FRAUNHOFER IZM

Impact of electromobility on power electronic modules

Einfluss der Elektromobilität auf Leistungselektronik-Module

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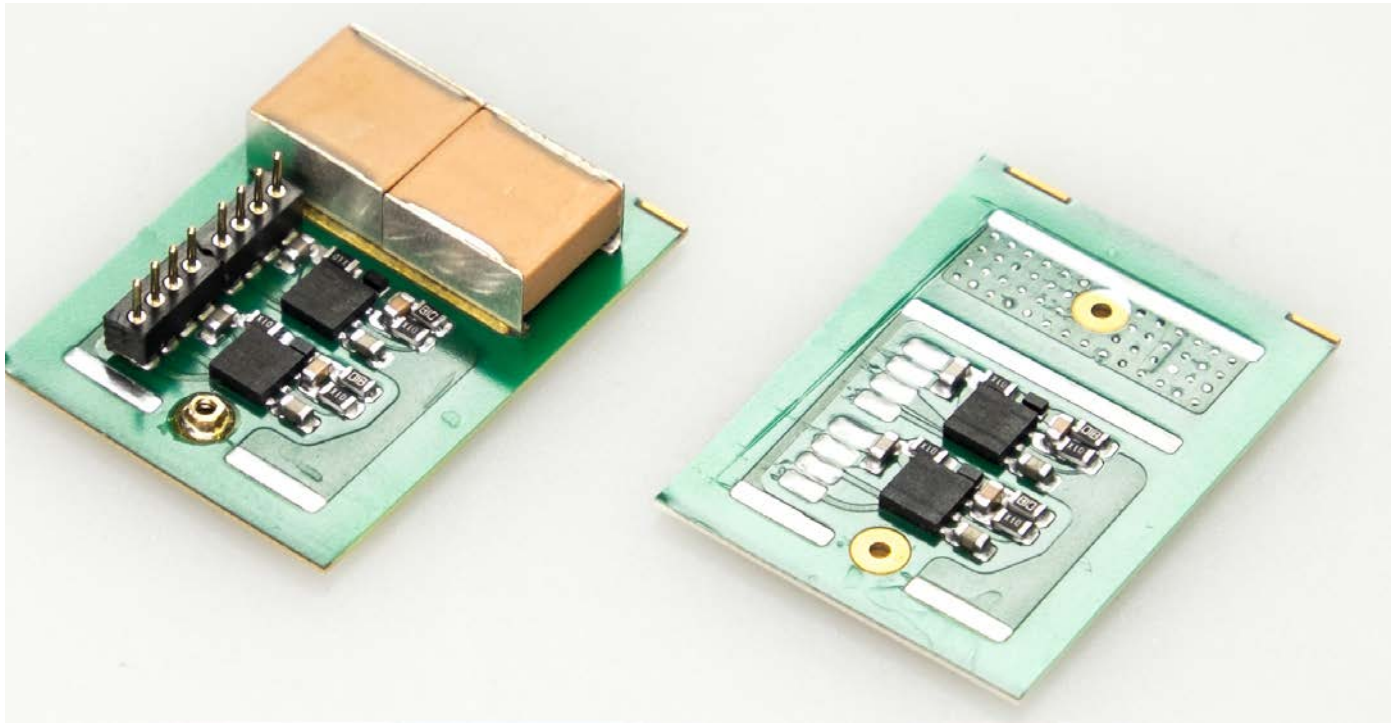

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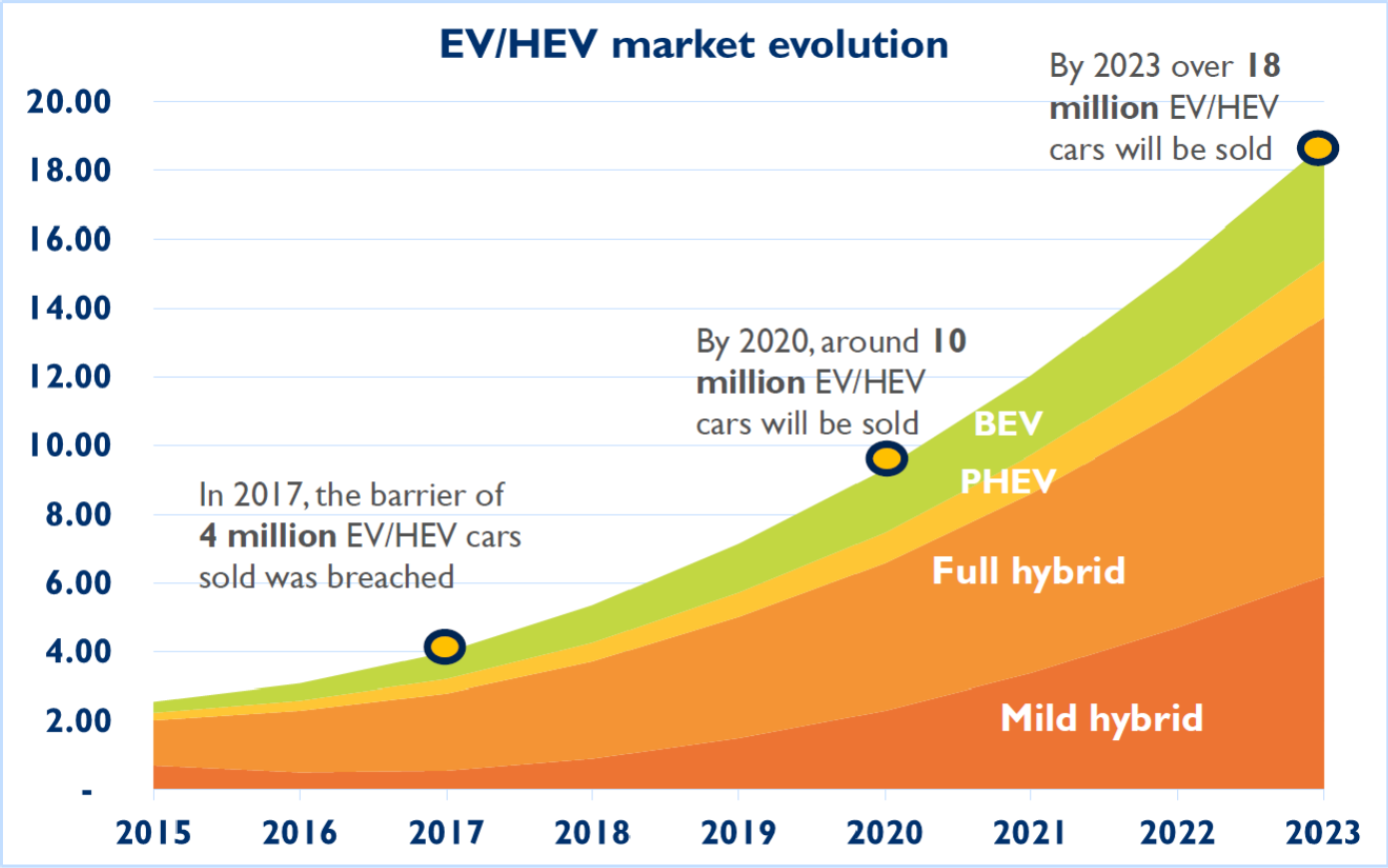
Agenda

- EV/HEV market evolution
- Impact on power electronic modules
  - Highly reliable, miniaturized, new materials and new interconnects
- Thoughts @ Fraunhofer IZM
- Possibilities for laser-based Interconnects
  - Converter (external) connectors -> Laserwelding
  - Converter (external) connectors / Heavy wire bonds -> Laserbonding
- Battery interconnection

