EVS30 Symposium
Stuttgart, Germany, October 9 - 11, 2017

New power electronics technologies enabling the Electric Vehicle market evolution

Dr.-Ing. Jochen Langheim, Quentin Beranger, Alberto Villegas[1],
Manuel Gärtner[2],
Mario Giuseppe Saggio, Michele Macauda[3]

[1]*STMicroelectronics, Paris, jochen.langheim@st.com*

[2]*STMicroelectronics, Munich, manuel.gaertner@st.com*

[3]*STMicroelectronics, Catania, mario.saggio@st.com, michela.macauda@st.com*

Summary

The introduction of automotive grade silicon carbide (SiC) technology will enable vehicle manufacturers to offer cost effective electric entry models with a level of performance acceptable to the wider public. SiC technology will increase efficiency, lower vehicle weight, reduce the subsystem volume and costs, whilst offering lower charge times and increasing range capability.

Silicon Carbide has inherent advantages over silicon for high power electronics circuits and exploiting these advantages of higher operating frequencies, temperatures, lower switching losses and smaller die sizes will be key, along with packaging and subsystem innovations, to taking the electric vehicle from a niche to a mass market product.

Keywords: Power Electronics, Electric Vehicle, Silicon Carbide, SiC, components

1 Introduction – Electromobility is gaining momentum

Electric vehicles recently have evolved from a niche solution to a reasonable alternative for mobility in the 21st century. Traditional combustion engine solutions are losing favour due to their adverse environmental impact and electric vehicle technologies for batteries and electronics are reaching performance and maturity levels that allow viable economic solutions for customers. The infrastructure for charging electric vehicles is becoming denser and more efficient, allowing longer travel distances for users contributing to user take-up.
Anti-pollution legislation concerning CO_2 emissions in most parts of the world, as well as access limitations to city centres combined with incentives to convert to electric vehicles are all factors in the increased demand for electrified vehicles.

This paper focuses on the latest power electronic components, based upon wide bandgap materials and in particular Silicon Carbide (SiC) technology, illustrating the benefits that they can bring to the full range of electric vehicle hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs).

2 Energy and pollution challenges in the world

The world (or almost all of it) is moving towards greener energy solutions becoming less dependent on fossil fuels. Large cities are reducing the pollution generated health risks for their inhabitants by limiting the access to city centres of the most polluting vehicles, notably diesel powered cars. Incentives to convert to greener vehicles are being put in place in many countries. These factors are driving consumers to consider electrified vehicles as a credible alternative to the traditional vehicles.

The cost and usability constraints that undermined consumer desire to go electric are being removed by the latest developments, notably in power electronics and battery technologies. Users of electric vehicles will expect the same level of reliability as for traditional cars at the same cost. The latest vehicles will be able to offer the right autonomy and reliability at the right cost. This market evolution is also reflected in the many market research studies across the world. It seems inevitable that sales of electric vehicles will increase considerably over the next decade.

To achieve the desired growth, a number of technological, technical, industrial and logistical issues will have to be solved and will require important levels of investment.

3 Wide Bandgap Material

Wide bandgap materials will become the mainstay of power electronics in the future. The principle advantages of SiC and GaN compared to Si technologies can be seen in Figure 1. “Figure of merit of Si, SiC and GaN”

Wide bandgap technologies have many advantages compared to Silicon. Operating temperatures are higher, heat dissipation is improved and switching and conduction losses are lower. However, wide bandgap materials are more difficult to mass produce compared to Si, which has delayed their introduction and cost competiveness.

SiC is a very hard material, and crystal growth takes considerable time and energy. Reducing defectivity has been a key manufacturing challenge. GaN is in fact a layer of GaN on a Si wafer with different temperature coefficients, which also creates manufacturing complexity.

4 Industrial deployment of new technologies

Introduction of new technologies in a market demanding high quality, long and reproducible lifetime at competitive costs is a not easy. Today, the difficulties in using wide bandgap materials in industrial production have been overcome for SiC and are well advanced for GaN.

The supply chain for SiC is becoming more robust, the cost of the basic material is decreasing as supplier competition increases. The quality of the material and the process is improving steadily. As the material and the products based upon SiC technology become mature enough for automotive applications, the ramp-up of production is also driving down costs by the economy of scale.

