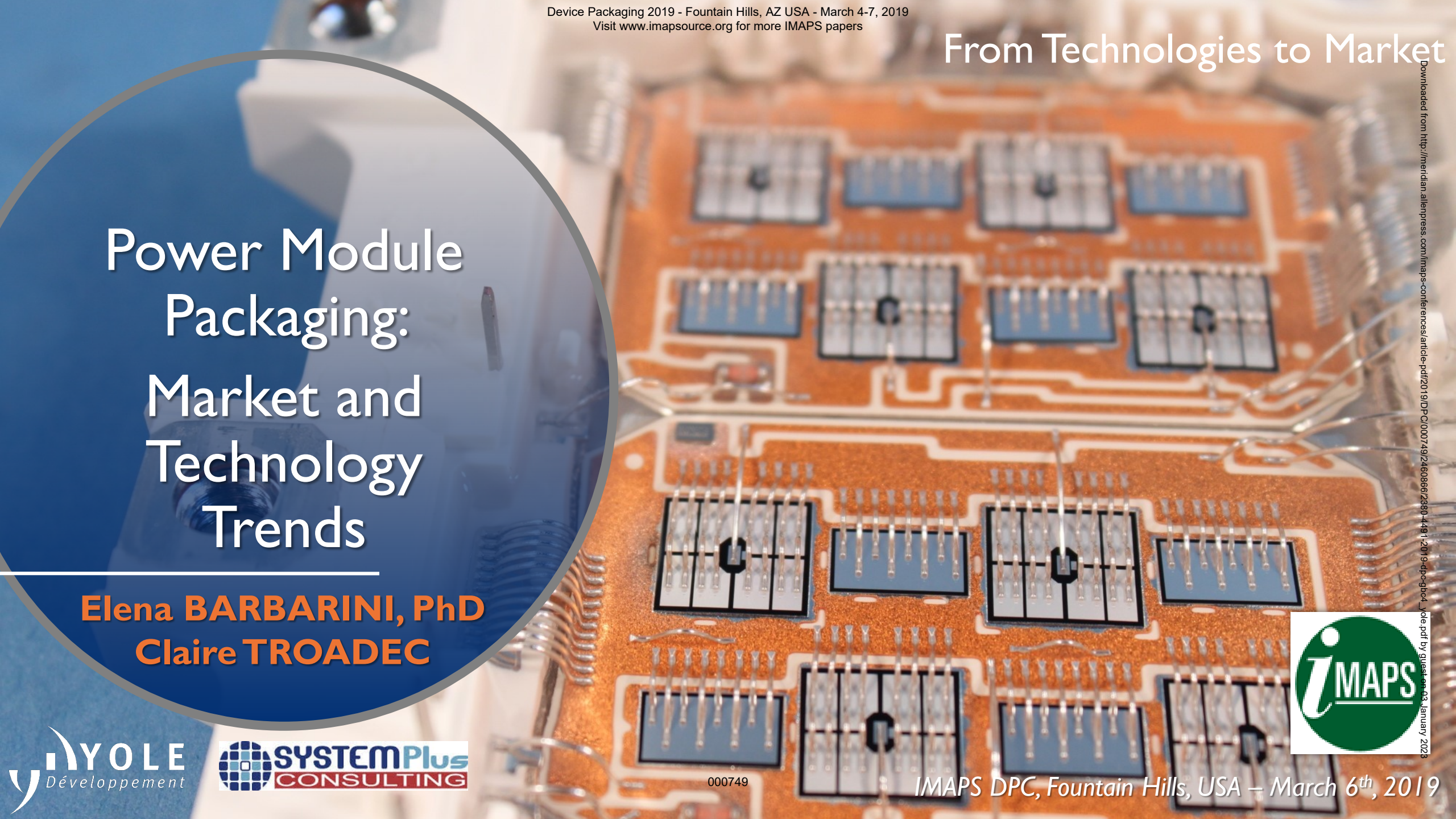
From Technologies to Market

Power Module Packaging: Market and Technology Trends

Elena BARBARINI, PhD
Claire TROADEC



000749

IMAPS DPC, Fountain Hills, USA – March 6th, 2019

6 COMPANIES TO SERVE OUR BUSINESS

Yole, Group of Companies

Market, technology and strategy consulting

www.yole.fr

Manufacturing costs analysis
Teardown and reverse engineering
Cost simulation tools

www.systemplus.fr

IP analysis
Patent assessment

www.knowmade.fr

Design and characterization of innovative optical systems

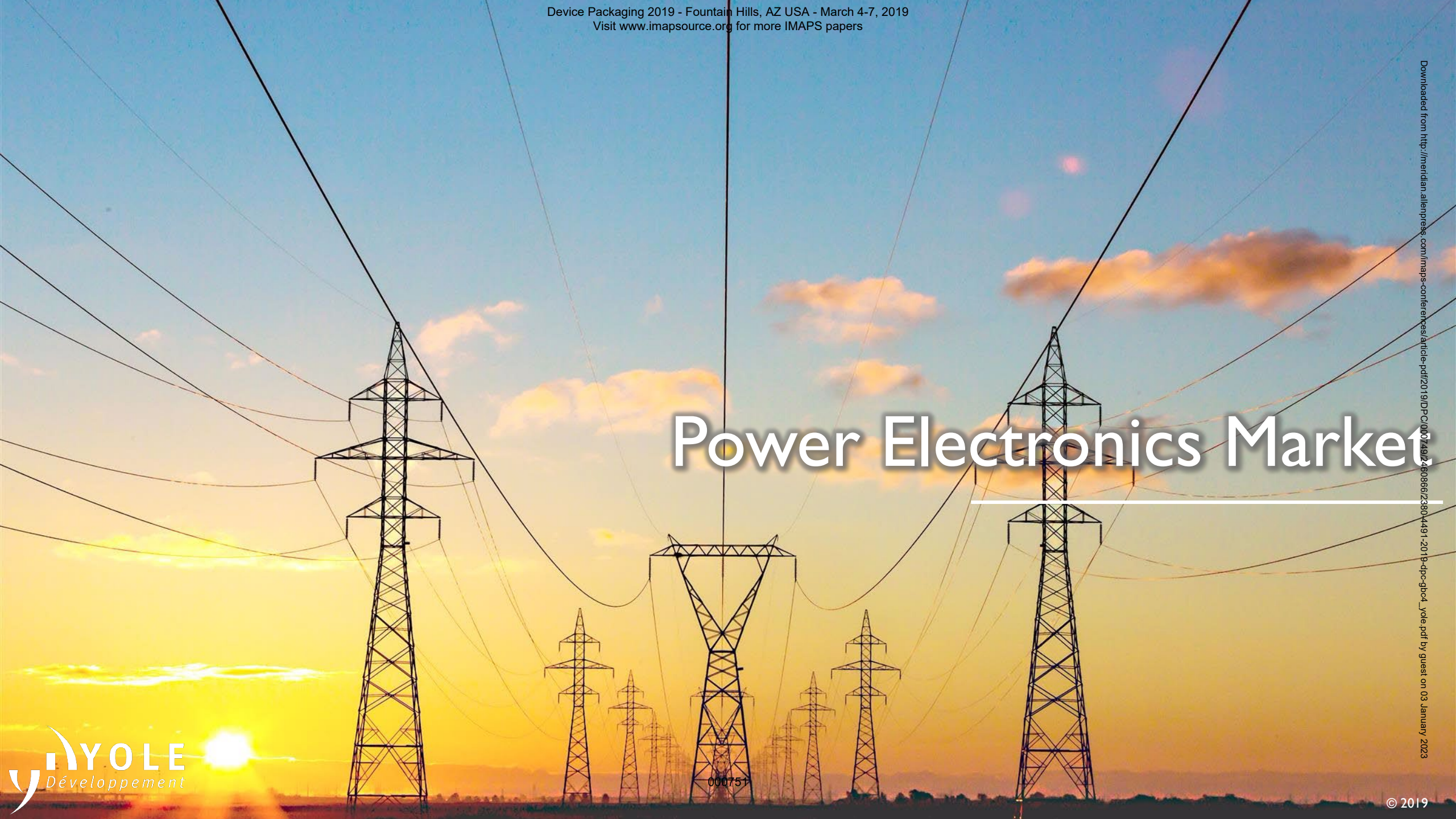
www.piseo.fr

Innovation and business maker

www.bmorpho.com

Due diligence
M&A (Mergers & Acquisitions)
IPO (Initial Public Offering)