EV/HEV market evolution



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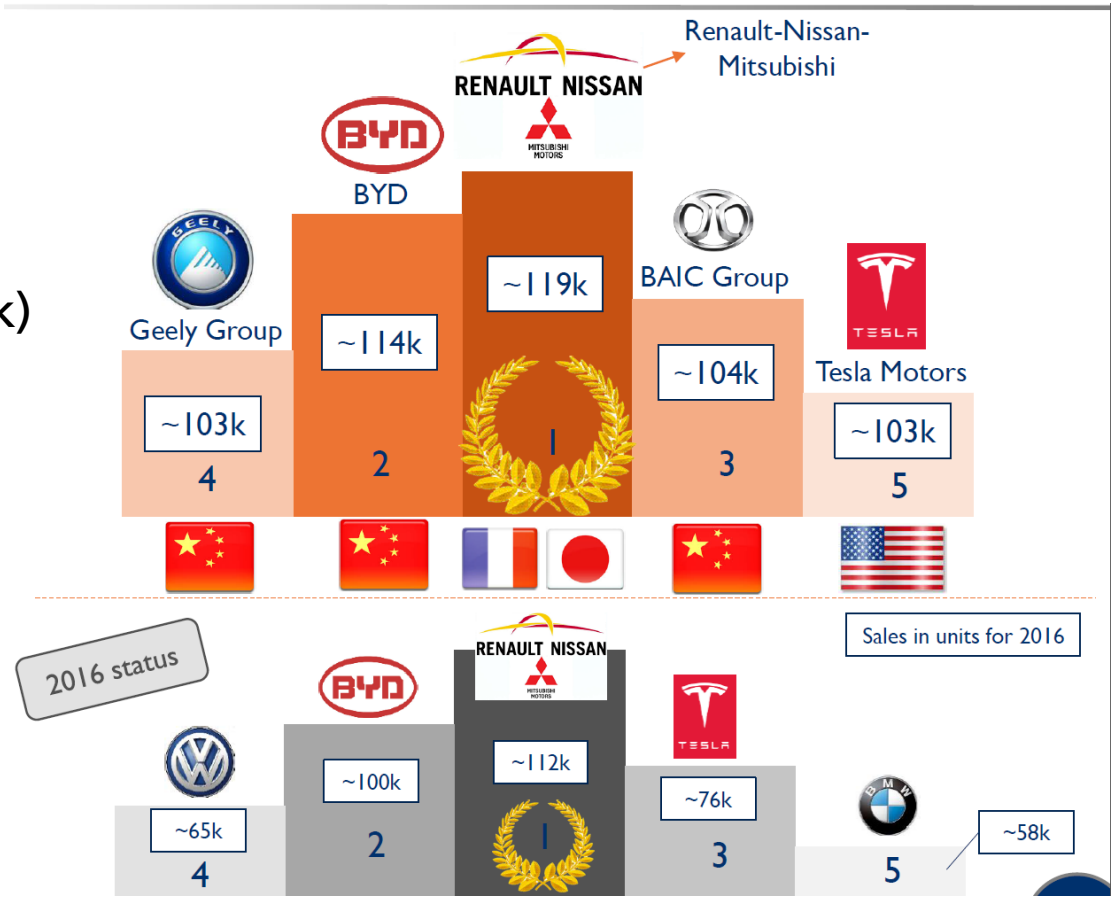
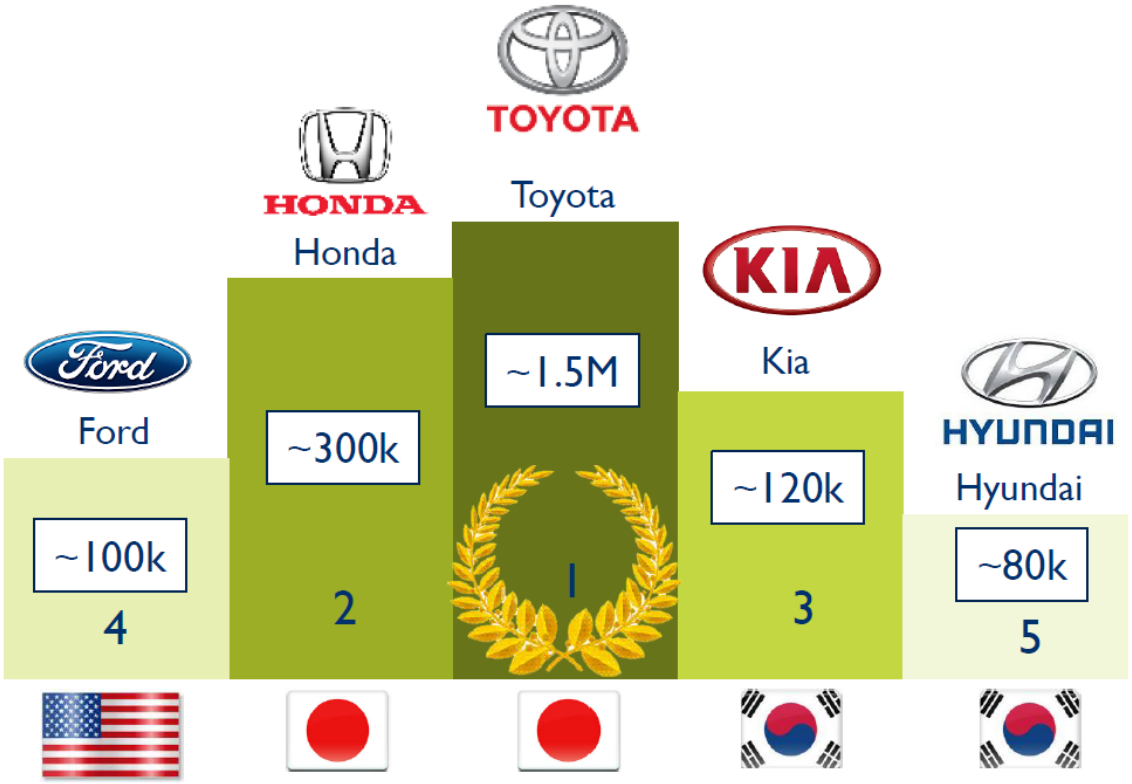
EV/HEV market evolution

Sales in units (PHEV + BEV)
for 2017 (BMW nearly 100k)



EV/HEV market evolution

Sales in units (Full HEV + Mild HEV) for 2017 (BMW nearly 100k)



There is no doubt that Toyota will remain the big leader of the hybrid market, as by 2030 they forecast to sell about 4.5 million hybrids worldwide.

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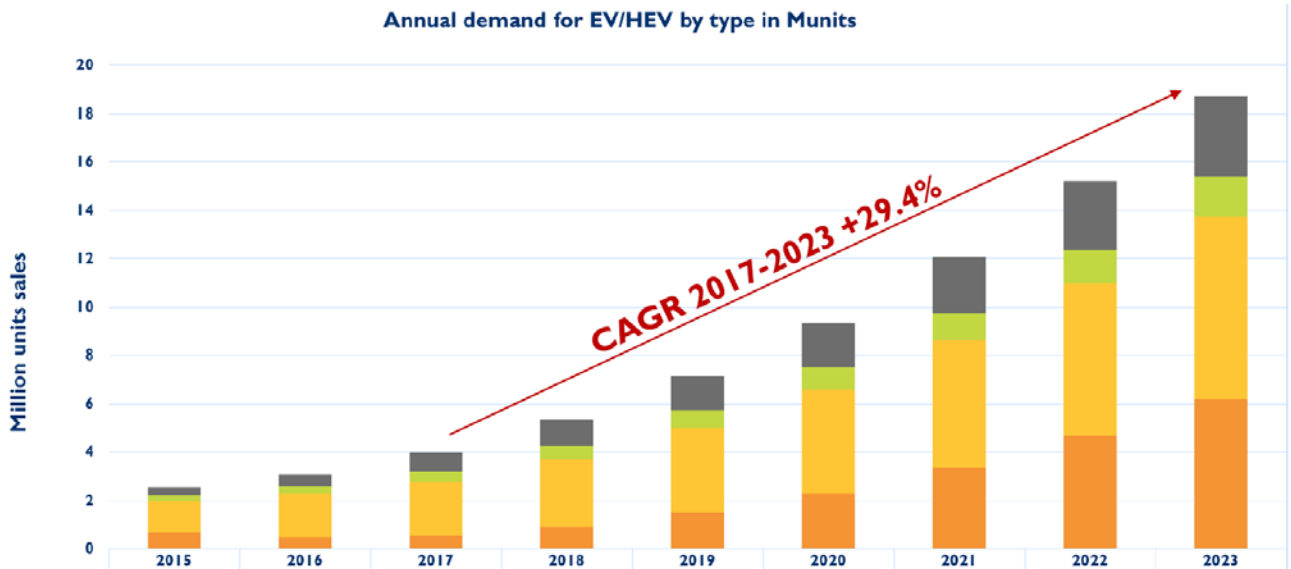
EV/HEV market evolution

Vehicle unit sales 2015-2023

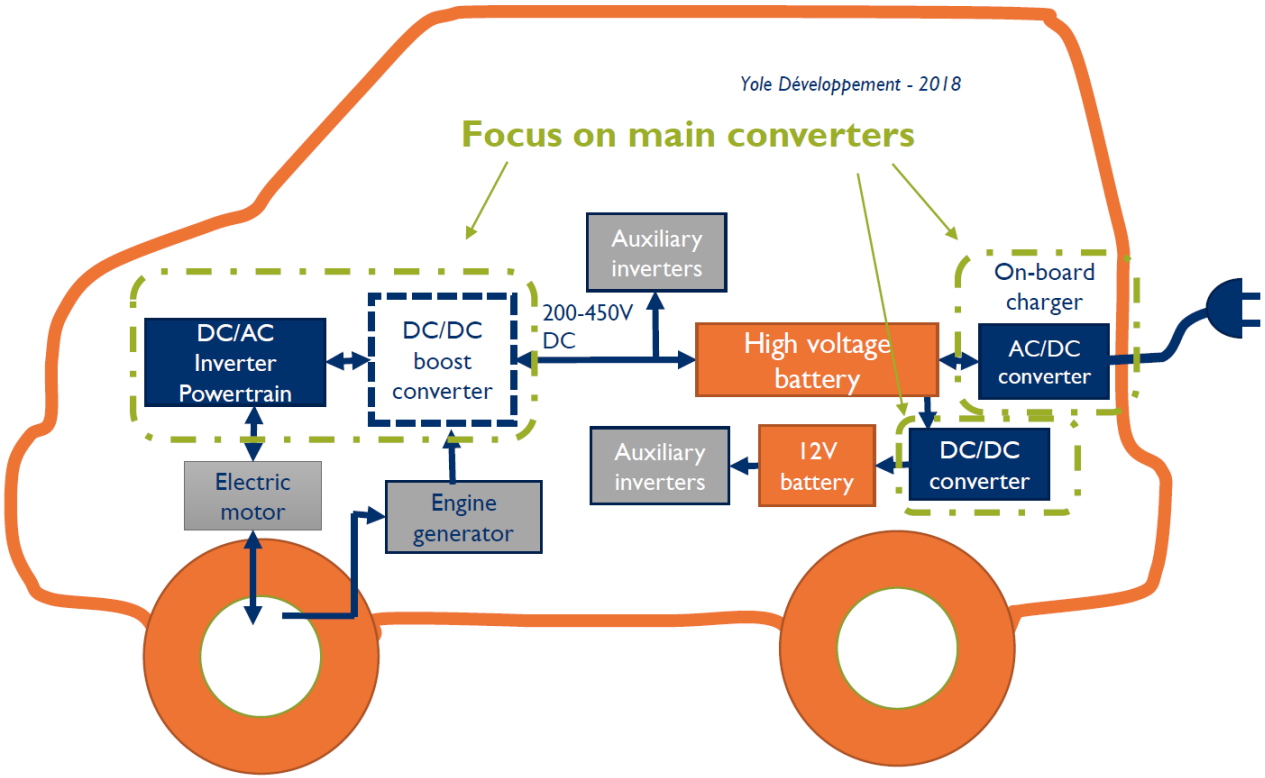
The mild-hybrid segment will experience an impressive increase of 49.7% between 2017-2023, driven by the 48-volt system.



