New Power Electronics Technologies for the Market Evolution of EVs

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EMEA Region - APG Marketing and Application

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evs 30 THE 30TH INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & TRADE FAIR

OCTOBER 9–11, 2017 MESSE STUTTGART, GERMANY

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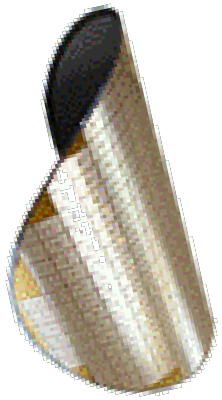
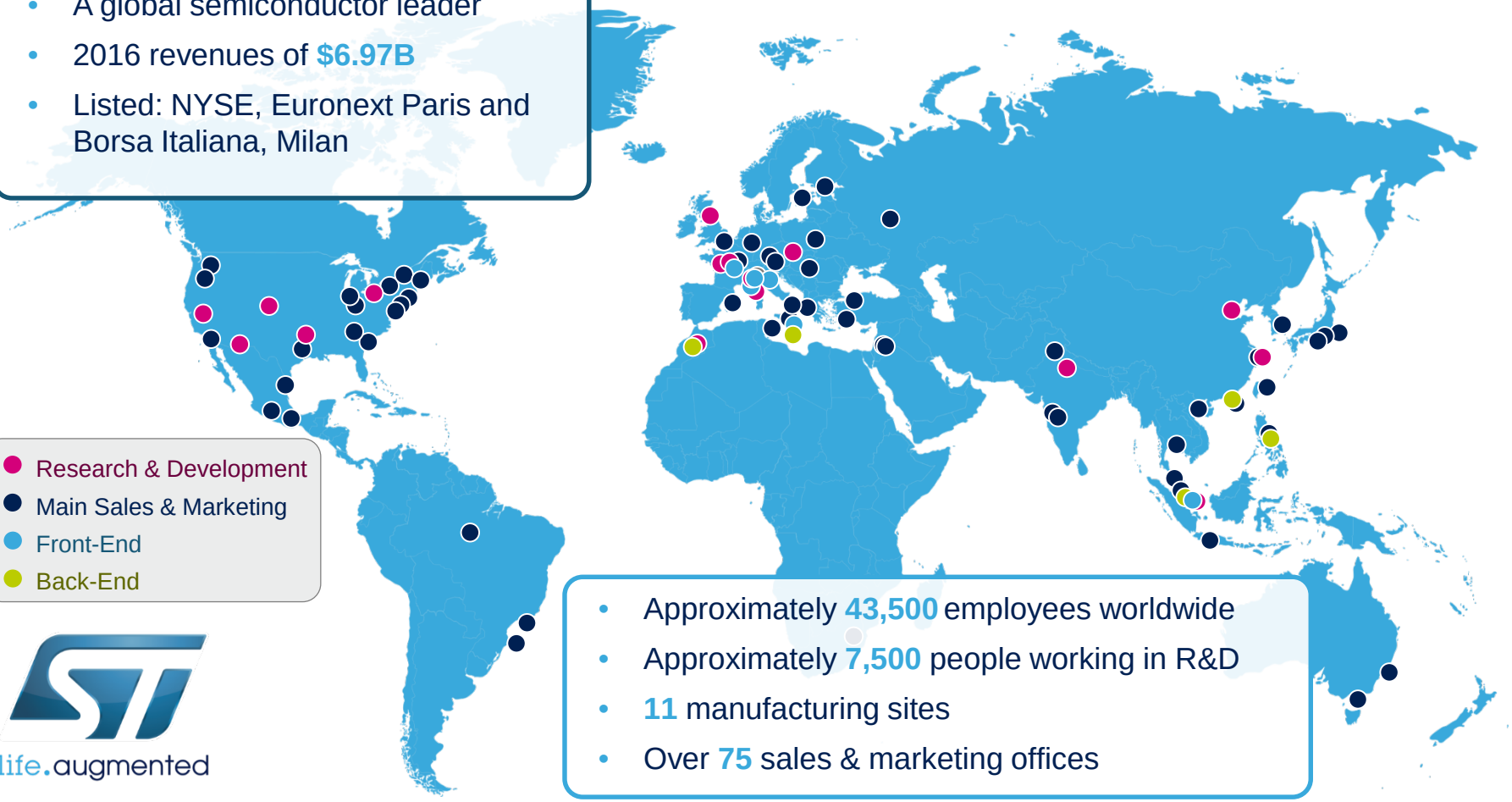
Agenda



- Introduction
- Wide Band Gap Materials
- SiC Power Devices in STMicroelectronics
- System Advantages enabled by SiC
- SiC enabling System Advantages Traction Inverter / OBC
- SiC Reliability & Value Proposition
- Conclusion

STMicroelectronics / Who We are

- A global semiconductor leader
- 2016 revenues of **$6.97B**
- Listed: NYSE, Euronext Paris and Borsa Italiana, Milan



