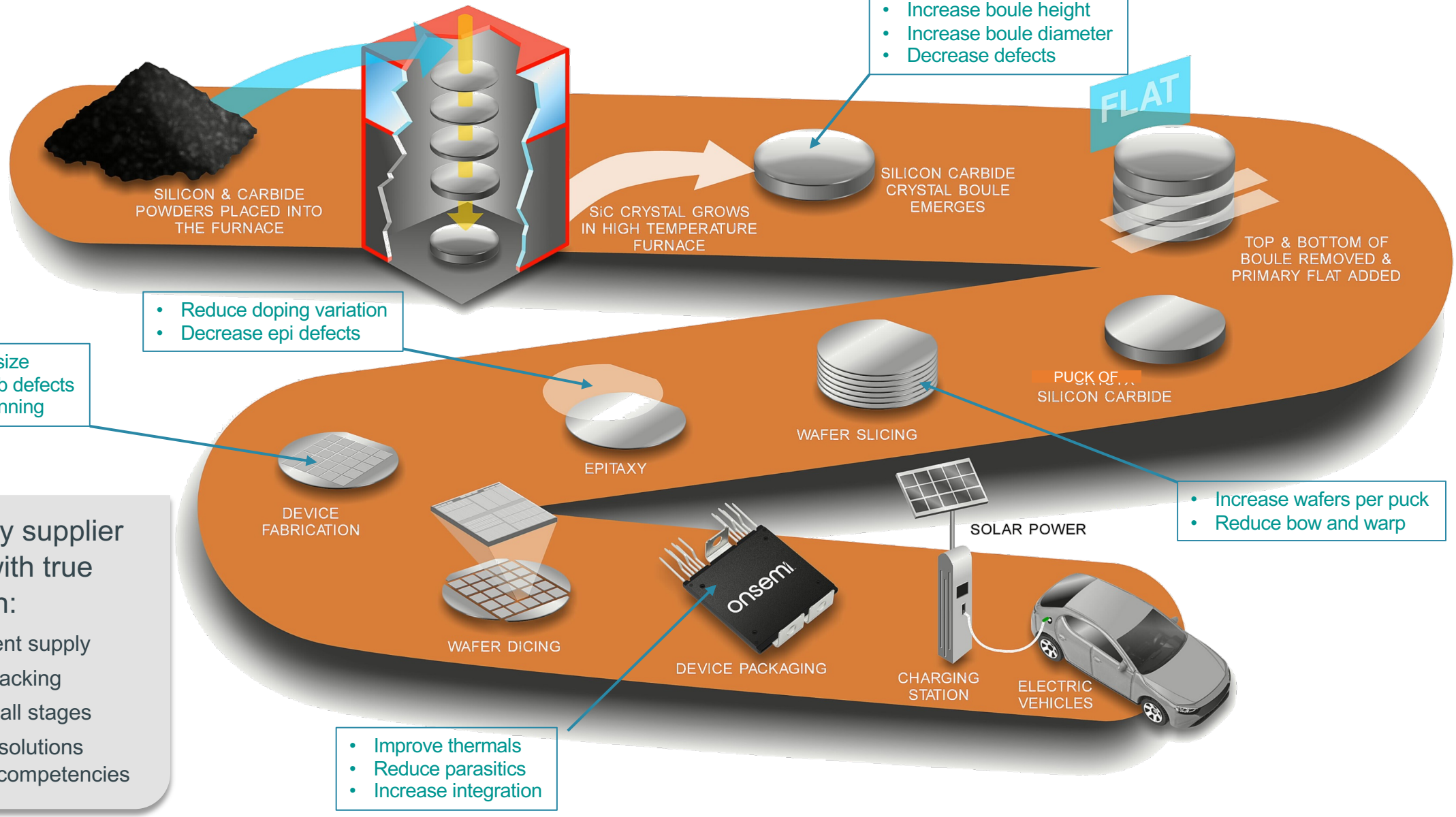
onsemi SiC Leadership: from Powder to Power Modules



onsemi is the only supplier of SiC solutions with true vertical integration:

- Assurance of resilient supply
- Eliminate margin stacking
- Drive innovation at all stages
- Customize system solutions leveraging all core competencies