	2015	2016	2017	2018	2019	2020	2021	2022	2023	CAGR 17-23
BEV	0.32	0.49	0.78	1.10	1.43	1.85	2.32	2.83	3.34	27.3%
Plug in HEV (PHEV)	0.22	0.29	0.41	0.55	0.71	0.89	1.11	1.39	1.67	26.6%
Full HEV	1.32	1.80	2.25	2.81	3.52	4.29	5.23	6.28	7.54	22.3%
Mild HEV	0.70	0.50	0.55	0.90	1.50	2.30	3.38	4.70	6.20	49.7%

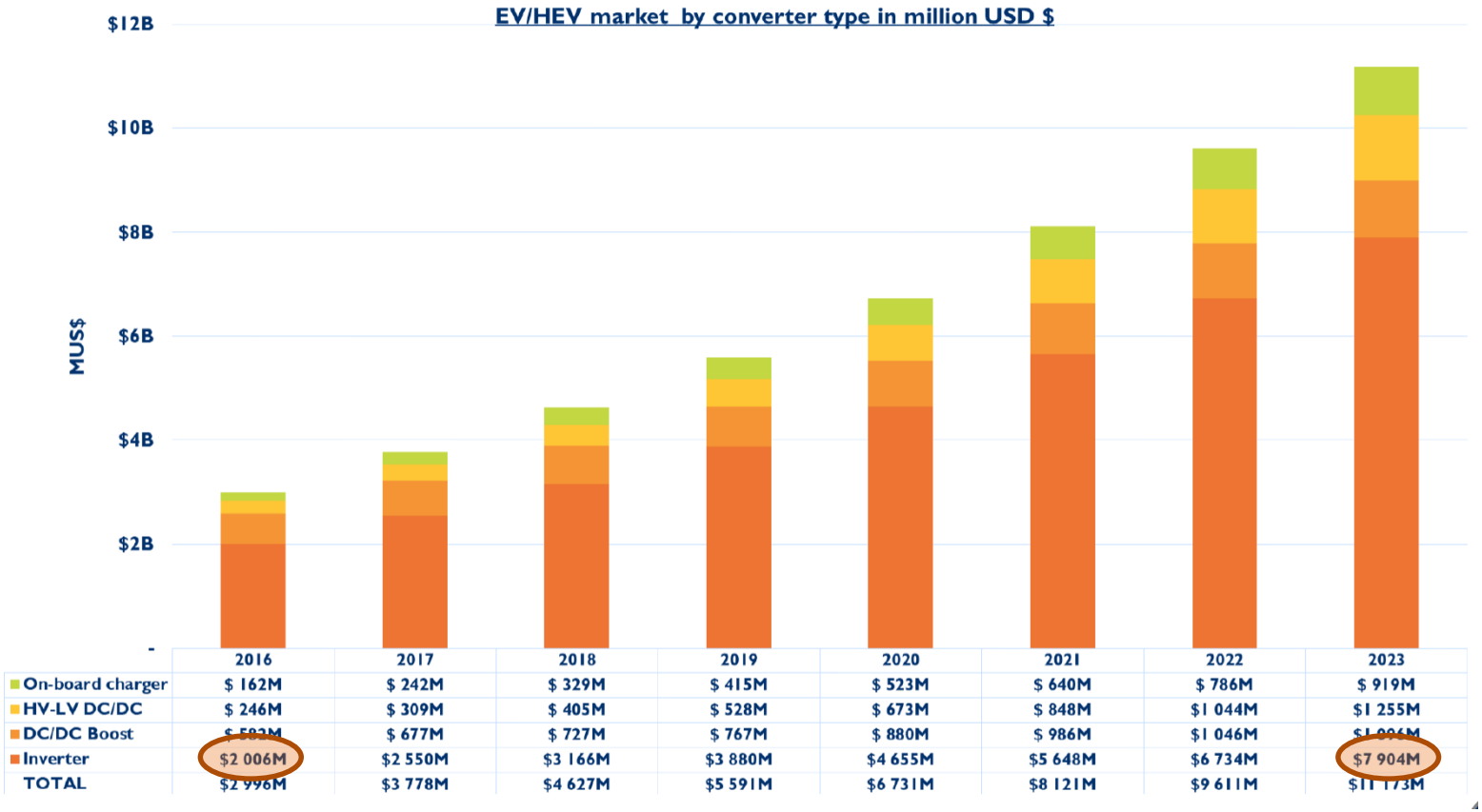
EV/HEV market evolution

Power Electronics and Automotive Application



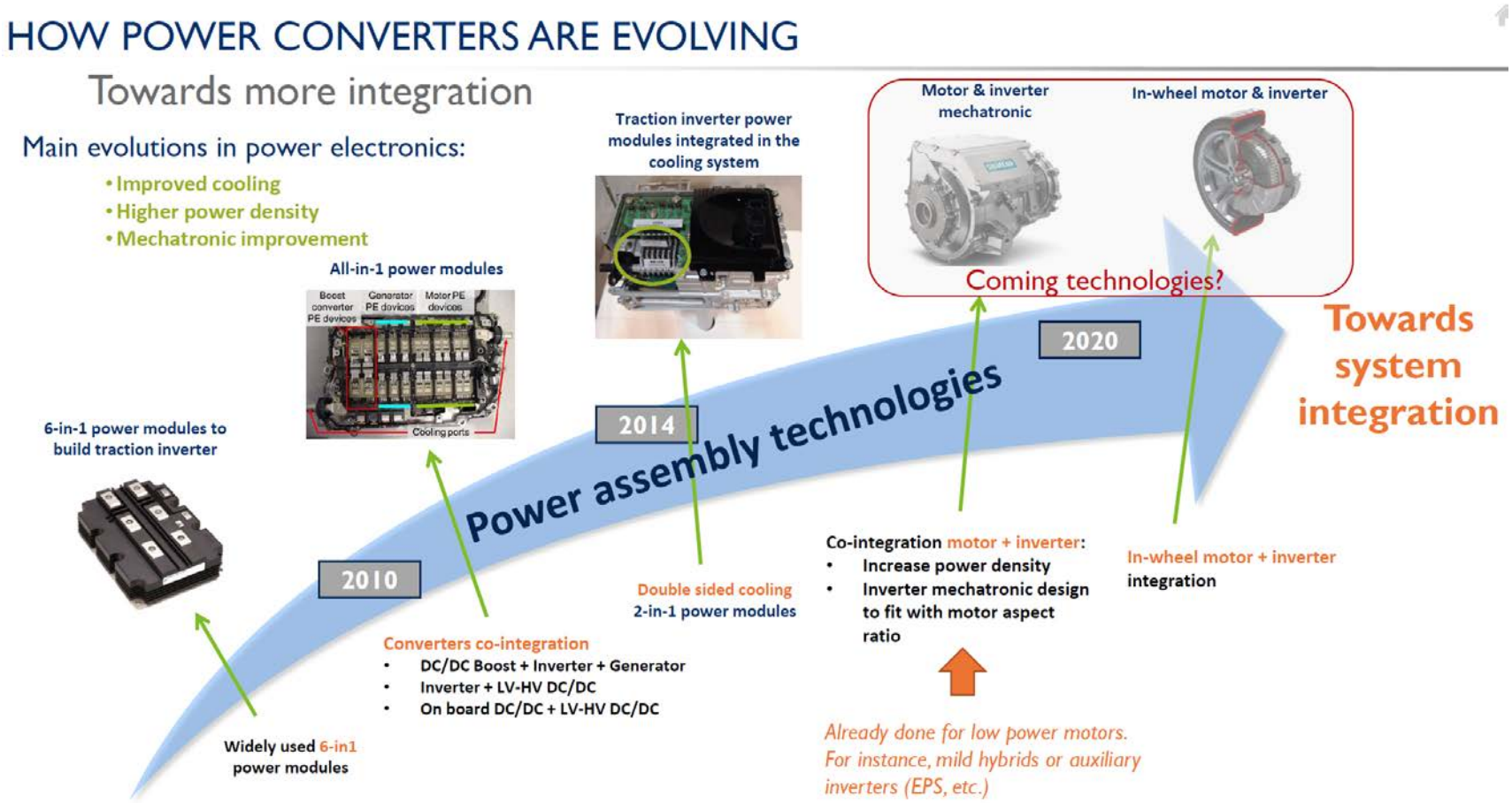
EV/HEV market evolution

EV/HEV converter market



	2016	2017	2018	2019	2020	2021	2022	2023
On-board charger	$ 162M	$ 242M	$ 329M	$ 415M	$ 523M	$ 640M	$ 786M	$ 919M
HV-LV DC/DC	$ 246M	$ 309M	$ 405M	$ 528M	$ 673M	$ 848M	$1 044M	$1 255M
DC/DC Boost	[illegible]	$ 677M	$ 727M	$ 767M	$ 880M	$ 986M	$1 046M	[illegible]
Inverter	$2 006M	$2 550M	$3 166M	$3 880M	$4 655M	$5 648M	$6 734M	$7 904M
TOTAL	$2 996M	$3 778M	$4 627M	$5 591M	$6 731M	$8 121M	$9 611M	$11 173M

Impact on power electronic modules



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Impact on power electronic modules

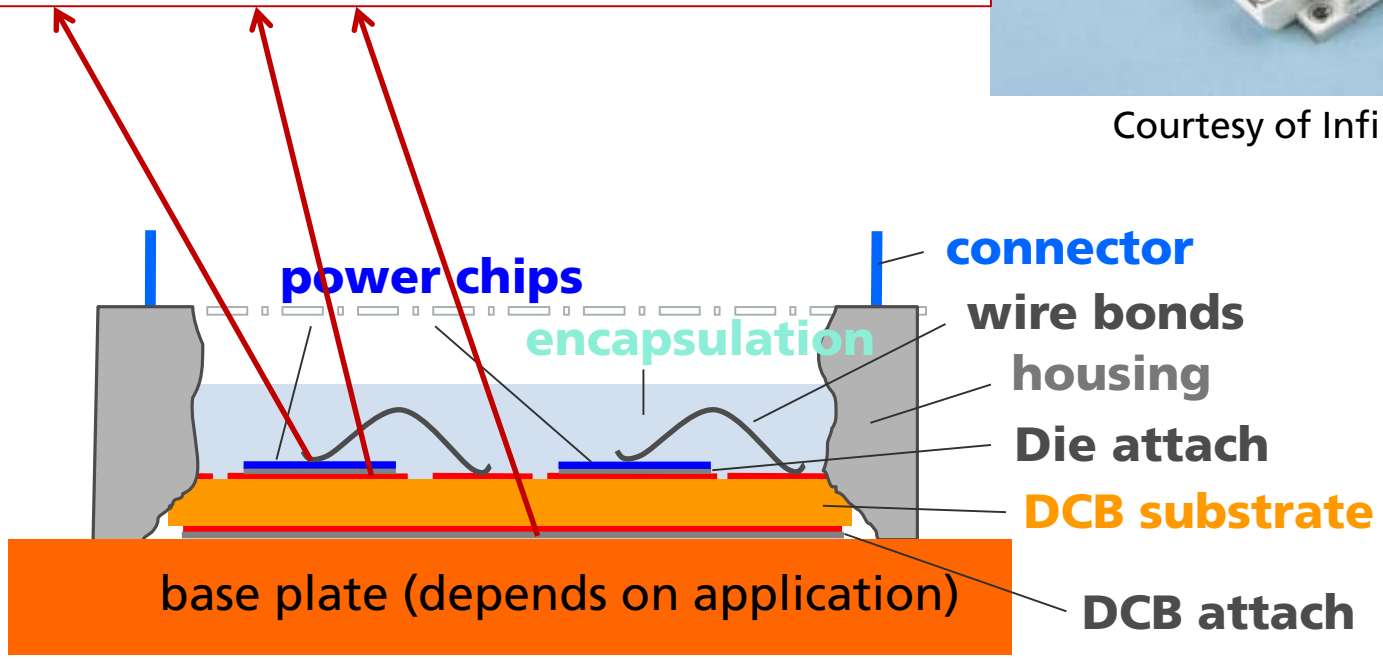
EconoPACK™+ Modul

(SixPACK up to1700 V / 450 A)

Courtesy of Infineon (Eupec)

Standard modules reliability problems

Wire bond fatigue
Solder die and substrate attach creep/fatigue



Schneider-Ramelow, M; et al.: Technologies and Trends to Improve Power Electronic Packaging. 44th IMAPS International Symposium on Microelectronics (2011).

