from idea to industrialization

boschman
advanced packaging technology

# Novel interconnect and packaging technologies for Next Generation Power Modules

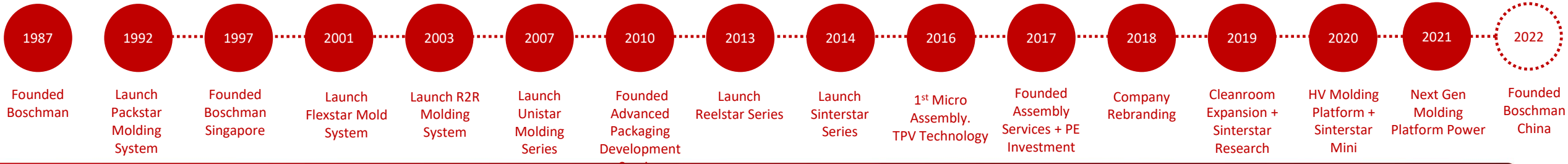
PE INTERNATIONAL CONFERENCE
ANGELTECH

**16-17 April, Brussels, Begium**

# 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), E-motors , 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

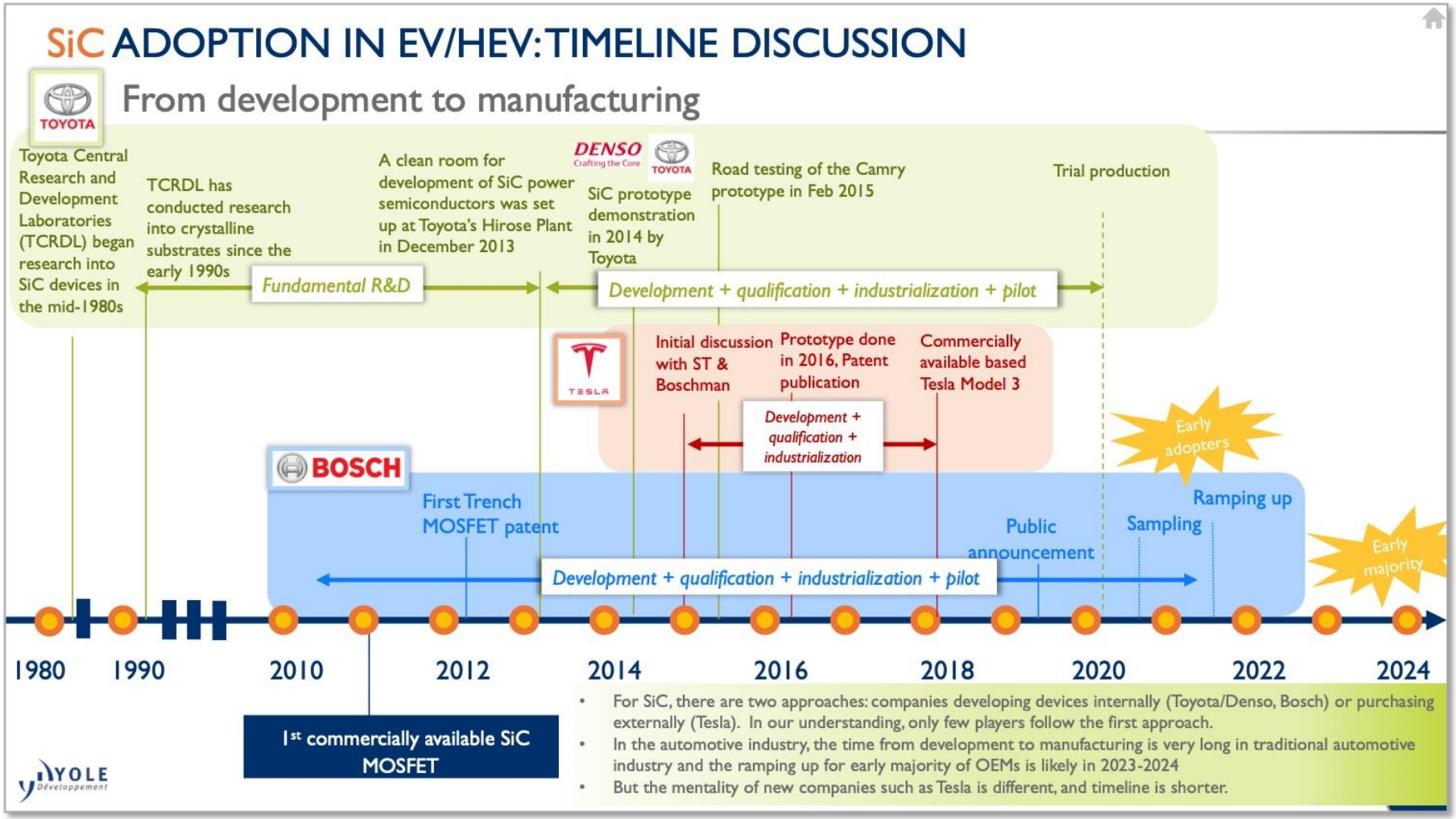
- We can manufacture low to medium volume quantities of your qualified products using semi- or fully automatic processes.
- Technology Transition Services & Support to High Volume OSATs.