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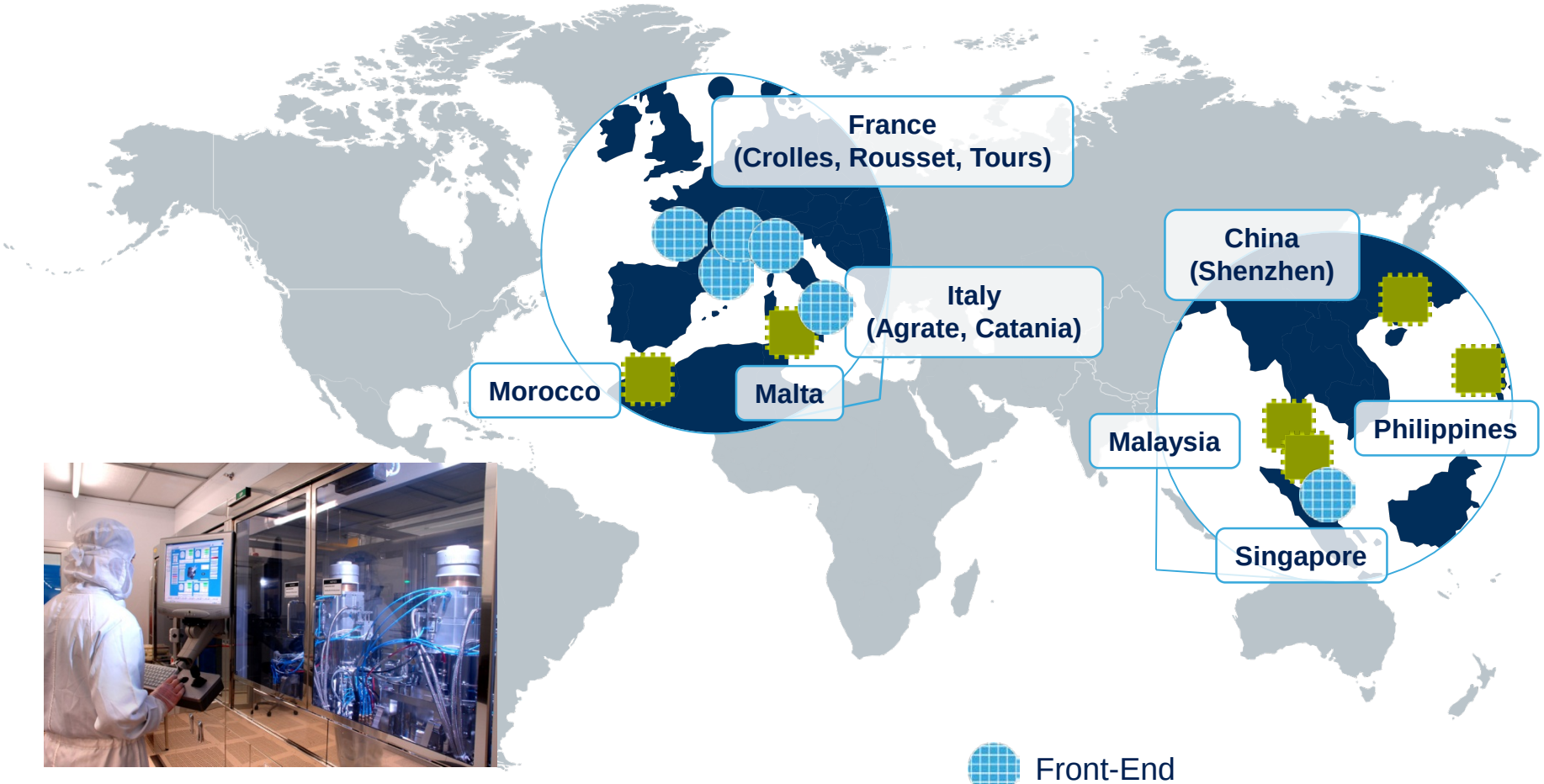
- Approximately **43,500** employees worldwide
- Approximately **7,500** people working in R&D
- **11** manufacturing sites
- Over **75** sales & marketing offices

As of December 31, 2016

Flexible and Independent Manufacturing



Industry Challenge / Greener Driving

ST is making driving greener

What Greener Driving Means

- Improving power and fuel efficiency in car electronics and helping people drive (or be driven) to minimize fuel consumption, emissions and wear and tear on their cars
- International CO_2 targets
- Moving towards electric vehicles

Key Challenge in Electric Vehicles

Mileage Extension Enabled by SiC

Industry Challenge	Market Trends and Benefits	ST Positioning

Mileage Extension

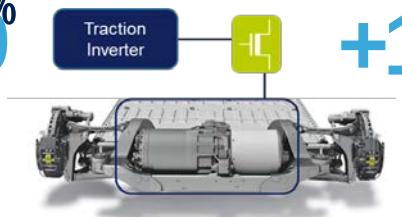
Cost of Ownership

(*) 20% power savings can result in gains of over $6,000 in battery cost, or 8% of the vehicle cost

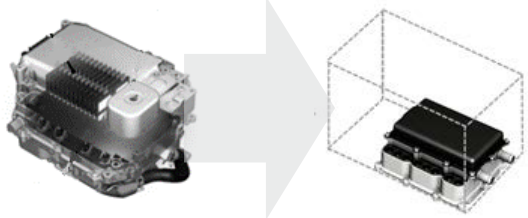
More Efficient Power Conversion (*)

Reduced Battery Cost **-10%**

Extended Mileage **+10%**



Power Control Unit

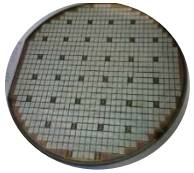


X5 form factor reduction

SiC MOSFETs

4X more efficient than IGBT

SiC Diodes



6 inch wafers from 2017

Cost competitiveness

Solution/Cost

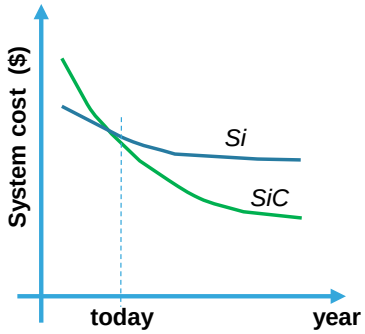


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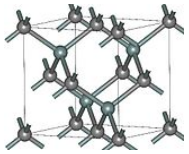
Figure of Merit

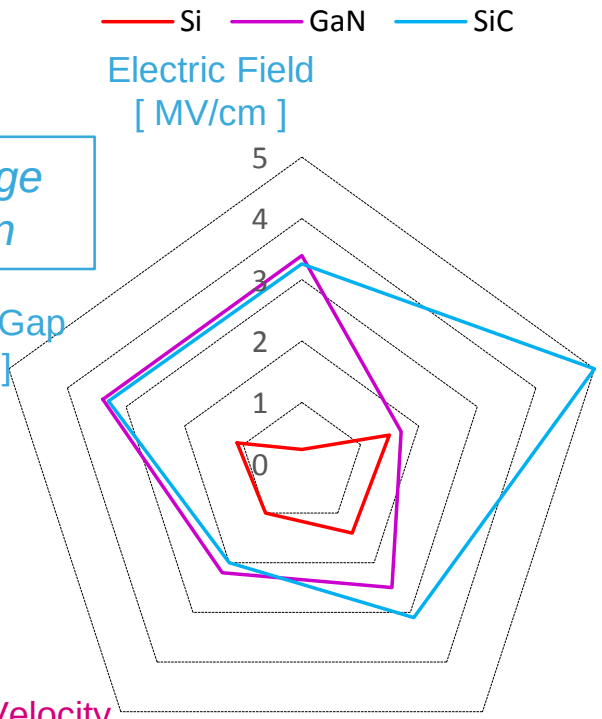
Si Silicon | **GaN** Gallium Nitride | **SiC** Silicon Carbide