Impact on power electronic modules

Weak points and solutions in power module packaging

Field	Kind of failure	Approach / solution
DCB-Cu on Cu base plate	Solder cracking (creep/fatigue)	- Other base plate material (AlSiC, AlSi, Al-Graphit, Cu/Mo/Cu, Cu/W/Cu) - spring/pressure contact, other TIM - no base plate or no DCB
Al wedge bond on chip	Al fatigue	- Ribbon (Cu/Al), Cu or AlX wire bonding - Sintering/soldering of formed parts - double-sided cooling/contacts
Chip on DCB-Cu	Solder cracking (creep/fatigue)	- Ag or TLP sintering - Nanofoil reactive joining - Pressure contact
DCB: Cu on ceramic	Ceramic cracking	- High strength ceramic - Dimples or thin Cu - DAB or other substrates
Cu to Cu connector	Cracks in solder or ceramic	- Welded bonds to external connectors - Pressure contacts

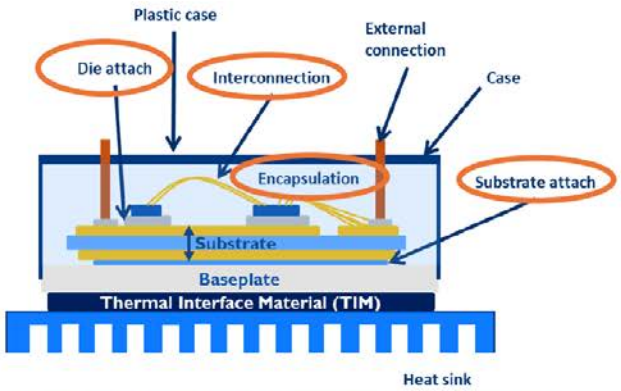
Schneider-Ramelow, M; et al.: Technologies and Trends to Improve Power Electronic Packaging. 44th IMAPS International Symposium on Microelectronics (2011). (adjusted Febr. 2019)

Impact on power electronic modules: new semiconductor materials like SiC

FULL SIC MODULE PACKAGING

Impact of SiC chips on choice of packaging materials

Full SiC modules require a new design and thus new packaging materials.



Structure of a wire-bonded power module on a heat sink.
Yole Développement

Old design

Main technologies that will need to evolve:

Substrate
High thermal conductivity ceramics such as AlN and Si3N4.

Encapsulation
High-temperature epoxy or silicone gel.

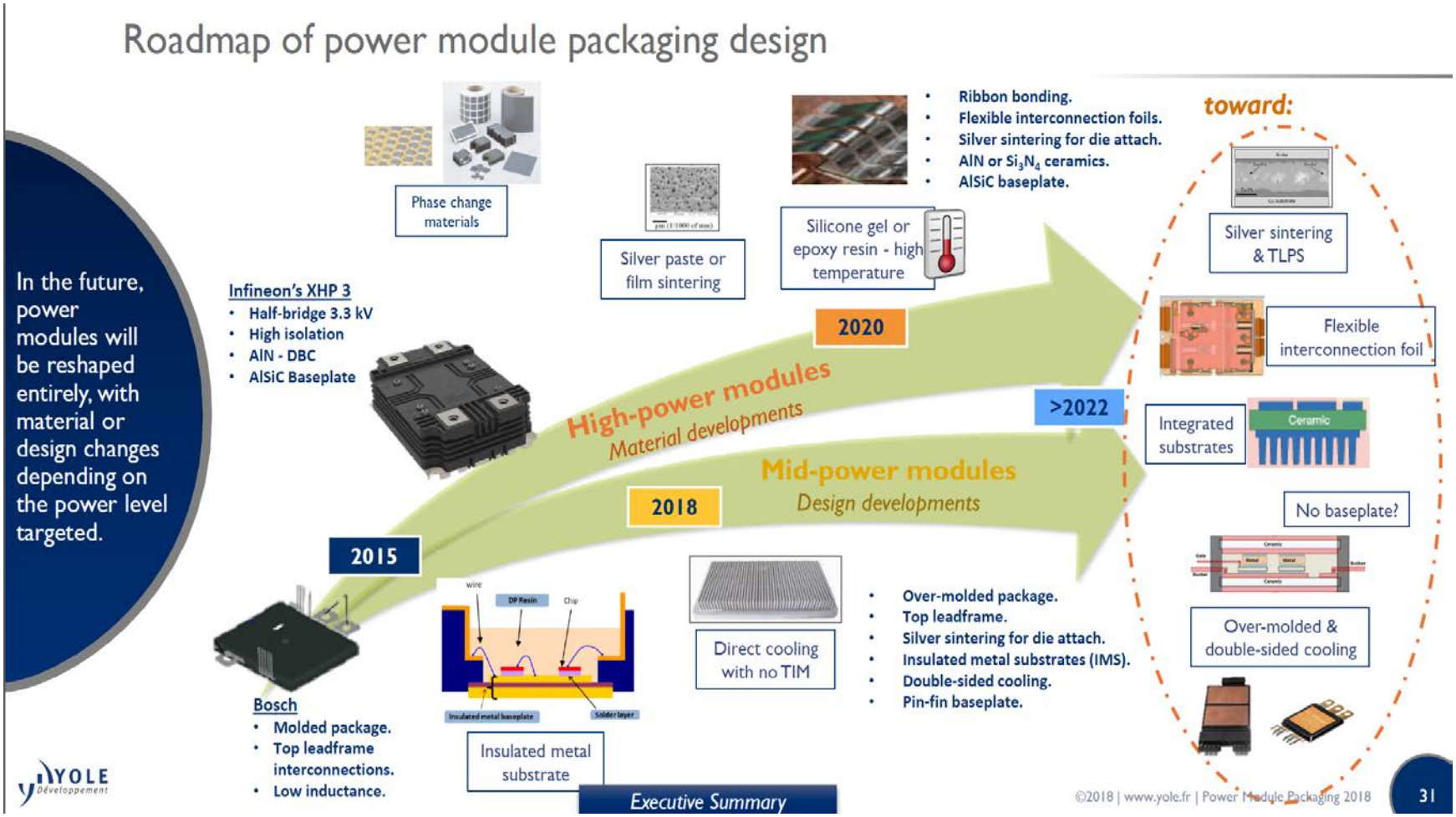
SiC chips:
High Tj and high frequency

Die attach
Silver sintering is expected to become the preferred choice.

Interconnections
Low-inductance interconnections.

New designs and new materials are needed

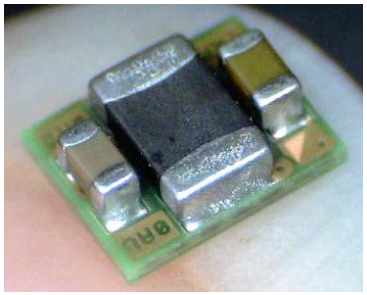
Impact on power electronic modules



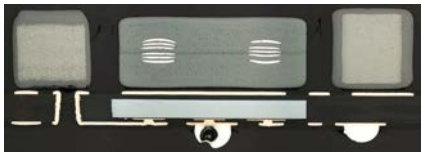
Thoughts @ Fraunhofer IZM

Is Integration the Next Milestone for Power Electronics?

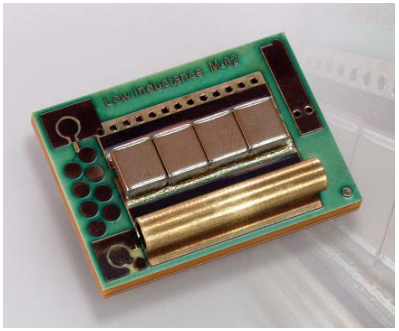
Three examples giving an idea on future development

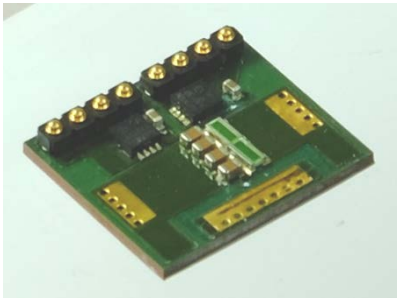


Texas Instruments

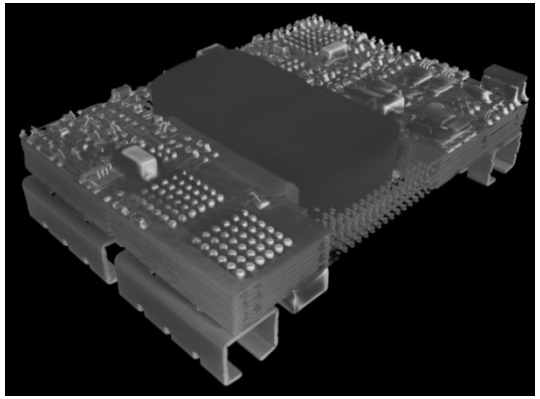


PCB with embedded semiconductors and SMD passives





Ultra Low Inductance modules in Embedding on DCB technology



Multilayer PCB including coil windings, overmolded

Hoene, E; Fraunhofer IZM 2016

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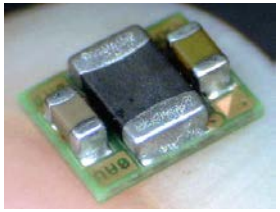
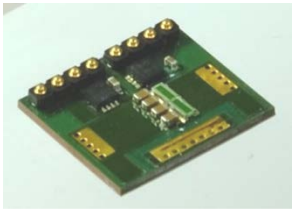
Thoughts @ Fraunhofer IZM

What makes sense to be integrated?



