Silicon carbide offers high hopes for EVs, but can they meet stringent automotive quality levels?

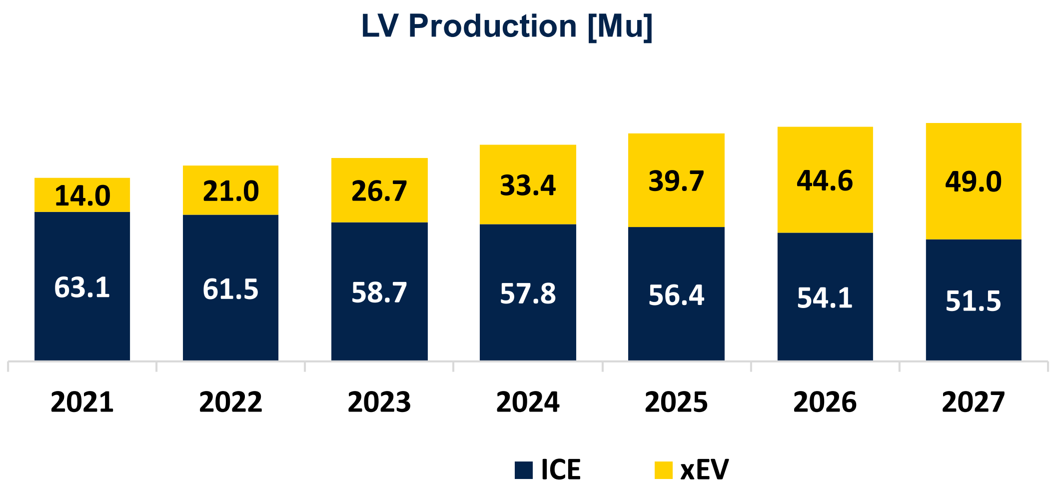
Filippo Di Giovanni

Power Transistor Sub-Group - Strategic Marketing Manager

STMicroelectronics

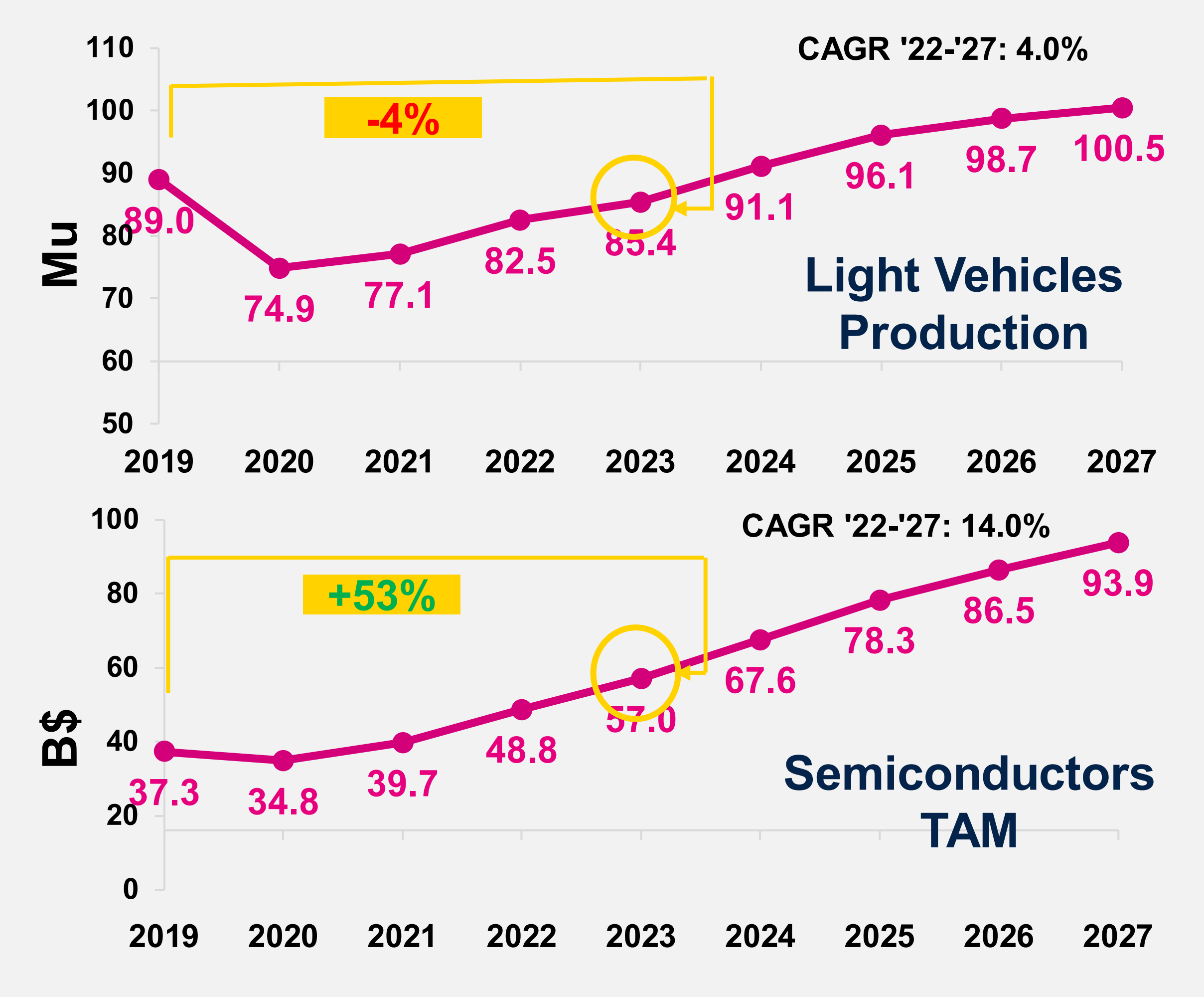
Semiconductor and vehicles production forecast