Si



Cubic

Figure of Merit: Si, SiC & GaN

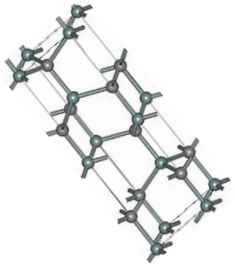


High Voltage Operation

High Switching Frequency

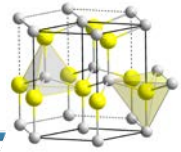
High Temperature Application

SiC



Hexagonal

GaN



Hexagonal (cubic)

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SiC Value Proposition

SiC Technology Benefits
SiC vs Conventional Silicon IGBT

Higher Performance & Voltage Operation

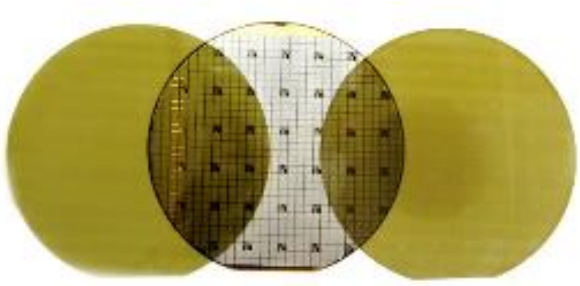
- Extremely low power losses
- High efficiency at low current
- Intrinsic SiC body diode (4 quadrant operation)

Higher Operating Frequency

- Lower switching losses
- Excellent diode switching performance

Higher Operating Temperature

- Operating up to 200°C junction



SiC Advantages for Automotive

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

- From ~2% (high load) to ~8% (low load) efficiency gain in average
- ~7x lower switching losses / ~7x lower chip size
- ~40% lower total loss (W)
- ~ 5 ..10 times higher switching frequency

Lower System Cost

- ~5x reduced form factor &
- ~50% cooling system down sizing
- simpler sub-systems like smaller passives, no external freewheeling diode,…

20 Years of ST SiC History

20 years of SiC History

June 1996
Collaboration with Physics Dept.

April 1998
1st contract on SiC with CNR-IMETEM (Dr. V. Raineri)

May 2002
Schottky Diode Demonstrator (CNR line)

February 2003
ETC Epitaxial reactor prototype installed in ST

November 2003
First ST internal product request

May 2004
Schottky Diode Demonstrator (ST line)

December 2005
Schottky Diode Mat 20

October 2007
1st Gen Diode Start Production

March 2009
Power MOSFET 3" Demonstrator

May 2012
2nd Gen Diode Start Production

September 2013
1.2kV Diode Start Production

June 2014
3rd Gen 3 Diode Start Production

September 2014
1st Gen MOSFET Start Production

June 2017
2nd Gen MOSFET AG 6" Start Production

1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016…

Pioneers..

June 2003
2" ST line

June 2006
3" ST line

June 2011
4" ST line

June 2016
6" ST line

...to mass production

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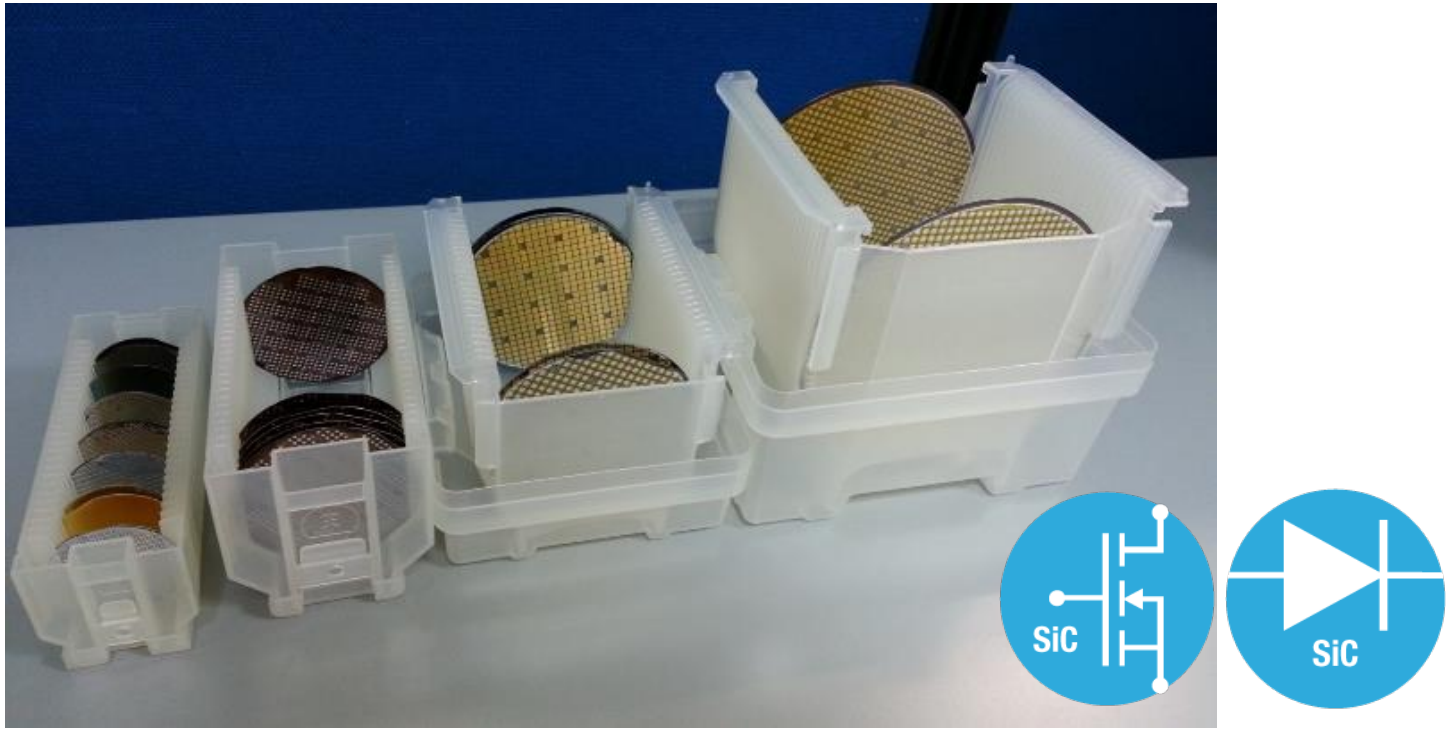
SiC Manufacturing