- Low power DC/DC converter with all necessary active and passive components
- Prepared for PCB mounting
- The semiconductor package is at the same time substrate for passives

-> reduction of manufacturing processes and space



- Switching cell in the package including driver, primary DC link and safety insulation
- Thermal interface on the one side, electrical interface on the other
- Electromagnetically optimized for fast switching

-> Integration of the “heart” of the circuit in a package

- High power DC/DC converter with all necessary active and passive components
- Double sided cooling
- Robust, thermally conducting and electrically insulating encapsulation

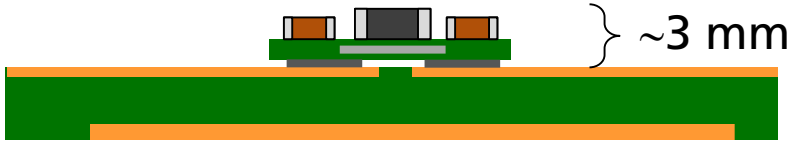
-> space saving and robust

Hoene, E; Fraunhofer IZM 2016

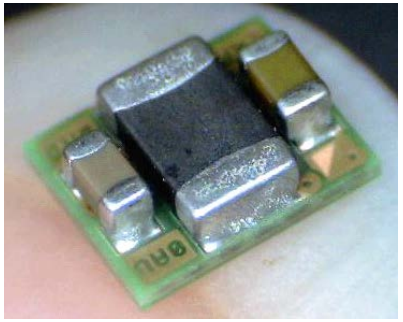
Thoughts @ Fraunhofer IZM

What is desired by the users?

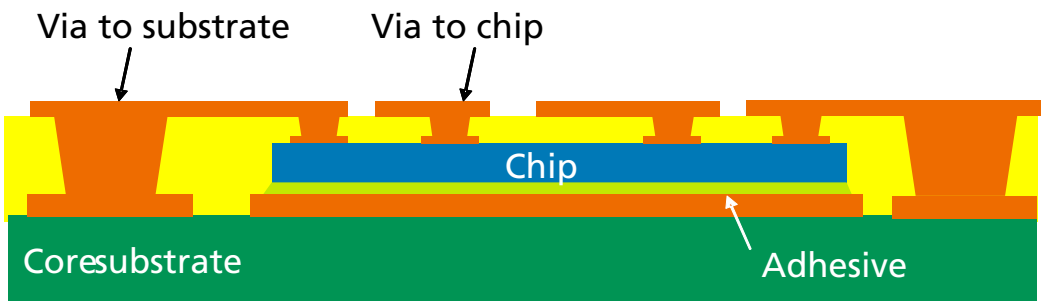
Low power: SMD mounting on PCB



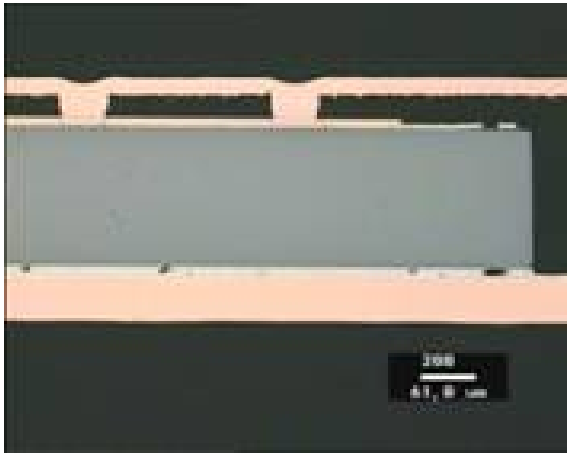
Size <1cm²



- 2 component layers integrated: chips and SMD
- Cooling by Master PCB, losses < 1W
- Handling like a SMD component



Dielectric



Hoene, E; Fraunhofer IZM 2016

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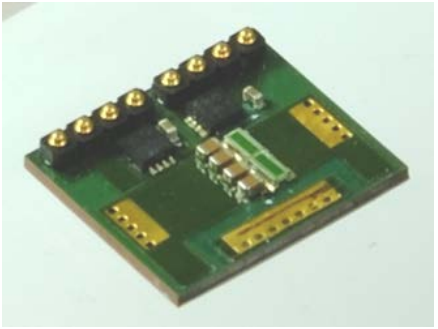
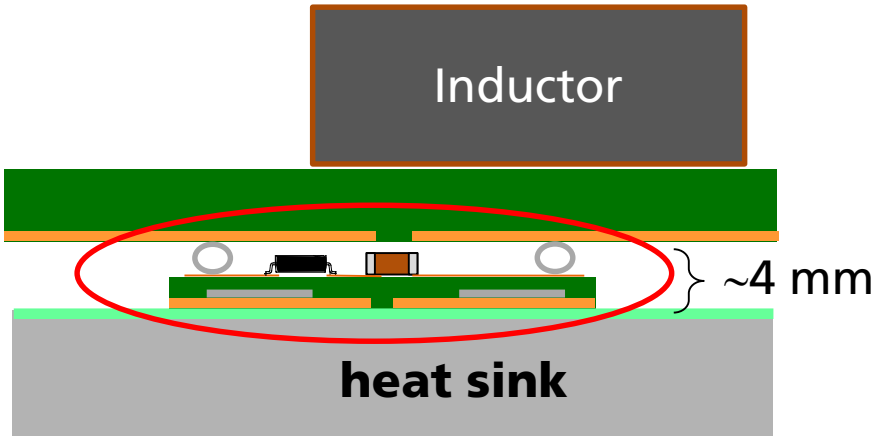
What is desired by the users?



Higher power requiring a heat sink and (safety) insulation



2.5cm² < size <25cm²

- "Switching Cell in Package"
- Thermal interface on the one side including (safety) insulation against heat sink
- 2 component layers integrated: Chips and SMD
- Electric interface on the other side by springs or soldering
- Peripherals on the module

Hoene, E; Fraunhofer IZM 2016

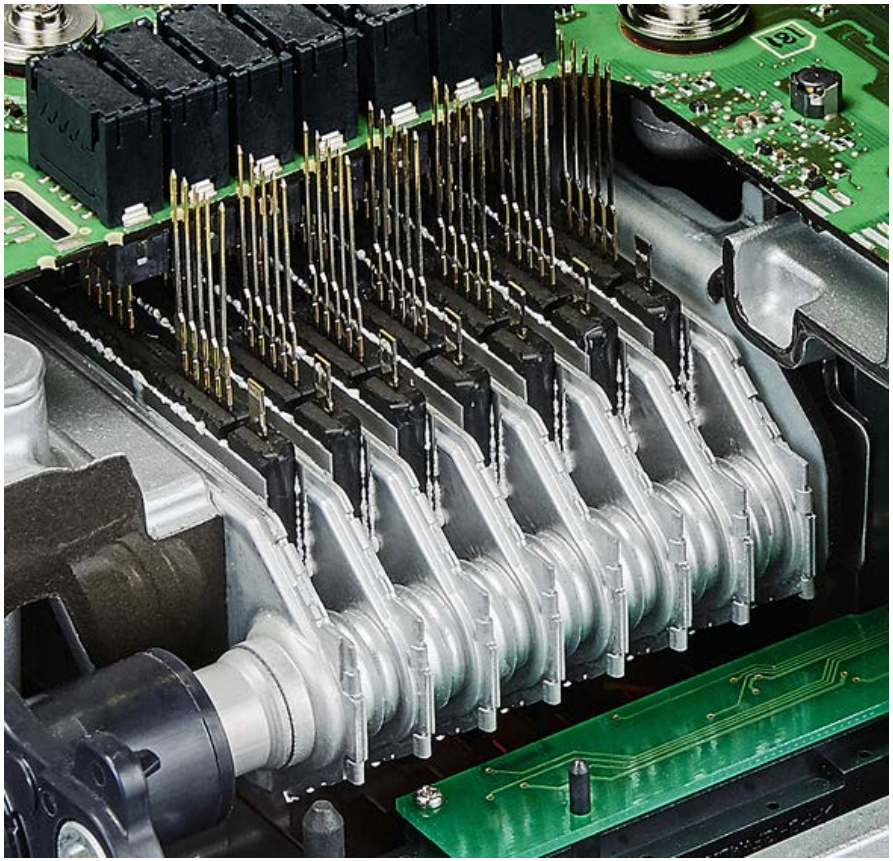
Thoughts @ Fraunhofer IZM

How will power electronics look like in future?

1st answer: **Flat**

- Thermal path must be kept short and is the No.1 bottle neck

- Stacked power modules with both side cooling by Toyota
- Safety insulation by ceramic substrates
- Assembly with thermal grease (performance bottle neck)



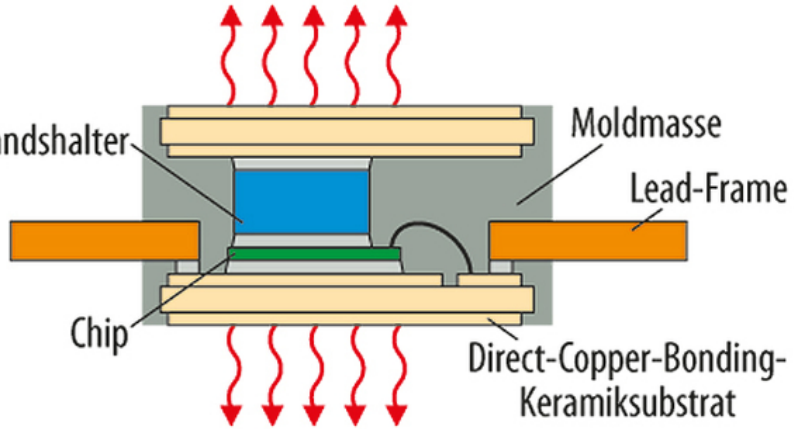
Hoene, E; Fraunhofer IZM 2016

Thoughts @ Fraunhofer IZM

How will power electronics look like in future?