Automotive semiconductor demand has become uncorrelated with car production



ICE: -3%
CAGR '22-'27

xEV: +18%
CAGR '22-'27



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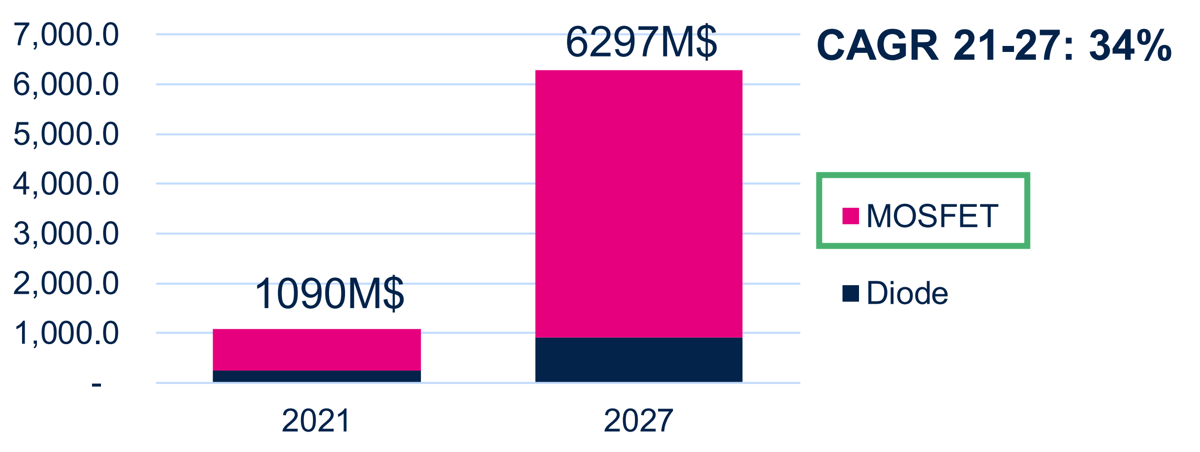
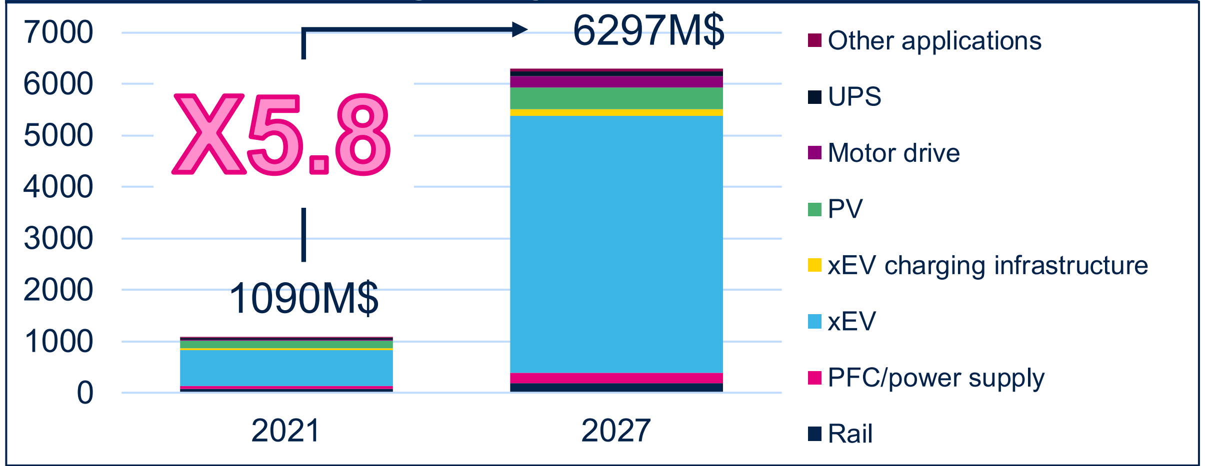
Sources: Strategy Analytics - October 2022 and ST internal
sensors are not considered

SiC semiconductor market

SiC by products



SiC by major applications



Other applications = Others, Wind, Oil and Gas, Military, Medical, R&D…
* including auxiliary power
** including air conditioning

Source: Yole Power SiC Market May 2022 Report

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SiC full vertical integration and roadmap

Vertical integration

Front-end

Catania 150mm capacity increase

> Singapore 150mm ramp-up

Catania “WSiC” substrate and 200mm integrated fab

>115

projects in development

>$1B

SiC revenues in 2023

Current offer and roadmap: from 650 to 2200 V

Gen1	Optimized **Ron** and **Tj** for **motor drive** applications
Gen2	Balanced **Ron** and **Qg** for industrial and automotive
Gen3	**Lower Ron** vs. Gen2 maximizing EV’s driving range
SiC VHV*	**Very High Voltage SiC** 2200V in bare die option
Gen4*	**Lower Ron** vs. Gen3 tailored for traction inverter
Gen5**	Innovative **high power density technology** structure
MDSiC**	Radical innovation, outstanding Ron value at elevated temperature and further Ron reduction vs. Gen5