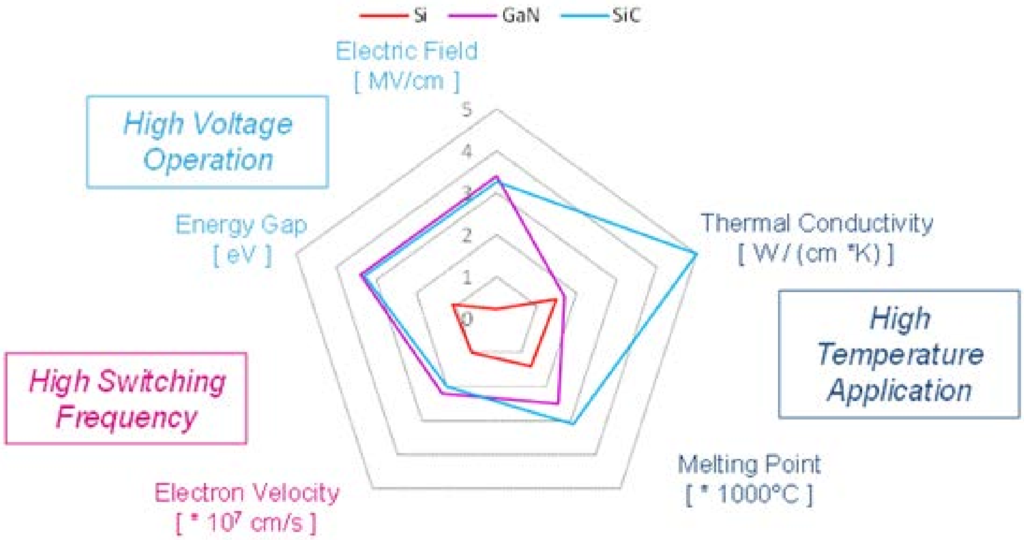

Fig 1: Figure of merit of Si, SiC and GaN

4.1 SiC Production in ST

SiC has been in production since 2004. It started first with 4” wafers, moved then on to 6”. 8” manufacturing is being studied. (Fig. 2) (2).

The epitaxy in STMicroelectronics is done in house. This assures a high quality and stable raw material, low production losses and the ability to move to higher currents.

