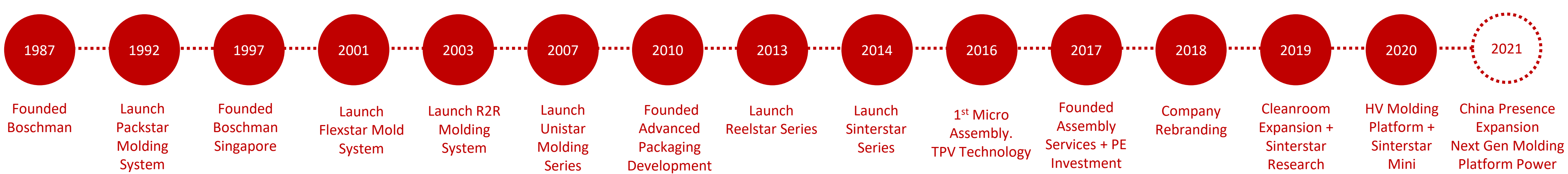
Packaging & Assembly Trends for Next Generation Power Modules

April 18, Brussels

Boschman Summary

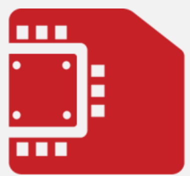
Advanced Solutions for Power Electronics

- Boschman is a high-tech, engineering driven Dutch company focusing on advanced back-end semiconductor packaging solutions;
- We provide a unique one-stop-shop concept, from idea to industrialization, for semiconductor packaging activities:
    - Package Development Services
    - Assembly & Test Services
    - Industrial Equipment
- We are a focused on well defined high growth market segments incl. Power Electronics (Automotive, Smart Grid and Industrial), MEMS and Sensors.
- The Global Energy Transformation is a fact, and the Electric Revolution requires next gen products, technologies, processes and materials.
- We focus on these opportunities with technology leadership in Pressure Sintering and Advanced Molding, supported by our Patented Technology (DIT, FAM, TPV,…) and unique, unparalleled packaging expertise.



Boschman Value Proposition

One-stop-shop from Idea to Industrialization



package development by boschman

- We research, design and prototype Advanced Packaging Concepts and Designs for Manufacturing (DFM).
- Together with our customers, we co-develop and assemble innovative, out-of-the-box package solutions.

assembly services by boschman

- We can manufacture low to medium volume quantities of your qualified products using semi- or fully automatic processes.
- Technology Transition Services & Support to High Volume OSATs.

production equipment by boschman

- We specialize in the development, supply & support of advanced back-end semiconductor packaging equipment:
  1. Pressure Sintering Equipment & Tooling
  2. Transfer Molding Equipment & Tooling

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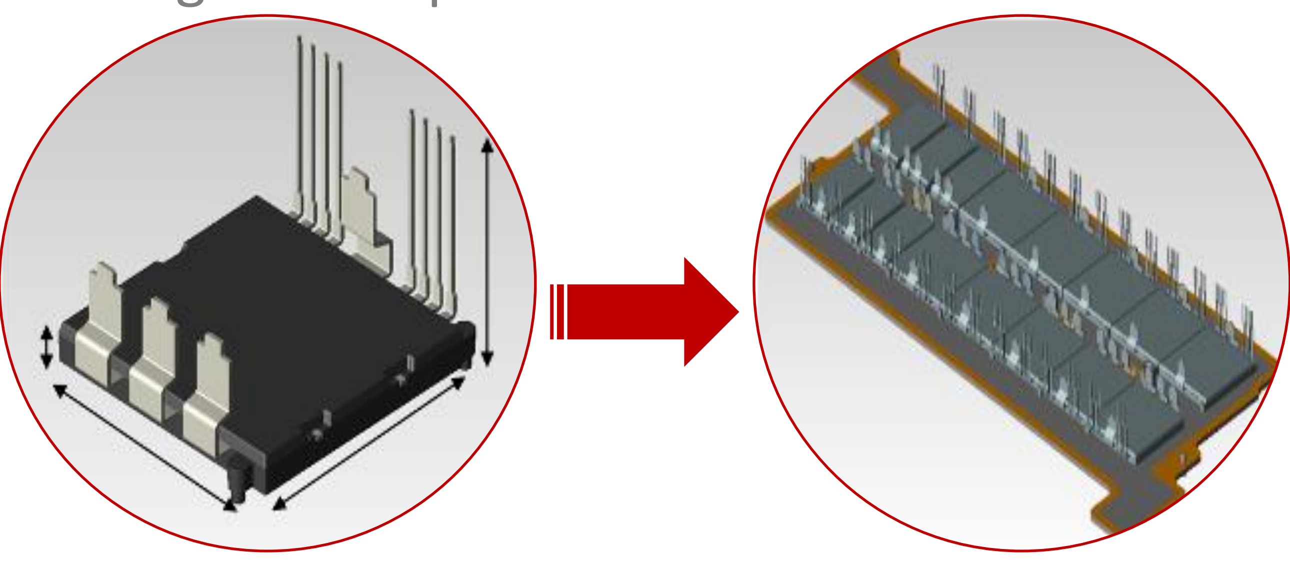
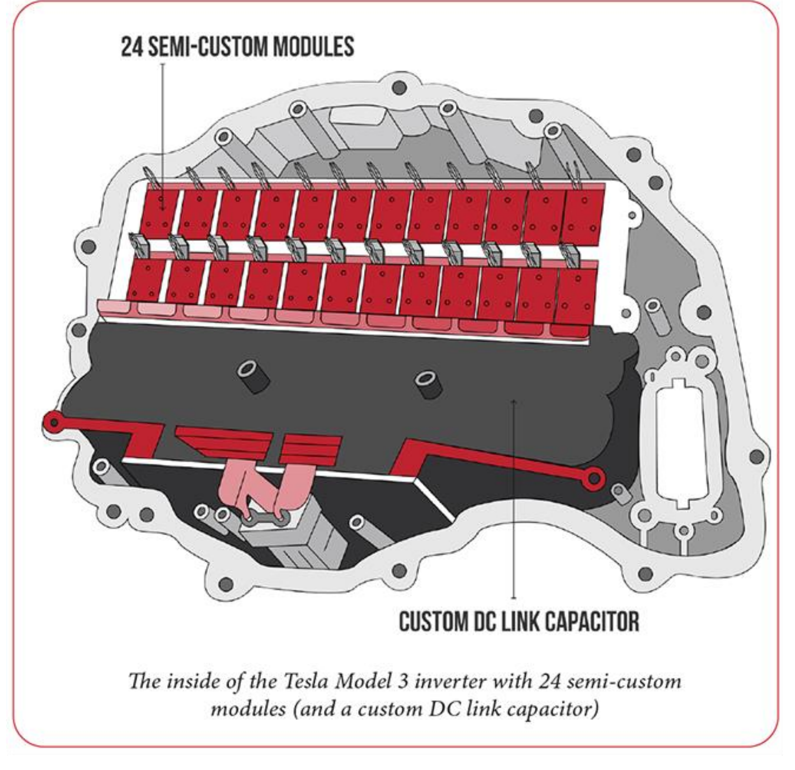
Power Electronics Supply Chain

Shifting Landscape





The inside of the Tesla Model 3 inverter with 24 semi-custom modules (and a custom DC link capacitor)

POWER MODULE APPLICATION

- Semiconductor Application
- Sinter used for Die & Topside Attach
- Established Industry + New Entrants (OSATs)
- Design typically by Semicon Power Module makers, strong trend towards OEM designs, outsourced manufacturing (OSATs)

INVERTER APPLICATION

- Assembly Application
- Sinter used for Module-to-Heatsink Attach
- PHEVs traditionally by T1s
- BEV entirely New Industry + New Players (EMSs)
- Design typically by OEM, inhouse manufacturing or outsourced (EMSs)

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Application Examples

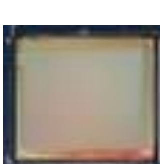
Overview

Optical/ Photonic Sensors

Flow/ Humidity Sensors

Power Packages

Camera Sensors



CPV (Solar Cells)

Clear Compound Solutions

Pressure/ MEMS Sensors

Bio/Micro Fluidic Sensors

WLM (Wafer Level Molding)