www.yole.fr

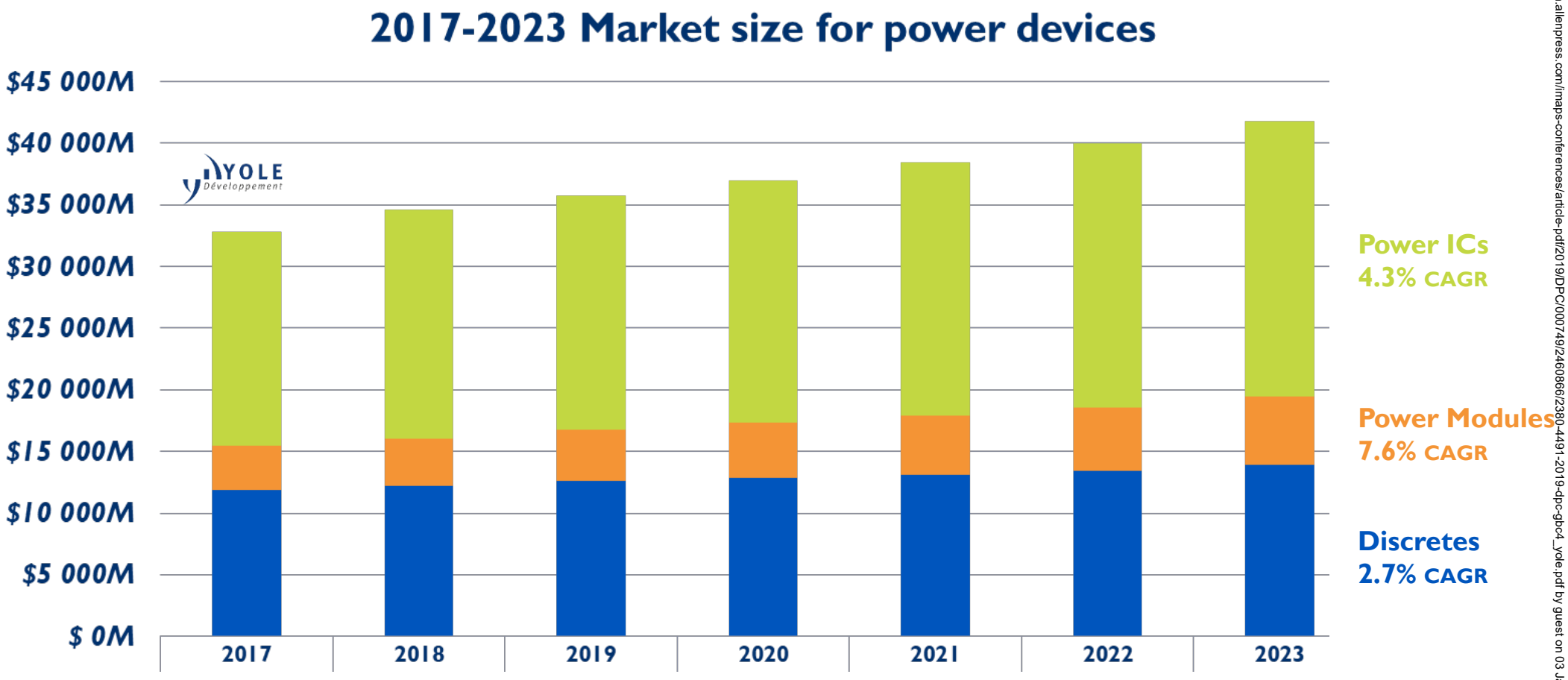


Power Electronics Market

GLOBAL POWER ELECTRONICS MARKET

Device market

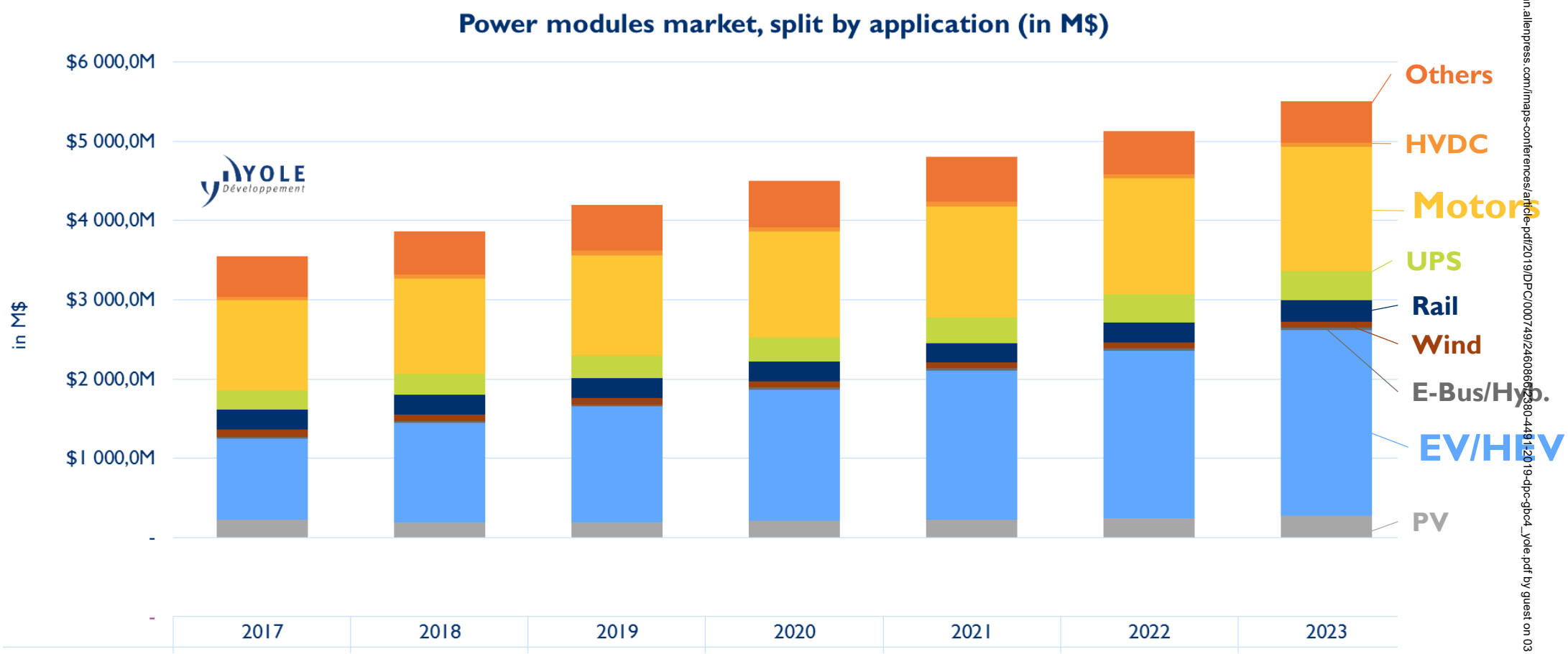
Power modules have an expected CAGR 2017-2023 of 7.6%



000752

POWER MODULE MARKET FORECAST 2017-2023

The module market will be driven by EV/HEV.

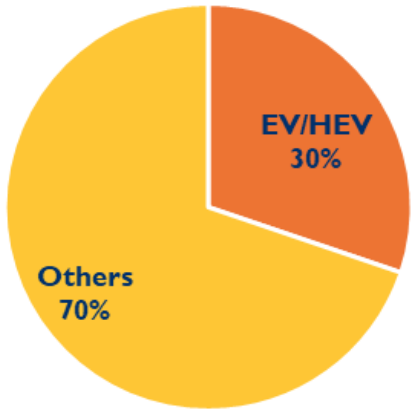


POWER MODULE MARKET FIGURES

Part of EV/HEV in overall power module market – evolution between 2017 and 2023

EV/HEV will take an important share in power module market to finally represent more than 40% of the market by 2023

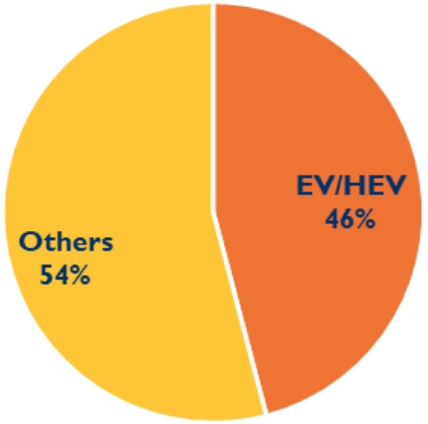
Shares represented by EV/HEV at power module level as of 2017 (in M$)



Yole Développement - 2018

2017 Total: $3.4B

Shares represented by EV/HEV at power module level as of 2023 (in M$)



2023 Total: $5.2B

**Power modules considered here are mostly IGBT modules, as these are most commonly used for EVs/HEVs.*

The predominance of the EV/HEV in the power module market means that the needs and requirement of this industry will impact the evolution of the power module packaging technologies.

Power Module Packaging Technology Evolution

SYSTEMPlus CONSULTING

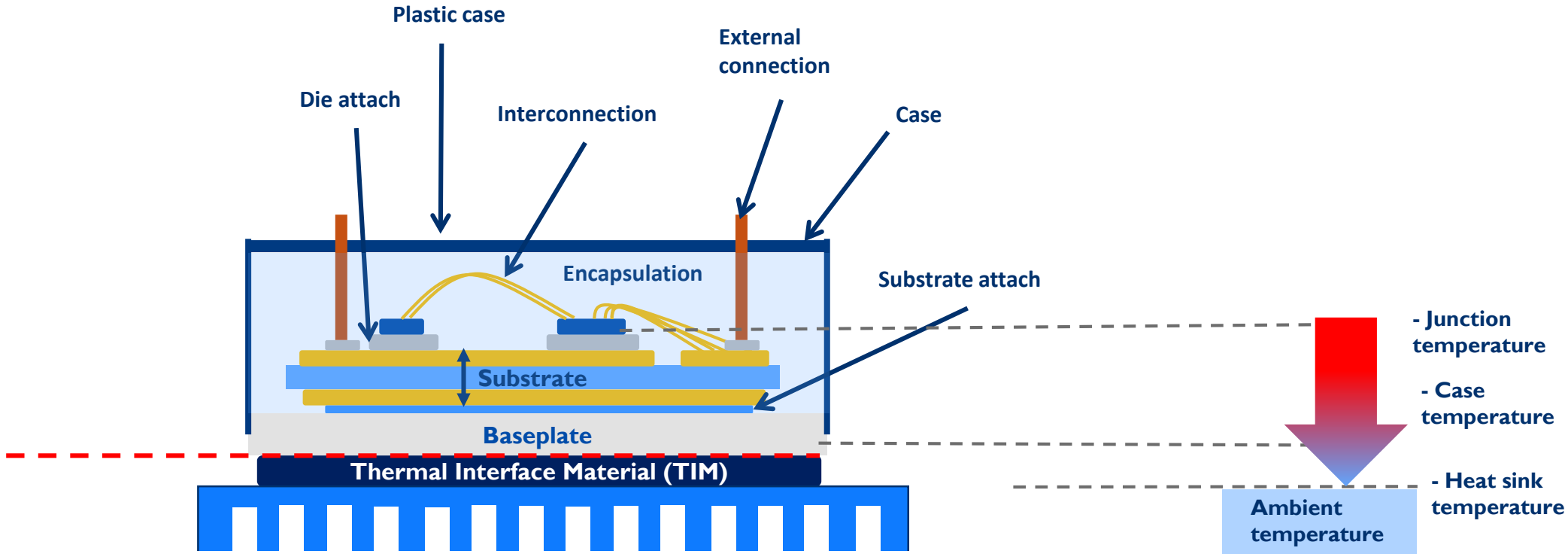
000755

Image: SystemPlus Consulting

THERMAL STRUCTURE OF A POWER MODULE

Heat generated from the chips or dies travels through multiple layers and is then dissipated from the bottom of the module.

In practice, the thermal paths may be much more complex.



000756

Pre-applied TIM

WHY ARE INNOVATIONS NEEDED AT THE POWER PACKAGING LEVEL?

Power packaging is now a key component that must be optimized in order to obtain good performance at the module level.

Macro-challenges

- Increase in energy demands.
- Need for reduction in CO_2 emission.
- Miniaturization of systems.

Impact on electronics

- **Higher reliability.**
- **Reduction of losses**, leading to higher efficiency.
- **Increase in power density.**

Impact on module

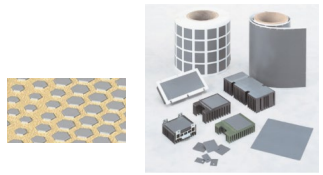
- **Higher thermal cycling technologies** needed.
- **Shorter** interconnections.
- **Higher temperatures to manage** inside the module.

Power packaging must be developed in accordance with the active devices in order to obtain good performance.

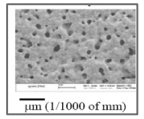
GLOBAL TRENDS FOR POWER MODULE PACKAGING

Roadmap of power module packaging design

In the future, power modules will be reshaped entirely, with material or design changes depending on the power level targeted.



Phase change materials

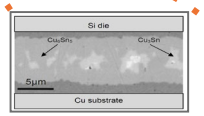


Silver paste or film sintering

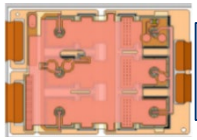
Silicone gel or epoxy resin - high temperature

- Ribbon bonding.
- Flexible interconnection foils.
- Silver sintering for die attach.
- AlN or Si_3N_4 ceramics.
- AlSiC baseplate.

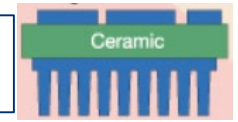
towards:



Silver sintering & TLPS

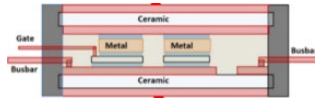


Flexible interconnection foil



Integrated substrates

No baseplate?



Over-molded & double-sided cooling

Infineon's XHP 3

- Half-bridge 3.3 kV
- High isolation
- AlN - DBC
- AlSiC Baseplate

2020

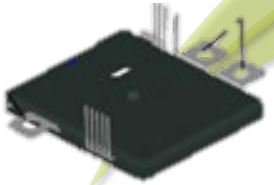
High-power modules
Material developments

>2022

Mid-power modules
Design developments

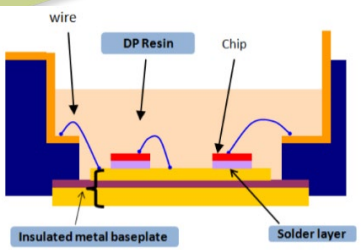
2018

2015

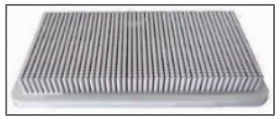


Bosch

- Molded package.
- Top leadframe interconnections.
- Low inductance.



Insulated metal substrate



Direct cooling with no TIM

- Over-molded package.
- Top leadframe.
- Silver sintering for die attach.
- Insulated metal substrates (IMS).
- Double-sided cooling.
- Pin-fin baseplate.