*Under development
** R&D stage

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Challenges of electrification

Mobility is all about efficiency

Reduce weight and cost of cooling systems

Reduce power losses and heat dissipation

Extend driving range above 600 km

Reduce the number of recharges

Increase reliability

Cost reduction

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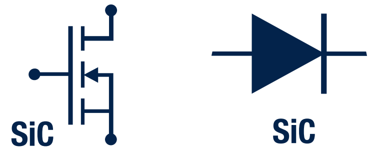

SiC value proposition

SiC technology benefits versus conventional Si IGBT

Higher performance & voltage operation

- Extremely low power losses
- High efficiency at low current
- Intrinsic SiC body diode (four quadrant operation)

Higher operating frequency

- Lower switching losses
- Excellent diode switching performance

Higher operating temperature

- Up to 200°C junction

SiC advantages for automotive

Electrification - range extension, smaller battery (or increased battery reliability), fast & efficient charging

Efficiency gain in average	Switching losses	Chip size	Total loss	Switching frequency
From ~2% (high load) to ~10% (low load)	~7x lower	~5x smaller	~50% lower	~ 5 ...10 times higher

Lower system cost

~7x reduced form factor	~80% cooling system downsizing	~Simpler subsystems: smaller passives, no external freewheeling diode…

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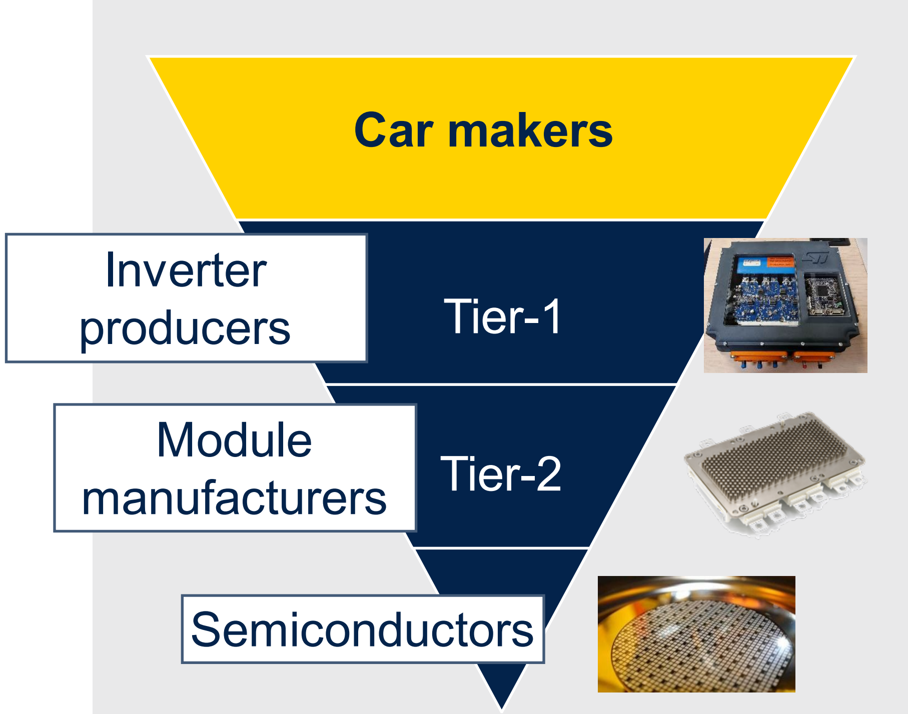
Car makers becoming mobility service providers

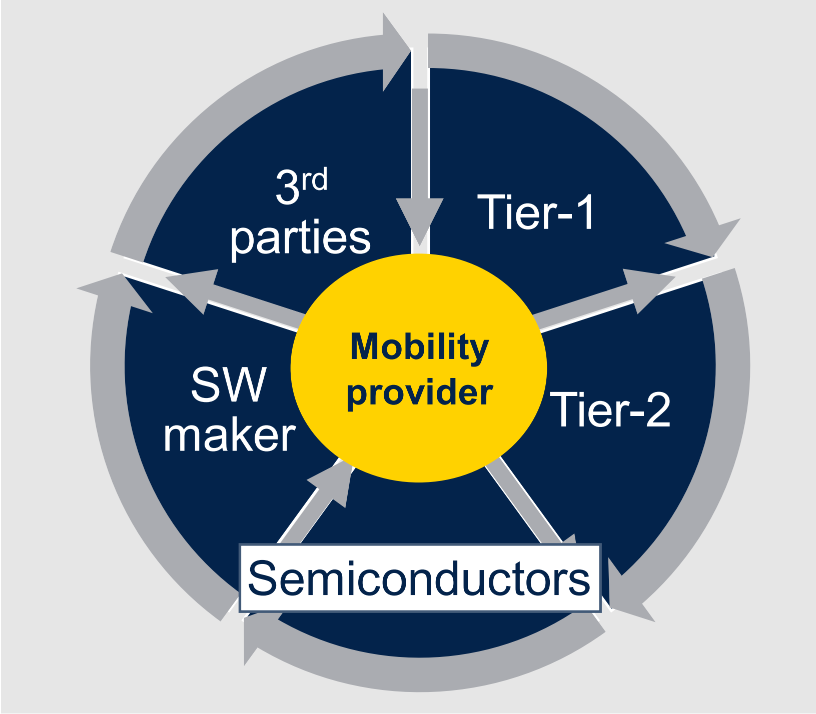
Traditional approach "buy model"