1st answer: **Flat**

- Example for highest performance package: double side cooled semiconductor, ceramic substrates as insulation, only metallic interconnects



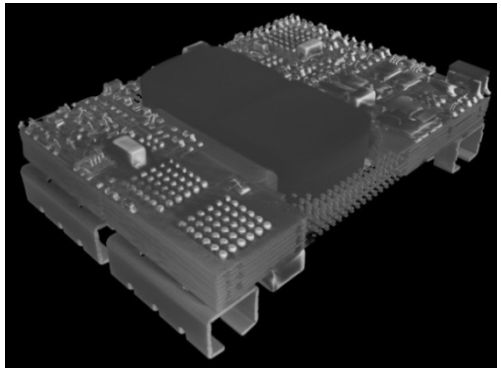
Thoughts @ Fraunhofer IZM

How will power electronics look like in future?

2nd answer: **It will use Heterogeneous Integration Technologies**

Power electronics cannot be monolithically integrated, it needs:

- Semiconductors (volume ~3%, CTE 2-4)
- Inductors -> ferrite (volume ~20%, CTE 10, pressure sensitive)
- Capacitors -> ceramics (volume ~10%, CTE 10, piezoelectric)
- Conductors -> copper (~15%, CTE 17)
- Control, drivers, sensors (~12%)
- Insulation and unused volume (~40%, shrinkage, non homogeneous CTE)

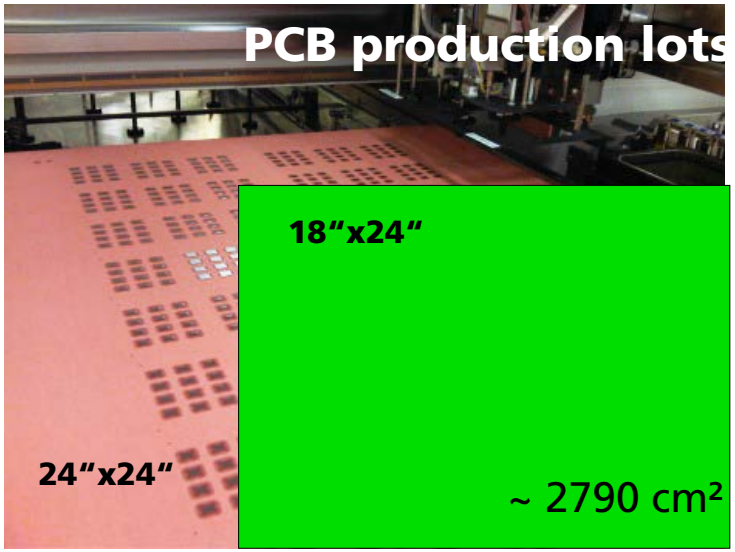


Thoughts @ Fraunhofer IZM

How will power electronics look like in future?

3rd answer: **PCB based technologies are the basis for integration**

- Soldering components onto PCBs is the common technology applicable to all types of components
- Especially transformers can be designed using PCB windings
- High interconnect numbers without extra costs
- Big production lots, established low cost technology



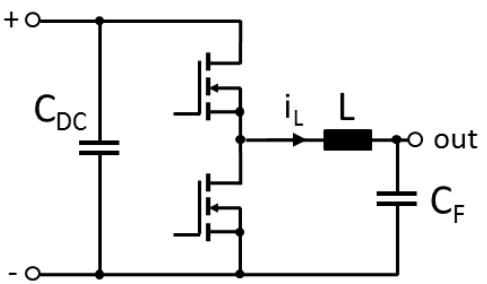
Hoene, E; Fraunhofer IZM 2016

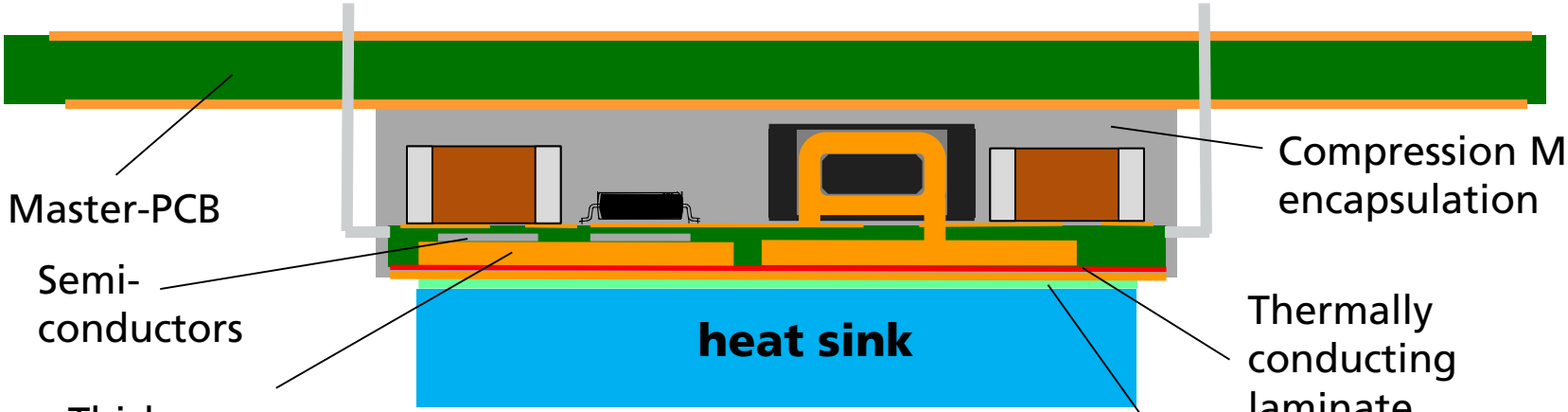
Thoughts @ Fraunhofer IZM

Which types of devices make sense?

Mid Power Power System in Package with insulation:
Switching Cell with output inductor

- Integration of no.1 performance defining components: Switching cell incl. drivers, output inductor, DC and filtering capacitors, PWM and protection





Master-PCB

Semi-conductors

Thick copper for heat spreading

Compression Mold encapsulation

Thermally conducting laminate

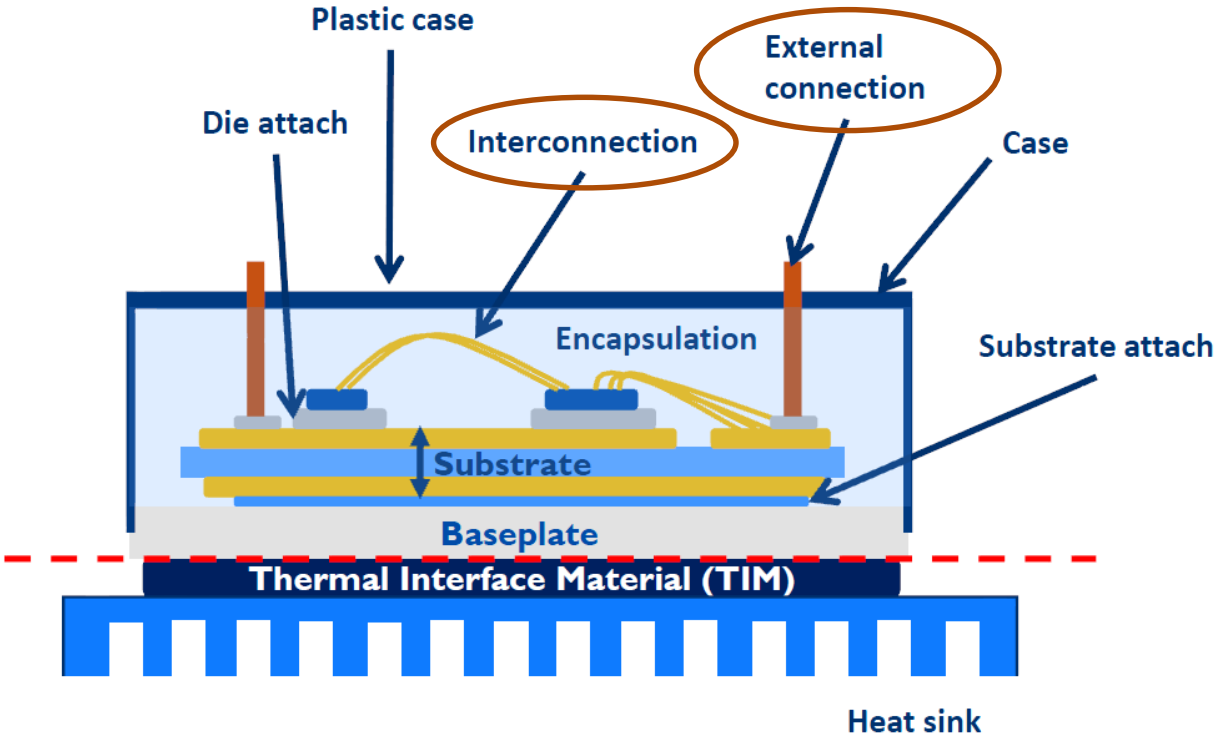
Thermal grease/ solder/sinter connection

- medium perf. insulation
- 2D interfaces
- 2 layers

Hoene, E; Fraunhofer IZM 2016

Thoughts @ Fraunhofer IZM

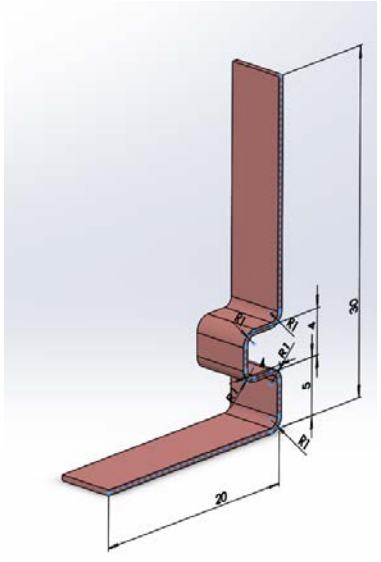
Possible application for laser technologies?