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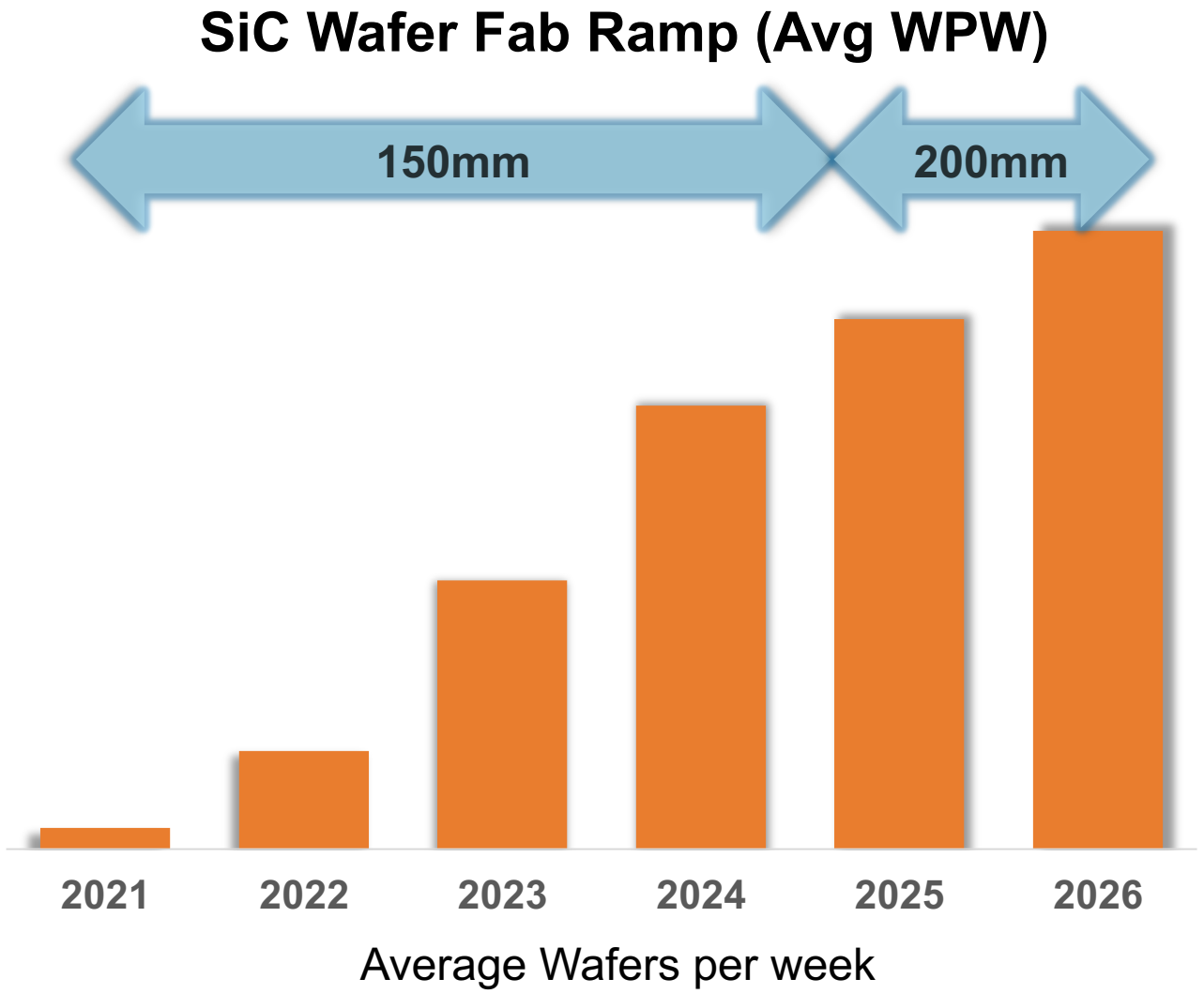
SiC Scale: Capacity Expansion Plan

Leverage Brownfield: Expansion at existing sites

- Hudson – Boules
  - Capacity will expand 5X by 2022
- Bucheon, KR – Device Fab, EPI
  - Capacity will expand ~3x by 2023
  - Capacity will nearly double again 2024
  - Capable of another 2x expansion
- Roznov, CZ – Wafering and EPI

200mm SiC Plan

- ✓ 200mm SiC boule capability
- ✓ 200mm SiC device fab capability
- ✓ All equipment is 200mm capable
- Wafer qualification in 2024
- 200mm revenue ramp in 2025



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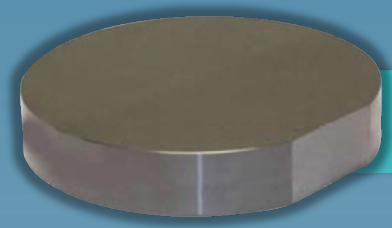
SiC Supply Assurance: From Substrate to Modules