Fingerprint Sensors

Gas Sensors

TPV

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Power Modules for xEV

Different Form Factors

FULL BRIDGE	HALF BRIDGE	SINGLE SWITCH
FRAME POWER MODULE	MOLDED POWER MODULE	POWER DISCRETE

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Next Gen Power Modules

New Designs & Materials are needed

	TRADITIONAL	NEXT-GENERATION	
	Si-based Modules	SiC-based Modules	
TECHNOLOGY	Wire-bonded Power Module on Heatsink	Epoxy Molded Single Sided Cooling Concept	Epoxy Molded Double Sided Cooling
TYPE	IGBT DIODE	MOSFET	
DIE	Silicon (Si)	Silicon Carbide (SiC)	
SUBSTRATE	Ceramic DBC (Al_2O_3)	Ceramic AMB (Si_3N_4)	
CASE	Plastic	Overmolded Design (DSC or SSC)	
ENCAPSULATION	Potting (Silicone)	Epoxy Molded Compound (EMC)	
DIE ATTACH	Solder	Sinter (Ag or Cu)	
TOPSIDE ATTACH	Al Wire Bonds	Clips/Leadframes/Cu Ribbon-Preforms	Sintered Spacers
BASE PLATE ATTACH	Solder (Flat Baseplate + Heatsink)	N/A (Direct Heatsink Attach)	
HEATSINK ATTACH	Thermal Interface Material (TIM)	Sinter (Ag or Cu)	
NUMBER INTERFACES	Bottom **3**x (+ Top)	Bottom **2**x (+ Top)	Bottom **2**x (+ Top)

Diagram labels – Traditional: Silicone Gel, Casing, Si Die, DBC Substrate, Base Plate, Al Heatsink, 1, 2, 3. Single sided: EMC, SiC Die, AMB Substrate, Al Heatsink, 1, 2. Double sided: Al Heatsink, AMB Substrate, EMC, SiC Die, Spacer, AMB Substrate, Al Heatsink, 1, 2.

CONSIDERATIONS:

1. New Designs
2. New Materials
3. New Processes
4. Secondary Attach
5. Higher Reliability
6. Higher Performance
7. Lower Overall Costs

Sintering Applications

Multiple Interconnects for Next Gen Power Modules

- Die-to-Substrate Sintering (DAS) currently established as mainstream attach method
- Topside Attach Sintering (TAS) is quickly gaining traction to attach Clips and/or Bond Buffer for Ribbon Bonding
- Package-to-Heatsink Attach Sintering (PAS) is a proven method to eliminate Base Plates
- Wafer Lamination is very promising technology for high-volume low-cost sintering (i.e. Discretes)

	DAS	TAS	PAS	WLS
DESCRIPTION	Attachment of Die-to-Substrate	Attachment of Topside-to-Die (including: Clips, Leadframes, Foils, Preforms, etc)	Attachment of Package-to-Heatsink (Coolplates, Inverters, Base Plates etc.)	Attachment of Laminate-to-Wafer (pre-laminate Sinter Film to an un-cut Wafer)
	DAS Die Attach Sintering EMC SiC Die AMB Substrate Al Heatsink	TAS Top Attach Sintering EMC SiC Die AMB Substrate Al Heatsink	PAS Package Attach Sintering EMC SiC Die AMB Substrate Al Heatsink	WLS Wafer Lamination Sintering
PROCESS	Pressure Sintering.	Pressure Sintering.	Pressure Sintering.	Pressure Sintering.
TECHNOLOGY TREND	Replacement of Solder, Conductive Epoxy or Pressureless Sinter by Pressure Sintering for Die Attach interconnects. Dramatically improves Thermal Conductivity and Mechnanical Reliability properties.	Replacement of Wire Bonds by Clips, Ribbons, Foils, Leadframes etc. to improve Fatigue Stress, Parasitic Induction and Thermal Resistance. In turn, Sinter replaces Hi-Temp Solder to improve Thermal Conductivity and Mechanical Reliability.	Elimination of Baseplates & Frames by attaching a Power Module directly on the Heatsink to dramatically improve Thermal Conductivity. In turn, use Sinter rather than Solder, Thermal Grease to maximize Thermal Conductivity and Mechanical Relaibility.	Patented Process to pre-laminate complete wafers prior to dicing with Sinter Film. After dicing, the Dies can be placed directly on Substrate ready for sintering, either through Hot Tack or Sinter Press (depending on Die size and required output).

Top Side Attach Options

Eliminating Wire Bonds

	WIRE BONDS	RIBBON BONDS	CLIP BONDS
INTERCONNECT	Aluminium Wire Bonding to Die Metallization.	Copper Wire/Ribbon Bonding to Copper Preform/Foil (Hybrid).	Copper or Silver Clips, Leadframes, Flexible Foils, etc (Wire Free).
FATIGUE STRESS			
PARASITIC INDUCTION			
THERMAL RESISTANCE	Legacy	Future	Future
RELIABILITY			
FLEXIBILITY			
COST			
COMMENT	Aluminium Wire Bonding is a mature, low-cost and widely used technology for electrical interconnects, but reaching its limits for Next Generation Power Modules in terms of Inductance and Reliability.	A Hybrid Solution between Wire Bonding and Clip Bonding. A Copper Preform/Bond Buffer/Foil is sintered to the topside of the Die, this buffer is used to bond heavy gauge Copper Wires or Ribbons to improve Parasitic Induction and Fatigue Stress. At the same time, it offers more flexibility than Clips. It is a 2-step process: Sinter Buffer + Bond Ribbons.	Wire-Free solution to provide highest levels of Reliability and lowest Inductance interconnects. Design-specific Clips, Foils or Leadframes are Soldered or Sintered to the top Die metallization. In case of (Vacuum) Solder, a high MP solder is used with embedded spacers to ensure an even BLT. Increasingly designs use Sinter for Topside Connects due to High Temp Capability.

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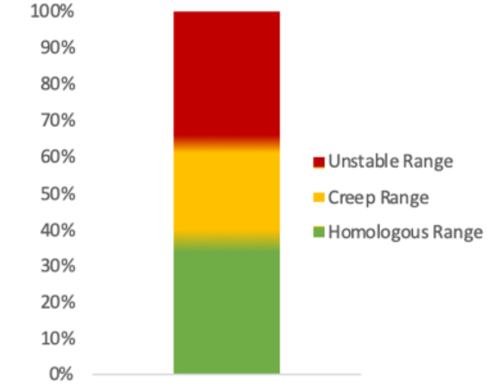
Sinter Technology

Properties

- A mature Lead-Free die attach technology offering a void-free, solid high reliability bond with very high thermal and electrical conductivity.
  - 80-95% Densification
- The combination of **High Temperature**, **High Thermal Conductivity** and **Low Electrical Resistivity** opens the window for new High Performance & High Reliability Designs.
  - E.g. Interfaces 34% of R_{TH}, Sinter reduced R_{TH} of total stack by 96%!
  - Thermal Path Die-to-Heatsink reduced by 87%
- Increased **Power Density** allows for Lower Total Cost of Ownership.
- Sinter Process = Time + Temperature + **Pressure**.

MATERIAL	COMPOSITION	MELTING POINT (℃)	THERMAL CONDUCTIVITY (W/m◦K)	ELECTRICAL RESISTIVITY (µΩcm)
Silver	100,0Ag	962	419,0	1,6
Copper	100,0Cu	1.085	401,0	1,7
Au/Sn	80,0Au/20,0Sn	280	57,0	16,0
SAC305	96,3Sn/3,0Ag/0,5Cu	228	55,0	14,5
High Lead	92,5Pb/2,5Ag/5,0Sn	296	26,0	17,0



MATERIAL	FBLT	THERMAL CONDUCTIVITY
Thermal Grease	~100um	~5 W/m◦K
Solder	~150um	~50 W/m◦K
Sinter	~80um	~250 W/m◦K

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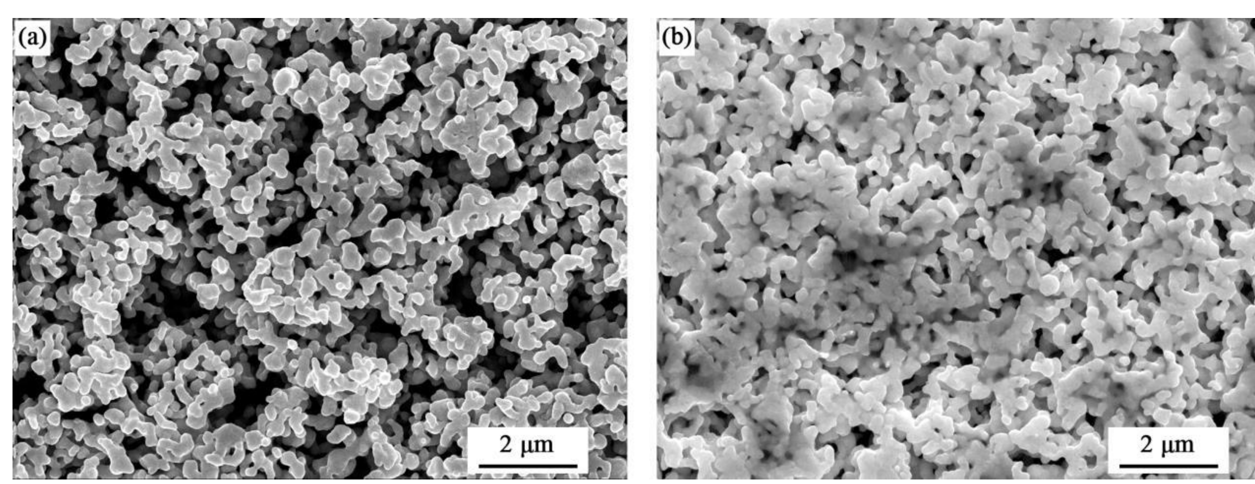
Sinter Technology
Effect of Pressure