SiC Wafer Line Evolution



2003 – 2”
line startup

2006 – 3”
line startup

2011 – 4”
line startup

2016 – 6”
line startup

SiC Positioning vs IGBT

Parameter	Si IGBT	SiC MOSFET
Switching Principle	Normally-OFF	Normally-OFF
Control parameter	Voltage	Voltage
Control power	Low	Low
Control circuit	Simple	Simple
On-resistance	Low	Low
Switching speed	**Medium**	**Fast**
Switching loss	Medium	**Extremely low**
Efficiency at low current	**Low**	**High**
Operating junction temperature	Up to 175°C	**> 200°C**

SiC Main Benefits at Component Level

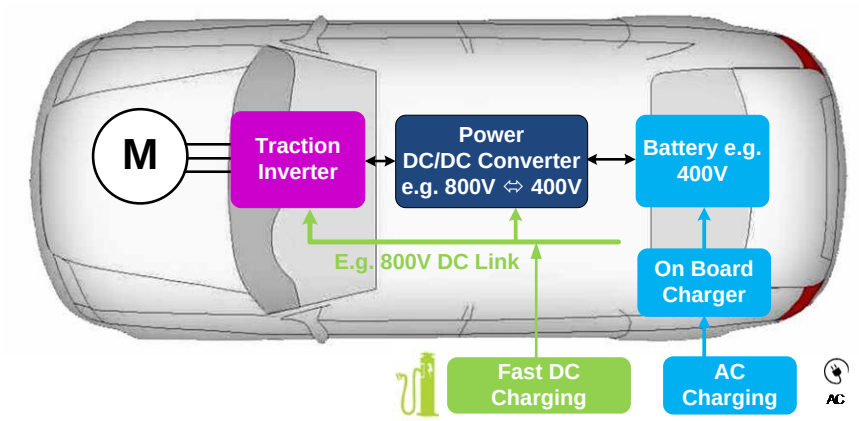
Extremely low Power Losses
Reduction of cooling requirements and heatsink sizes

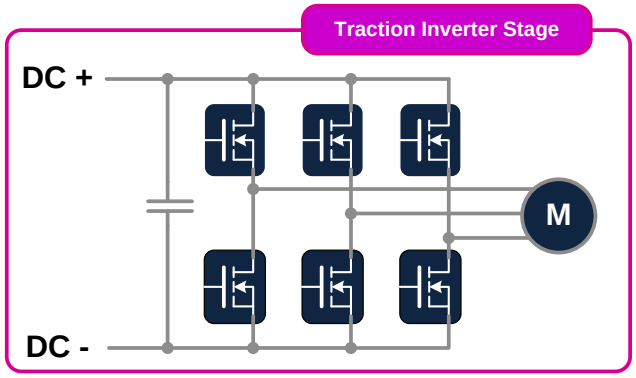
High operating Frequencies
Reduction of bulky passive components

Extended Junction Temperature up to 200°C
For extended reliability and reduction of heatsink sizes

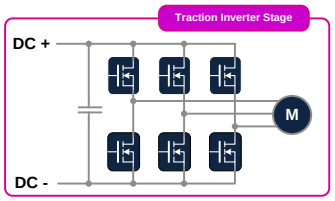
Drive Train Electrification
Enabled by SiC Technology

Traction Inverter





- High power inverter stage to **drive the traction motor** of a vehicle
- Replacing silicon based IGBTs and Diodes in the inverter stage by **SiC MOSFETs**, resulting in **higher efficiency**, smaller form factor, less cooling efforts….
- Comprehensive **ST portfolio of SiC MOSFETs** as bare die, package or module solution in 650V as well as 1200V technology



Drive Train Electrification

SiC advantages in Traction Inverters

	Silicon IGBT & DIODE	SiC MOSFET
Die area for 100A nominal current [mm²]	150	25
Max Junction temperature [°C]	175	200
Normalized switching energy	7	1
Normalized Power loss(*) (typical mission profile)	10	1
Average junction temperature at nominal power [°C] (*)	110	90

End user value proposition

- Power Semiconductors size: up to 70% smaller
- Cooling system: up to 70% smaller
- Passive components: up to 80% smaller (**)

→ Up to 75% size reduction

→ Up to 10% Extended Mileage

→ Extended life in use

(*) 90kW Traction Inverter, 800V bus, f_{PWM}=16kHz, T_{fluid} = 60°C
(**) applicable to DC to DC converter when present