- Deploy new technologies and semiconductor solutions more effectively and rapidly to the car
- Directly drive the semiconductor roadmap with a closer link to final application
- Secure capacity of key technologies applicable to electric vehicles

OEM direct contact with semiconductor supplier

New ecosystem "make model"



OEM = Original Equipment Manufacturer

SiC (and GaN next) targets energy-efficient applications

Wide-bandgap semiconductors offer superior performance and characteristics thanks to:

Faster switching	Lower switching losses and higher efficiency	**SiC and GaN**
Higher switching frequencies	Smaller filters and magnetics	**SiC and GaN**
Higher operating voltages with low on-resistance	Reduced currents and lower conduction losses	**SiC**
Higher junction temperatures	Reduced cooling requirement	**SiC**

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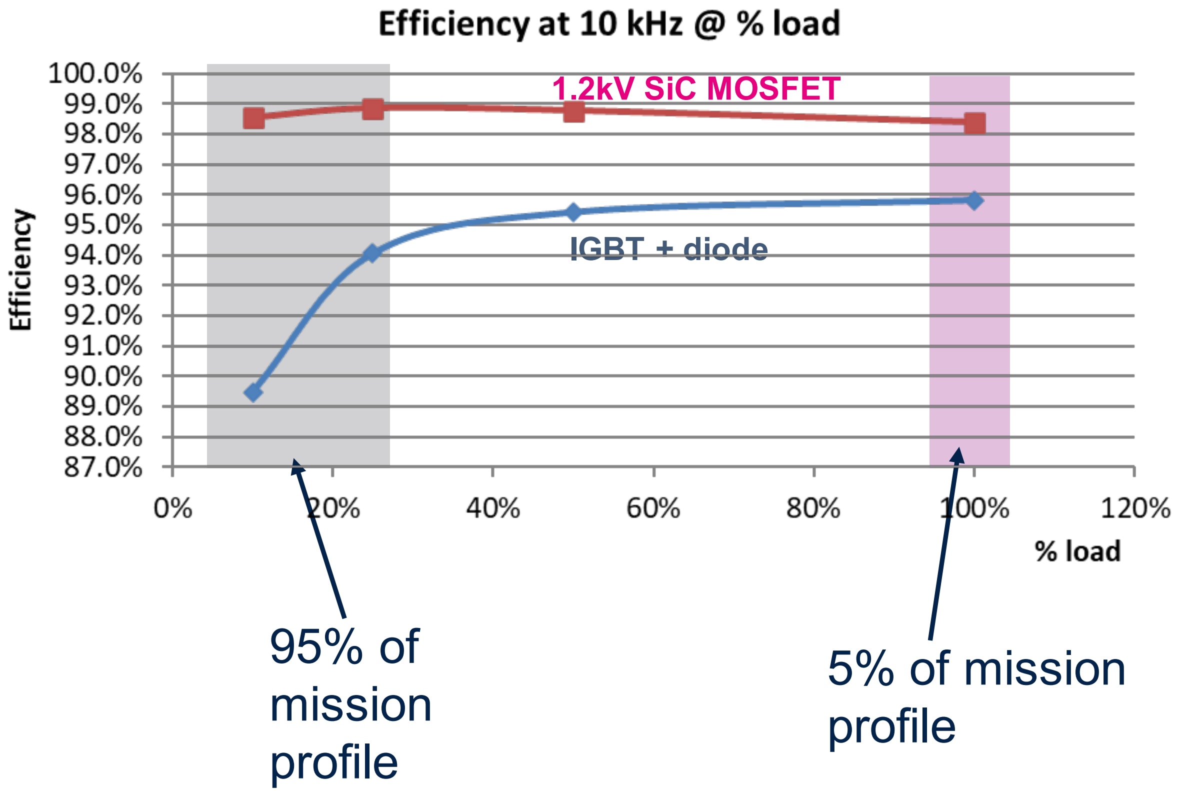
SiC MOSFET efficiency gain in EV traction inverter

1200V SiC MOSFET vs. IGBT: 210 kW traction inverter @ 10 kHz

		IGBT + diode		1.2kV SiC MOSFET
Typ. power losses per switch @ 350 A_{rms} peak power	**total chip area (mm^2)**	**600**	**x5**	**120**
	conduction losses (W)	300		307
	switching losses (W)	**564**	**x4**	**143**
	total losses (W)	**864**	**x2**	**450**
	Junction Temp (°C)	134.8		132.4

		Time (%)	Load
Mission profile of a typical EV traction inverter	**City**	45%	10%
	Highway	40%	20%
	Top speed	10%	7%
	Accelerating	5%	100%
	Regeneration	Braking	30%