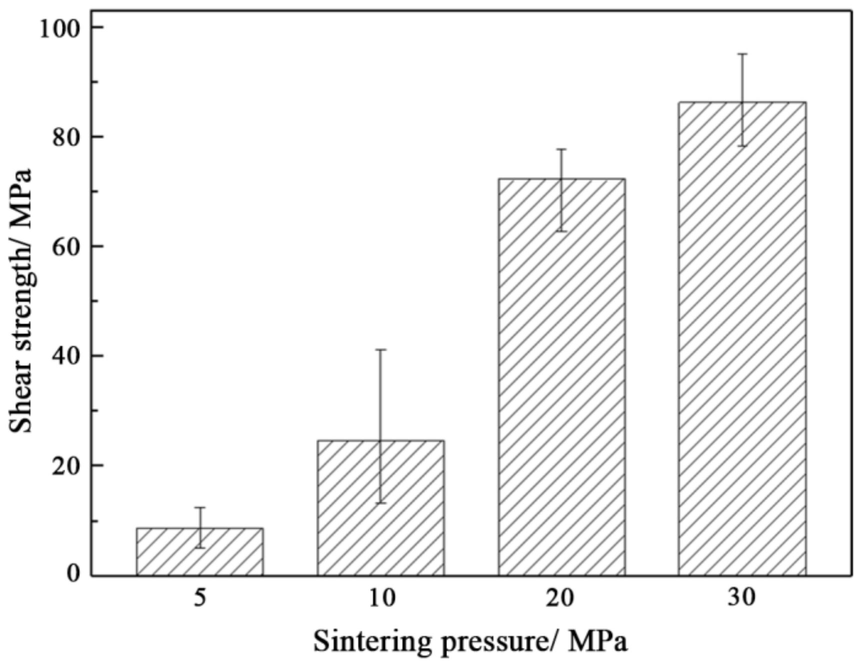
SEM Nano Silver morphology after sintering



a) **No Pressure (3 min at 250C):**
- Bonding has occurred to irregular polycrystalline structure.
- Some of the particles only combine with the nearest ones, resulting in discontinuous matrix.
- Porosity 16,26%

b) **5MPa Pressure (3 min at 250C):**
- Dense well-structured layer.
- Most of the particles combined in continuous matrix.
- Porosity 5,38%

Instrom 5569 (MIL-STD-883E, Method 2019.5)

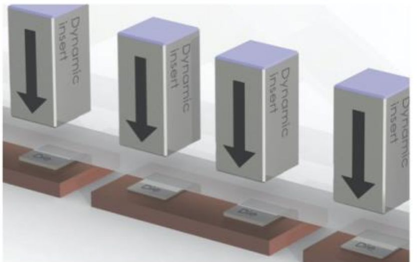


- **5MPa Pressure:** average shear strength is 8,71 MPa
- **10MPa Pressure**: average shear strength is 24,68 MPa
- **20MPa Pressure:** maximum increase rate of 65,83%
- Empirical evidence that pressure-assisted sintering will increase the mechanical reliability.

Sinter Technology

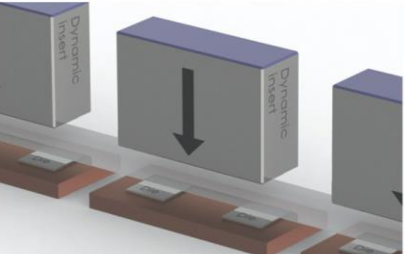
Dynamic Inserts for Uniform & Controlled Pressure

Individual, Group or Insert-in-Insert Configurations Possible



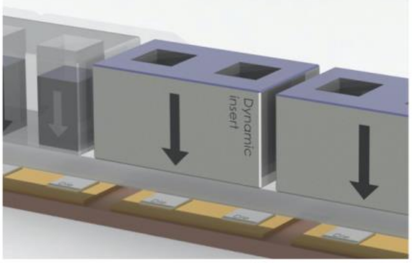
Individual dynamic insert technology:

Each insert presses on one individual die. Ideal for modules which have different die heights



Group dynamic insert technology:

Each insert presses on more than one individual die. Ideal for modules which have multiple dies with same die height.

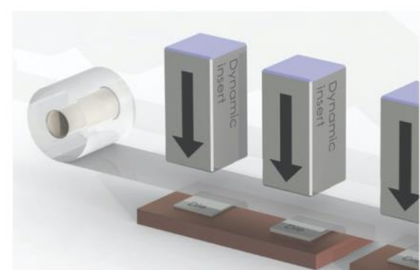


Insert in Insert dynamic insert technology:

In one sinter cycle we can sinter multiple areas and levels. I.e. die to dbc and dbc to heatsink.

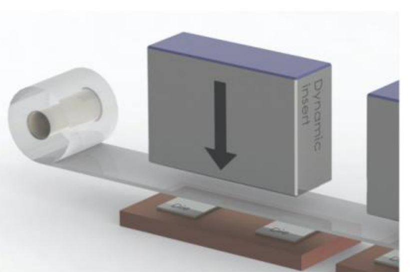
Combinations and Design Flexibility for Emerging Applications

Single, Double of Thick Film Configurations



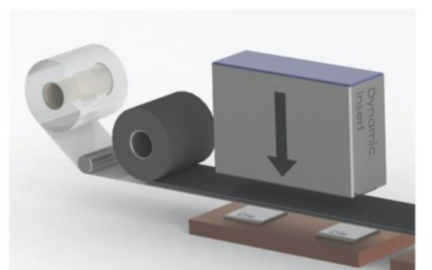
Standard film configuration:

We use a standard 50 um protection film between inserts and dies.



Thick film configuration:

We can use up to 300 um protection film which also serves to equalize pressure on dies which have a small die height difference.



Dual film configuration:

Double film handling. A thick compensation layer can be handled in combination with a protective layer.

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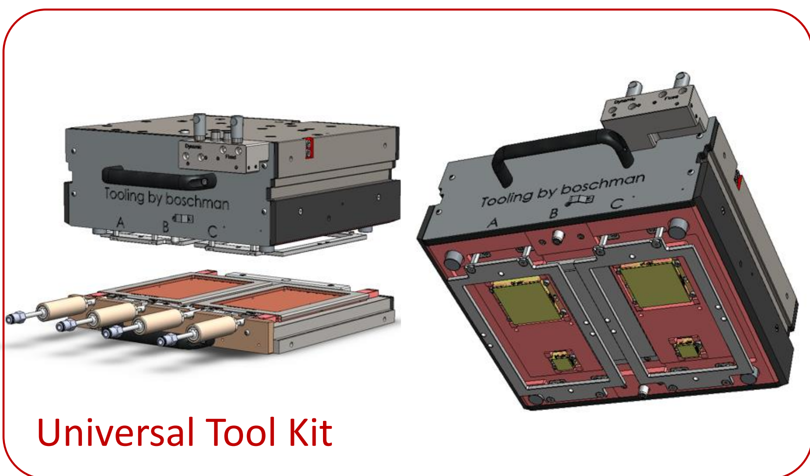
Industrial Sinter Solutions

Modular Sinterstar Platform

Sinterstar Innovate



Universal Tool Kit

Sinterstar Platform

- Modular and Flexible Configurations with many options available
- Different Levels of Automation
- Dynamic Insert Technology
- Largest Effective Area
- Industry Standard
- Innovate + Universal Tool = ideal "starter kit" for R&D and Prototyping