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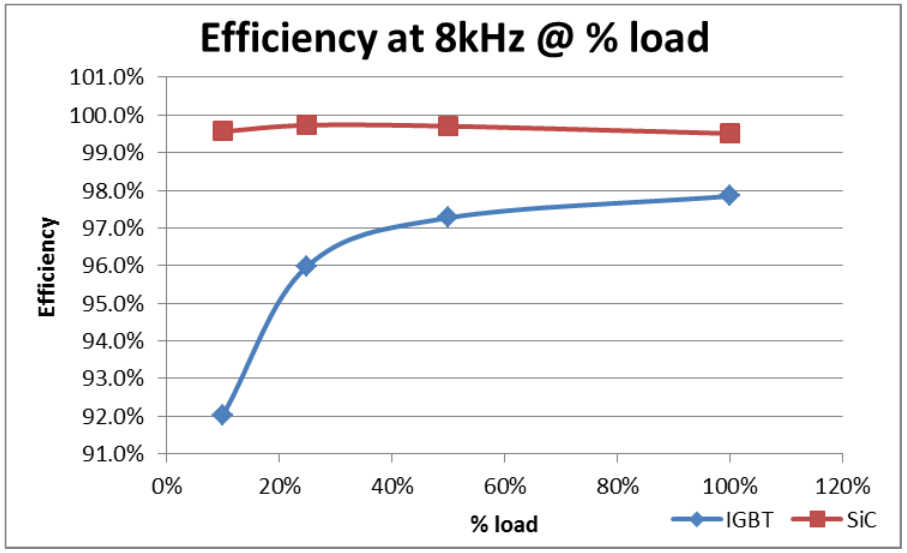
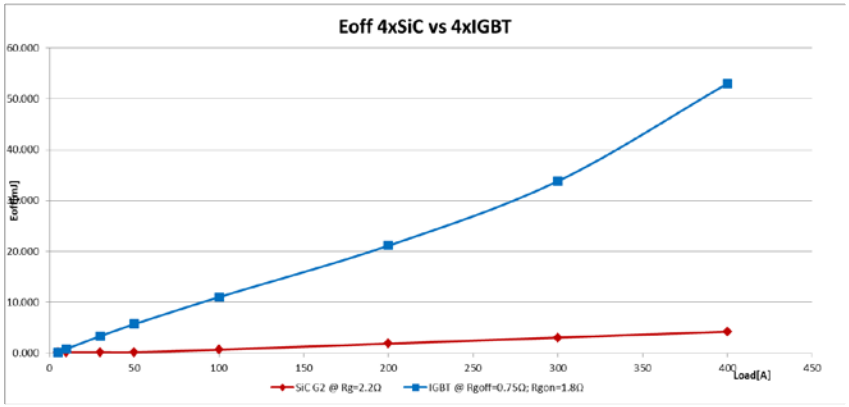
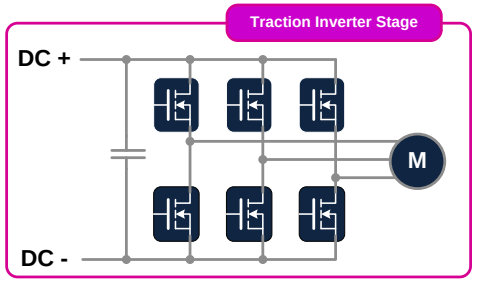
SiC Solution: Lower Losses and Higher Efficiency 90kW,8kHz

From about 2% at max load, to 8% higher efficiency at low loads







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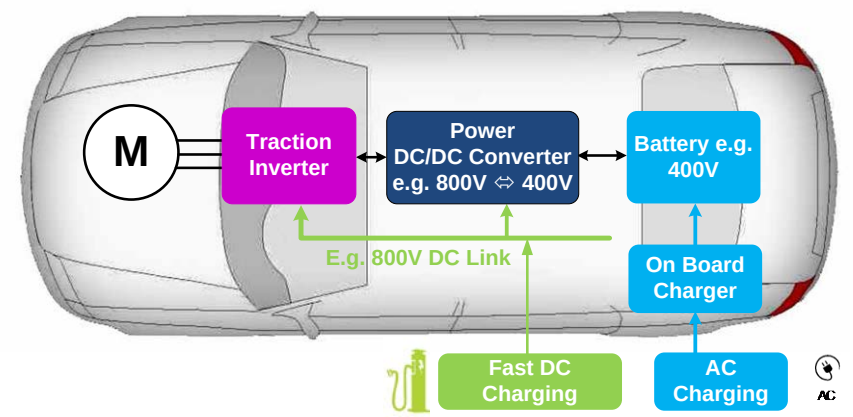
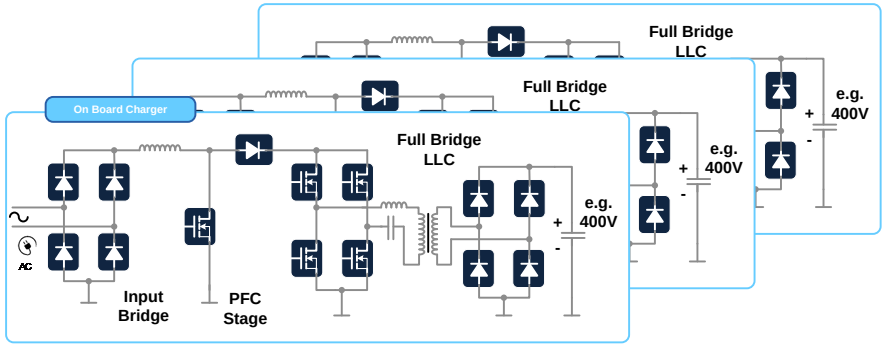
* The simulated efficiency takes into account only the losses due to the switches and diodes forming the bridge inverter