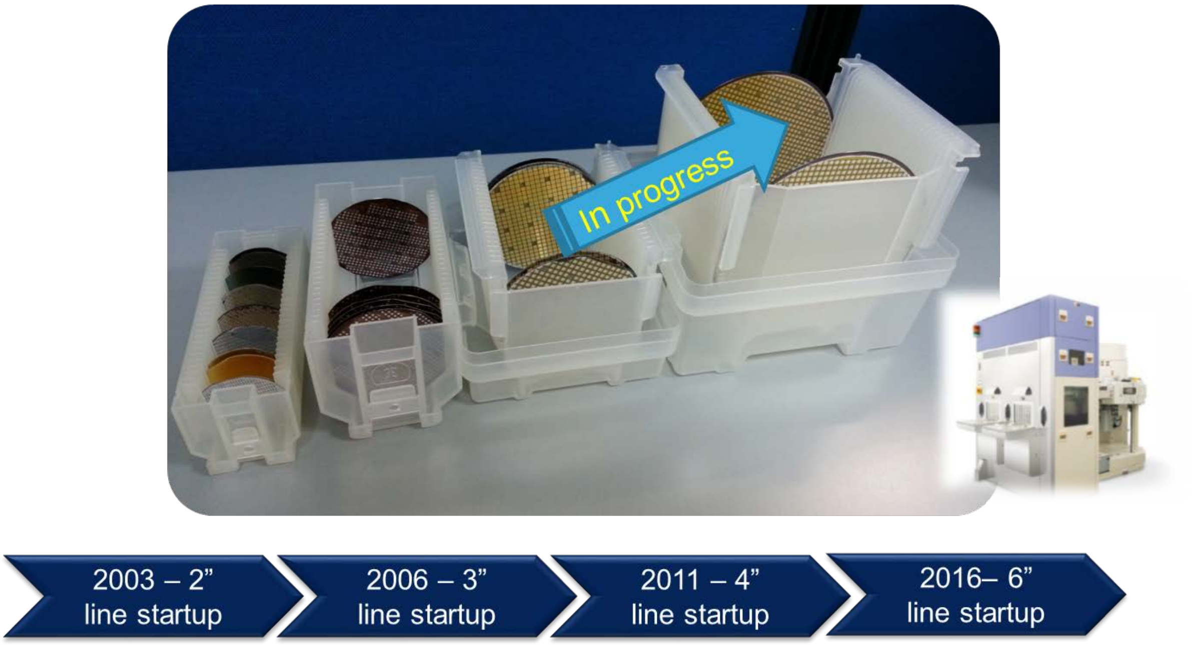

Fig 2: Evolution of wafer sizes for SiC production over time

SiC diodes and MOSFETs were initially used in industrial applications. The experience in terms of reliability, quality helped prepare for automotive qualification of our products. Automotive qualification is now assured and overall quality is matching Si levels. Automotive customers are converting to SiC technology for the EV markets based upon successful field trials.

This conversion to SiC will have an impact on the cost of ownership of electric cars from 2021 onwards, improving consumer confidence in the ability of electric vehicles to deliver the required levels of practicality at an acceptable cost.

4.2 System aspects and packaging

Packaging solutions also need to evolve to maximize the benefits of the new technologies. Today’s packaging is mainly based on traditional Si experience. To achieve higher operating temperatures will need further R&D, as will combating the parasitics introduced by the faster switching capabilities of the wide bandgap materials. Reducing leakage inductance in the DC link also needs to be focused upon in new packaging technologies. Solutions exist, but costs and size are not optimized. New architectures may offer the opportunity for further optimisation.

5 System comparisons: wide bandgap and traditional silicon

A comparison of an inverter application highlights what SiC technology can offer in terms of improved performance

For this comparison we have assumed the following configuration (Fig. 3):

- Topology: Three phase inverter

- PWM Strategy: Bipolar
- DC-link voltage: 900Vdc
- Switching frequency: 8kHz
- $T_j \leq 80\%*T_{j,max}$ at any condition
- P_{OUT}=90kW (peak power 180kW)

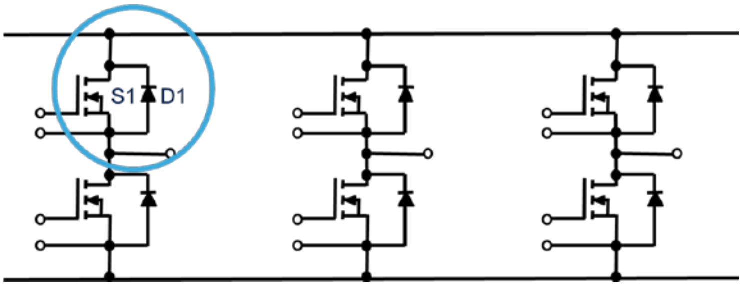

Fig. 3: Switch under comparison

Table 1 summarizes the key results. In terms of real-estate the SiC based solution takes up about seven (7) times less space than the equivalent silicon based one..

The total reduction in terms of losses is about half in this configuration leading to a slightly increased temperature at the junction.

It should be emphasized that SiC is capable of operating at higher temperatures with a very stable $R_{DS,on}$. Reliability is extended to 200 °C, but in order to benefit completely from this increased temperature capability, advances in packaging, passives and manufacturing are required, at a cost level that is acceptable to the automotive market.

Table 1: Comparison 1200V SiC MOSFET vs Si IGBT
*) Typical power losses values at peak power 190kW

Solution	Si-IGBTs + Si-diodes Solution	Full-SiC Solution
Total chip-area	400 mm² (IGBT) + 200mm2 (diode)	80 mm² **(=1/7)**
Conduction losses* (W)	121.9	192
Switching losses* (W)	357	31 **(= 1/11)**
(S1+D1) Total losses* (W)	479	223
Junction Temperature (°C)	135.1	154.8

The efficiency of the system is shown in Fig. 4. The improvement in terms of efficiency is remarkable, especially at low load. This can lead to reductions in energy consumption in all of the different vehicle driving cycles. Driving cycle efficiency will be improved by at least 5% and the OEMs can consider reducing the total cost of ownership by downsizing the battery accordingly, without an impact on the total available mileage. Considering that the battery is the most expensive component of the electric car justifies the higher cost for a SiC based PCU (Power Control Unit).