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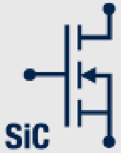
Opportunities and challenges of SiC in EV inverter design

Opportunities

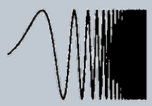
Reduced switching losses and system cost through silicon carbide technology

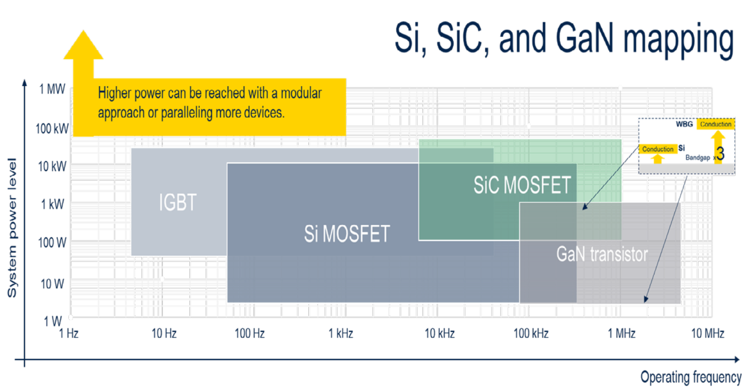


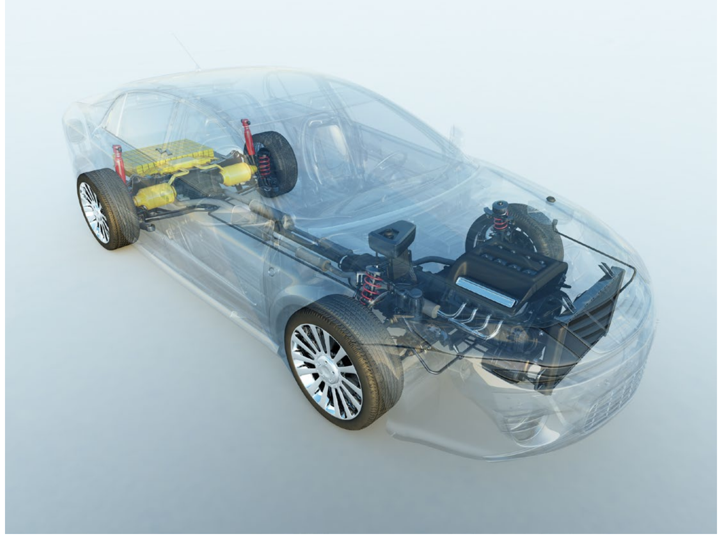
Higher breakdown field (MV/cm) leading to better efficiency

Higher power density with battery voltage increase

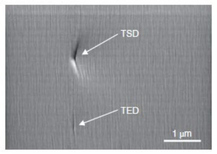
New architecture and integration in the car's power unit



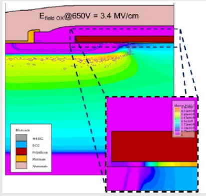




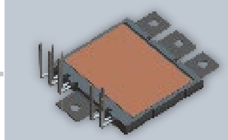
Reliability challenges



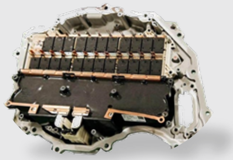
High substrate and process defectivity



Higher critical electric field also on gate oxide



Package capability to manage high power density switching



New failure mechanism and parasitic effects at system level

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SiC MOSFET automotive technology