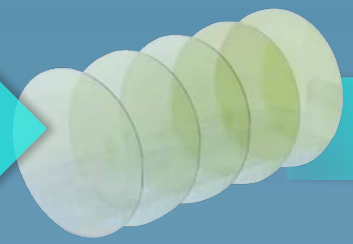
SiC Substrates



- 150/200mm SiC wafering internal in onsemi today

Hudson, NH, USA

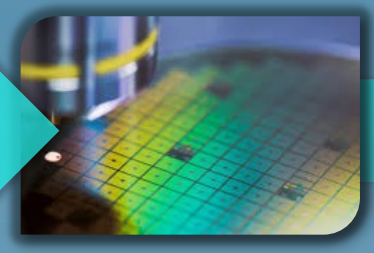
SiC Epi



- 150/200mm SiC epi internal in onsemi today

Bucheon, KR
Roznov, CZ

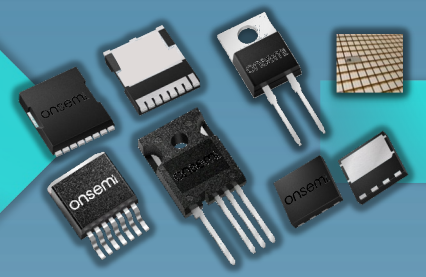
SiC Fab



- Fabs ready today for 150mm→200mm migration

Bucheon, KR

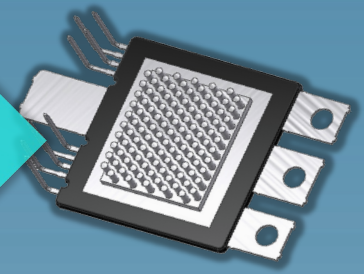
SiC Devices / Die



- Broad base of packages
- Die only & metal options
- Auto & Industrial devices

Binh Duong Province, VN
Suzhou, CN
Shenzhen, CN
Seremban, MY

SiC Modules



- Case and transfer molded options
- Full portfolio of half & full bridge modules
- Single & dual cooling, direct & indirect

onsemi's end to end capabilities drive superior performance and quality

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Losses vs Gate Drive Voltages with 1200V M3S SiC MOSFETs

Conduction Losses highest with VGS 15V

25% lower losses

Conduction Losses Lower with VGS 18V

Conclusion:

- 15V/0V is totally fine with onsemi EliteSiC
- 18V drive always technically better
- 18V/-3V drive gives the best results

EON Losses highest with VGS 15V/0V

25% lower losses

EON Losses Losses Lower with VGS 18V/0V

3% lower losses

EON Losses Losses Lowest with VGS 18V/-3V

Lower Rg:
Lower losses
Higher dv/dt
Higher di/dt

EOFF Losses highest with VGS 15V/0V

3% lower losses

EOFF Losses Losses Lower with VGS 18V/0V

25% lower losses

EOFF Losses Losses Lowest with VGS 18V/-3V

Lower Rg:
Lower losses
Higher dv/dt
Higher di/dt

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onsemi SiC MOSFET and Diode Families

2000V Releasing Soon

Family	Series	Optimization	650V	900V	1200V	1700V	Primary Applications
M1	M1	Low RDS(ON) High SCWT			..120SC1	..170M1	
M2	M2	Low RDS(ON) High SCWT	..065SC1	..090SC1			
M3	M3S	High speed	..065M3S		..120M3S		
	M3P, M3e	Low RDS(ON) High SCWT			..120M3x SCWT dependent		

Family	Optimization	650V		1200V	1700V	Primary Applications
D1	High IFSM	..065A		..120A	..170A	
D2	Low QC	..065B				
D3	Low QC x VF			..120C		

Traction | On-board Charger | EV Charging Station | UPS/Energy Storage | Solar | High Power Industrial

In Development

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650V SiC MOSFETs – M3 Family

In Development
(Sample / Release Date)
In Plan

$R_{DS(ON)}$ (mΩ) Typical @Vgs:18V	TO-247-3L	TO-247-4L	D2PAK-7L	TOLL	BPAK (Top Cool SMD PKG)
					