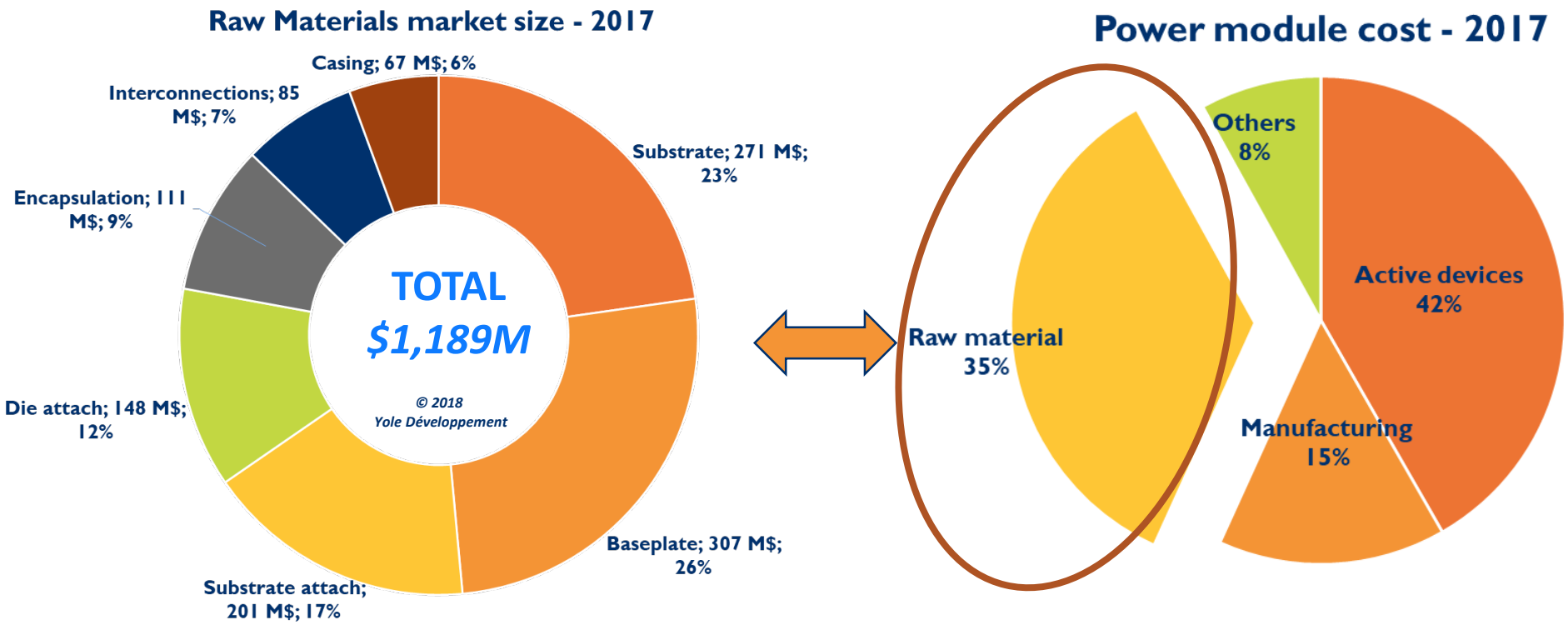
000758

RAW MATERIAL MARKET FOR POWER MODULE PACKAGING

Raw materials market size in 2017

- In a power module, the materials cost for the packaging represented about 35% of the power module cost in 2017. This percentage is decreasing due to reduced material cost and number of interfaces.
- This percentage does not include chassis materials, such as plastic moldings, leadframes, busbars and various chassis sealants.

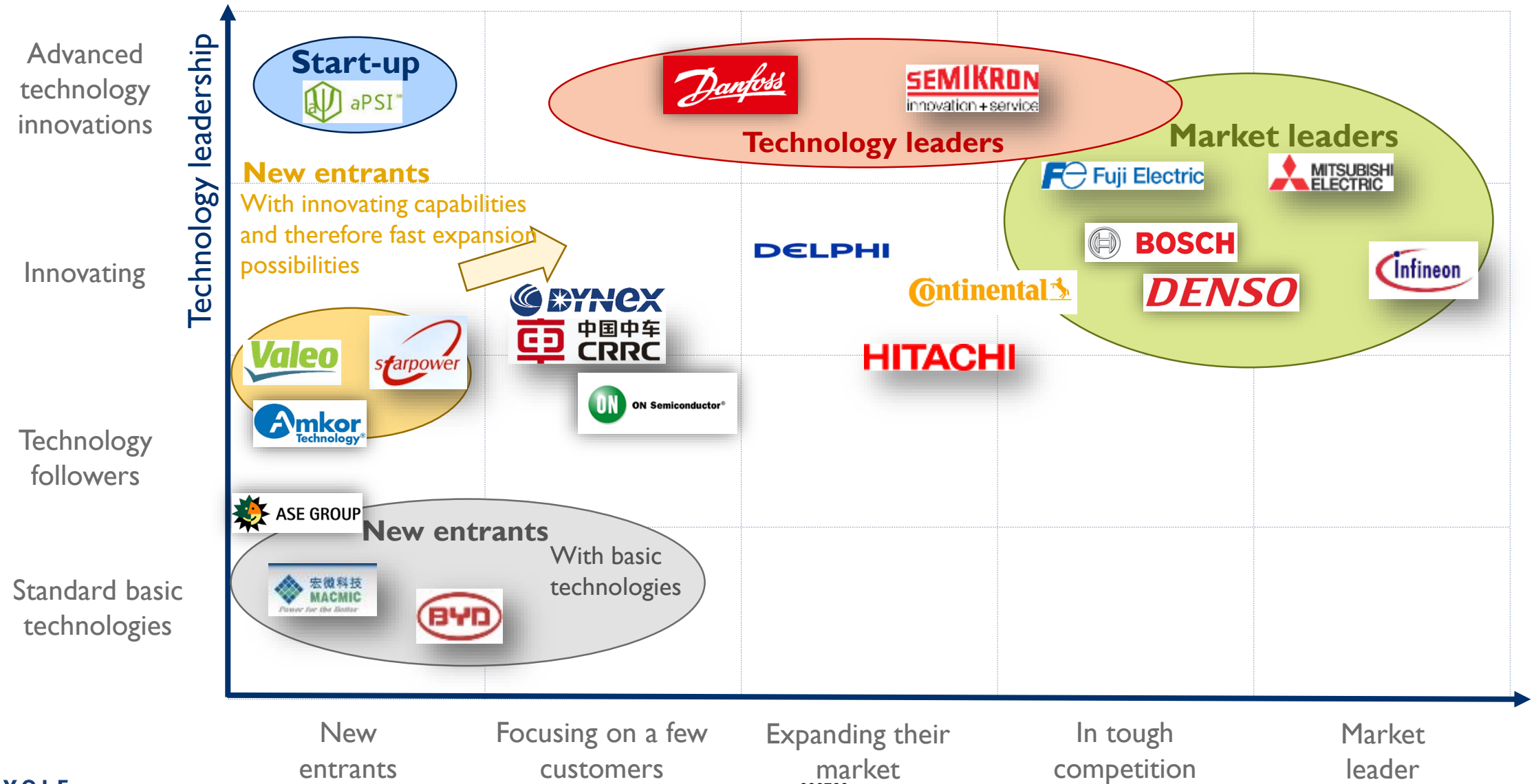
Power module packaging raw materials represented a $1,180M market in 2017.



BUSINESS MODEL

Technology and market leaders in power modules

Non-exhaustive list

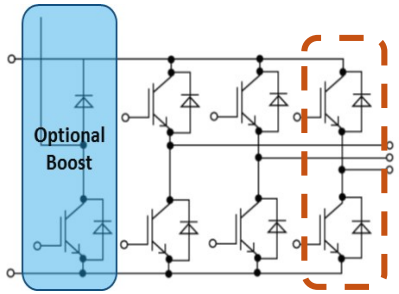


000760

POWER MODULE Die LEVEL: towards single integration

To achieve further system cost and package volume reduction, it is common to integrate the electrical motor and the motor drive inverter.
These offer new space saving solutions that require high power density electronics

2-in-1 power module



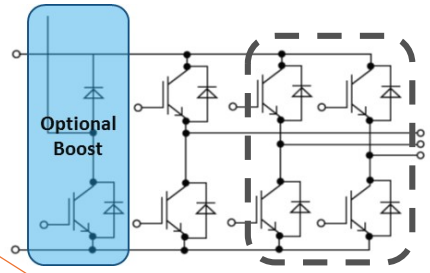
e-up! 2013
Golf 2014

Civic &Fit 2010

Camry 2013
Prius &Mirai 2015

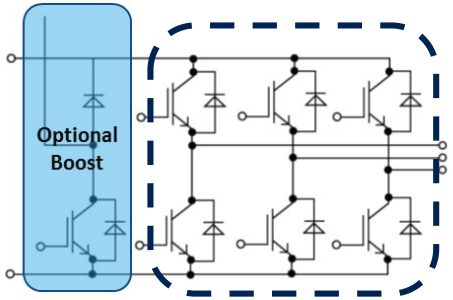
Outlander 2014

4-in-1 power module



C-max 2015

6-in-1 power module

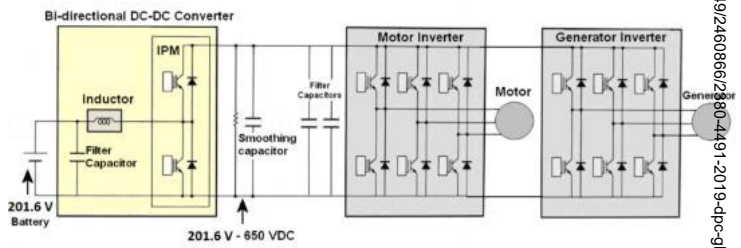


Focus 2014

Leaf 2011
Leaf 2012

Zoe 2013

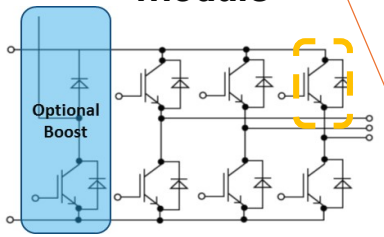
all-in-1 power module



Prius 2004
Prius 2010
Auris 2011
Yaris 2012

Accord 2013

1-in-1 power module



Model3 2017

Volt 2015

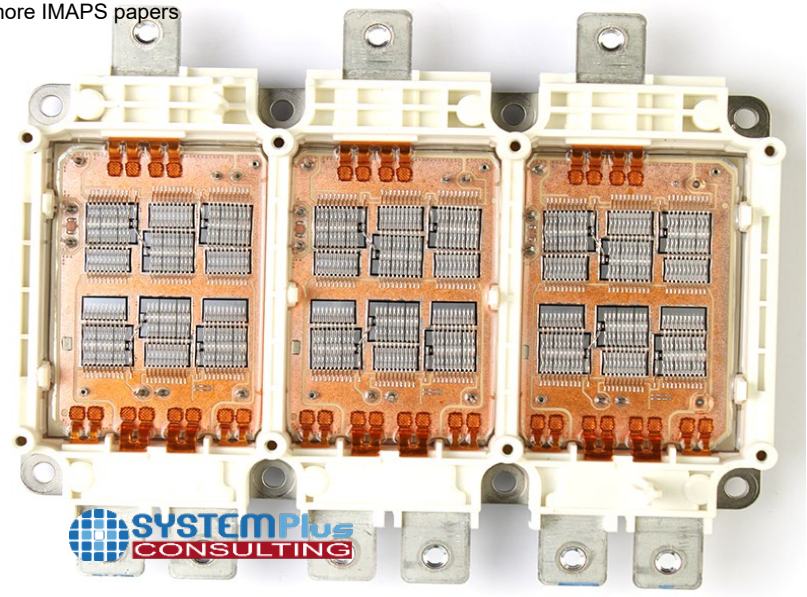
Infineon HybridPACK Drive

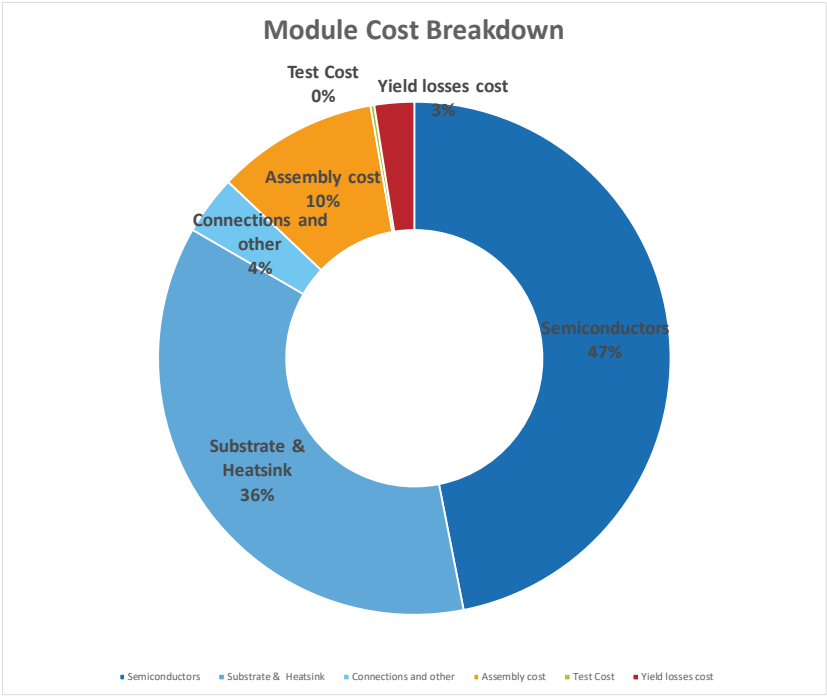
The standard solution for power module is the 6-in-1 module.