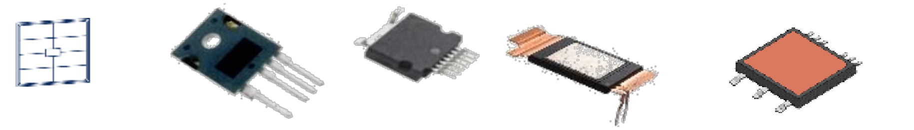
>60%
Today market share in automotive

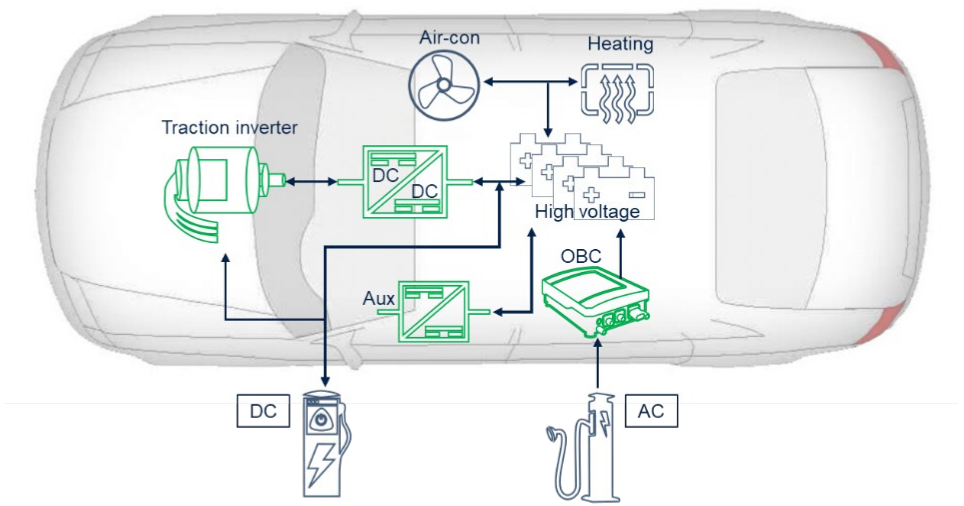
Technology roadmap

Gen1	Optimized **Ron** and **Tj** for **motor drive** applications	Planar
Gen2	Balanced **Ron** and **Qg** for industrial and automotive	Planar
Gen3	**Lower Ron** vs. **Gen2** maximizes the driving range of EVs	Planar
Gen4*	**Reduced Ron** vs. **Gen3** tailored for traction inverter	Planar
Gen5**	Innovative **high power density technology** structure	Planar
MDSiC**	Radical innovation, outstanding Ron value at hot temperature and further Ron reduction vs. **Gen5**	Not Planar

Gen4: Technology qualification by Q4 2023
Gen5: Technology qualification by Q4 2025
MDSiC: Technology qualification by 2027

Advanced packaging





Traction inverter	From Gen2 to Gen5
DC-DC converters	From Gen1 to Gen5
OBC	From Gen2 to Gen5

*Under development
** R&D stage

■ Planar ■ Not Planar

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Four vectors for quality and robust validation

1. **Failure analysis**
2. **Design for reliability**
3. **Testing effectiveness**
4. **Mission profile assessment**

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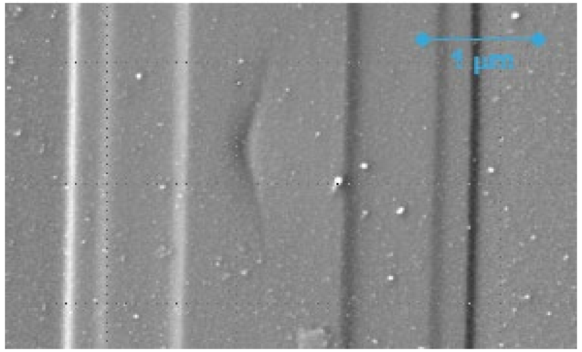
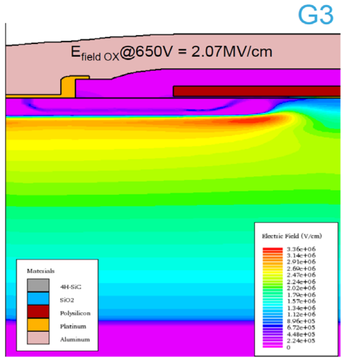
Four vectors for WBG deployment and validation

Failure analyses



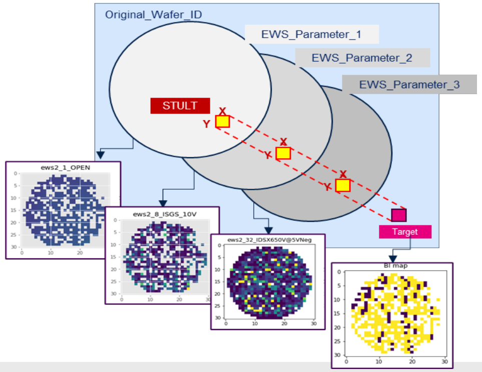
- Identification of new failure modes
- Effectiveness evaluation of screening methods
- Support for customer use in application
- New FA techniques

Design improvement



- Design fine tunings based on new failure mode
- Design for reliability and more margin
- Front-end & back-end new material and design solution evaluation

Testing improvement



- Fine tuning of testing in EWS and back-end
- Burn in testing for new technologies
- DOLI implementation for known defects

Mission profile assessment

- Analysis of customer specific mission profile
- Fine tuning of testing and reliability assessment
- Equivalent FIT evaluation

FA = Failure Analysis, EWS = Electrical Wafer Sorting, DOLI = Defect Offline Inking, FIT = Failure in Time

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Integrated approach for mission profile assessment

FM = failure mode

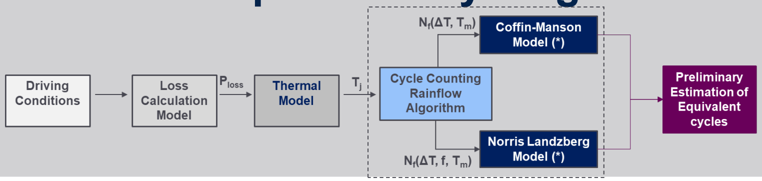
Temperature stress

$$TF_2 = TF_1 \cdot e^{\frac{E_a}{K}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)}$$

Passive temperature cycling

$$\frac{N_{Cust\ \Delta T}}{N_{ST\ \Delta T}} = e^{Ea/K\left(\frac{1}{Tmfield} - \frac{1}{Tmlab}\right)} * \left(\frac{ST\ \Delta T}{Cust\ \Delta T}\right)^m$$

Active temperature cycling



Customer Mission Profile

Portion A	Portion B	Portion C
FM 1,2,3	FM 3,4	FM 1,3

$\%T_{portion\ 1}$ x $FIT_{Portion\ 1}$ + $\%T_{portion\ 2}$ x $FIT_{Portion\ 2}$ + … + $\%T_{portion\ N}$ x $FIT_{Portion\ N}$ = FIT_{Total}

Overall mission profile FIT is calculated as weighted average of the FITs of the single portions.

