Industrial Power Control Business Update
Dr. Peter Wawer
Division President Industrial Power Control
Dr. Peter Friedrichs
Senior Director Silicon Carbide Technology

PCIM, Nuremberg, 8 May 2019
<table>
<thead>
<tr>
<th></th>
<th>Agenda</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IPC Division business update</td>
</tr>
<tr>
<td>2</td>
<td>Infineon – the leading player in power semiconductors</td>
</tr>
<tr>
<td>3</td>
<td>SiC: how Infineon grabs the lion’s share in industrial applications</td>
</tr>
<tr>
<td>4</td>
<td>SiC: planar versus trench</td>
</tr>
<tr>
<td>5</td>
<td>SiC: to be or not to be vertically integrated</td>
</tr>
</tbody>
</table>
Q2 FY19 results and outlook

IPC revenue and Segment Result margin

- **IPC revenue** and **Segment Result margin**
- **CAGR** (FY13-FY18): +15.2%
- **Revenue growth**: Above group-average due to strong regional presence, growth in strategic target applications, and portfolio enhancement.
- **Segment Result margin** improved due to product portfolio optimization and manufacturing landscape restructuring.

IPC half-year revenue development

- **H1 FY19** showed strong y-y growth.
- **H2 FY19** expected to be about flat y-y.
- Revenue in **H2 FY19** driven by traction and infrastructure, especially in China.
- Home appliances.
- Renewables, both wind and solar.
IPC at a glance: well-balanced portfolio of applications; China represents ~1/3 of sales

IPC FY18 revenue by application

- Traction
- Home appliances
- Renewable energies
- Drives
- Others

Distribution share: ~40%

IPC FY18 revenue by region

- Americas
- Japan
- China
- APAC
- EMEA

US$ exposure: ~30%

2019-05-08
Copyright © Infineon Technologies AG 2019. All rights reserved.
Infineon – the leading player in power semiconductors
While market shares in some IGBT markets are difficult to increase IPMs offer room to grow

<table>
<thead>
<tr>
<th>Discrete IGBTs</th>
<th>IPMs</th>
<th>IGBT modules*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2017 market share</strong></td>
<td><strong>2017 market share</strong></td>
<td><strong>2017 market share</strong></td>
</tr>
<tr>
<td><strong>total market in 2017: $1.10bn</strong></td>
<td><strong>total market in 2017: $1.57bn</strong></td>
<td><strong>total market in 2017: $2.63bn</strong></td>
</tr>
<tr>
<td><strong>Market share development</strong></td>
<td><strong>Market share development</strong></td>
<td><strong>Market share development</strong></td>
</tr>
<tr>
<td>24.7%</td>
<td>28.2%</td>
<td>37.1%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2017 market share</th>
<th>2017 market share</th>
<th>2017 market share</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Infineon</strong></td>
<td><strong>Mitsubishi</strong></td>
<td><strong>Infineon</strong></td>
</tr>
<tr>
<td>38.5%</td>
<td>36.4%</td>
<td>32.6%</td>
</tr>
<tr>
<td><strong>Fuji Electric</strong></td>
<td><strong>ON Semi</strong></td>
<td><strong>Fuji Electric</strong></td>
</tr>
<tr>
<td>12.0%</td>
<td>18.7%</td>
<td>10.5%</td>
</tr>
<tr>
<td><strong>ON Semi</strong></td>
<td><strong>Infineon</strong></td>
<td><strong>Semikron</strong></td>
</tr>
<tr>
<td>11.6%</td>
<td>10.3%</td>
<td>9.9%</td>
</tr>
<tr>
<td><strong>STMicro</strong></td>
<td><strong>Mitsubishi</strong></td>
<td><strong>Semikron</strong></td>
</tr>
<tr>
<td>5.2%</td>
<td>9.6%</td>
<td>8.3%</td>
</tr>
<tr>
<td><strong>MagnaChip</strong></td>
<td><strong>Infineon</strong></td>
<td><strong>Vincotech</strong></td>
</tr>
<tr>
<td>4.1%</td>
<td>38.5%</td>
<td>5.9%</td>
</tr>
</tbody>
</table>