8	NTHL008N065M3S	NTH4L008N065M3S	NTBG008N065M3S		NTTC008N065M3S
12	NTHL012N065M3S (Mar '24 / Nov '24)	NTH4L012N065M3S (Available / Nov '24)	NTBG012N065M3S (Available / Nov '24)	NTBL012N065M3S (Mar '24 / Q1 '25)	NTTC012N065M3S
16	NTHL016N065M3S (Available / Nov '24)	NTH4L016N065M3S (Available / Nov '24)	NTBG016N065M3S (Available / Nov '24)	NTBL016N065M3S (Mar '24 / Q1 '25)	NTTC016N065M3S
23	NTHL023N065M3S (Available / Jul '24)	NTH4L023N065M3S (Available / May '24)	NTBG023N065M3S (Available / May '24)	NTBL023N065M3S (Feb / Dec '24)	NTTC023N065M3S
32	NTHL032N065M3S (Available / Jul '24)	NTH4L032N065M3S (Available / Jul '24)	NTBG032N065M3S (Available / Jul '24)	NTBL032N065M3S (Feb / Dec '24)	NTTC032N065M3S

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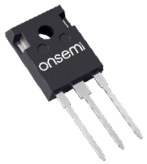
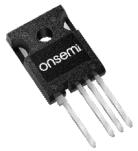
1200V SiC MOSFETs – M3 Family

Released
In Development
(Sample / Release Date)

Automotive grade uses “NV” Industrial grade uses “NT”

$R_{DS(ON)}$ (mΩ) Typical @Vgs:18V	TO-247-3L	TO-247-4L	D2PAK-7L	BPAK (Top Cool SMD PKG)	Die
					
13		NTH4L013N120M3S (Available / Nov ’23)			NTCR013N120M3S (Oct ’23 / Nov ’23)
14		NTH4L014N120M3P	NTBG014N120M3P		
22	NTHL022N120M3S	NVH4L022N120M3S NTH4L022N120M3S	NVBG022N120M3S NTBG022N120M3S	NVTC022N120M3S NTTC022N120M3S (Available / Q4 ’24)	
29	NTHL030N120M3S	NVH4L030N120M3S NTH4L030N120M3S	NVBG030N120M3S NTBG030N120M3S	NVTC030N120M3S NTTC030N120M3S (Available / Q4 ’24)	
40	NTHL040N120M3S	NVH4L040N120M3S NTH4L040N120M3S	NVBG040N120M3S NTBG040N120M3S	NVTC040N120M3S NTTC040N120M3S (Available / Q4 ’24)	
65	NTHL070N120M3S	NVH4L070N120M3S NTH4L070N120M3S	NVBG070N120M3S NTBG070N120M3S	NVTC070N120M3S NTTC070N120M3S (Available / Q4 ’24)	

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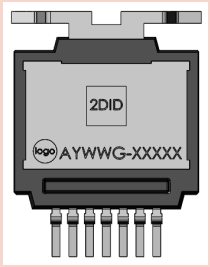
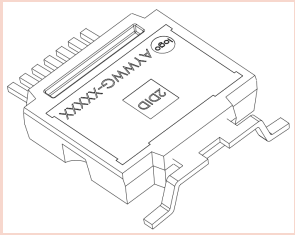
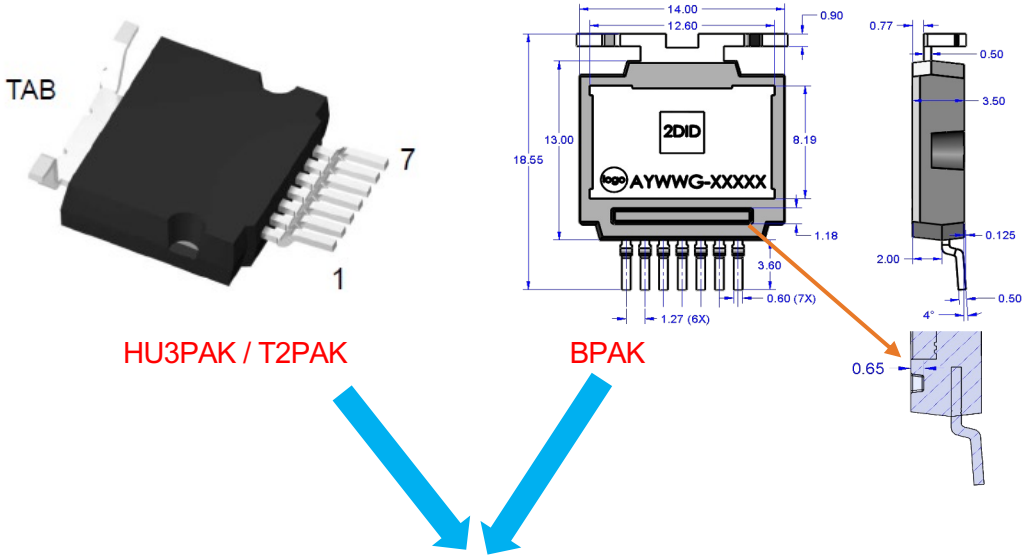
BPAK Top Cool SiC: Introduction