Sinterstar Inline

Sinterstar Inline HC

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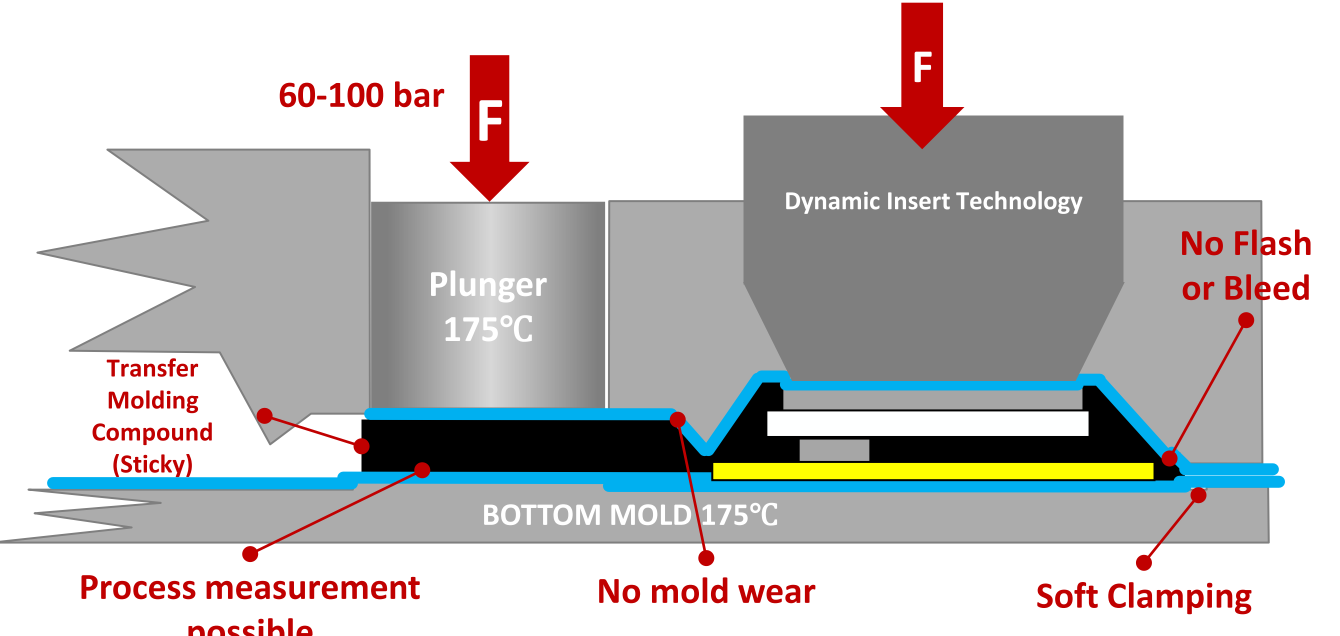
Advanced Transfer Molding

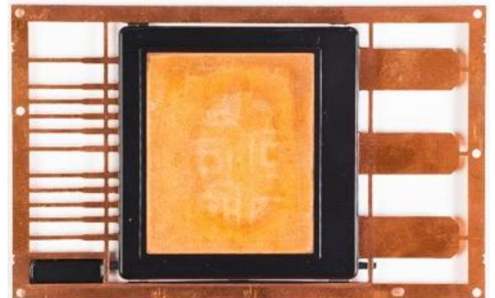
Film Assist + Dynamic Insert Technology

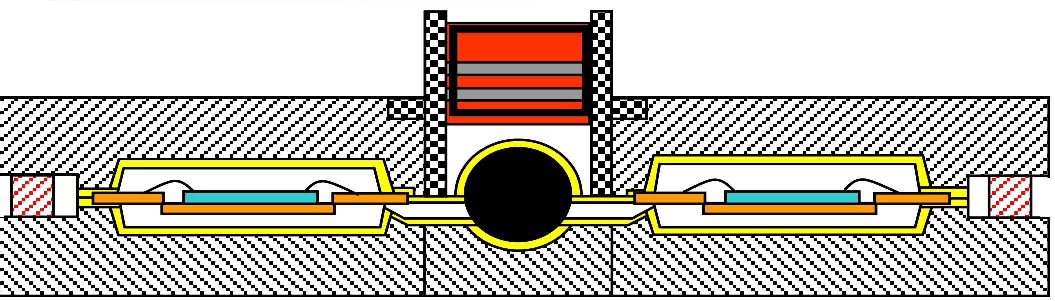
- Molding is an established technology to package semiconductor parts with EMC (Epoxy Mold Compound)
- Large and mature market with many players.
- Boschman focusses on advanced high-end applications (MEMS, Sensors, Power …)
- Trend towards overmolded Power Modules requires Advanced Molding Solutions



POWER

MEMS & SENSORS





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Advanced Transfer Molding

Equipment Overview

Reelstar

Unistar-Innovate-1

Unistar-Innovate-2

Unistar-Auto-2

XXX star

All System are available with film in Top and/or Bottom mold or without film configuration

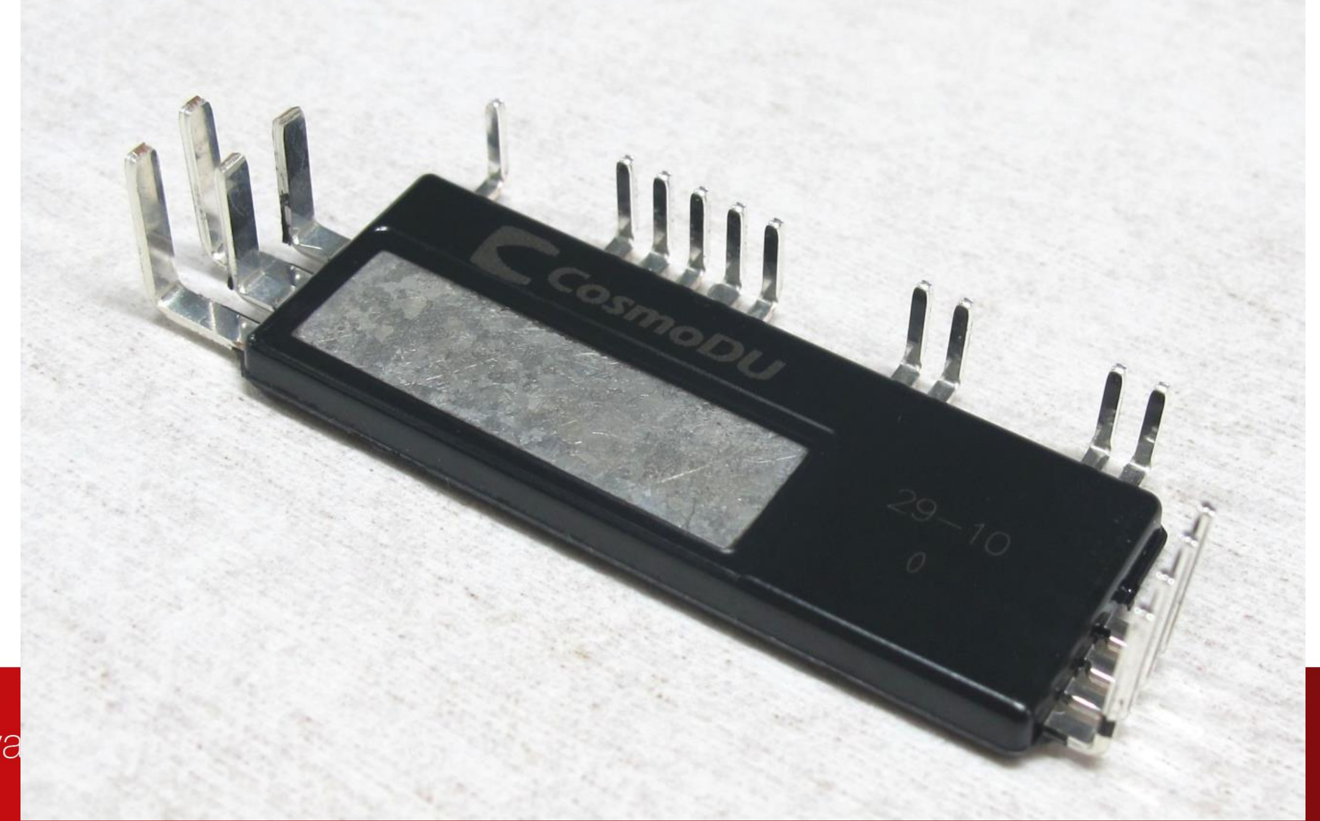
Example: CosmoDU

CosmoDU: DSC Module with sintered SiC Mosfets inside

Bringing Intelligence to Electric Drives for Industry 4.0 Manufacturing

Background:

CosmoDU, a EUREKA PENTA cluster project managed by AENEAS, is bringing intelligence to the electric drives that control production machines such as industrial robots or conveyor belts. The project aims to create the first hardware platform able to implement self-learning capabilities within applications, allowing them to adjust and improve the performance of the applications during operation and to ensure timely preventive maintenance.