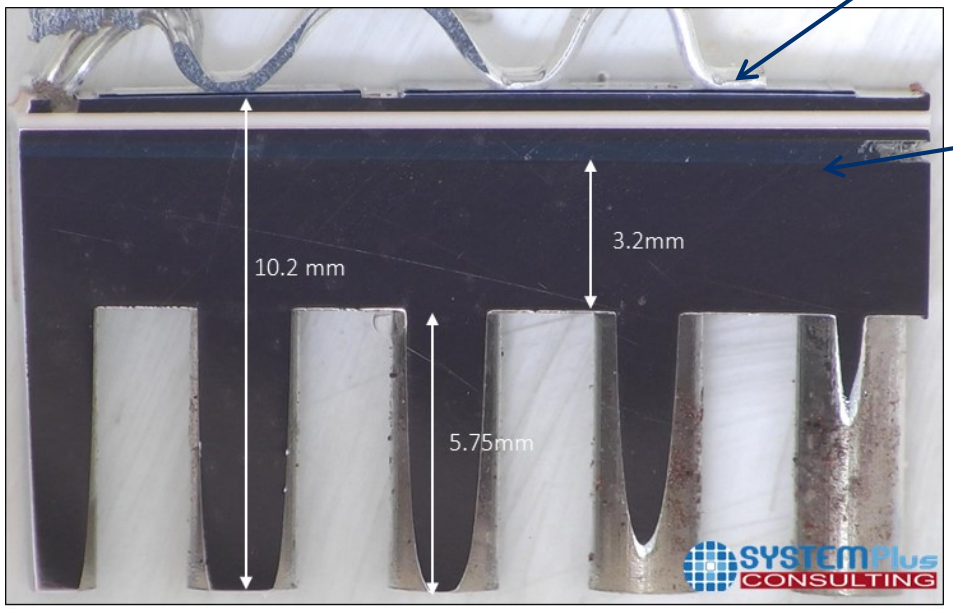
Infineon, starting from 2012 proposed a solution with:

- ✓ 650V/600A
- ✓ Al wire bonding
- ✓ Silicon gel encapsulation
- ✓ Plastic case
- ✓ Cu Pin Fin
- ✓ Al2O3 ceramic

- ✓ Bring 6-in-1 from industry to automotive
- ✓ Pin Fin
- ✓ Molded vs machined Cu







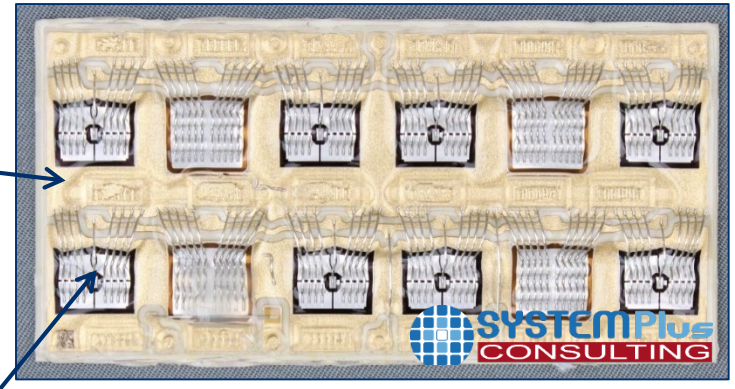
000762

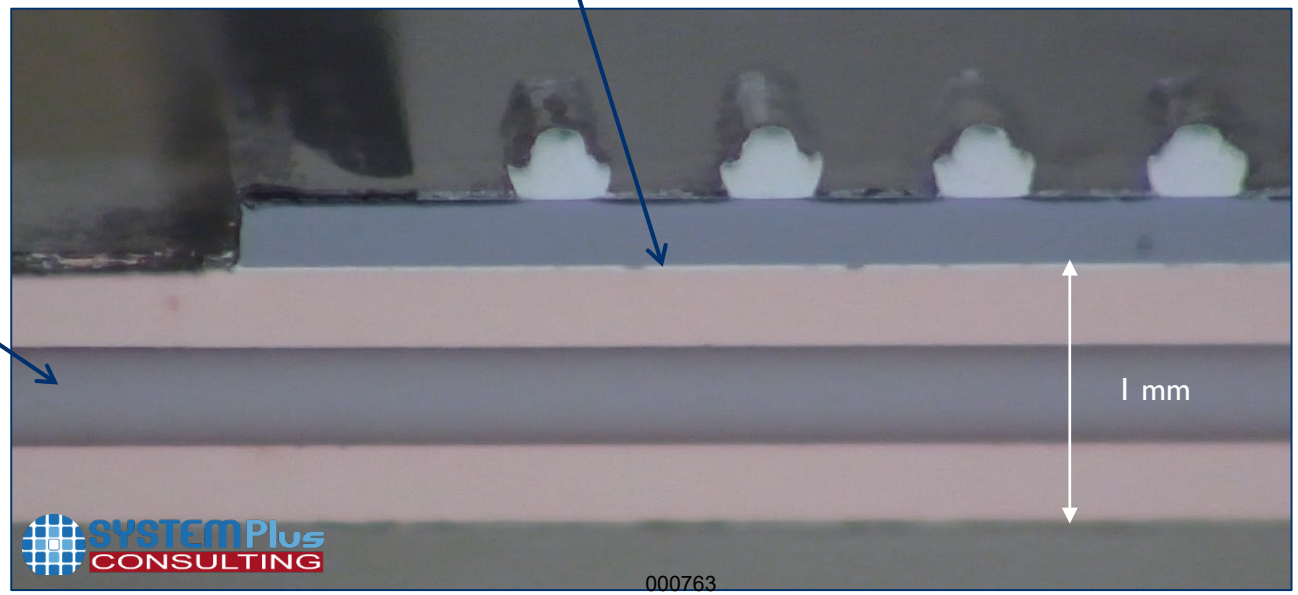
Details DBC substrate: Cross-Section optical view

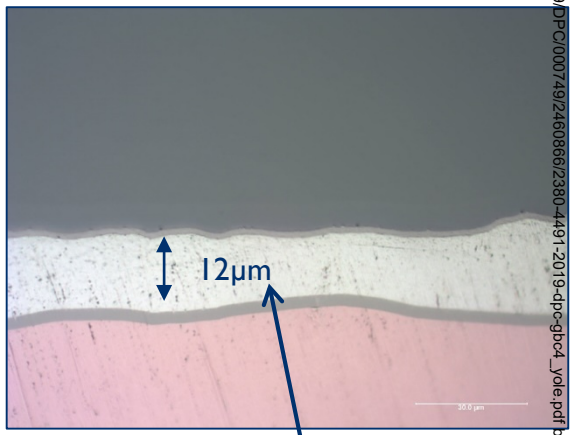
Semikron SKiM

Innovative Semikron solution:

- ✓ 1200V/300A
- ✓ Al wire bonding
- ✓ Silicon gel encapsulation
- ✓ Ag sintering solder
- ✓ Al2O3 DBC





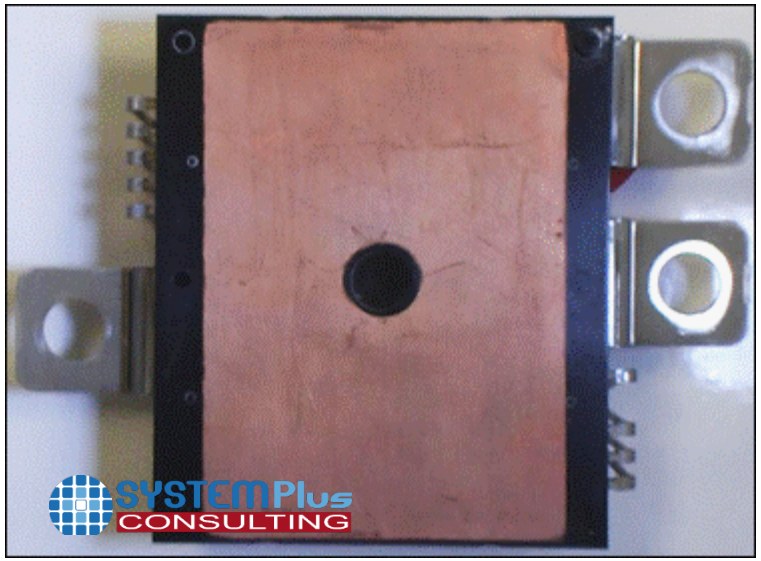


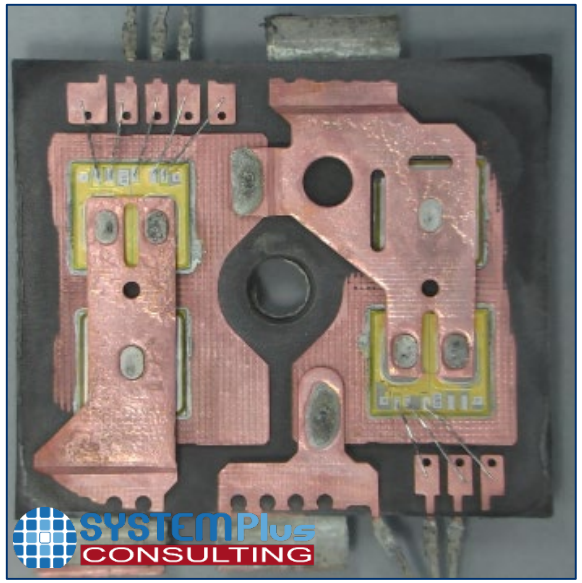
Details DBC substrate: Cross-Section optical view

Mitsubishi for Honda

Mitsubishi Electric was one of the first companies to offer molded modules for automotive applications

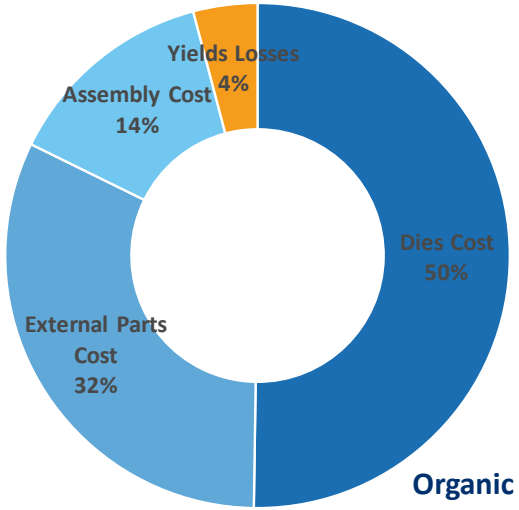
- ✓ 600V/300A capability
- ✓ Molded package
- ✓ Thick Cu layer of IMS