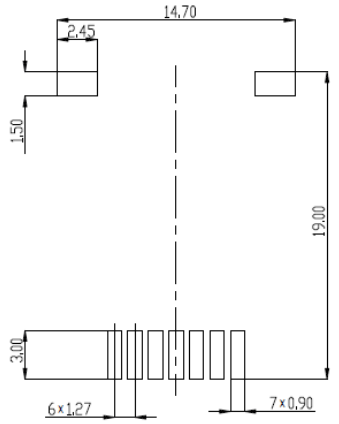
POD Option#	Top view	Side view	Angle view
Top Cool			

Selling points:

1. Clip: up to 5X Ampacity and Power cycle capability
2. High creepage design: 5.8 mm (T2PAK: 3.75 mm)
3. M3S technology: best in class performances for hard switching applications
4. Scalable platform: IGBT and SiC offered



Same footprint and package thickness.
Pin-to-Pin compatible



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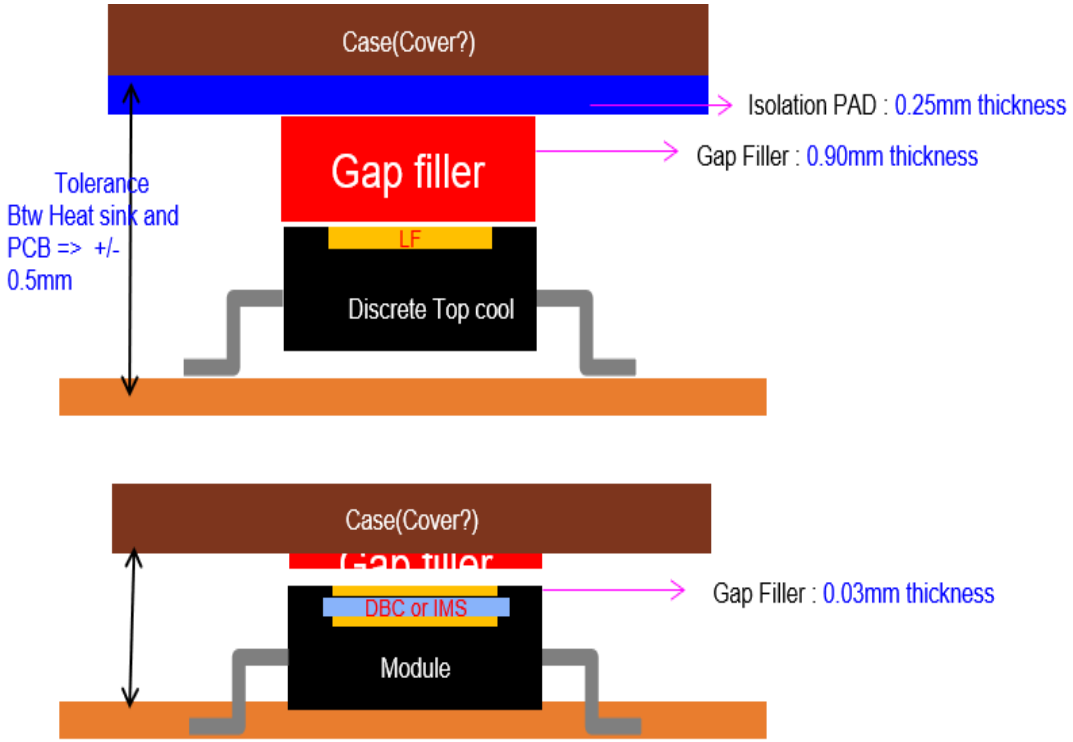
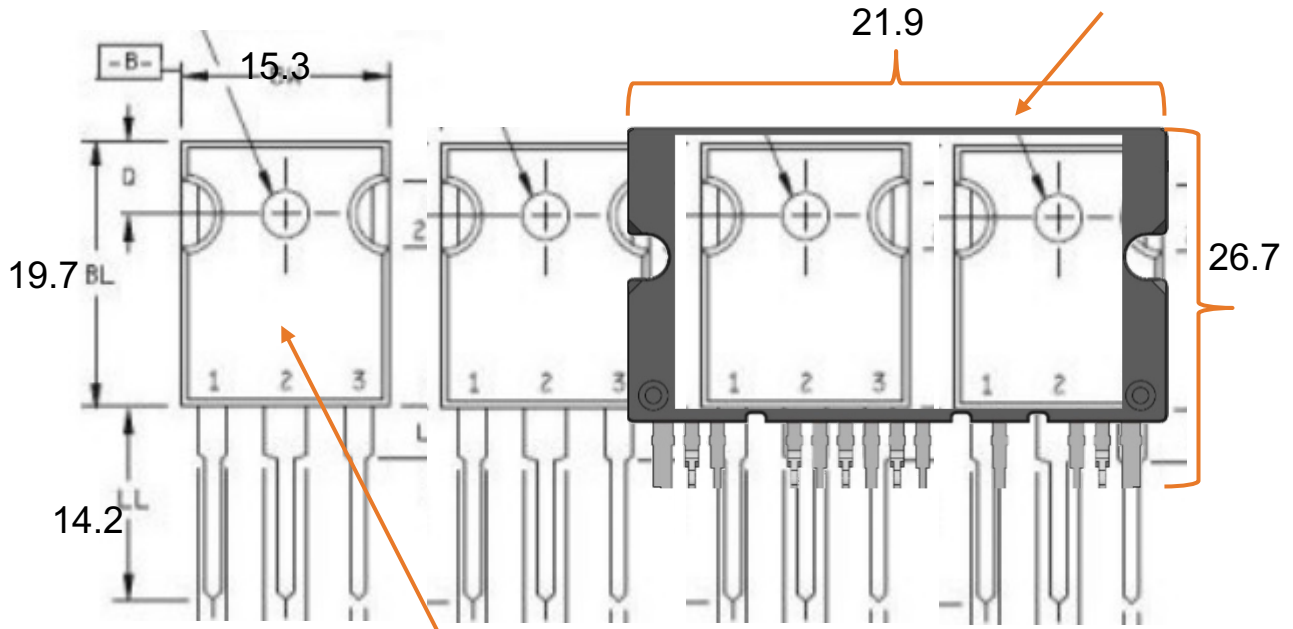
Why Module over Discrete?