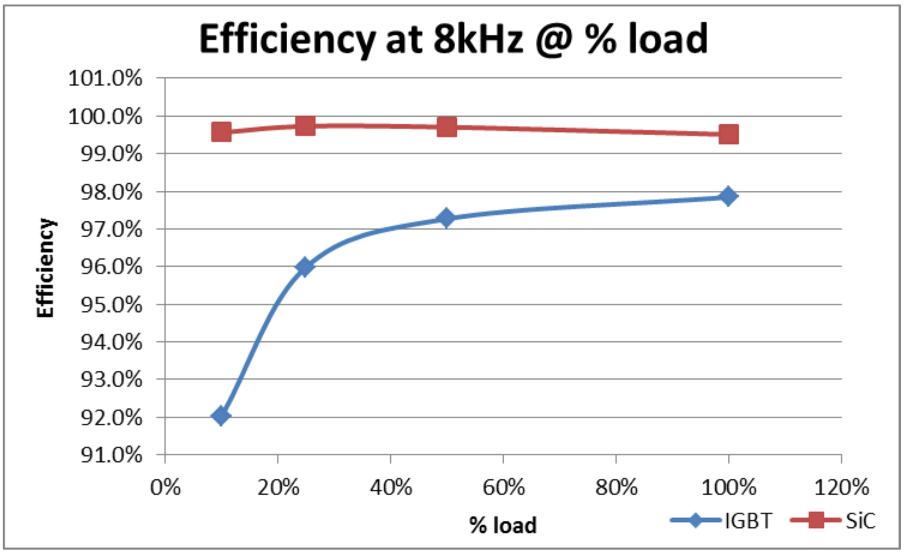

Fig. 4: Efficiency of SiC and IGBT inverter solutions

A particular characteristic of ST's SiC solutions is their minimal drift of parameters over lifetime. Fig. 5 shows the evolution of V_{th} after 0, 500 and 1000 h of operation.

- ST specifies lower leakage current (100nA)
- IGSS specified at 22V → more margin with respect to gate drive voltage (20V)
- Test to guarantee min -6V
- After 1000 hrs HTGB (@200°C and V_{GS}=22V) V_{th} increase by 4.8%
- After 1000 hrs HTGB (@200°C and V_{GS}=-10V) V_{th} increase by 4.17%
- After 1000 hrs HTRB (@200°C and V_{DS}=520V) V_{th} increase by 1.3%