Next Gen Power Modules

Modular Designs using Advanced Assembly Techniques

High Level Assembly Steps:

1. **Die to Bottom DBC**
2. **Shunt to Bottom DBC**
3. **Spacers to Die**
4. Wire Bond
5. **Lead Frame to Bottom DBC**
6. **Lead Frame to Top DBC**
7. **Top DBC to Spacers**
8. Transfer Molding
9. Trim & Form
10. **Module to Heatsink**

package development

assembly services

production equipment

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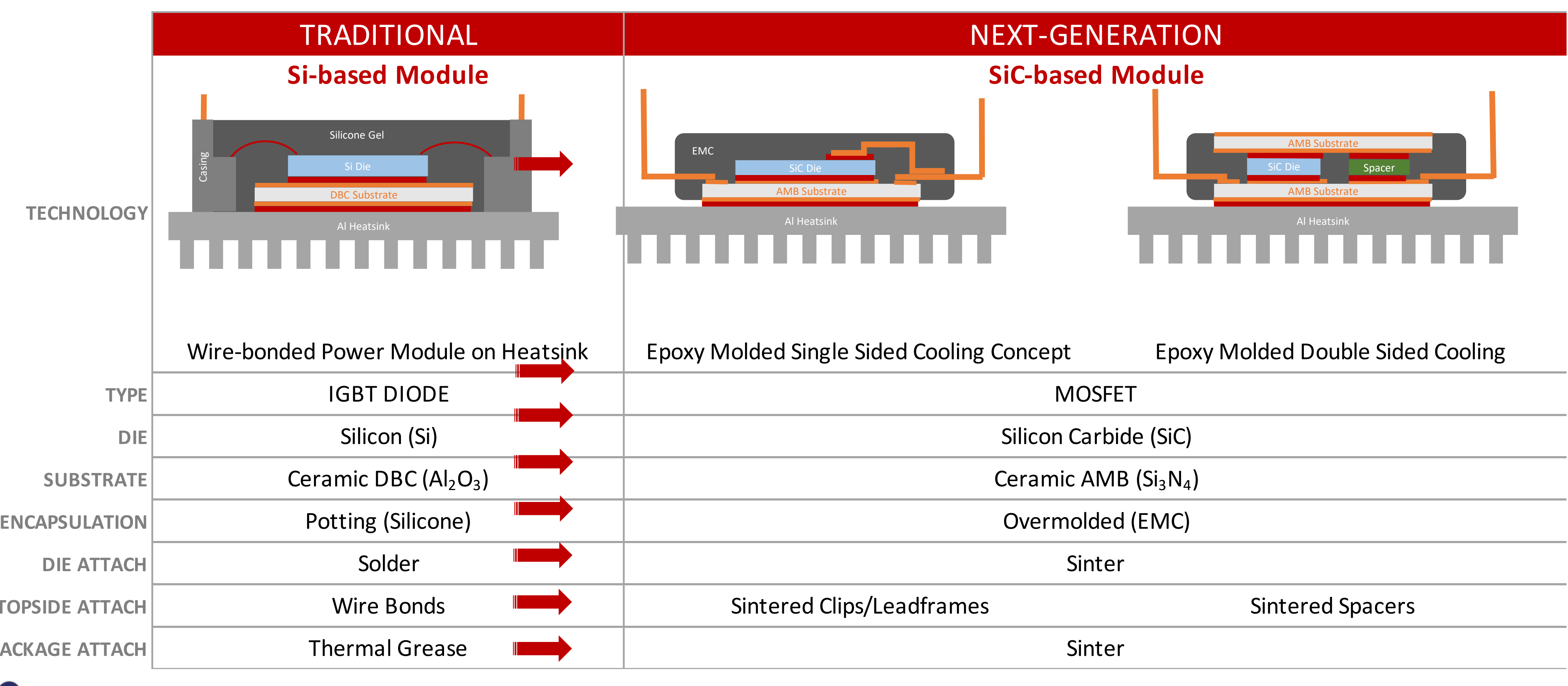
Next Gen Power Modules, Trim and Form of Power and Signal leads

New Designs & Materials are needed



	TRADITIONAL	NEXT-GENERATION	
	Si-based Module	SiC-based Module	
TECHNOLOGY	Wire-bonded Power Module on Heatsink	Epoxy Molded Single Sided Cooling Concept	Epoxy Molded Double Sided Cooling
TYPE	IGBT DIODE	MOSFET	
DIE	Silicon (Si)	Silicon Carbide (SiC)	
SUBSTRATE	Ceramic DBC (Al_2O_3)	Ceramic AMB (Si_3N_4)	
ENCAPSULATION	Potting (Silicone)	Overmolded (EMC)	
DIE ATTACH	Solder	Sinter	
TOPSIDE ATTACH	Wire Bonds	Sintered Clips/Leadframes	Sintered Spacers
PACKAGE ATTACH	Thermal Grease	Sinter	

TFA

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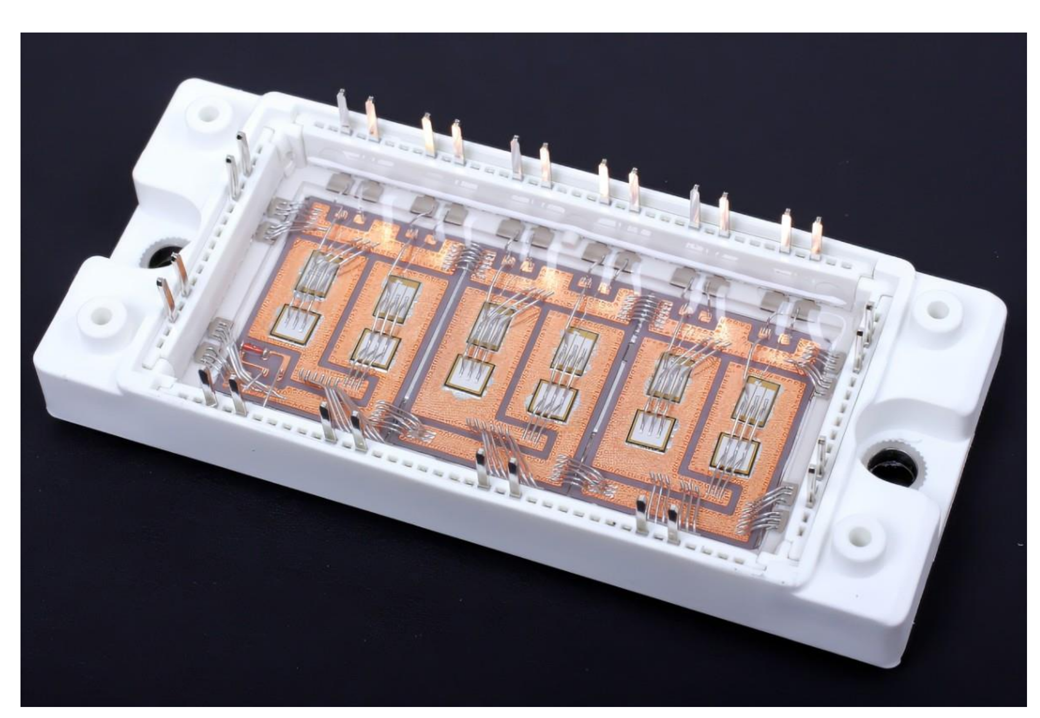
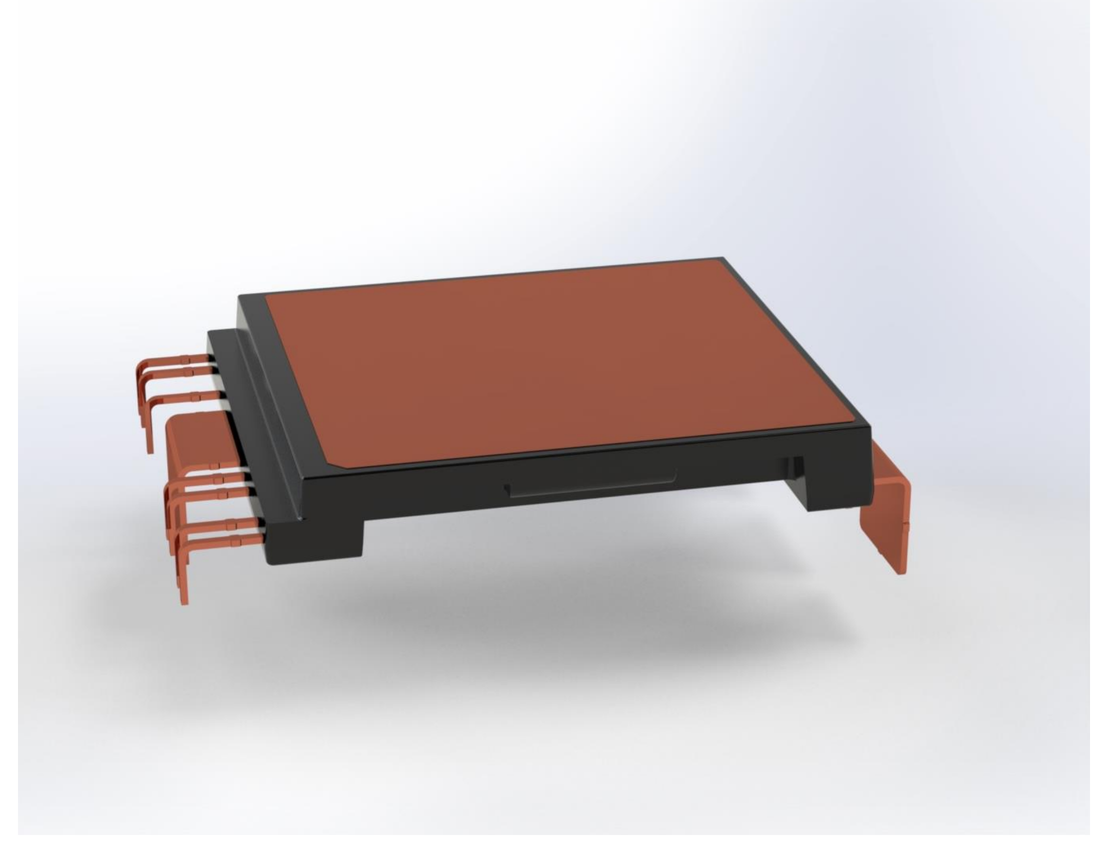
From Casing to leadframe based Power Module