- **Thermal performance**
- **Save Metal PCB (in case of D2Pack)**
- **Tolerance of Gap filler for the Top Cool**
- **Fit Rate Improvement**
- **Power Density**



- **APM16 Example**
  - **Power Density**
  - **Single in line pins**

APM16
Full Bridge



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SiC SPM®31 (Mini)

Features

- 1200V M3T SiC MOSFET (Vgs : 0V ~ 15/18V)
- Miller Clamp function into gate drivers
- High power density in small die size & High efficiency
- Fast switching capability
- Pin compatible with ‘M’ Competitor Mini DIP & Onsemi IGBT SPM31
- Very low thermal resistance with DBC substrate
- Built in bootstrap circuit
- No side dummy for more creepage

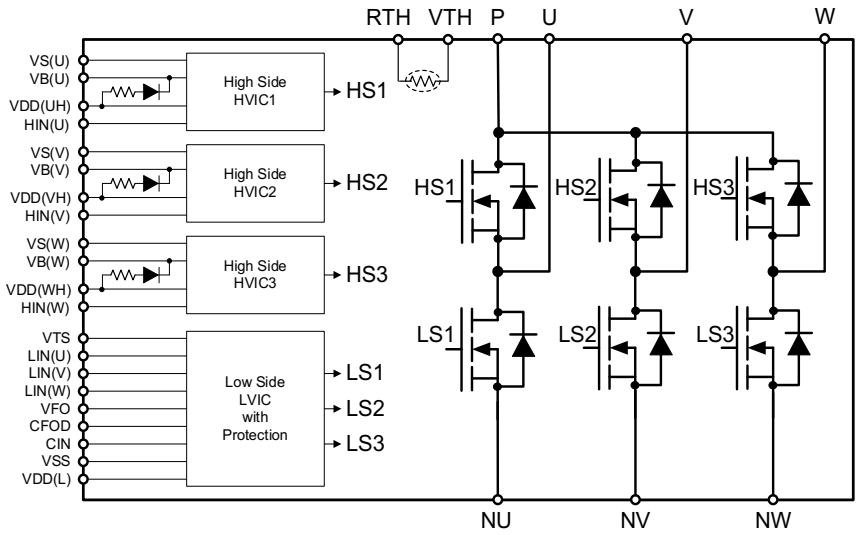
1200V Line-up

Product	Voltage	Rds(on)	Substrate	Remark
NFAM5812SCBUT	1200V	58 mΩ (40A)	DBC (AIN)	ES : Q4`23 MP : Q1`25
NFAM4512SCBUT	1200V	45 mΩ (50A)	DBC (AIN)	
NFAM3212SCBUT	1200V	32 mΩ (60A)	DBC (AIN)	