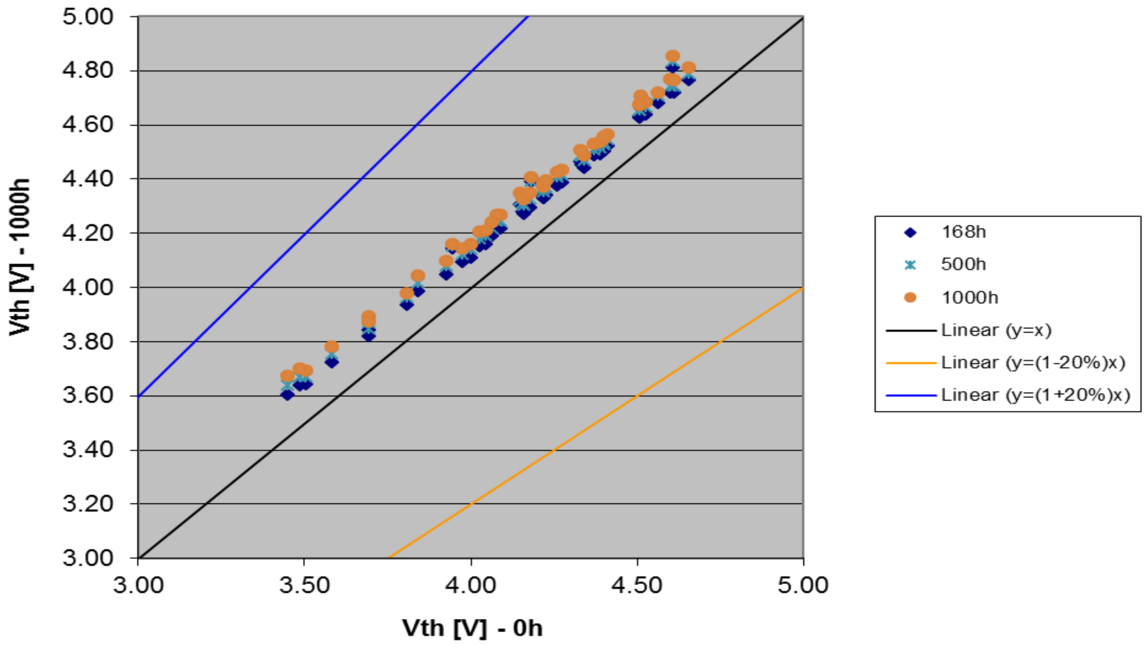

Fig. 5: Drift of Vth over lifetime

6 SiC vs Si comparison for a 11kW on-board charger (OBC)

SiC technology is still relatively new in the automotive field. Different studies at application level have been conducted and here we present the case of an 11kW on-board charger for EVs.

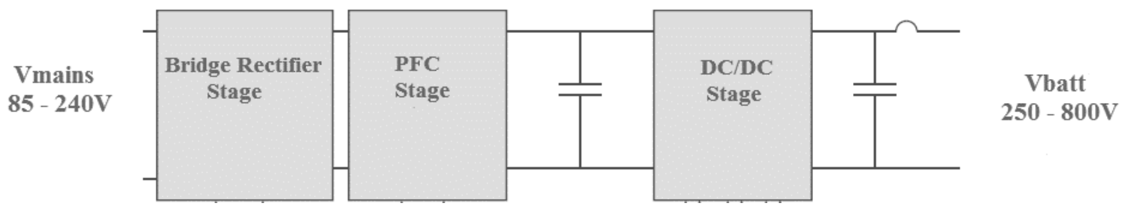

Fig. 6: Topology of the charger

Two case studies were performed, one with Si switches and another one with SiC switches:

- Case 1: Si solution @ 25kHz
- Case 2: SiC solution @100kHz (PFC) / @150kHz (DC/DC)

6.1 Efficiency comparison

Comparing efficiency, case 2 is better by about 0.75% compared to case 1. ST's SiC high voltage diodes improve the efficiency of the power factor corrector (PFC) and have been tested in the latest generations of on-board chargers (OBC) reaching best-in-class efficiency levels.
OBC efficiency has no direct impact on the range of the car. However, a loss reduction of about 80 W has an impact on the overall energy consumption for the consumer and hence the cost per km. The environmental impact can be estimated as a difference of approximately 2g.CO_2/km between case 1 and 2 depending of electricity source (Fig. 7).