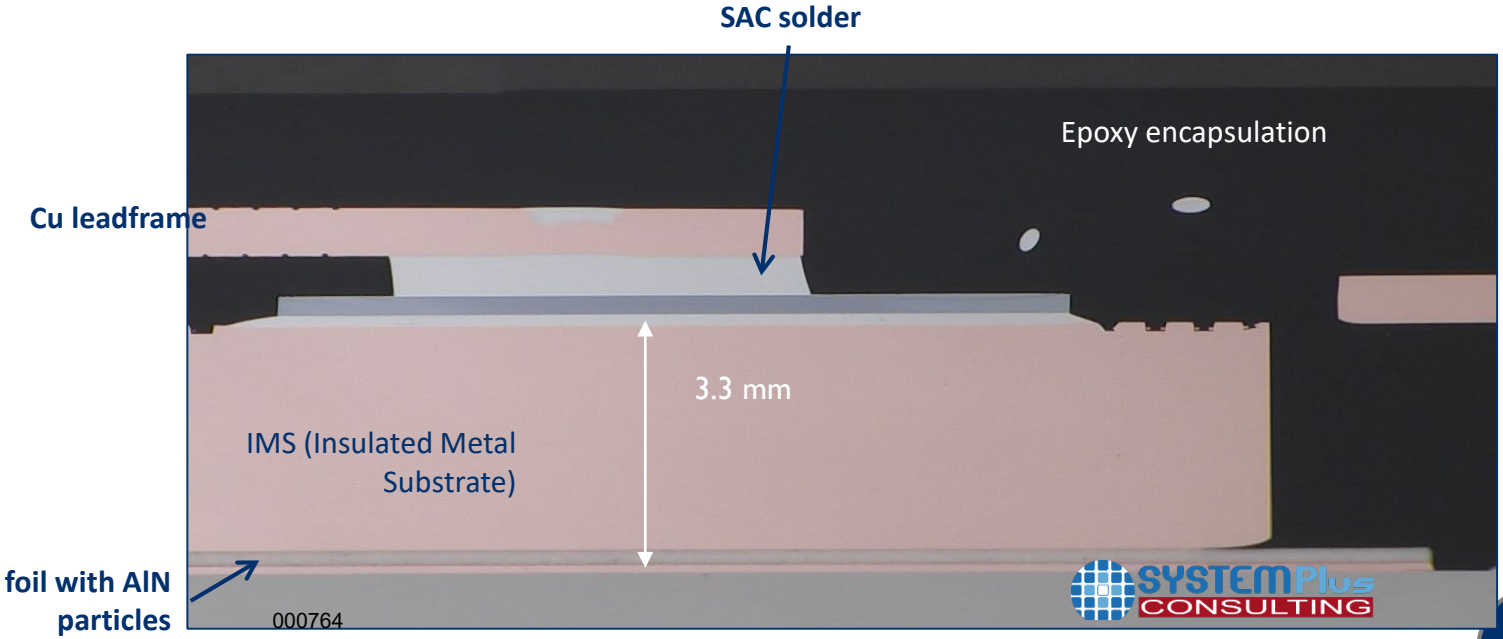




- ✓ Bring IMS from low power
- ✓ Organic insulator worst thermal conductivity but higher design flexibility

Module Cost Breakdown





Details substrate: Cross-Section optical view

EV/HEV IGBT POWER MODULE MARKET

Tentative market shares for power modules suppliers in 2017 for automotive

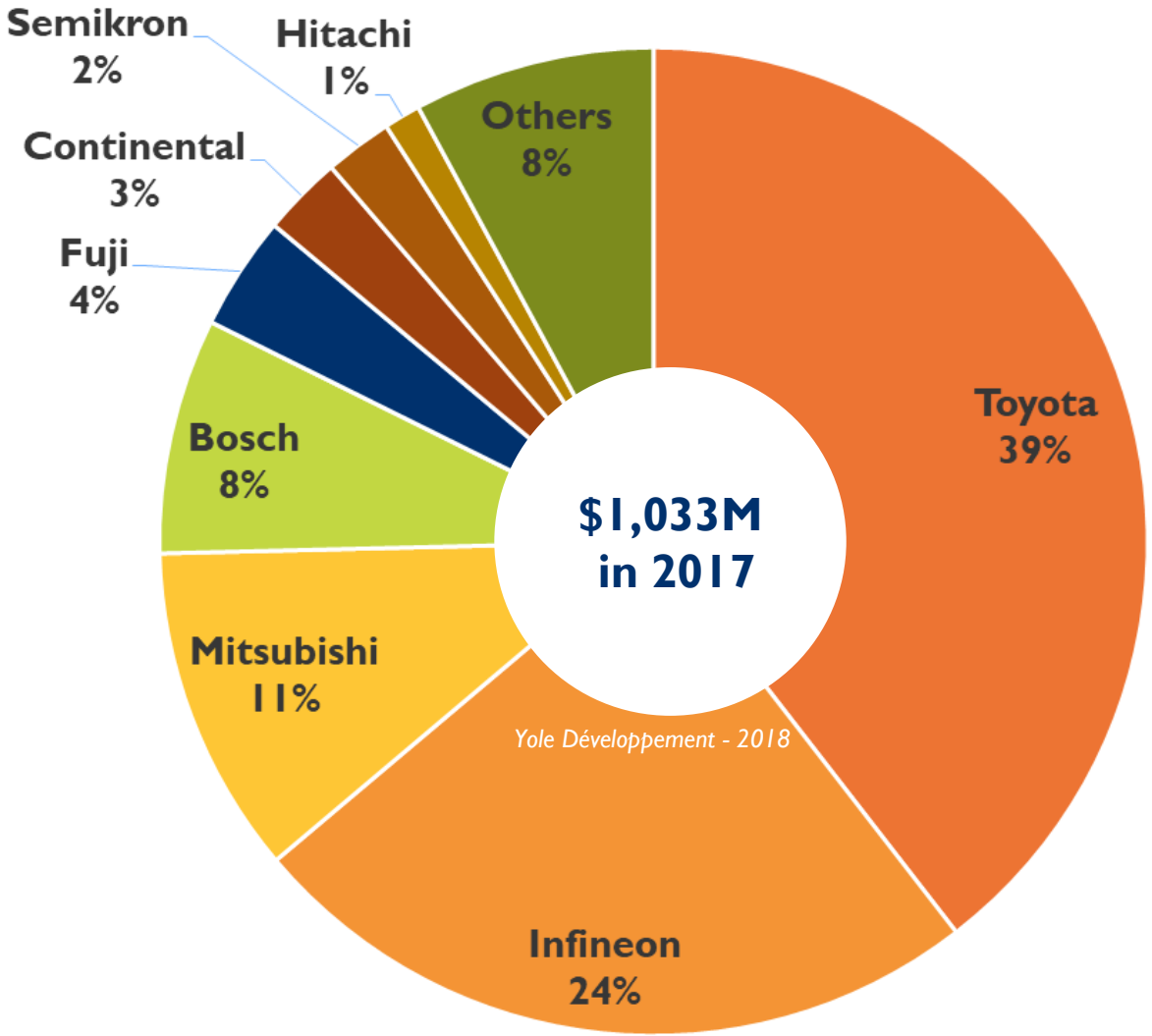
Toyota and Infineon are the leaders for supplying power modules in the automotive industry.

Mitsubishi Electric lost some market shares from our 2016 estimations.

While Toyota and Infineon have strengthened their market leaderships.

**Tesla uses Infineon's discrete IGBTs, which are as well included in this pie-chart.*

**Denso's numbers are included into Toyota's market shares, as most of Denso power module are co-design and used in Toyota's cars.*



000765

TWO MAIN TRENDS ON POWER MODULE DESIGN

How companies are positioned today for EV/HEV modules

- Two main trends for power module designs for EV/HEV:

Double-sided cooling modules are the new trend for EV/HEV. But not everyone is so enthusiastic about them.

- Transfer-molded epoxy package
- Top leadframe / Top DBC
- Mechatronics integration with cooling system

Double-sided cooling

TOYOTA
DELPHI
Hitachi Automotive Systems
DYNEX
ON Semiconductor
HYUNDAI
GM

IMS type substrates

BOSCH
Valeo

Single-side cooling + Pin Fin

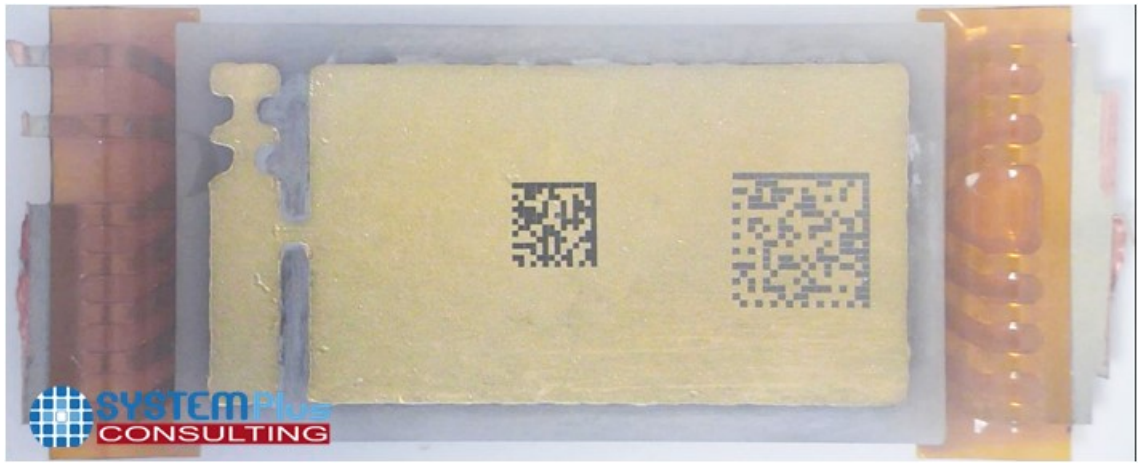
DAIMLER
Audi
PSA GROUPE
BOSCH
SEMIKRON innovation+service
RENAULT Passion for life
BMW
MITSUBISHI ELECTRIC
Danfoss
Continental

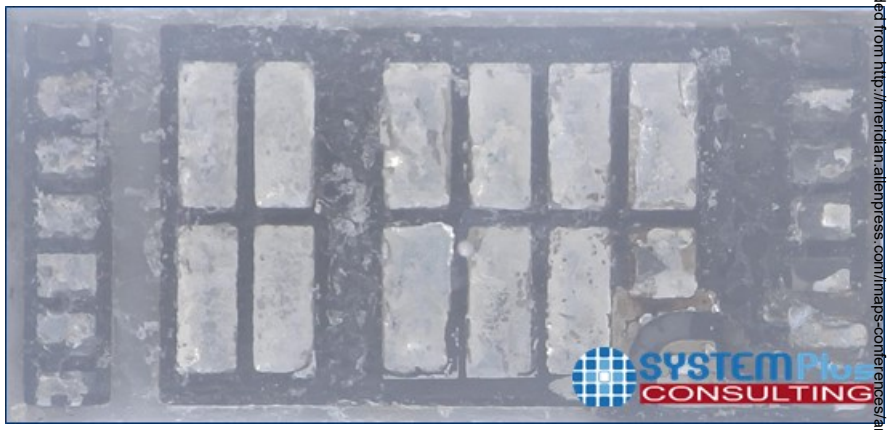
- Silicone gel or epoxy resin encapsulation
- New interconnections: ribbon bonding, flexible polyimide interconnections, etc.
- Toward substrate + Pin-fin baseplate integration

Viper/CoolIR

Delphi was the first to propose the double side cooling solution:

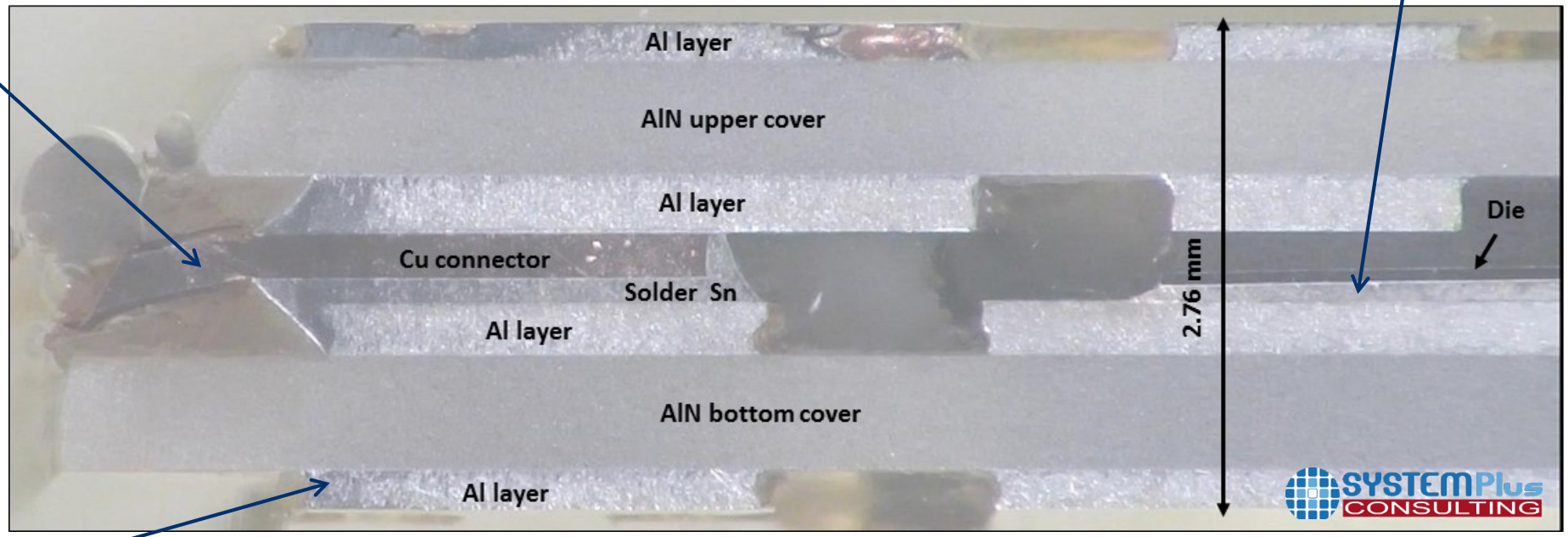
- ✓ DSC
- ✓ No encapsulation
- ✓ Flex connection
- ✓ Ceramic layers





SAC solder

Flex connection



Ceramic substrate

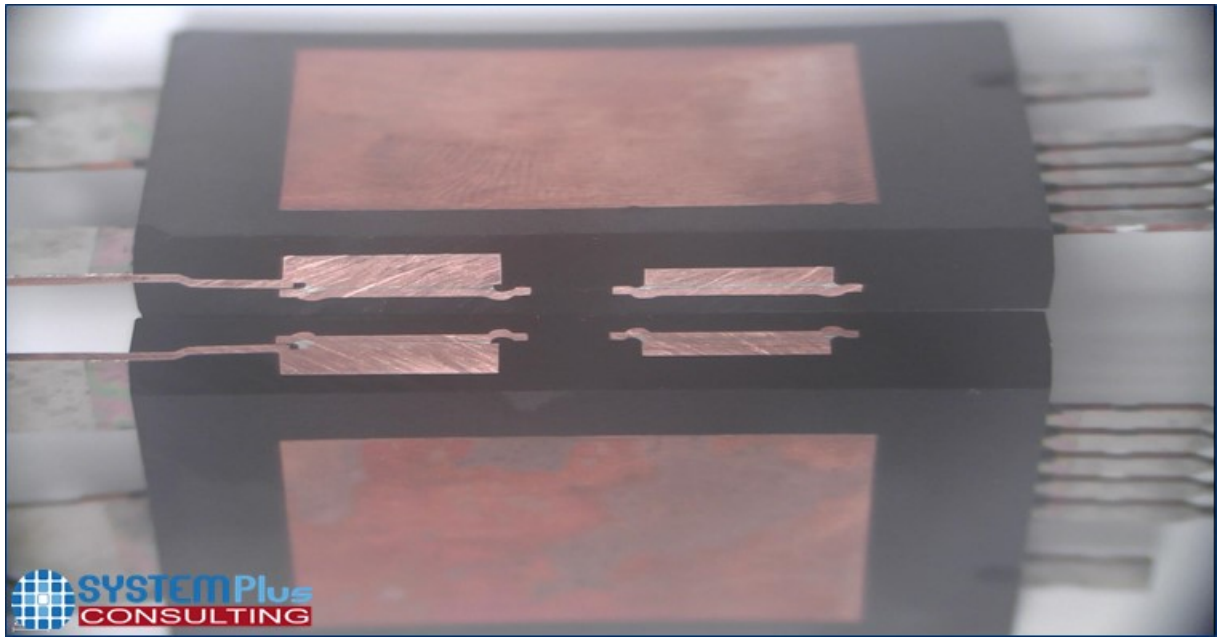
000767

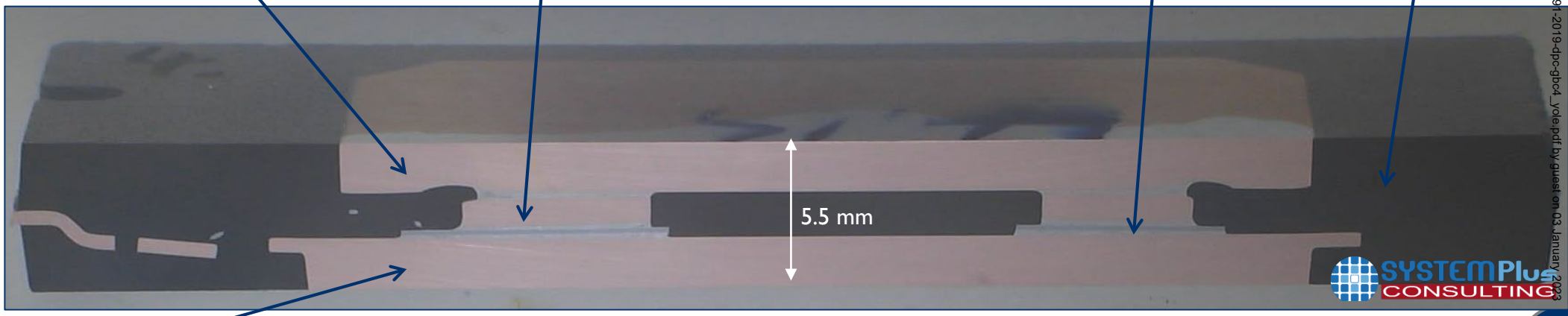
Details substrate: Cross-Section optical view

Toyota Prius IV DSC

In 2015 Toyota changed completely the module design:

- ✓ 750V
- ✓ DSC
- ✓ Molded
- ✓ Al wire bonding
- ✓ Cu spacer/connection
- ✓ External Isolator





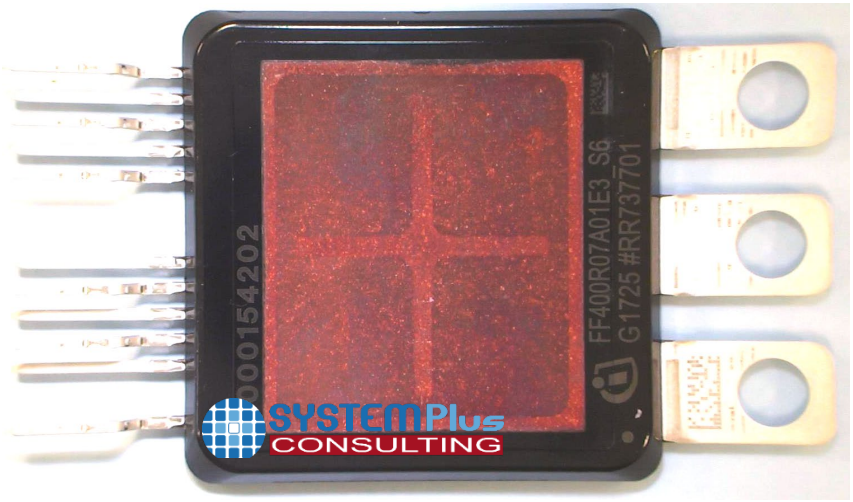
000768

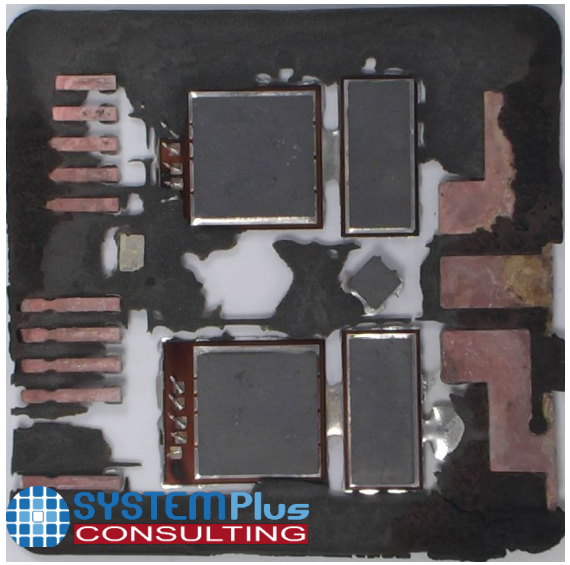
Details substrate: Cross-Section optical view

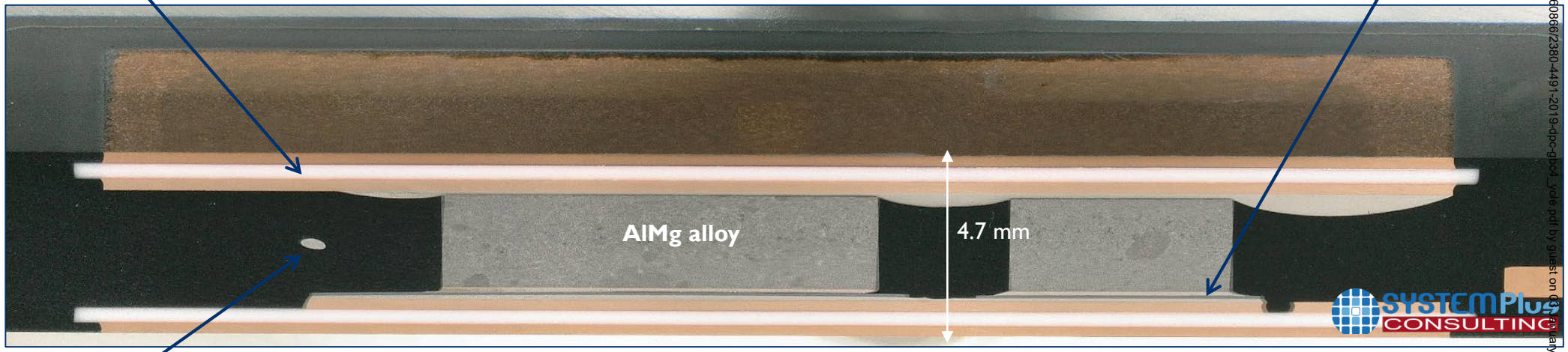
Infineon HybridPACK DSC

In 2017 Infineon too proposed a DSC:

- ✓ 700V/400A
- ✓ DSC
- ✓ Epoxy encapsulation
- ✓ Al wire bonding
- ✓ Alloy spacer
- ✓ DBC substrate
- ✓ Integrated isolation







Details substrate: Cross-Section optical view

000769

SUBSTRATE TRENDS IN THE EV/HEV

Power packaging trends in the automotive industry

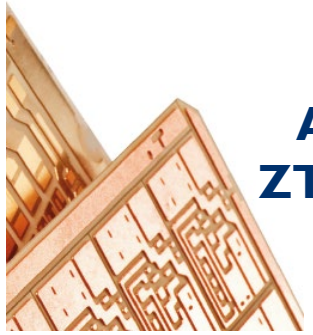
Many innovations are being developed at substrate level, such as integrated substrates or high thermal conductivity epoxy resin layers.