Drive Train Electrification
Enabled by SiC Technology

On-Board Battery Charger



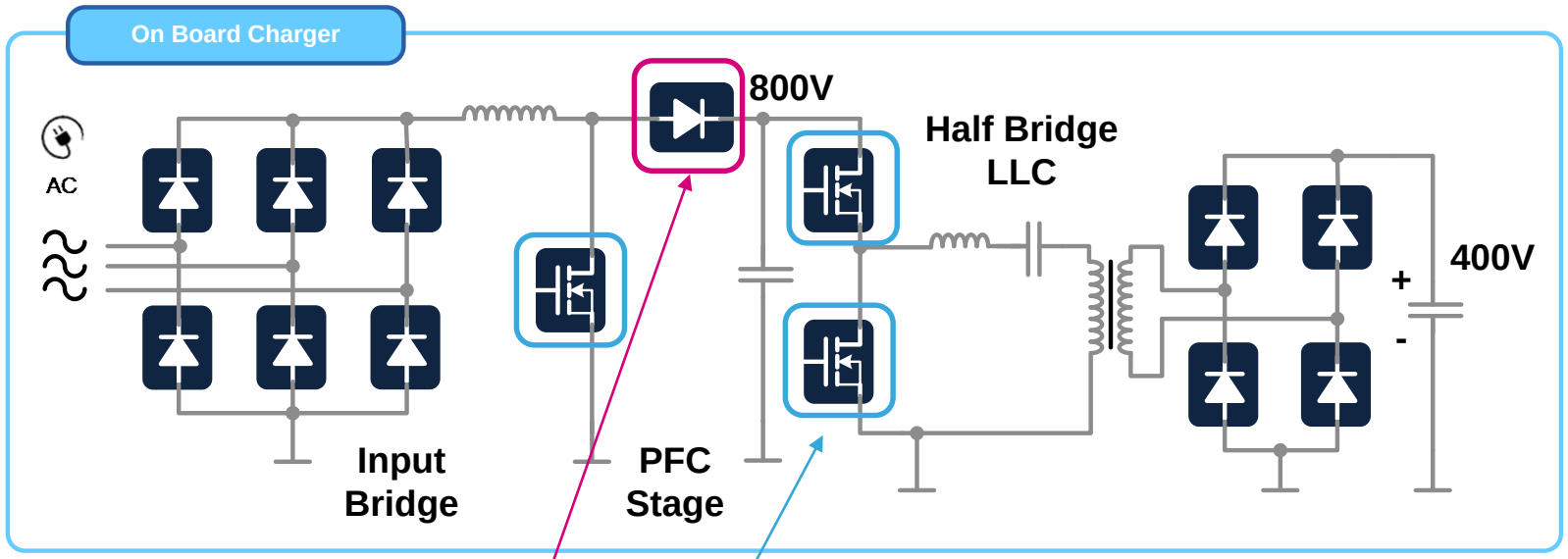


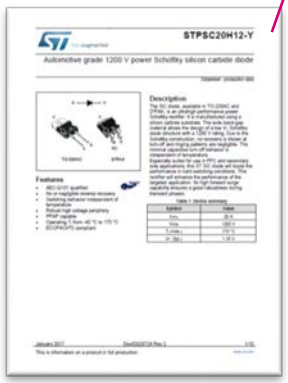
Example: 3 Phase interleaved with full bridge LLC

- **Charging the battery** of plug in HEVs and EVs from the 1-phase or 3-phase power grid
- Different architectures and topologies in automotive require to **support scalable solutions**
- ST solutions enable **compact and efficient** designs
  - SiC MOSFETs & SiC Diodes
  - Super Junction FETs, IGBTs, fast Diodes & SCRs

Drive Train Electrification
Enabled by SiC Technology

On-Board Battery Charger / Case Study *





*** Silicon carbide (SiC) components integration in On Board Charger for electric & hybrid cars**

Final year internship report 2015
5th year of engineering school
At Polytech Tours / BERANGER Quentin

SiC Advantages in On-Board Battery

Case Study 11kW 3 Phase On-Board Charger

	Silicon MOSFET & DIODE	SiC MOSFET & Diode
Losses [W]	300	216
Switching Frequency [kHz]	25	100/150
Volume* [cm3]	4593	1986
Weight* [g]	7708	3074
Efficiency** [%]	96.9	97.7

End user value proposition

- Losses [W] → Reduce heatsink size
- Switching Frequency [kHz] → Reduce passive component size
- Volume* [cm3] / Weight* [g] → Reduce congestion and decrease car weight

60% weight, volume reduction

- Efficiency** [%] → Higher Efficiency

including heatsink , passive components, switches, filters

**only due to semi-conductor components*

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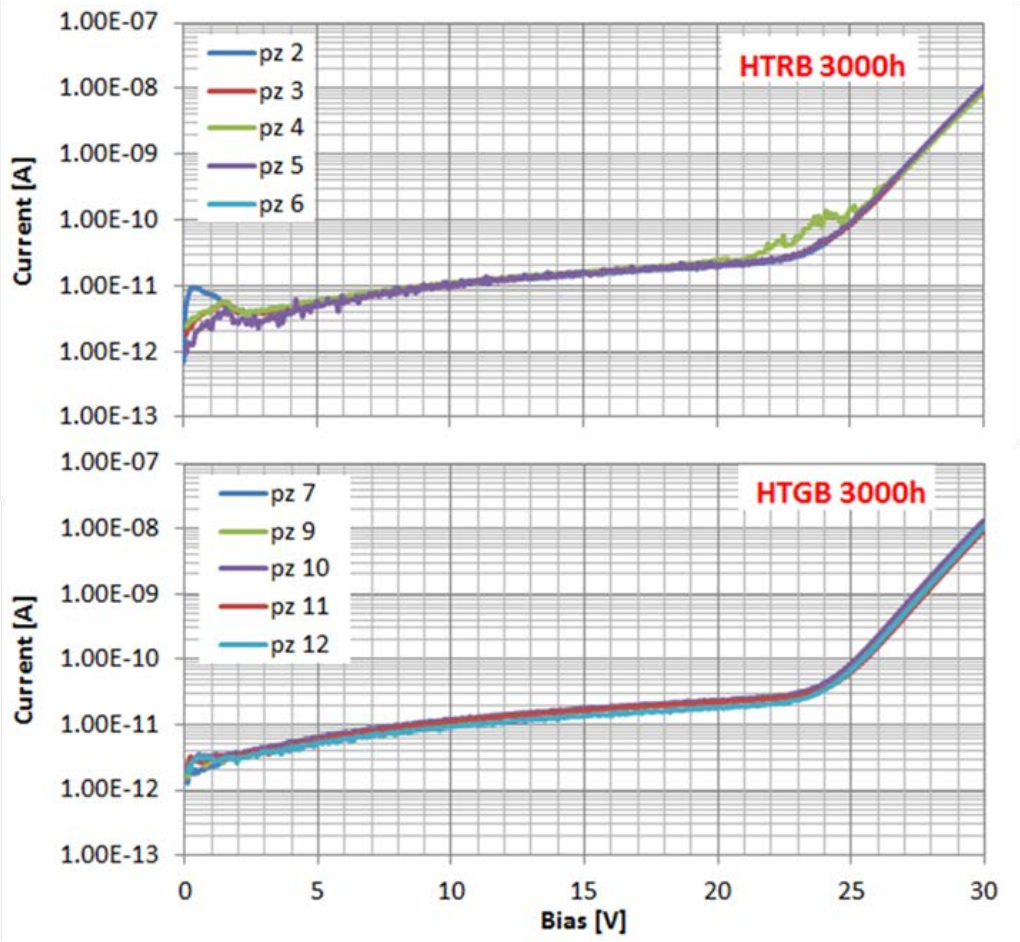
SiC MOSFETs
Extended Reliability at 200°C