Example : CosmoDU leadframe design, Trim & Form process

Background:
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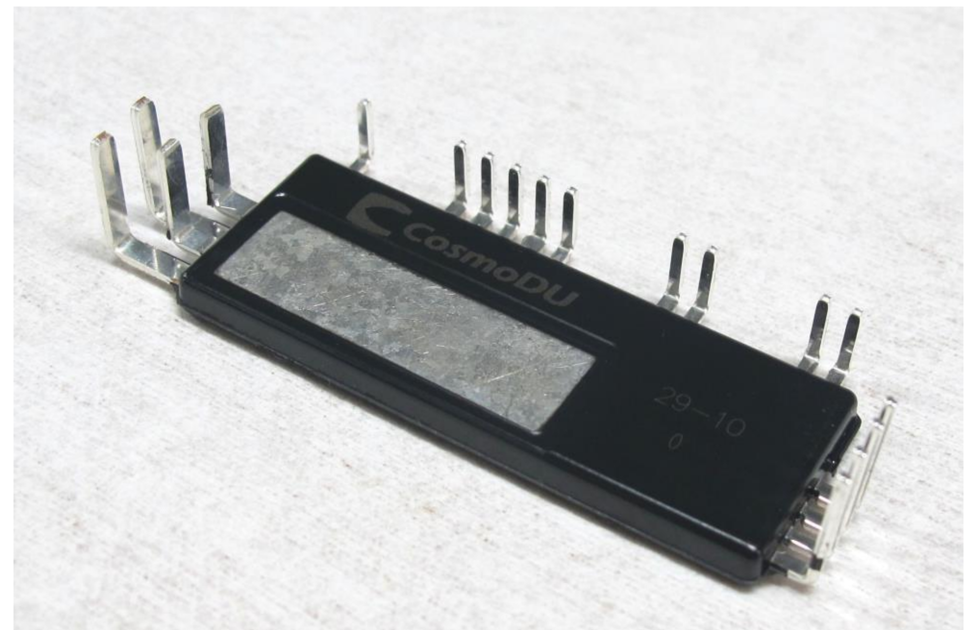
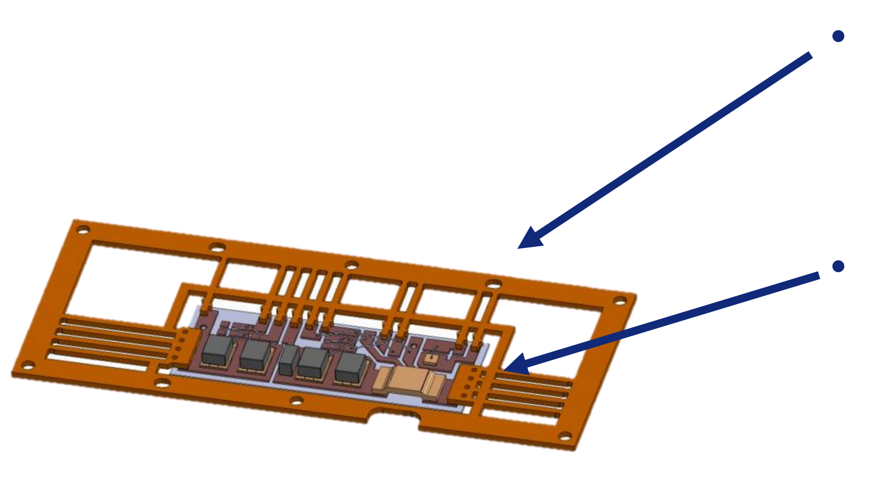
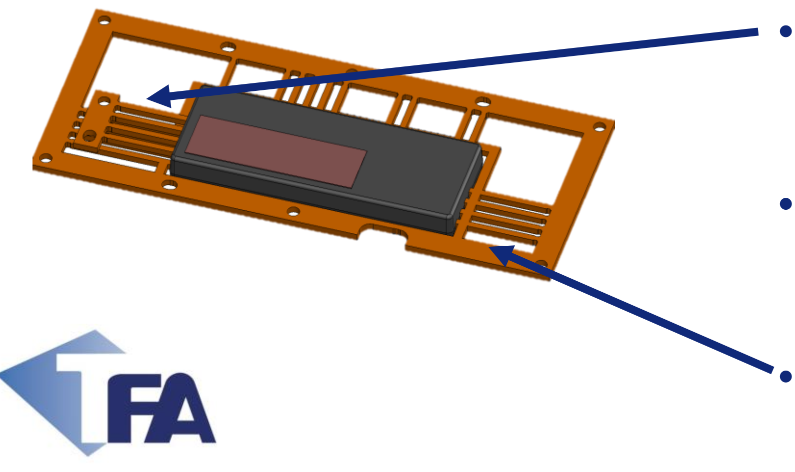


(Boschman Advanced packaging Technology)

General considerations: Leadframe design:





- Outside leaframe / use as carrier
  - center holes
  - runner area
- Inner leadframe design
  - dambar area
    - space for anti flash profile in mold tool
    - avoid blow-out
    - accuracy of downsets –influence on DBC/Substrate
- Stress reliefs
  - avoid leadframe stress during molding process
- Power leads
  - shape requirements /forming process (space for forming tools)
- Signal leads
  - - shape requirements / forming process (space for forming tools)