Overmolded packages

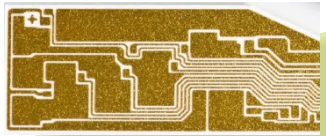
- Epoxy resin
- Top copper leadframe connections

2016

Al2O3 and ZTA ceramics

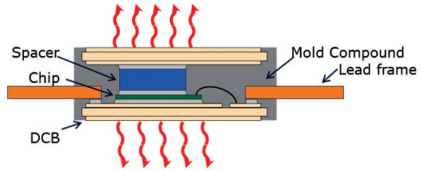


Si3N4-AMB



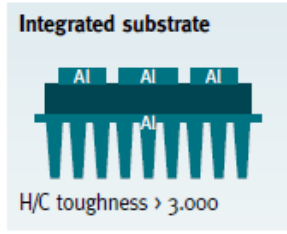
2020

Double-side cooling modules

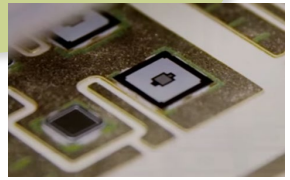


Integrated substrates:

- Copper/Al metallization + ceramic + baseplate with pin-fin



2022



Silver sintering attach

- SiC chips Ag sintered
- Si3N4-AMB

IMS

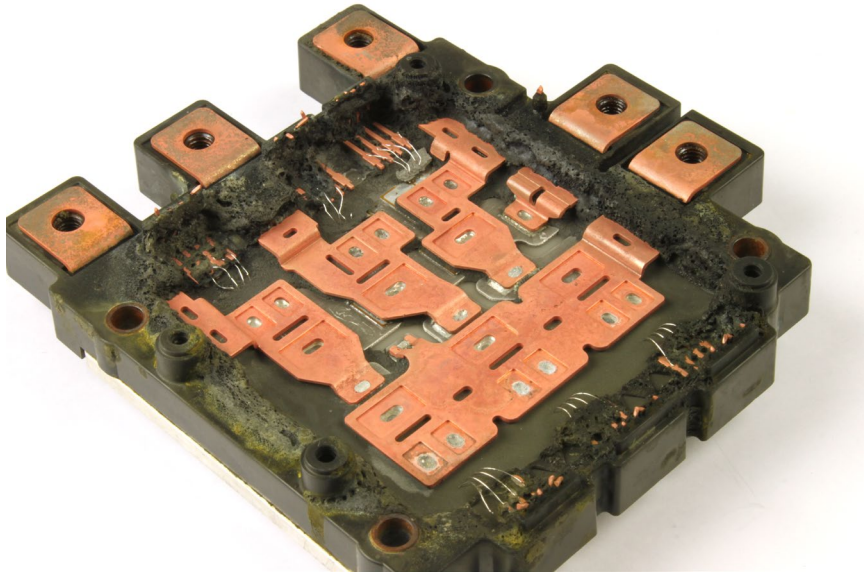
- High thermal conductivity epoxy resin insulation: 20W/mK

000770

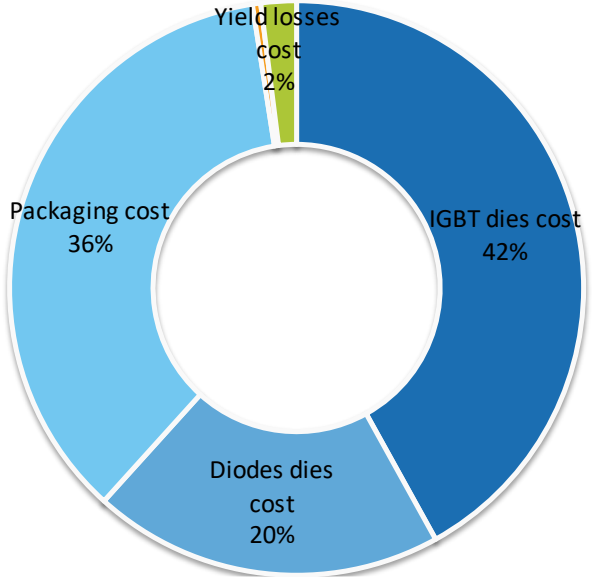
Mitsubishi J1 serie

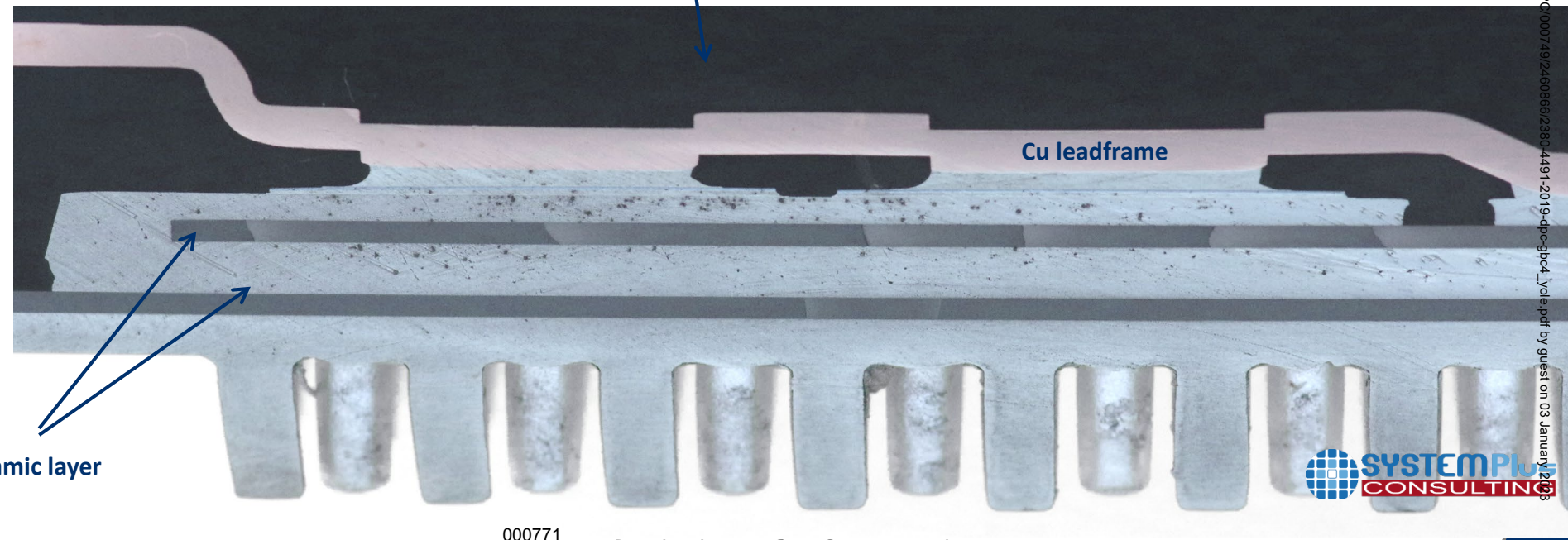
Mitsubishi innovates with J1 series:

- ✓ Cu leadframes
- ✓ Molded
- ✓ Integrated Al Ceramic substrate



Module Cost Breakdown (Medium Yield)





000771

Details substrate: Cross-Section optical view

APPROACHES TO INCREASE DRIVING RANGE / REDUCE SYSTEM COSTS

What are the approaches chosen by different players?

Three main approaches exist today.

SiC technology can be an ultimate goal for all three of them.

TESLA

Traction inverter: Silicon → SiC

Tesla Model 3 inverter

PORSCHE

Battery voltage: 400V → 800V

Porsche Taycan

TOYOTA

Battery voltage boost converter

Toyota Prius

? Si → SiC

Si → SiC

SiC

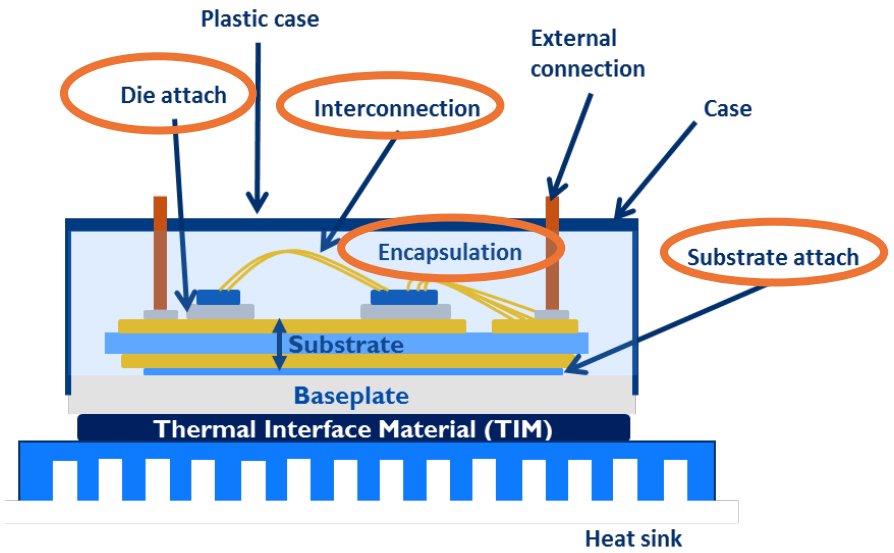
Present → Future

000772

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 dV/dt

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

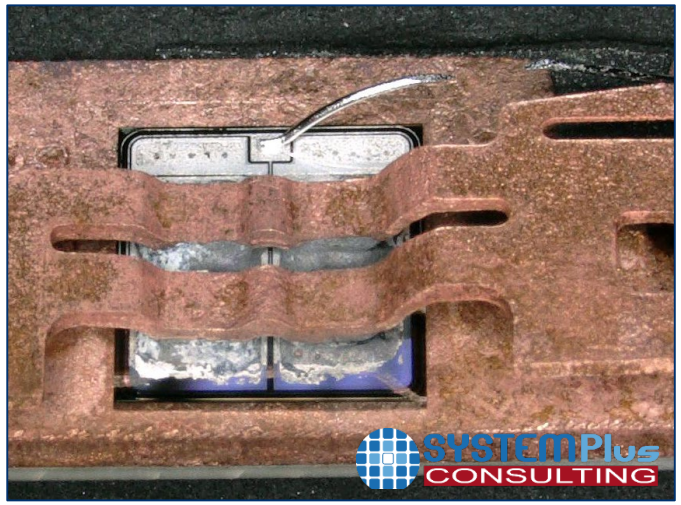
Interconnections
Low-inductance interconnections.