* Including standard (non-integrated) IGBT modules and power integrated modules (PIMs) / converter inverter brake (CIB) modules.
Source: Based on or includes content supplied by IHS Markit, Technology Group, "Power Semiconductor Market Share Database 2017", September 2018.
Due to the extensive power module portfolio Infineon can address the whole range of drives applications

<table>
<thead>
<tr>
<th>Servo drives</th>
<th>Low-power drives*</th>
<th>Mid- and high-power drives</th>
</tr>
</thead>
<tbody>
<tr>
<td>370 W</td>
<td>370 W</td>
<td>500 kW</td>
</tr>
<tr>
<td>75 kW</td>
<td>500 kW</td>
<td>10 MW</td>
</tr>
</tbody>
</table>

- high positioning accuracy
- fast response with no overshoot
- high reliability

- robotics
- material handling
- machine tools

- performance and reliability
- safety features
- good price/performance ratio

- pumps and fans
- process automation
- cranes
- marine drives

- safety
- durability
- high reliability and low downtime

- oil & gas industry
- chemical industry (e.g. air compressors)
- cement mills

**Key applications**

- **CIPOS™ IPM**
- **Easy 1B**
- **Easy 2B**

- **iMOTION™**
- **CIPOS™ IPM**
- **EasyPack**
- **EconoPACK™**

- **PrimePACK™**
- **IHM**
- **IHV**

*Low-power drives include compact drives, standard drives, premium drives and brushed DC drives.*
Already today, renewables achieve lower production costs than conventional power plants.

Solar provide competitive electricity cost already today

World’s cheapest prices for Saudi Arabia’s first solar project (US$0.018/kWh)

The National

Overview: levelized cost of energy

LCOE [USD/MWh]

<table>
<thead>
<tr>
<th>Source</th>
<th>LCOE [USD/MWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Combined Cycle</td>
<td>$41 - $74</td>
</tr>
<tr>
<td>Coal</td>
<td>$60 - $143</td>
</tr>
<tr>
<td>Nuclear</td>
<td>$112 - $189</td>
</tr>
<tr>
<td>Wind</td>
<td>$29 - $56</td>
</tr>
<tr>
<td>Solar PV - Utility Scale</td>
<td>$36 - $46</td>
</tr>
<tr>
<td>Solar PV - Rooftop Residential</td>
<td>$160 - $267</td>
</tr>
</tbody>
</table>

Legend:  
- At grid parity  
- Close to grid parity (< 5%)  
- Not yet near grid parity  

1) Financial Times, “Chinese solar industry starts to hit grid parity”, April 2019, referring to Citigroup research  
2) Lazard, “Levelized Cost of Energy Analysis – Version 12.0”, November 2018; unsubsidized analysis
Infineon is a key player in the PV market providing solutions to the leading inverter manufacturers.

Global installed PV capacity

- **China**: 44.8 GW (2018), estimated to 50.5 GW (2023e) with a CAGR of 13% (2018-2023).
- **Rest of World**: 58.2 GW (2018), estimated to 109.4 GW (2023e) with a CAGR of 2% (2018-2023).


Infineon is present at top-10* inverter manufacturers (2017):

1. Huawei
2. Sungrow
3. SMA
4. TBEA Sunoasis
5. Wuxi Sineng
6. ABB
7. Kstar
8. Goodwe
9. Growatt
10. Power Electronics

* Infineon is serving the top-10 but not necessarily as a sole supplier.