### 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

# From Idea to Industrialization

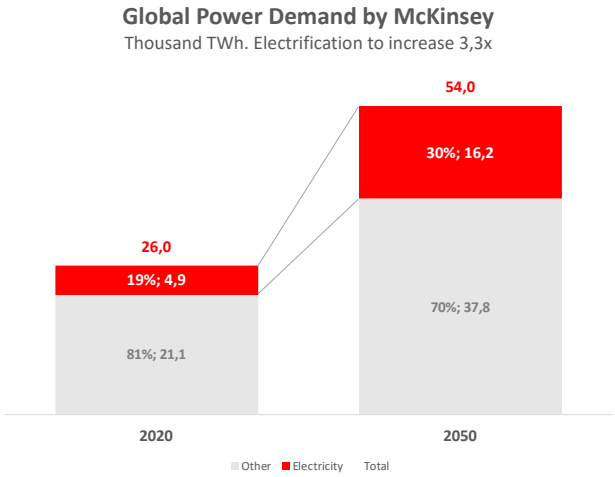
## Time to Market

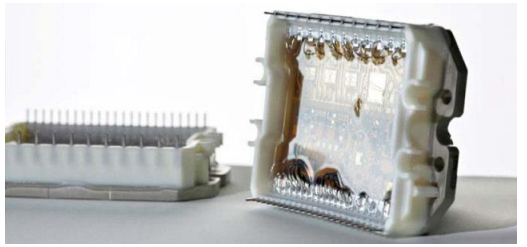


# Background

## The Electric Revolution

- Electrification levels are expected to increase 3,3x in the next three decades.
- Power Density is critical in this energy transformation, including batteries, fuel cells, motors and **power units**.
- Power Density has increased 8x in the past 30 years, reaching 250 kW/cm2.
- With higher power density comes higher operating temperatures (≥175C), reaching the physical limits of Si-based designs.
- Whether it's latest generation Si-IGBT or next gen SiC power modules, cooling becomes the key to reliability and performance.
- This sparks a new technology trend to replace solder die attach/ interconnectsw ith Silver Sintering technology
- This sparks a new technology trend to replace Silicone Gel Encapsulation with Epoxy Mold Compound designs.
- There are 2 form-factors:
  - Single Side Cooled Modules (SSC)
  - Double Side Cooled Modules (DSC)



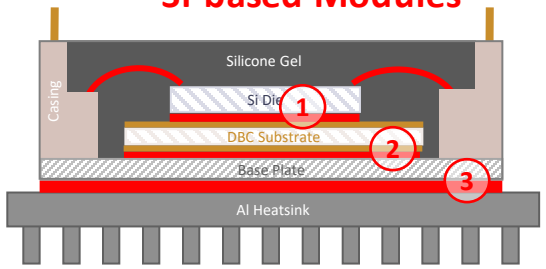
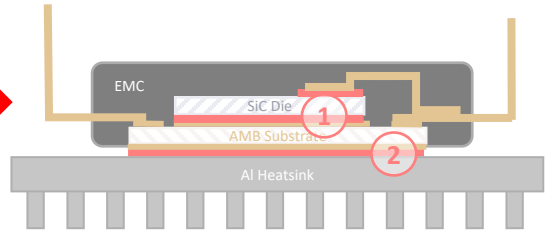
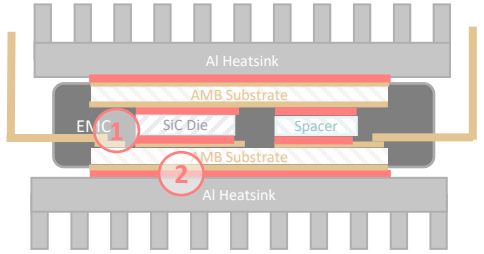
TYPICAL GEL-ENCAPSULATED POWER MODULE