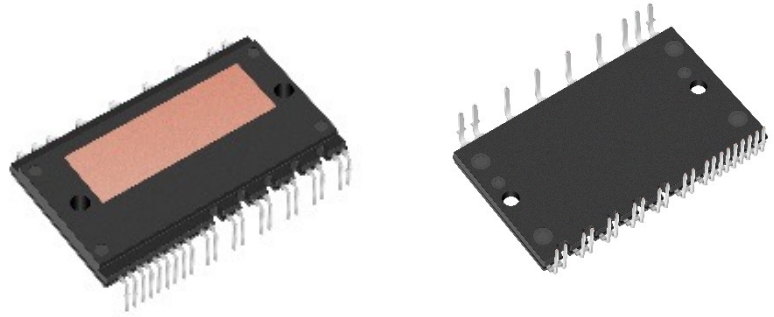
Target Application

- Servo Motor
- Industrial Inverter
- HVAC

Block Diagram



Package: 54.5 mm × 31 mm × 5.6 mm



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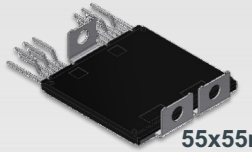
Differentiated Transfer Molded Packages – also for eCav

Transfer-molded half-bridges
Differentiated, ↓ $/kW

SiC



55x55mm²

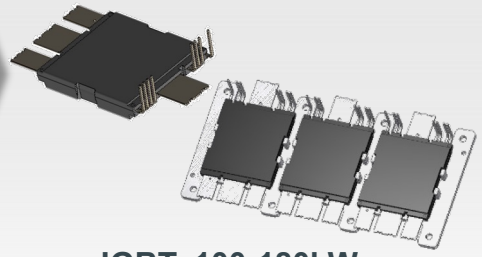
Indirect cooling
150-180kW

IGBT

55x55mm²

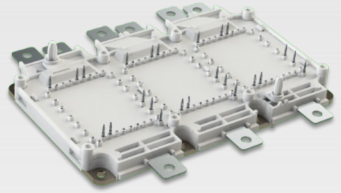
Dual-side cooling
100-150kW

Modular IGBT/SiC + Direct Cooling platform



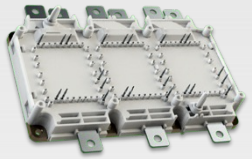
IGBT: 100-180kW
SiC: 150-350kW

Gel-Filled 6-pack
Easy Integration, broad access



Direct cooling
IGBT: 100-180kW
SiC: 150-200kW

Eco+ IGBT
SiC PCT Facelift
(clip/epoxy)



	Transfer Molded	Gel-Filled 6-pack
Reliability	Advanced interconnect technology to enable **increased power density**	Limited by wire bond & solder interconnect
Stray inductance	**Low stray inductance**, maximize performance esp. w/ SiC	Higher stray inductance due to interconnect technology & footprint
Operating Tj	Option for **200°C** & beyond operation	Limited to 175°C
$/kW Roadmap	**Broad path forward**, bigger potential on SiC	Narrow path, chip shrink & yields a limiting factor
Market Access	Customized towards **differentiation**	**Broad market access**, but tough competitor landscape

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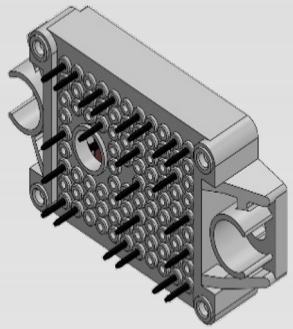
Gel-filled Modules for Energy Infrastructure