1) based on or includes content supplied by IHS Markit, Technology Group, "PV Installations Tracker – Q1 2019"; March 2019; including off-grid
2) by shipped capacity in MW: based on or includes content supplied by IHS Markit, Technology Group, "PV Inverter Market Tracker – Q4 2018"; December 2018
Infineon is the leading power semiconductor supplier for the wind turbine industry

Global installed wind capacity¹

- China
- Rest of World

CAGR₁₈⁻²₃: 6%

[GW]

67.5

50.2

29.6

20.6

2018

2023e

CAGR₁₈⁻²₃: 5%

CAGR₁₈⁻²₃: 7%

Infineon is present at top-10* wind turbine manufacturers (2018)²

1 | Vestas ✔
2 | Goldwind ✔
3 | Siemens Gamesa ✔
4 | GE ✔
5 | Envision ✔
6 | Enercon ✔
7 | Nordex ✔
8 | Mingyang ✔
9 | Sewind ✔
10 | United Power ✔

* Infineon is serving the top-10 but not necessarily as a sole supplier.
2) by shipped capacity in MW; Wood Mackenzie, Power & Renewables, "Historic wind turbine OEM market share", March 2019
Being at the heart of wind turbines: PrimePACK™ with IGBT5 and .XT technology

- IGBT5 chip technology
- .XT joining technology
- PrimePACK™ module

- High reliability and robustness, esp. for off-shore wind turbines
- Long lifetime
- Power cycling capabilities increased by factor of 10
- High power density: using IGBT5 and .XT power modules, with the same number of cabinets about 30% more electrical power increase feasible
- Excellent system efficiency
Inverterization is driving the global demand for power semiconductors for the next years

Note: Based on or includes content supplied by IHS Markit, Technology Group, “Home Appliance Database: All Devices & Associated Electronics”, May 2018
What comes next? Examples for mid- to long-term structural growth opportunities

- **EV Charging**
- **Fuel Cell in Traction**
- **Robotics**
- **eDelivery vehicles**
- **Energy Storage**
- **eAviation**

Emerging fields

Courtesy: Lilium GmbH

Copyright © Infineon Technologies AG 2019. All rights reserved.
How Infineon grabs the lion’s share in SiC for industrial applications
Four key success factors: Infineon well positioned to defend its leadership in power semis also in SiC

1.) Substrate
   - multi-year SiC wafer supply agreement
   - acquisition of Siltectra

2.) Device
   - trench-based architecture
   - 150 mm conversion completed

3.) Module
   - expertise from industrial heritage
   - high-volume manufacturing

4.) System
   - deep application and system know-how
   - Product-to-System

Courtesy: Kaco and pv magazine

<table>
<thead>
<tr>
<th>Year</th>
<th>Power (kW)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>100</td>
<td>1129</td>
</tr>
<tr>
<td>2011</td>
<td>50</td>
<td>151</td>
</tr>
<tr>
<td>2016</td>
<td>50</td>
<td>70</td>
</tr>
<tr>
<td>2018</td>
<td>125</td>
<td>77</td>
</tr>
</tbody>
</table>
SiC MOSFET has passed or will soon reach the tipping point of various applications

- **Photovoltaic**
  - reduction of system cost
  - reduction of system size

- **EV charging**
  - faster charging cycles

- **IPS**
  - higher efficiency,
  - reduced total cost of ownership

- **eMobility**
  - higher reach per charge
  - more compact main inverter

- **Traction**
  - lower system cost
  - higher seat capacity

- **Drives**
  - reduced system size
  - reduced total cost of ownership
Infineon’s SiC revenue opportunity for industrial applications amounts to more than €1.2bn

### SiC revenue potential by customer

<table>
<thead>
<tr>
<th>Customer</th>
<th>[EUR m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer 1</td>
<td></td>
</tr>
<tr>
<td>Customer 2</td>
<td></td>
</tr>
<tr>
<td>Customer 3</td>
<td></td>
</tr>
<tr>
<td>Customer 4</td>
<td></td>
</tr>
<tr>
<td>Customer 5</td>
<td></td>
</tr>
<tr>
<td>Customer 6</td>
<td></td>
</tr>
<tr>
<td>Customer 7</td>
<td></td>
</tr>
<tr>
<td>Customer 8</td>
<td></td>
</tr>
<tr>
<td>Customer 9</td>
<td></td>
</tr>
<tr>
<td>Customer 10</td>
<td></td>
</tr>
</tbody>
</table>