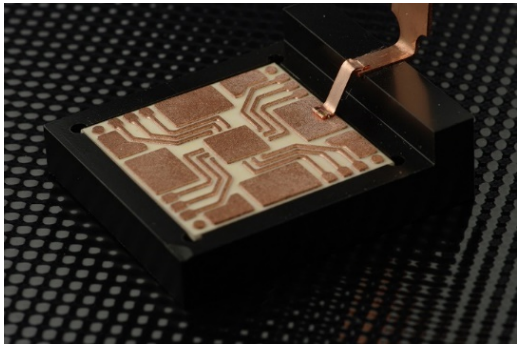


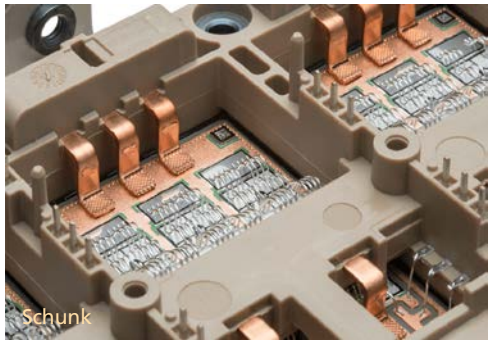
Possibilities for laser-based Interconnects

Converter (external) connectors

- US welding [Kido 2010]
- **Laser beam welding [ILT 2013/14]**
- Resistance welding [Waltrich 2015]







[2] Kido, K.; *et. al*.: „Development of Copper-Copper Bonding by Ultrasonic Welding for IGBT Modules," 34th International Electronic Manufacturing Technology Symposium (IEMT 2010), pp. 1-5.
[3] Mehlmann, B.; et.al.: „Laserstrahlschweißen elektrischer Anschlüsse an DAB-Substrate", ILT Jahresbericht13/14]
[4] Waltrich, U.; *et. al*.: „Bonding Copper Terminals onto DBC Substrates of Power Modules by Resistance Projection Welding," 5th International Electric Drives Production Conference (EDPC 2015)

Possibilities for laser-based Interconnects

Converter (external) connectors / Heavy wire bonds -> Laserbonding

The typical Laser Bonder

Laser Unit

- 1000 W Infrared Fiber Laser (1070 nm)
- Laser Control PC
- Water recirculating cooler

Standard Heavy Wire Bonder Base

- Add-on Scanner for Laser beam
- Laser connected by fiber
- No other modification
- Manual or automatic parts handling

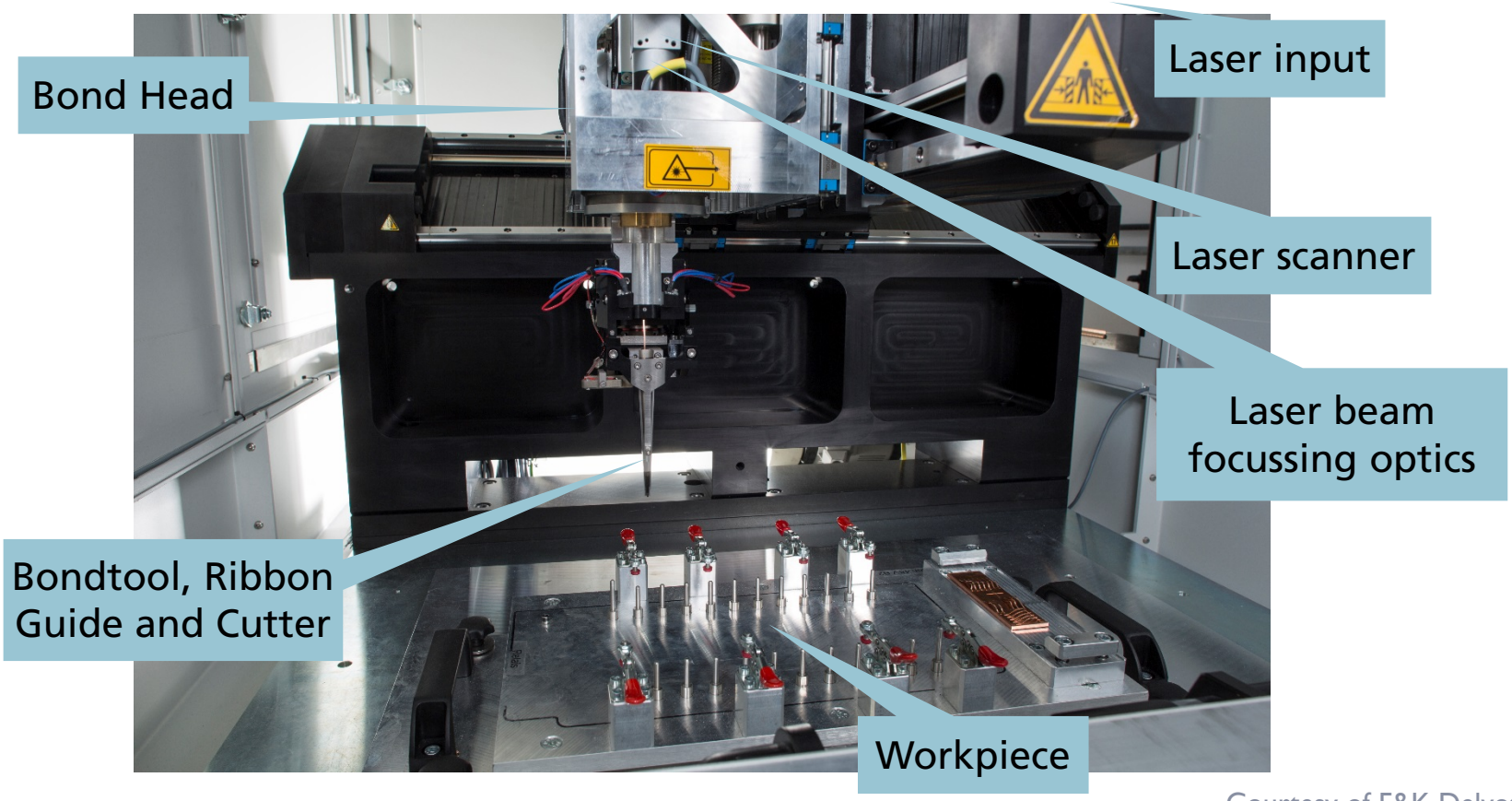
For high current interconnection of power chips and housing components

Courtesy of F&K Delvotec

Possibilities for laser-based Interconnects

Converter (external) connectors / Heavy wire bonds -> Laserbonding

The bond head with Laser



Courtesy of F&K Delvotec

Battery interconnection

Standard heavy wire bonds

Connected with 3 aluminum wires of 400 µm each

Courtesy of F&K Delvotec

Battery interconnection

Standard heavy wire bonds

Each cell connected to a joint connector mask by 400 µm Al wire

Courtesy of F&K Delvotec

Battery interconnection

Laserbonding for battery cells

Use laser instead of ultrasonic power

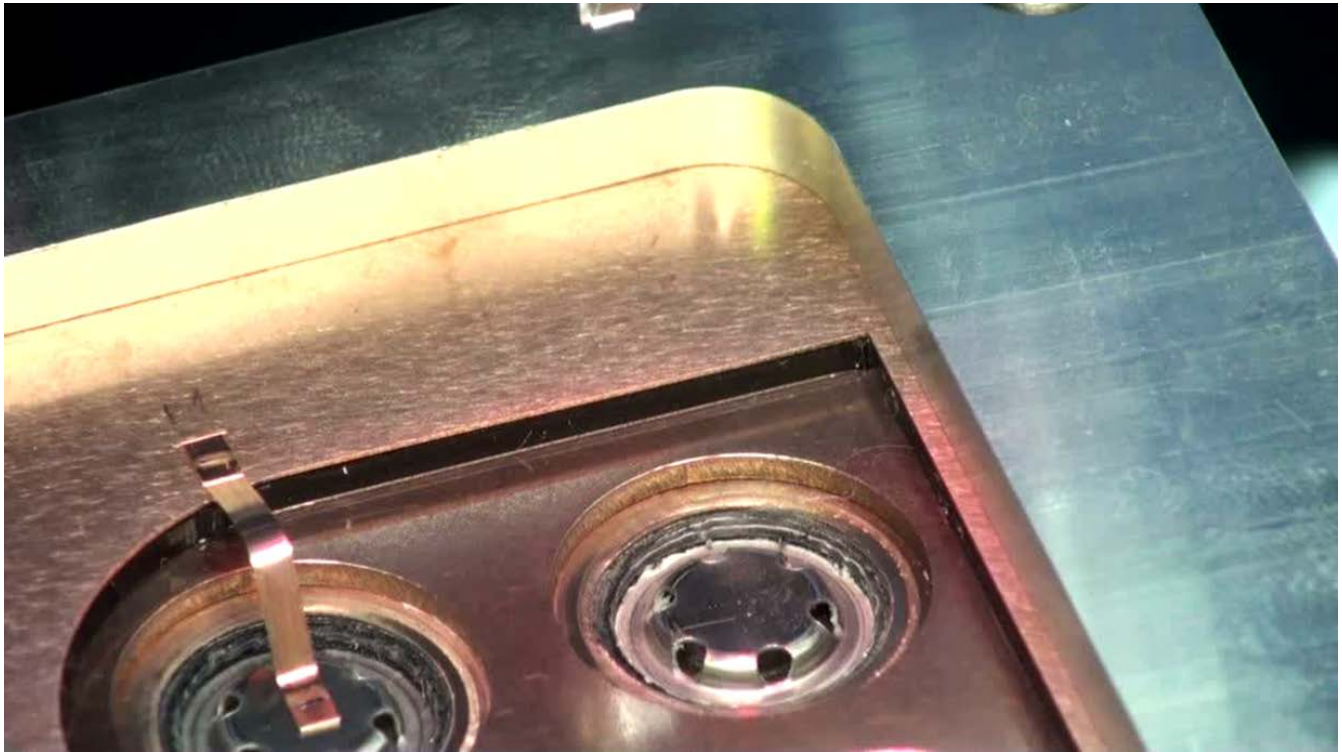
Advantages

- Usage of cheap copper ribbons
- No problems with vibrations
- Welding geometry is adjustable
- Simple part clamping
- Higher tolerance for variations in surface conditions

Courtesy of F&K Delvotec

Battery interconnection

Process for battery production



Laser bonding on plus terminal of cylindrical cell (type 18650)
with copper ribbon (2 mm x 0.3 mm)

Courtesy of F&K Delvotec

Battery interconnection

Process – What is possible?

US-Laserbonding by F&K Delvotec Bondtechnik GmbH

Ribbon / Surface	Al	Cu	Ni
Al	+	o/-	
Al-Diecast	+/o		
Cu	o	+	+*
CuSn6		+	+*
CuFe2P		+	+*
ENIG on Al	+		
ENIG on Cu	o	+	+*
Steel	-	+	+
Steel (Ni)		+	+

* Unaudited, theoretical statement. Depending on the product, each process needs to be qualified.