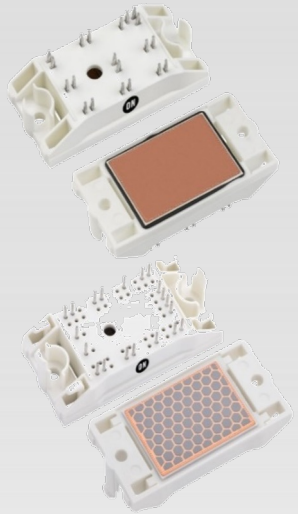
F1



1.2 mm press-fit pins
Solder pins

With TIM/no TIM

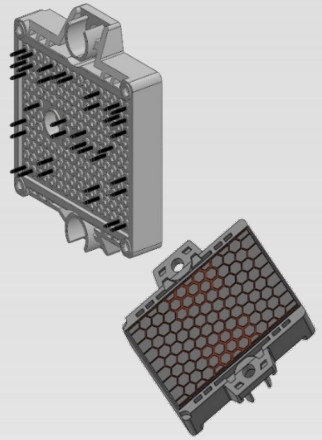
Q0



1.2 mm press-fit pins
1.6 mm press-fit pins
Solder pins

With TIM/no TIM

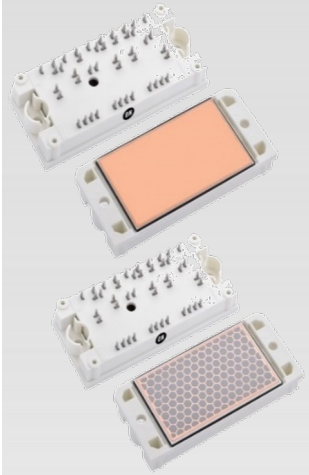
F2



1.2 mm press-fit pins
Solder pins

With TIM/no TIM

Q1



1.2 mm press-fit pins
1.6mm press-fit pins
Solder pins

With TIM/no TIM

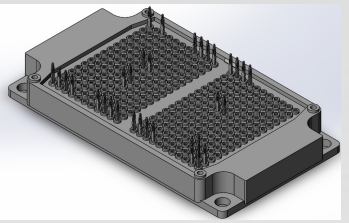
Q2

with base plate

1.6 mm press-fit pins
Solder pins

With TIM/no TIM

F5+BP



with base plate

1.2 mm press-fit pins
Solder pins

With TIM/no TIM

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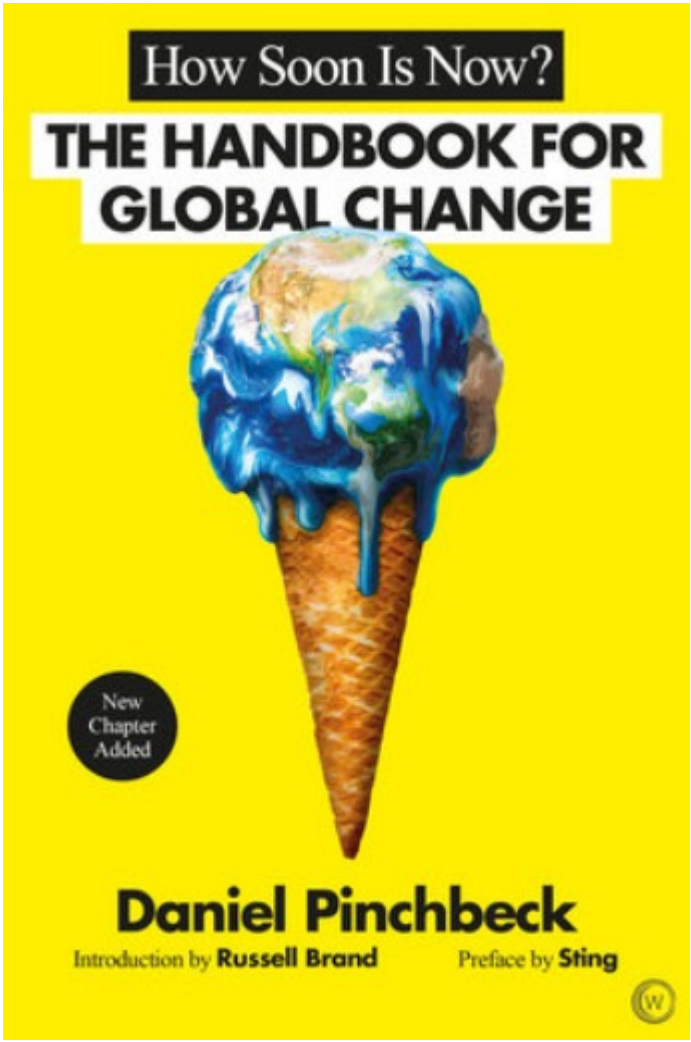
So…….. How soon is NOW ?

Conclusion:

- SiC technology is Mature !
- SiC have Surpassed Si quality level !
- SiC is competitive at solution Level !
- SiC is available in high volume from onsemi !
- SiC market have already taken off !

The Rubber is hitting the road !
Get on the bus or be left behind….



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Thanks For Your Attention

Please Reach Out For Further Conversation !!!

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