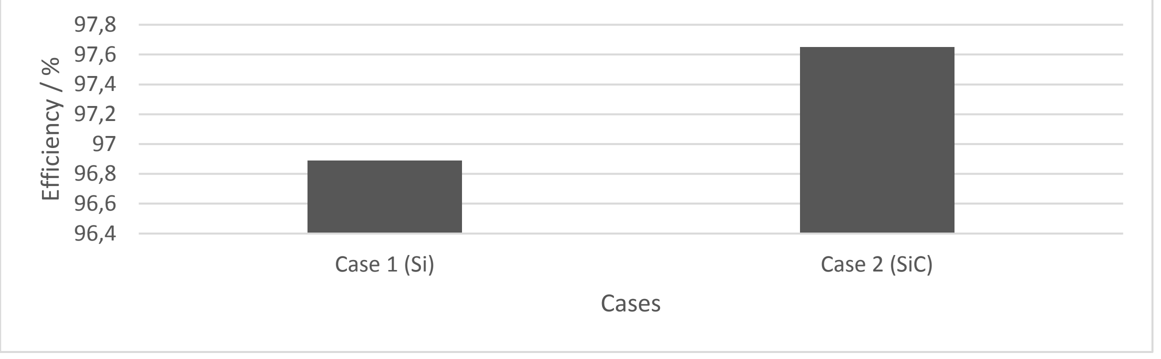

Fig. 7: Efficiency evolution

6.2 Volume & weight comparison

This comparison of volume and weight takes into account electronic and passive components as well as the heat-sink. Volume and weight are strongly reduced as a result of low loss SiC components and an architecture with a higher switching frequency. The higher $T_{j,max}$ of the SiC components allows a further reduction in the size of the heat sinks (Fig. 8).

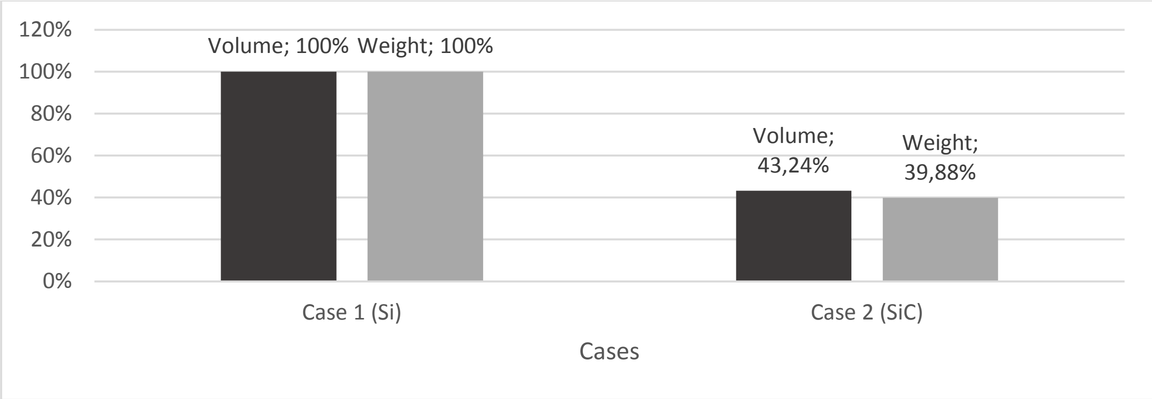

Fig. 8: Volume and Weight reduction through use of SiC instead of Si

6.3 Cost comparison

Our study showed that it is also possible to reduce the total volume and weight of the system. System suppliers with a complete mastery of the sub-system components and architecture will be able to make design decisions to optimize performance or cost of their offers to the market. ST's internal studies identify exists an important cost reduction potential based upon the component selection and the heat-sink. It should be possible, taking into account future improvements to the SiC product range and performance to achieve a break cost point between conventional Si based systems and SiC based systems soon.

7 Range anxiety and operating frequency

As owners of an electric car, everyone would like to have the possibility to drive as many kilometers as possible before having to stop and recharge the battery. Car makers are working on making vehicles lighter to increase range. Several systems used in electric cars need heavy and bulky elements, like inductors, capacitors, heat sinks, cooling systems, etc. Often the size of the components is related to the frequency of operation: the lower the frequency, the bigger and heavier they need to be. Another inconvenient of current systems is the electric efficiency; there are undesirable losses (conduction losses, switching losses) reducing the mileage range. The higher frequency capability of silicon carbide allows significant opportunities to reduce the weight of vehicles and hence increase range.

8 Conclusions

The Electric Vehicle revolution cannot be achieved with traditional silicon components. Benchmarking results in this paper for an inverter and an on-board charger application illustrate the advantages of SiC technology. Similar advantages could exist for their use in other sub-systems of the electric vehicle such as DC/DC converters.

SiC power solutions are generating much academic and commercial interest, not only in the automotive sector but also in aerospace, defense, industrial and transportation fields. ST is investing heavily in wide bandgap technologies to develop tailored solutions for these sectors.

SiC is a therefore a key enabling technology that will and can replace silicon in power applications. Further improvements can be expected from the industrialization process, the maturity of SiC and also the introduction of new technologies such as GaN. Economy of scale and further innovation will allow wide bandgap materials to expand into other markets.