### SiC revenue potential by application

<table>
<thead>
<tr>
<th>[EUR m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMPS (server, PC, ind., telecom, other)</td>
</tr>
<tr>
<td>Solar string inverter</td>
</tr>
<tr>
<td>fast xEV charger</td>
</tr>
<tr>
<td>UPS, industrial PS</td>
</tr>
<tr>
<td>Solar central inverter</td>
</tr>
<tr>
<td>Energy storage</td>
</tr>
<tr>
<td>Solar micro inverter</td>
</tr>
<tr>
<td>Servo motor</td>
</tr>
<tr>
<td>Commercial vehicles</td>
</tr>
<tr>
<td>Heating, welding</td>
</tr>
</tbody>
</table>

### SiC revenue potential by product type

- SiC low-power modules
- SiC bare dies
- SiC diodes
- SiC discrete MOSFETs
Planar versus trench: Advantages and challenges of next-generation SiC cell concepts
Multiple electrical characteristics of a SiC MOSFET have to be balanced

**Performance**
- static behavior based on
  - resistance x area ($R_{on} \times A$)
  - and more
- dynamic behavior based on
  - total loss energy ($E_{tot}$)
  - device capacitances (C’s)
  - gate and recovery charges (Q.s)
  - and more

**Robustness and manufacturing stability**
- high threshold voltage
- high gate oxide reliability
- short circuit capability (~3µs)
- $V_{GS\_on}$ 15 V .. 18 V
- stable manufacturing process
- and more
Power transistors are a parallel connection of multiple cells

**Power Transistor - MOSFET**

*Structure*

> Cell width is a key indicator for high material utilization

> Concept with best volume utilization favored

A single power MOSFET may contain several thousands parallel cells.

These individual cells are paralleled to form large-area devices.
General MOSFET considerations – planar versus trench cell concept

**Planar**

- Current flow needs to change direction
  - Certain space required to avoid crowding
- Critical dimension channel length in **lateral** direction

**Trench**

- Current flow directly vertical
- Critical dimension channel length in **vertical** direction

During the semiconductor manufacturing process, vertical dimensions can be better controlled than lateral ones.
Implications on the cell concept based SiC-specific interface properties

SiC Planar

› High density of defects lead to high channel resistance
› Low on-resistance achievable via high electric fields across the gate oxide
› All planar SiC MOSFETs today with more than 3 MV/cm for turn on, low $V_{\text{GS\_th}}$ and high $V_{\text{GS\_on}}$

SI C Trench

› Low density of defects leads to low channel resistance
› Low on-resistance achieved at oxide field below 3 MV/cm
› Possible to achieve high $V_{\text{GS\_th}}$ and IGBT like $V_{\text{GS\_on}}$
Summary Trench vs. Planar in SiC – focus on long term success

**SiC Planar**
- Easy/cheap process
- Good shielding of oxide possible
- Very low channel mobility
- Limited shrink options

**SiC Trench**
- Low channel resistance
- Shrink potential higher than in DMOS
- Sophisticated process knowledge needed
- Protection of oxide corners needed

**Infineon Trench**
- Granted by Infineon Trench technology experience over > 25 years

Grant by Infineon SiC folded double Trench structure
Infineon’s trench-based CoolSiC™ technology has been optimized for highest reliability.

Combine best $R_{DS(on)}$ with robustness levels equivalent to IGBTs.
To be or not to be vertically integrated: Does a device manufacturer need to own the SiC substrate crystal growth process?
A deeper look into real dimensions of a SiC MOSFET

In the actual device the substrate has no active role.

The substrate delivers

- the crystallographic information for the epitaxial growth, and
- mechanical stability.
The SiC material irony

- The growth process is expensive, risky and time-consuming
- Today, 80% of the grown material is turned into dust during processing

For extracting a 350 µm thick epi-ready wafer more than 700 µm crystal length is needed in case of wire saw technology today.

During thin-wafer processing (final die thickness ~100 µm) further 250 µm are grinded away.