Devices tested in: HTGB (22V 200°C), HTRB (520V 200°C)

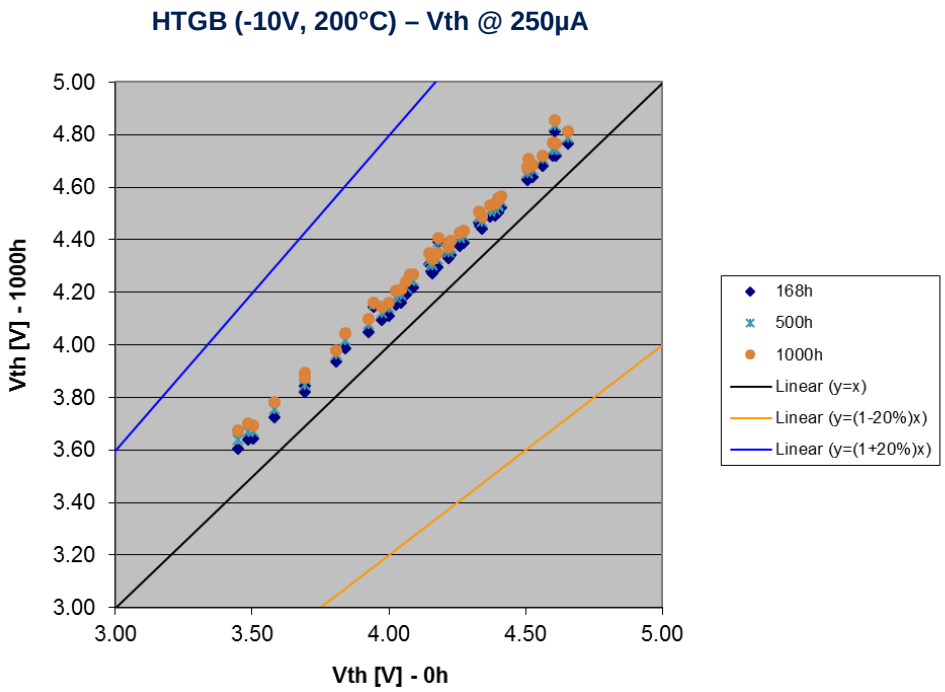


- ST specifies lower leakage current (100nA)
- IGSS specified at 22V → more margin with respect to gate drive voltage (20V)
- Test to guarantee min -6V

Gate Oxide Reliability

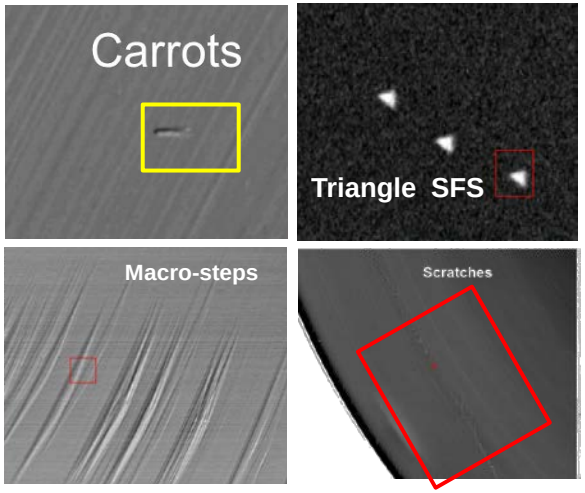
Vth Drift analysis after 1000hrs

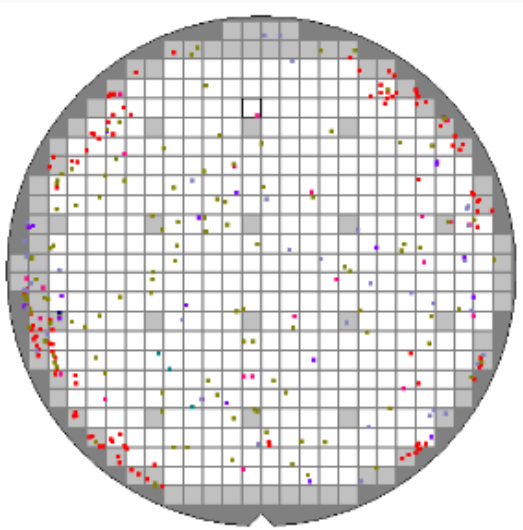
- After 1000 hrs HTGB (@200°C and VGS=22V) Vth increase by 4.8%
- After 1000 hrs HTGB (@200°C and VGS=-10V) Vth increase by 4.17%
- After 1000 hrs HTRB (@200°C and VDS=520V) Vth increase by 1.3%



DEFECTS in SiC Substrates vs EPITAXY

In-house capability for quality monitoring

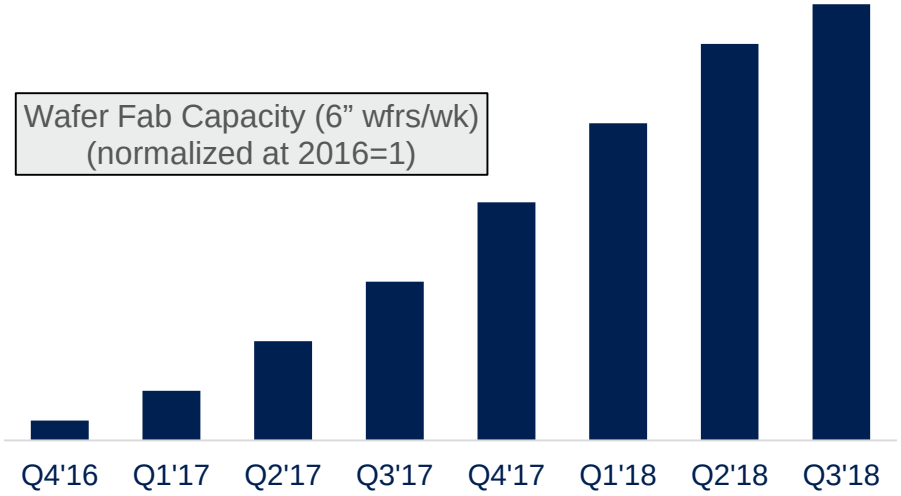




Specific substrate defects produce yield losses at EWS testing.
If some locations with defects are good in EWS we make over-inking on the same location where we detected the defects