Cosmic ray

$$\lambda(V_{DC}, T_j, h) = \lambda_1 \cdot \left(\frac{\lambda_2}{\lambda_1}\right)^{\left(\frac{V_{DC}-V_1}{V_2-V_1}\right)} \cdot e^{\left(\frac{25-T_j}{47.6}\right)} \cdot e^{\left[1-\left(1-\frac{h}{44300}\right)\right]/0.143}$$

Voltage stress

$$TF_2 = TF_1 \cdot 10^{\gamma(Eox1-Eox2)} \cdot e^{\frac{E_a}{K}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)}$$

Humidity stress

$$Af(RH, T, V) = \left(\frac{RHa}{RHu}\right) * e^{\left[\frac{Ea}{k} * \left(\frac{1}{Tu} - \frac{1}{Ta}\right)\right]} * \left(\frac{Va}{Vu}\right)^y$$

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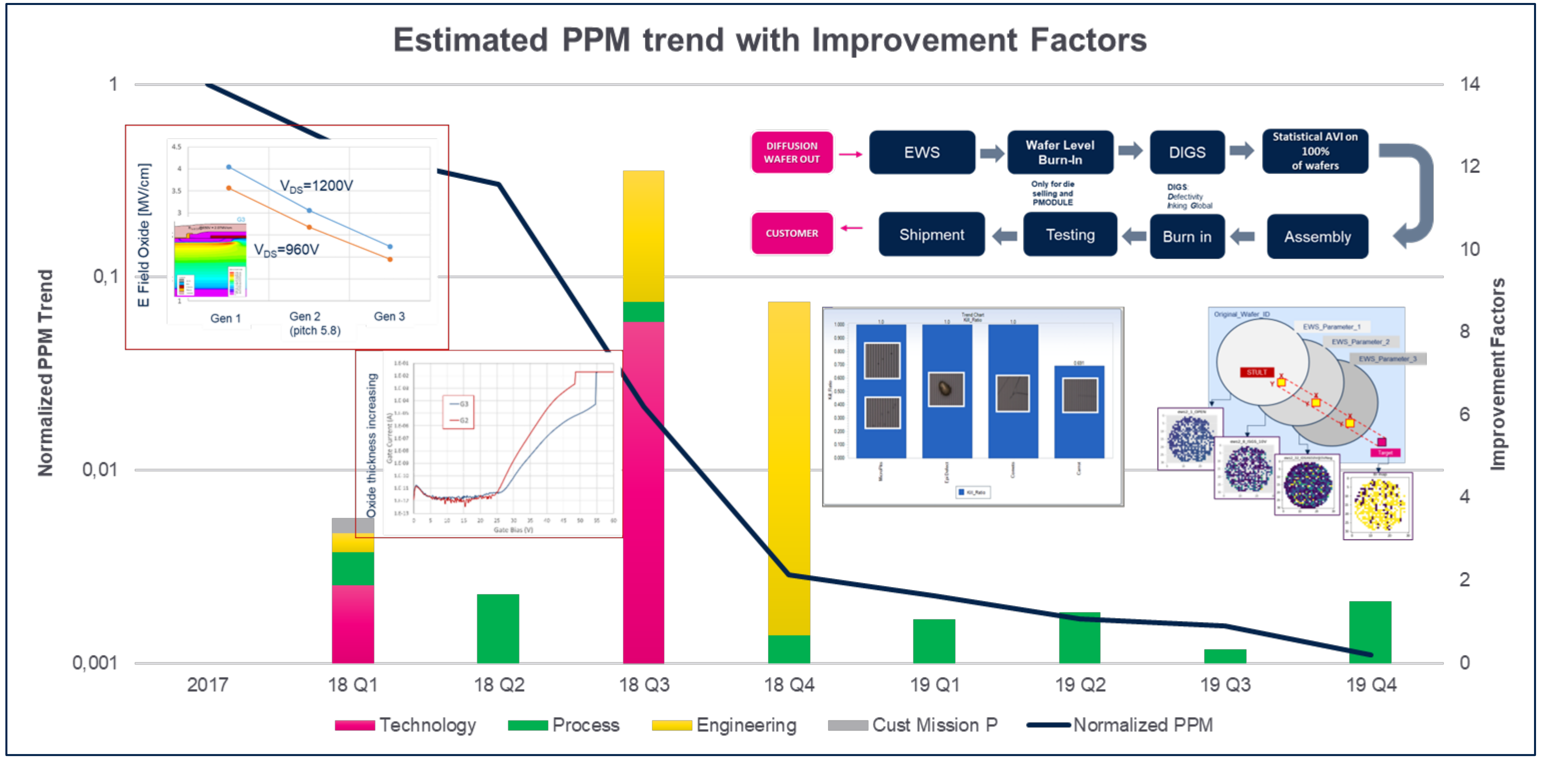
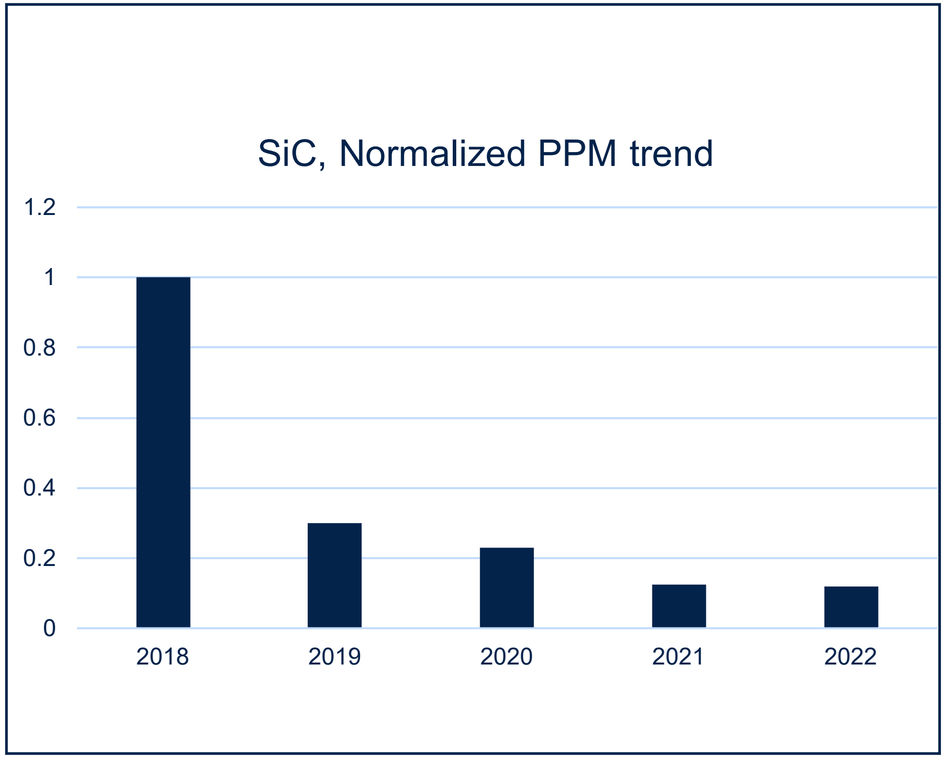
From internal step-down plan to field figures