Significant increase of boule utilization by Cold Split technology.
Infineon strategy: instead of growing own crystals improve material efficiency and keep capex low

SiC raw wafer → device processing, first run → wafer splitting (several individual steps, see below) → device processing, second run → dicing

- 350 µm
- epi layer

Cold Split technology

1. Laser
2. Deposit polymer
3. Cool down and split
4. Remove polymer

Cold Split technology
infineon

Part of your life. Part of tomorrow.
Dr. Peter Wawer
Division President Industrial Power Control

› since 2016: Division President Industrial Power Control
› 2012: Member of the Management Board of the Power Management & Multimarket Division
› 2011: Senior VP Technology and Production at Q-Cells SE in Bitterfeld, Germany
› 2008 – 2011: Senior VP Technology at Q-Cells SE
› 1997 – 2008: various position at Infineon

› Dr. Peter Wawer was born in Berlin, Germany, in 1967. He holds a Diploma in Electrical Engineering from the Technical University in Berlin where he also received his PhD.
› He joined Infineon (Siemens AG until 1999) in 1997.
Dr. Peter Friedrichs
Senior Director SiC Technology

› since 2011: Senior Director SiC Technology at Infineon
› 2004 – 2011: Managing director of SiCED (Joint venture of Infineon and Siemens)
› 1996 – 2004: various positions at Siemens and SiCED

› Dr. Peter Friedrichs was born in Aschersleben, Germany, in 1968. He holds a Diploma in Microelectronics from the Technical University in Bratislava, Slovakia, and received his PhD from the Friedrich Alexander University in Erlangen, Germany. In addition, he holds a Diploma in Industrial Engineering from the University in Hagen, Germany.
› He joined Infineon (Siemens AG until 1999) in 1996.
### Glossary

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>epi</td>
<td>epitaxy</td>
</tr>
<tr>
<td>HiRel</td>
<td>high-reliability products</td>
</tr>
<tr>
<td>IPS</td>
<td>industrial power supply</td>
</tr>
<tr>
<td>IGBT</td>
<td>insulated-gate bipolar transistor</td>
</tr>
<tr>
<td>LCOE</td>
<td>levelized cost of energy</td>
</tr>
<tr>
<td>MOSFET</td>
<td>metal-oxide silicon field-effect transistor</td>
</tr>
<tr>
<td>OBOR</td>
<td>China’s initiative „One Belt One Road“</td>
</tr>
<tr>
<td>PV</td>
<td>photovoltaic</td>
</tr>
<tr>
<td>PS</td>
<td>power supply</td>
</tr>
<tr>
<td>SiC</td>
<td>silicon carbide</td>
</tr>
<tr>
<td>SMPS</td>
<td>switch-mode power supply</td>
</tr>
<tr>
<td>UPS</td>
<td>uninterruptable power supply</td>
</tr>
<tr>
<td>VSD</td>
<td>variable speed drive</td>
</tr>
<tr>
<td>xEV</td>
<td>all degrees of vehicle electrification (EV, HEV, PHEV)</td>
</tr>
</tbody>
</table>
Disclaimer

This presentation contains forward-looking statements about the business, financial condition and earnings performance of the Infineon Group.

These statements are based on assumptions and projections resting upon currently available information and present estimates. They are subject to a multitude of uncertainties and risks. Actual business development may therefore differ materially from what has been expected.

Beyond disclosure requirements stipulated by law, Infineon does not undertake any obligation to update forward-looking statements.

Specific disclaimer for IHS Markit reports, data and information referenced in this document:

The IHS Markit reports, data and information referenced herein (the "IHS Markit Materials") are the copyrighted property of IHS Markit Ltd. and its subsidiaries ("IHS Markit") and represent data, research, opinions or viewpoints published by IHS Markit, and are not representations of fact. The IHS Markit Materials speak as of the original publication date thereof and not as of the date of this document. The information and opinions expressed in the IHS Markit Materials are subject to change without notice and neither IHS Markit nor, as a consequence, Infineon have a duty or responsibility to update the IHS Markit Materials or this presentation. Moreover, while the IHS Markit Materials reproduced herein are from sources considered reliable, the accuracy and completeness thereof are not warranted, nor are the opinions and analyses which are based upon it. IHS Markit and the trademarks used in the data, if any, are trademarks of IHS Markit. Other trademarks appearing in the IHS Markit Materials are the property of IHS Markit or their respective owners.