STMicroelectronics with is at the forefront of the introduction of these new technologies with the advantage of a full in-house manufacturing pipeline and long standing power electronics heritage.

References

[1] Eric Kirstetter, Roland Berger Insights: *Future of xEV*, Automotive Power Electronics Conference (APE), Paris, 2017

[2] M. Gärtner, J. Langheim, M. Macauda: *Consequences of new Power Electronics Technologies on the Market Evolution of EVs,* e-Motive, Schweinfurt, 2016

Authors

Dr. Jochen Langheim is Vice President of Advanced Systems R&D projects at STMicroelectronics, Chairman of EURIPIDES² and VP International of MOVEO and can look back on more than 25 years and more than 30 publications.
He is working mainly in Automotive Systems R&D projects in France and on European level, e.g. autonomous & connected driving and electric vehicles.
Furthermore, he is representative of ST in different industrial organisations ZVEI, FIEEC or SIA.
Jochen chairs the biggest automotive electronics conference in Paris, the CESA congress on automotive electronics as well as the APE congress on automotive power electronics.

Manuel Gärtner joined STMicroelectronics Munich in 1999 and is working as a Senior Team Leader and Marketing Manager for ASSP/ASIC and Power Discrete Devices. Before joining STMicroelectronics he worked in Infineon Technologies as development engineer for Smart Power Products and as a research engineer in the "Fraunhofer Institut für Siliziumtechnologie" and at the university of Berlin. He published several articles on power electronics and is holding different patents.

Quentin Beranger, electronics graduate in 2015 from Polytech Tours received, the congratulations of the jury on the master thesis about SiC vs Si comparison in an 11kW On-Board Charger. This work was done in STMicroelectronics during his final year internship. Hired following this, he still works in automotive by supporting technically ST's automotive customers.

Alberto Villegas, born in Manizales, Colombia obtained his Engineer diploma from ENSEA – Paris in 1985. After working in design, manufacturing and characterization of GaAs MMICs in Philipps research laboratory he joined Sales & Marketing at Philipps Semiconductors in Paris. There, he was involved in small signal MOSFETs, Infrared Sensors and Power RF/Microwave transistors.
When he joined ST Microelectronics in Paris in 1990, he was first in charge of the Marketing of RF & Microwave power products (for applications in Radars, Avionics, TV & Radio emitters, PMR, CB) for Mediterranean countries.
Since 2000, Alberto has contributed to boosting the sales in the Automotive field in Europe and is today part of the EMEA Sales and Marketing team promoting in particular AEC-Q Power Solutions in Silicon Carbide and Silicon (mainly MOSFETs, Rectifiers) as well as Silicon active Protections.

Mario Giuseppe Saggio joined ST R&D Department in 1995 in New Power Devices Design Group.
In ST he worked on technology development of new Fast IGBTs based on innovative concepts for carrier lifetime control. He coordinated and lead the team designing and industrializing superjunction MOSFETs (MDmeshTM technology). Since 1999 he started a pioneer work on Silicon Carbide (SiC) in order to put technological bases for SiC Power Devices development in ST.
From 2005 to 2012 he leaded the ST R&D High Voltage Device Design team.
From 2013 he leads the ST R&D Silicon Carbide Power Device Design Group.
In 2015 he was one of the organizer of the International Conference on Silicon Carbide (ICSCRM) held in Sicily (Italy) and in 2016 he was in the Technical Program Committee of ECSCRM in Halkidiki (Greece).
Mario is author of 30 patents on device structures in Silicon and in Silicon Carbide. He is author or coauthor of 40 peer reviewed papers in international journals or conference.

Michele Macauda was born in Modica, Italy, in 1965. He received in 1990 the M.S. degree in electronic engineering from the University of Catania, Italy, and an MBA from Polytechnic of Milan in 1991.
In 1994, he joined STMicroelectronics by covering several technical roles for the main silicon technologies (LV&HV MOSFETs, IGBTs, Power Modules) with the relevant applications. He is currently cover the role of Product Marketing Manager for Wide Bandgap Technologies, with a focus on SiC MOSFET.