More than 250 millions SiC chips shipped into the automotive field until now, with quality level well below 1 ppm





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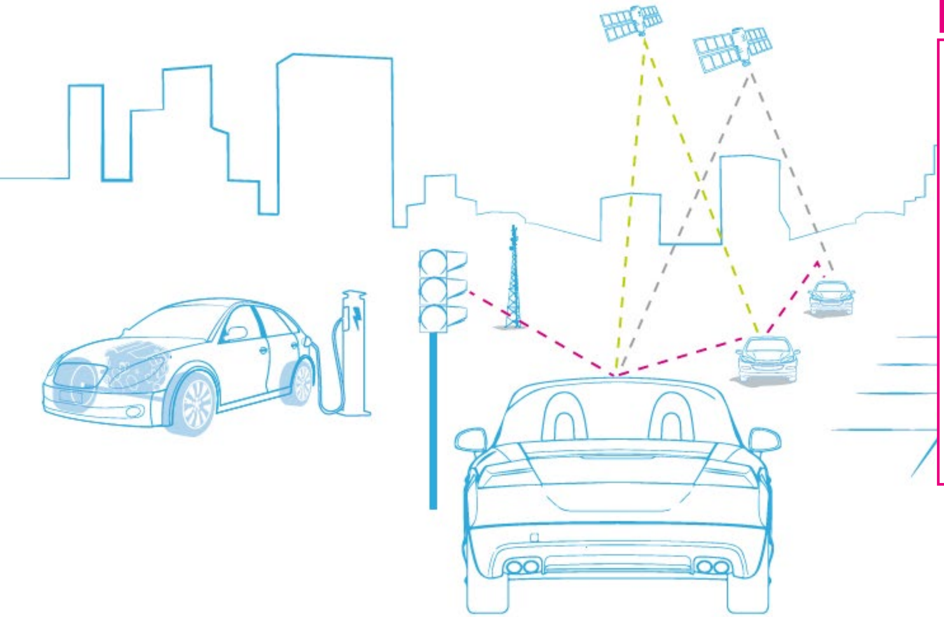
Future evolution of electric vehicles

Electronic device's operation lifetime of future vehicles is expected to increase 10x vs. traditional ICE* cars



Future electric vehicle grid integration

Lifetime requirement:

Up to 120.000 hrs

(Car-to-x communication, swarm intelligence, over-the-air software updates)

Electric vehicle

Lifetime requirement:

8.000 – 40.000 hrs
(charging + driving)

Spec: AEC-Q101 & AQG 324

Combustion engine

Lifetime requirement:

8.000 - 12.000 hrs

Spec: AEC-Q101

* Internal Combustion Engine

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Key takeaways

EV market is growing > 25% CAGR 2021-2026 pushing SiC MOSFET volumes up and urging new investments

More than 5 million EVs running worldwide with ST's SiC MOSFETs onboard

PPM levels in the field with WBG material have been continuously reduced by dedicated plans in response to mission profile assessments

WBG semiconductor content in EV application will grow in the coming years and product lifetime is being extended continuously

Need for **new standards** for longer lifetime assessment and alternative solutions taking advantage from **big data, Artificial Intelligence and massive system simulation**

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Our technology starts with You

Find out more at www.st.com

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