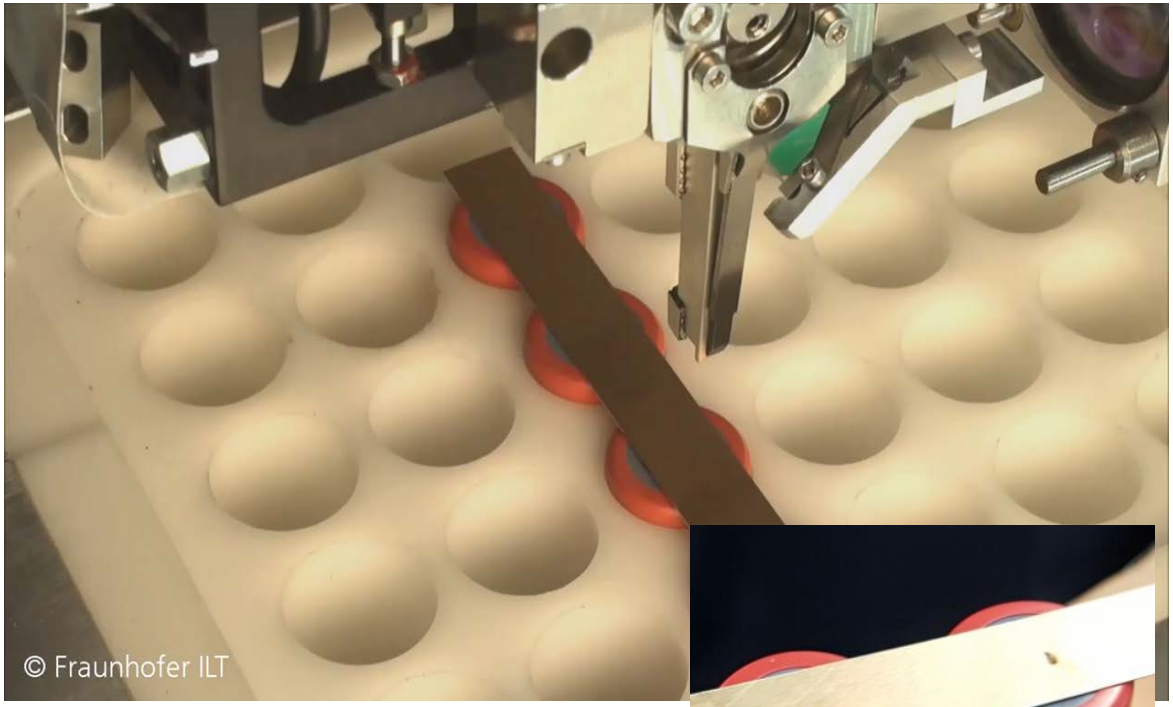
+…recommended
O…depending on application
-…not recommended

- Ribbon thickness up to 0,5 mm
- Ribbon width from 0,5 mm up to 2,0 mm
- Design Rules:
  - Ribbon should be of equal thickness as the bond pad or at most 50% thicker
  - Depending on ribbon width, the tool requires a space of about 4 x 4 mm²
  - Surface and base of the second bond must permit cutting the ribbon

Courtesy of F&K Delvotec

Battery interconnection

Laser tab bonding of battery terminal

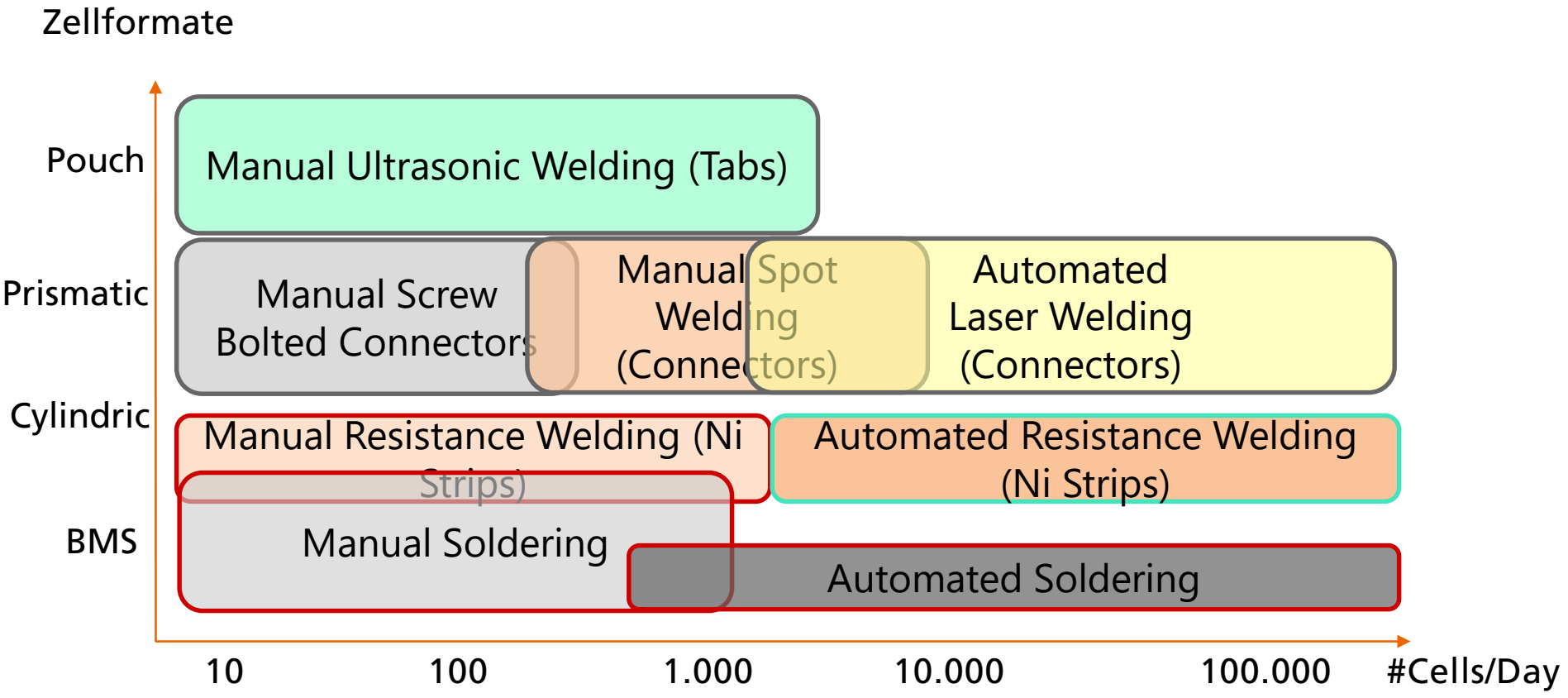


Advantages

- Process can bridge gaps between sheet material and battery cell
- Controlled deformation of sheet material to minimize the gap
- The laser spot is exactly where it is supposed to be (focal position to the surface and on battery tab)
- Time between two welds: < 0.7 s

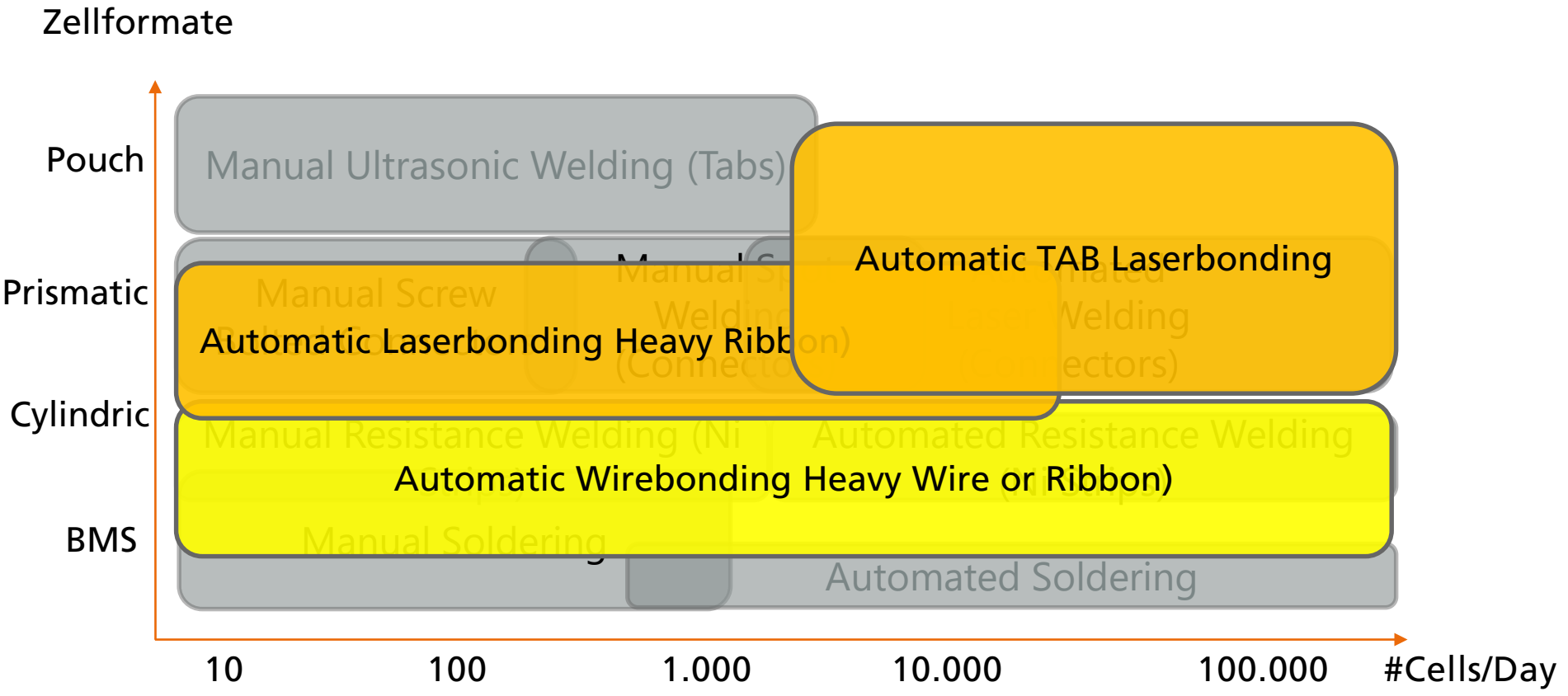
Courtesy of F&K Delvotec

A zoo of interconnecting technologies



Courtesy of F&K Delvotec

Wire- and Laser Bonder are very versatile



Courtesy of F&K Delvotec

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Thank you for your attention!

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