TYPICAL SSC POWER MODULE

TYPICAL DSC POWER MODULE

# 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) |

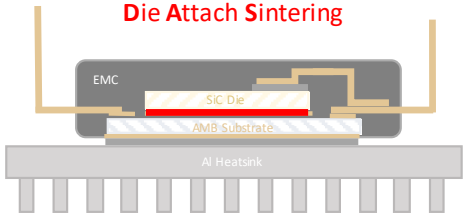
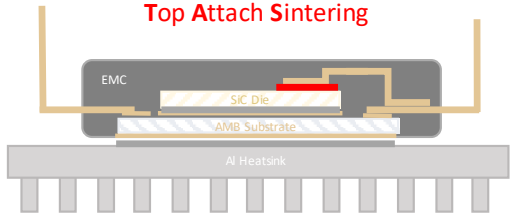
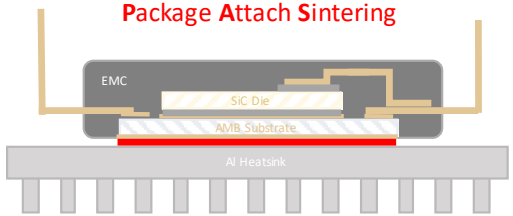
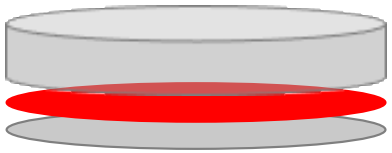
**CONSIDERATIONS:**

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 Sintering (WLS) is very promising technology for high-volume low-cost sintering (i.e. Discretes)

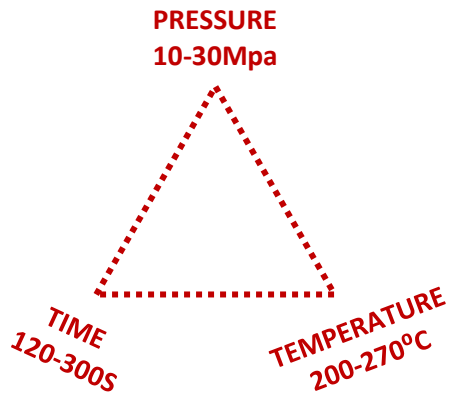
| | DAS | TAS | PAS | WLS |
|---|---|---|---|---|
| **DESCRIPTION** | Attachment of Die-to-Substrate | Attachment of Topside-to-Die (including: Clips, Leadframes, Foils, Preforms, etc) | Attachment of Package-to-Heatsink (Coolplates, Inverters, Base Plates etc.) | Attachment of Laminate-to-Wafer (pre-laminate Sinter Film to an un-cut Wafer) |
| | **DAS**<br>**D**ie **A**ttach **S**intering<br>  | **TAS**<br>**T**op **A**ttach **S**intering<br>  | **PAS**<br>**P**ackage **A**ttach **S**intering<br>  | **WLS**<br>**W**afer **L**amination **S**intering<br>  |
| **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). |

# 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 |

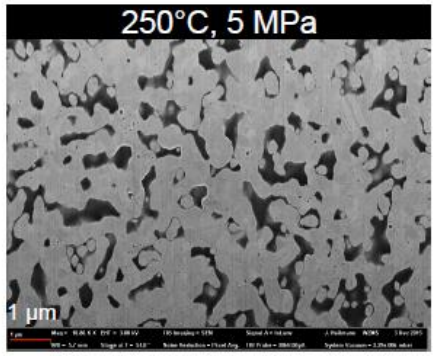


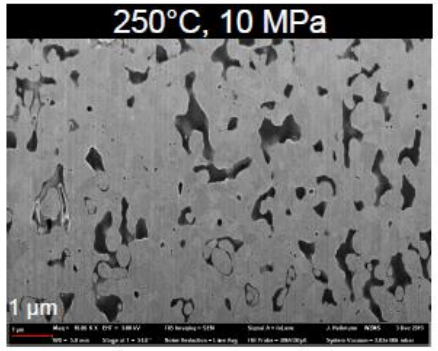

| MATERIAL | FBLT | THERMAL CONDUCTIVITY |
|---|---|---|
| Thermal Grease | ~100um | ~5 W/m◦K |
| Solder | ~150um | ~50 W/m◦K |
| Sinter | ~80um | ~250 W/m◦K |