ST Catania

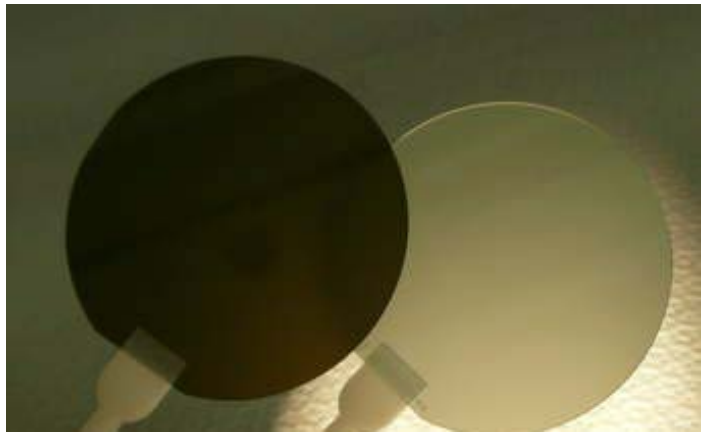
SiC Manufacturing at glance



Catania Manufacturing Site

Key Dedicated Equipment

- Metal deposition tools
- Ion Implanters
- Defectivity tools
- High temperature furnaces
- Epy reactors
- Trench dry etchers



SiC transparent wafers

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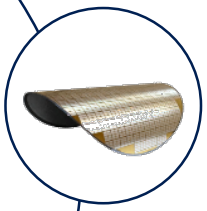
SiC Technology SiC Summary

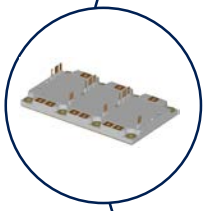


6” wafer production
and EPI process step
in-house in ST

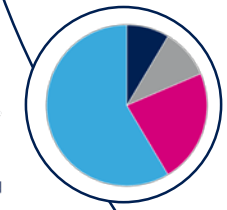
AEC-Q101

Automotive Grade

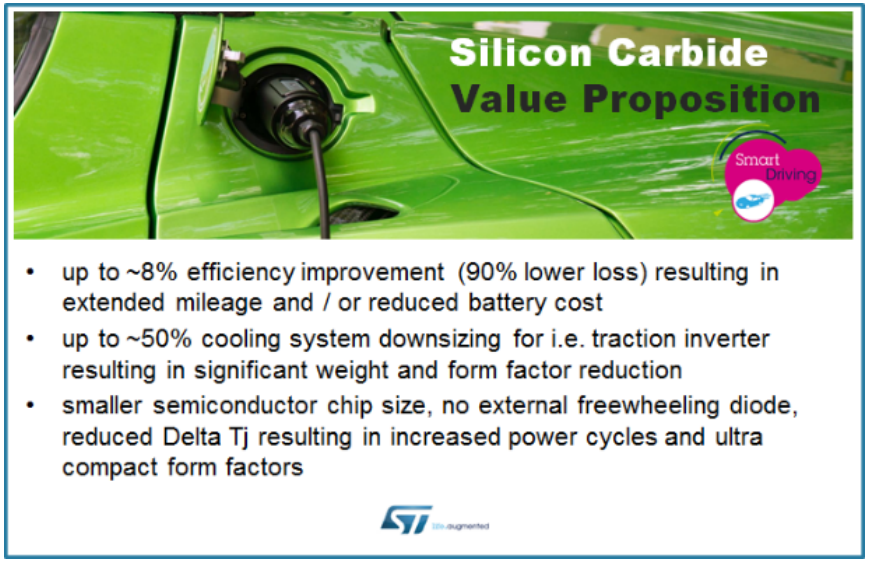
MOSFET and Diode Product portfolio available and under significant extension for 1200 and 650V



Bare Die, Discrete Package and Module offer



Standard product offer
and customized solutions



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Conclusion

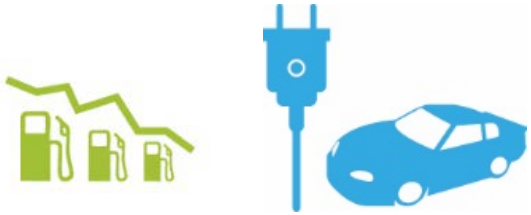
Towards the mass deployment of electrical vehicles

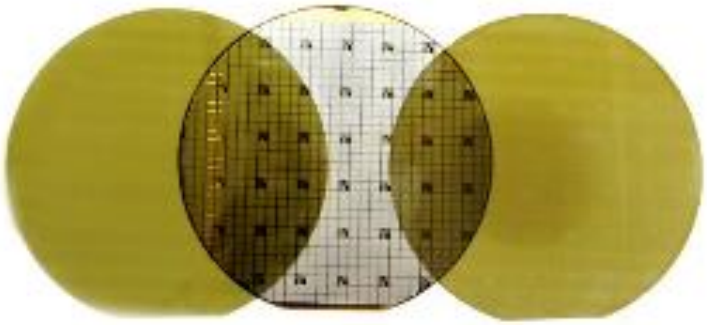
ST is enabling greener driving with advanced technology for

- Battery management and energy recovery
- OBC (on-board battery chargers)
- Main Traction inverters
- DC/DC converters
- 48V Applications

Including

- Battery Management (ASICs) and 32-bit MCUs
- SiC & Si MOSFETs, Rectifiers, SiC Diodes,
- GAPdrives, HV SCR for Soft-start
- IGBT & Soft Diodes





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