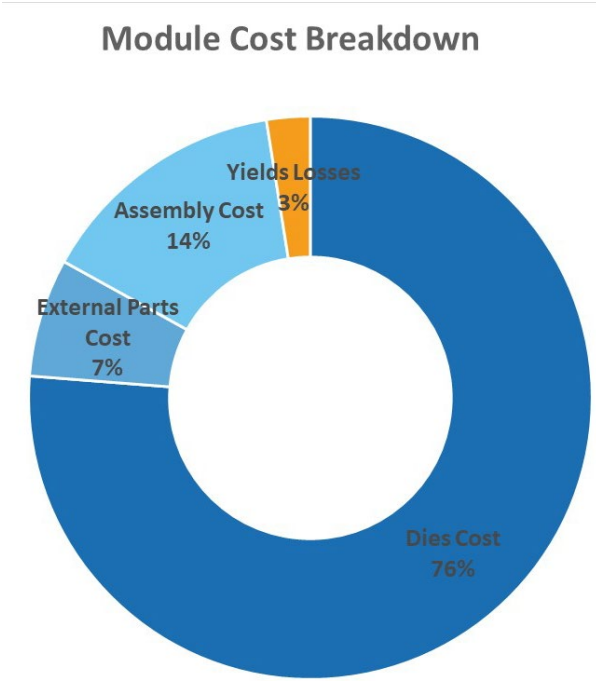
New designs and new materials are needed

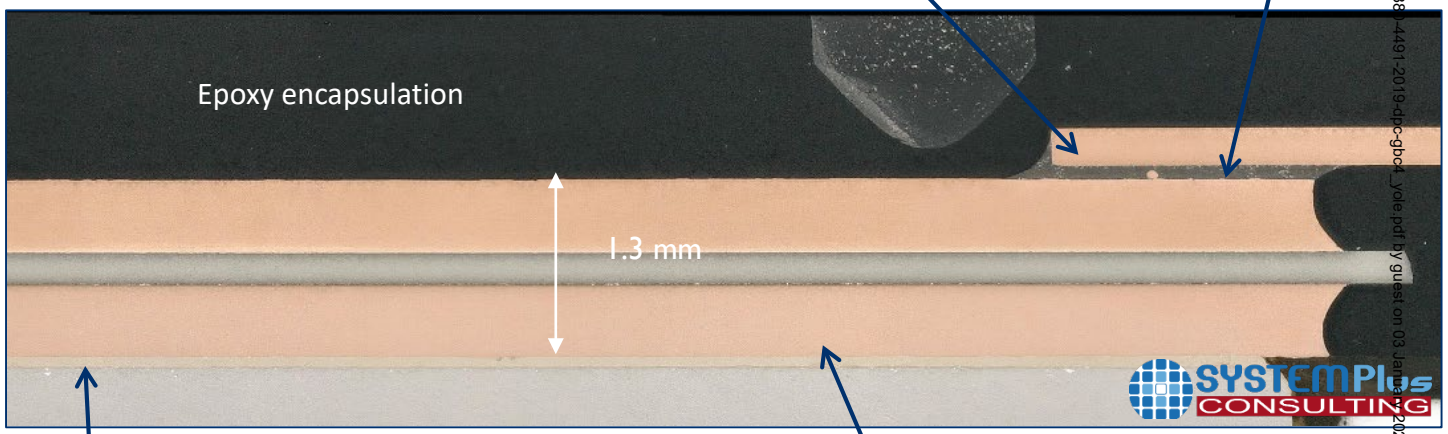
ST for Tesla Module

In 2017 ST proposed a SiC module:

- ✓ SiC MOSFET
- ✓ 650V/300A
- ✓ Molded
- ✓ Silver Sintering
- ✓ SiN substrate





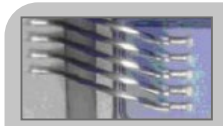


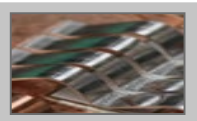
Details substrate: Cross-Section optical view

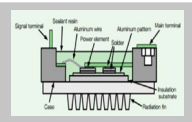
Conclusion

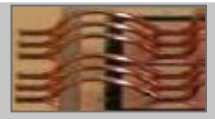
GLOBAL TRENDS FOR POWER MODULE PACKAGING

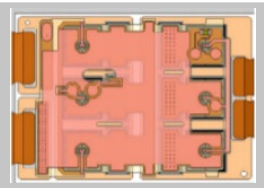
Both materials and design are evolving in power modules.


Aluminum wire bonding


Ribbon bonding


Topside bonding


Copper wire bonding



Flexible interconnection foil

Interconnections



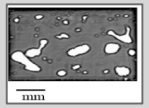
Silicone gel or epoxy

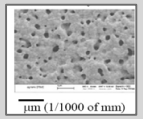

Epoxy resin

Silicone gel or epoxy resin - high temperature

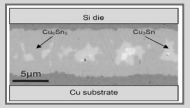
New materials and processes such as parylene coating

Encapsulation


Tin soldering

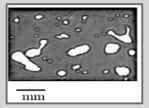

Silver paste or film sintering

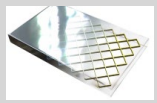
AuSn Brazing

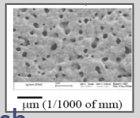


TLPS

Die attach

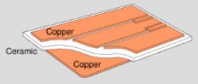

Tin soldering

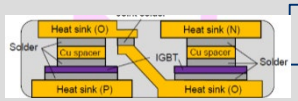

Solder with metal mesh


Silver paste or film sintering

No baseplate?

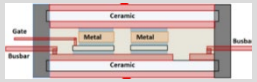
Substrate attach


DBC



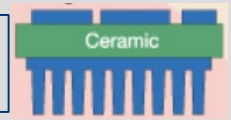
Lead frame

Si_3N_4 AMB



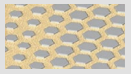
Double-sided cooling with two ceramics?

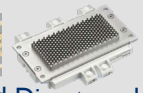
Integrated substrates

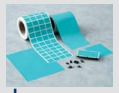


Substrate


Thermal grease


Pre-applied TIM


Direct-cooled baseplate


TIM pads


PCM

Direct cooling with no TIM?

TIM

Standard baseplate


Pin-fin baseplate

Other direct-cooled baseplates

No baseplate?

Micro-channel cooling?

Baseplate

2016

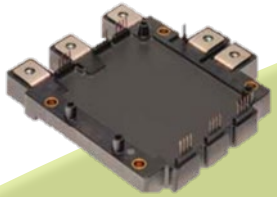
2020

2025 and beyond

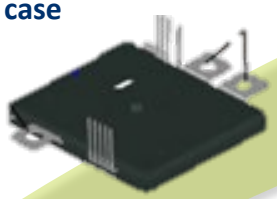
Main trends for design

Every manufacturer proposes its solutions; but some main trends are evident.

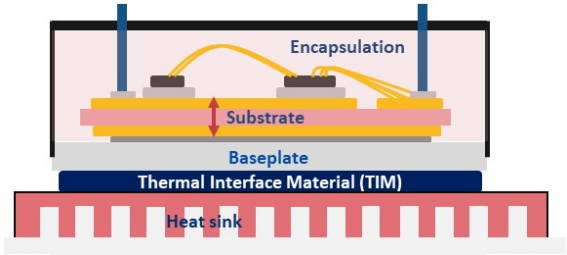
Epoxy encapsulation



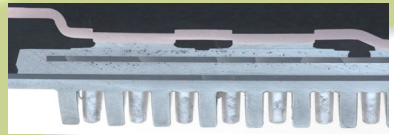
Molding case



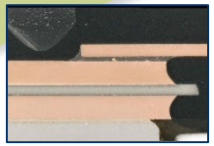
Ribbon Bonding



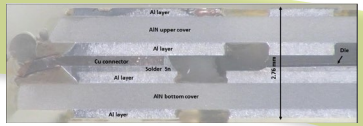
Integrated substrate



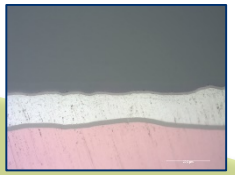
Cu leadframes



Cu/DBC substrates

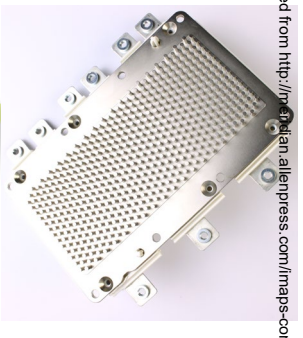


Ag sintering



Cu/Alloy spacers

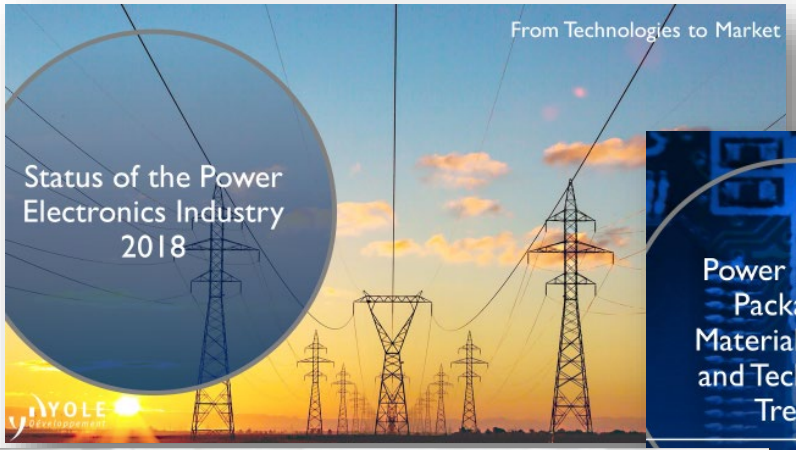
Single side cooled

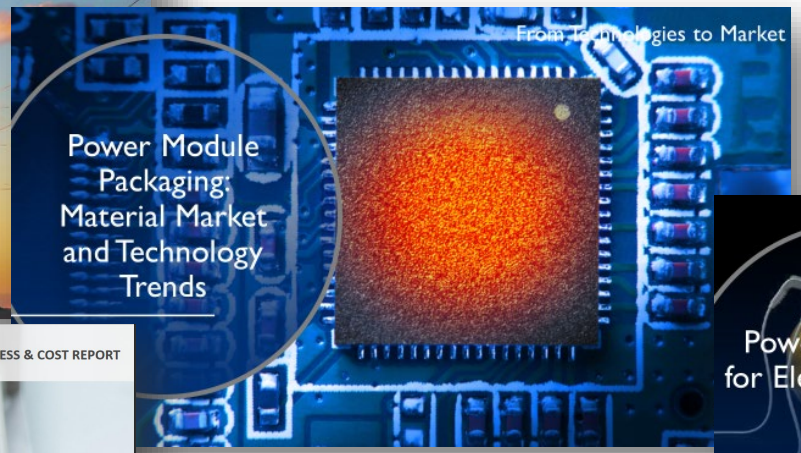


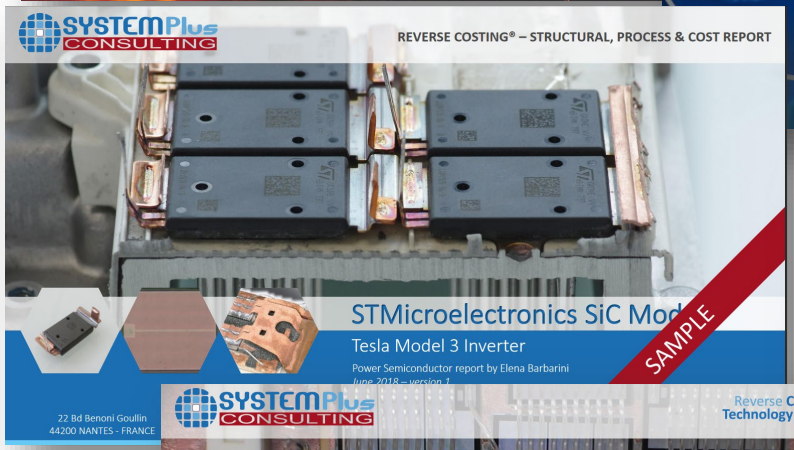
Double Side Cooled

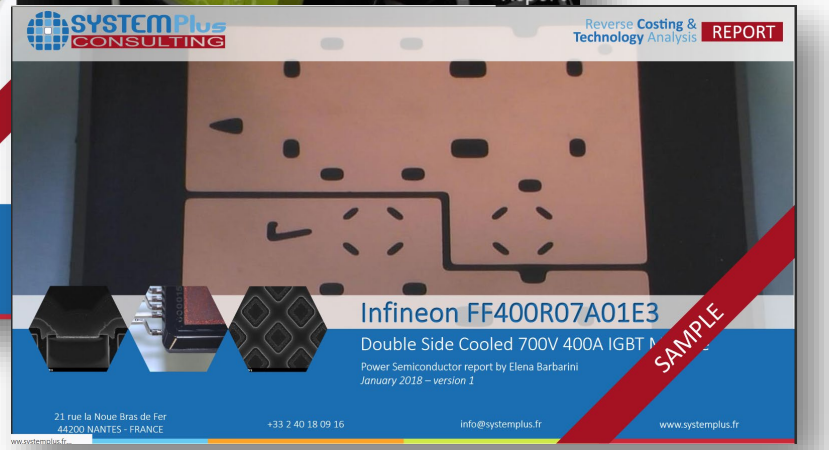
000777

THESE SLIDES WERE EXTRACTED FROM VARIOUS REPORTS…









→ *Stay tuned on*

www.i-micronews.com

000778

CONTACT INFORMATION

Follow us on

Elena Barbarini, Head of Department, Semiconductor Devices, ebarbarini@systemplus.fr

Claire Troadec, Division Director, Power & Wireless troadec@yole.fr