TFA
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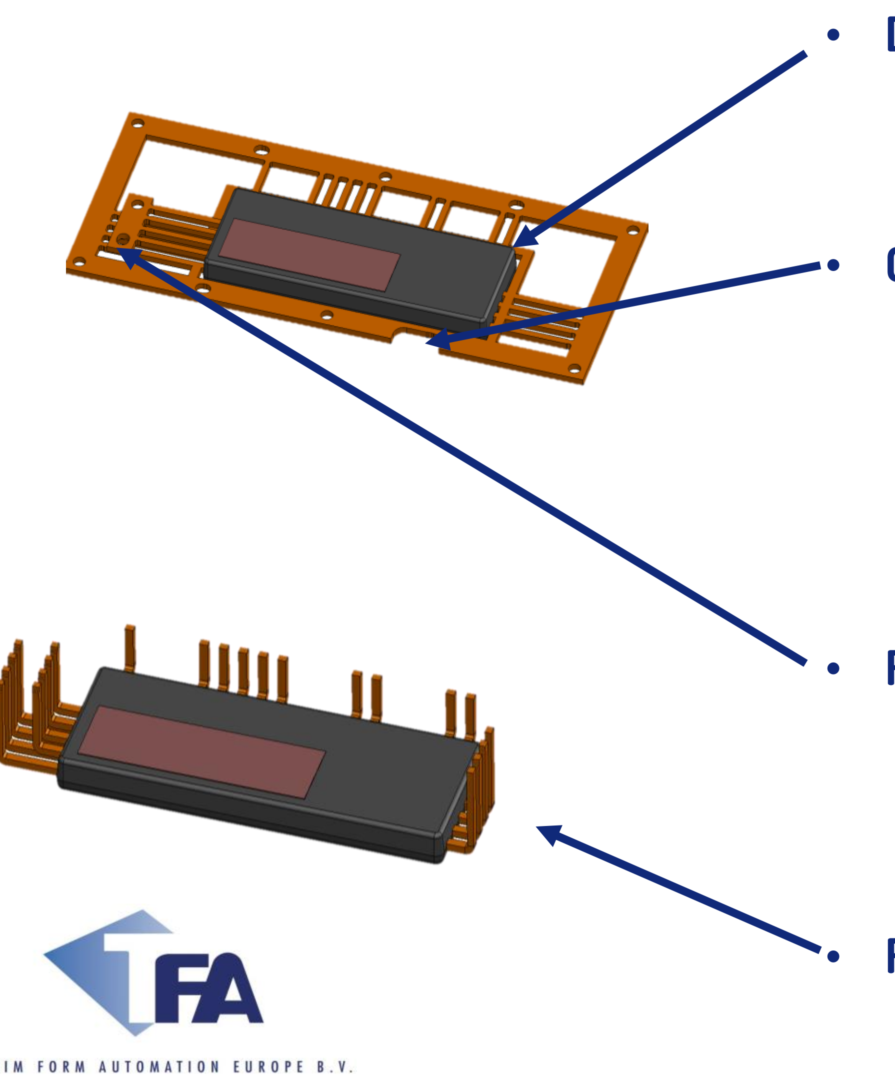
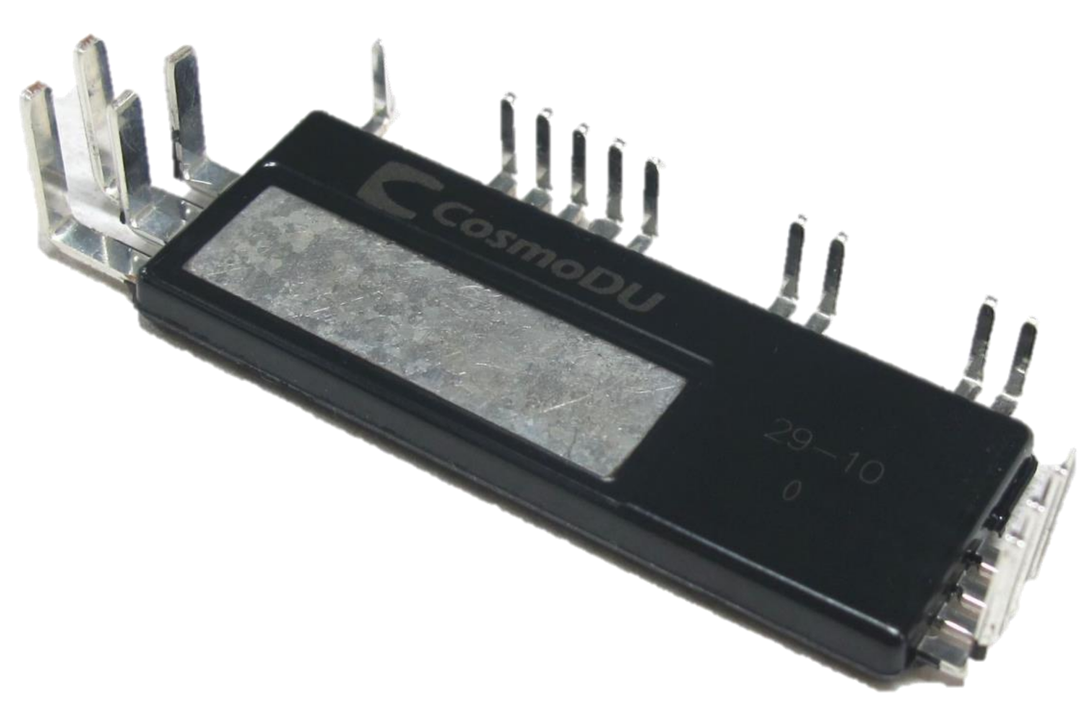
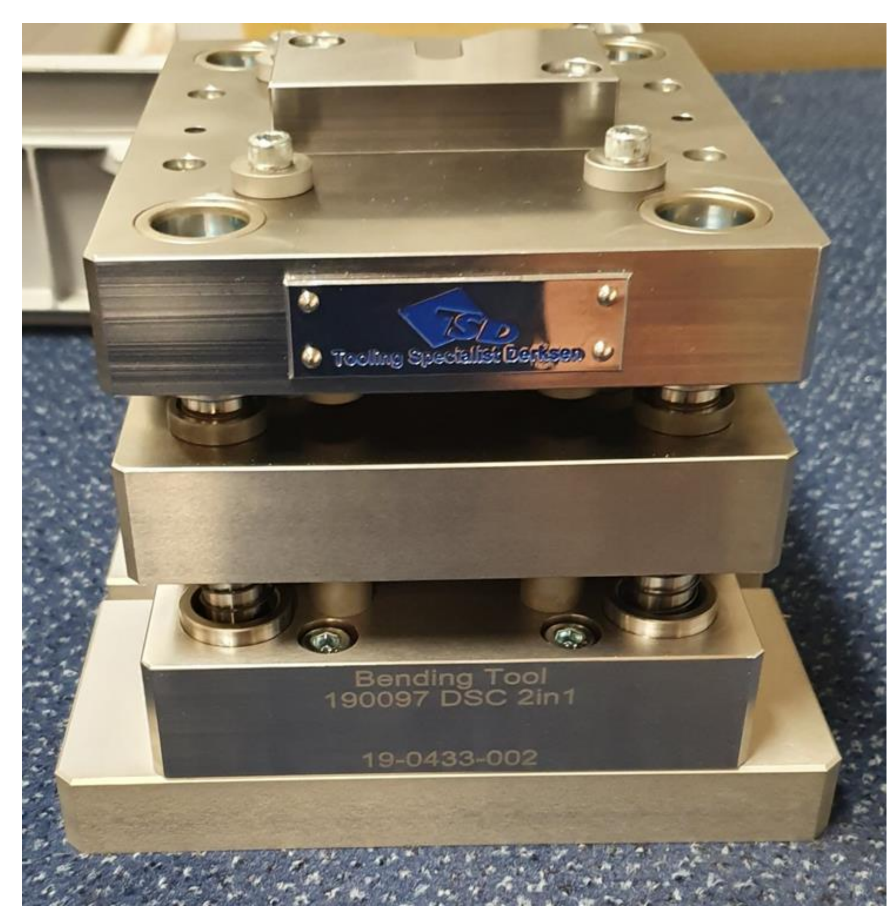
General considerations: Trimming and Forming process



- Dambar cutting / deflashing
  - isolate the leads
  - remove excessive flash
- Gate remain removal
  - punch off the remaining gate
    - requires specific gate design in mold tool and design features in the outer leadframe
    - avoid blow-out
    - accuracy of downsets –influence on DBC/AMB
- Final leadlength cut
  - avoid cutting burrs
    - might effect the forming process
    - avoid cupper smearing / contaminations of tools
- Forming process
  - shape requirements /forming process (avoid scratches / roller forming)

Final result after Trimming & Forming





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Automation solution: Trim & Form Systems for Power Modules

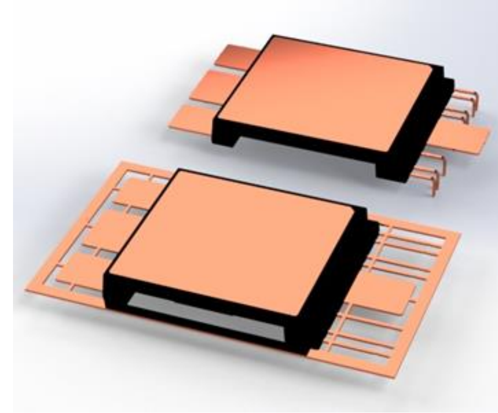
TFA Flex Line

High press force and up to 3 force controlled presses

High productivity up to 1200 Power Modules per hour

Product change within 15 minutes

Flexible integration with other process steps



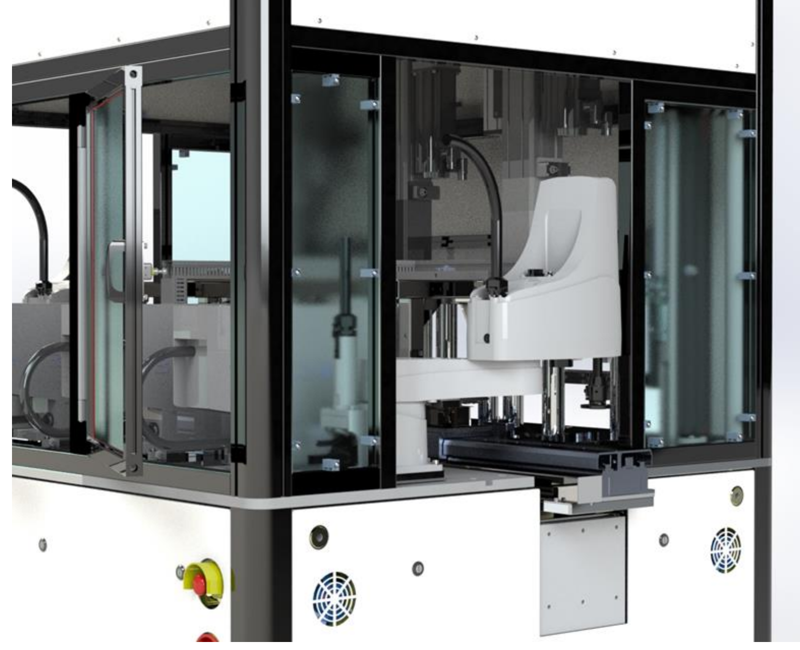
Loading and offloading options
- Magazines
- Trays
- In-line
- AGV's

Optional items
- Barcode / DMC reader
- Laser marking
- Product inspection
- MES integration

Flexible product handling

Enables handling of different power modules in one system

- **Scara robot input and output handling**
  - Flexible handling of the Power modules
  - Input and output in magazine, tray, AGV, inline track
- **Linear motor product carrier handling**
  - Flexible product positioning depending on process step
  - Accurate product positioning: +/- 5 um
  - High speed product handling 2500 mm/s
- **Pick and place robot handling**
  - Handling from product carrier into press modules
- **Product change within 15 minutes**
  - Product related parts are easy changeable:
  - Tools, product carriers, robot grippers and system program



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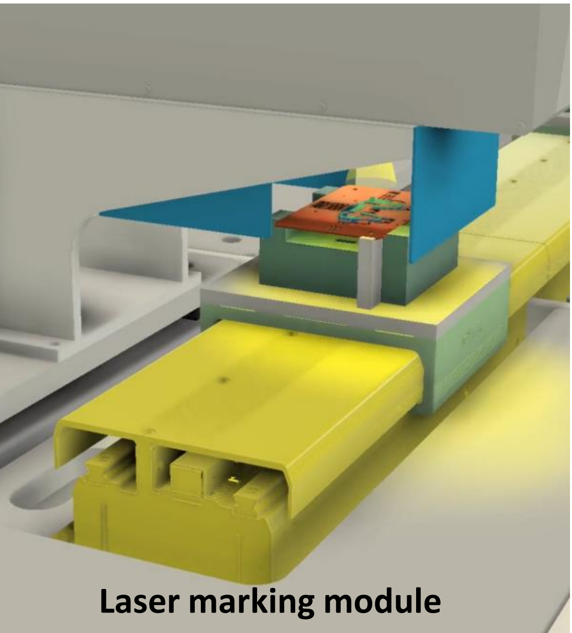
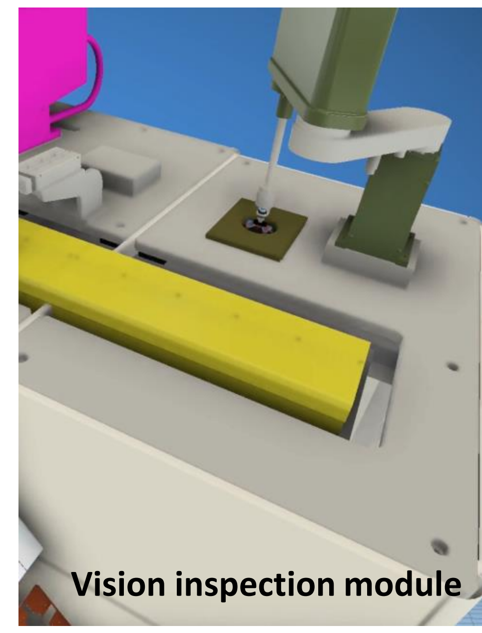
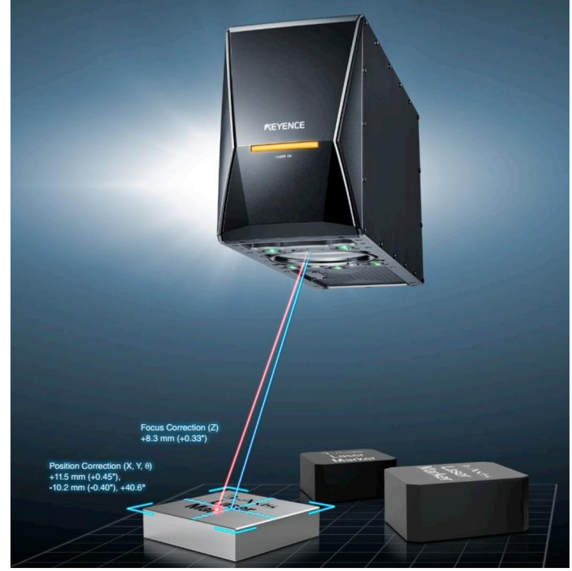
Options

- Barcode / DMC code reader
- Laser marking module
- MES integration
- Vision inspection module


Laser marking module


Vision inspection module



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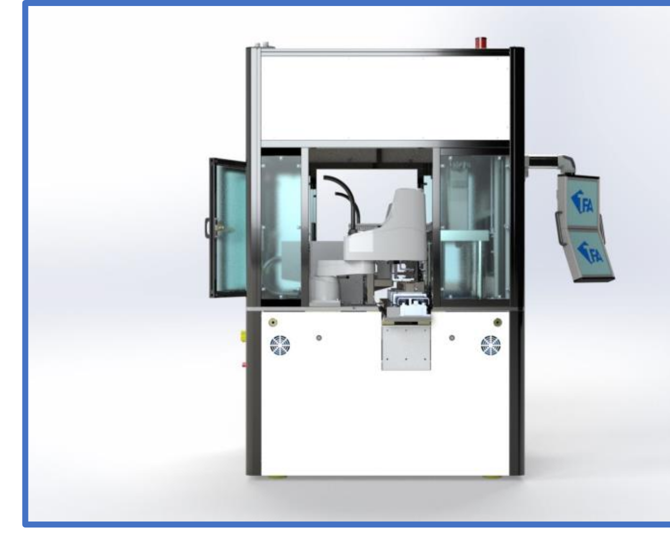

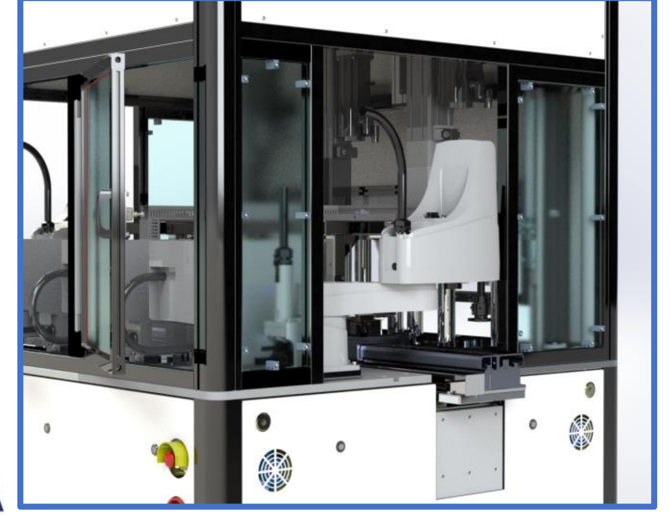

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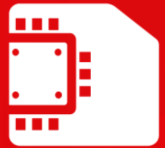
Boschman Advanced Packaging Technology

One Stop Shop from Package Development to Production Equipment

from idea to industrialization



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