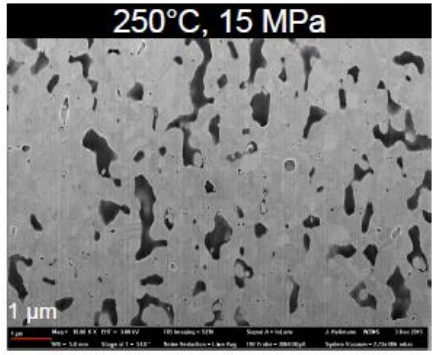
# Porosity and Shear strength

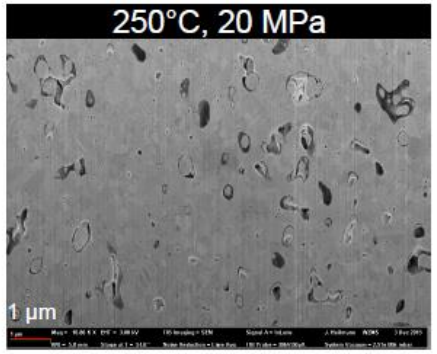
## Effect of Pressure and Time

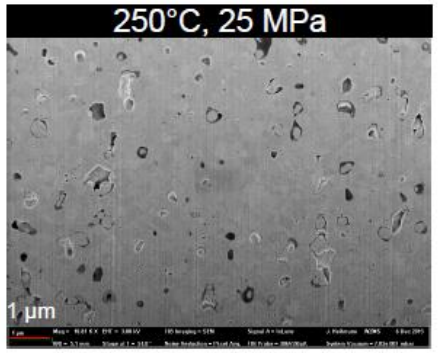
POROSITY AS FUNCTION OF SINTERING PRESSURE

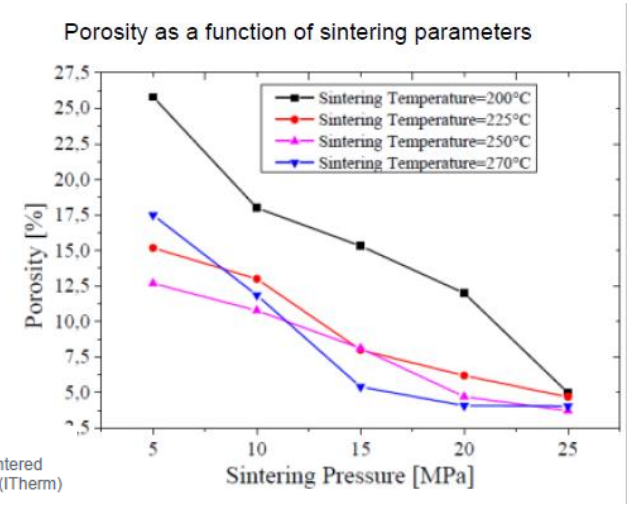


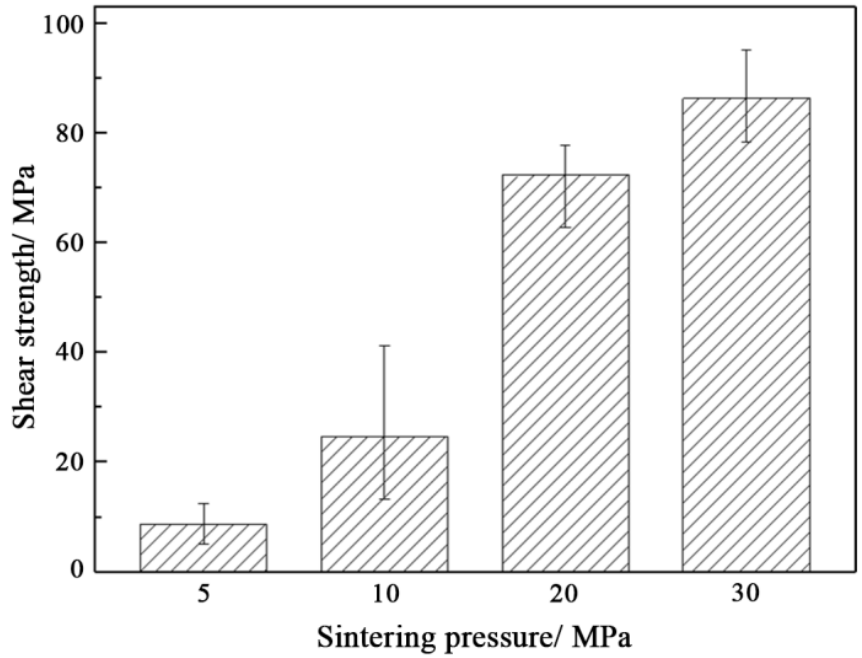




[1] M.A. Ras, D. May, J. Heilmann, S. Rzepka, B. Michel, B. Wunderle "Processing-Structure-Property Correlations of Sintered Silver", 2016 15th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm)

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

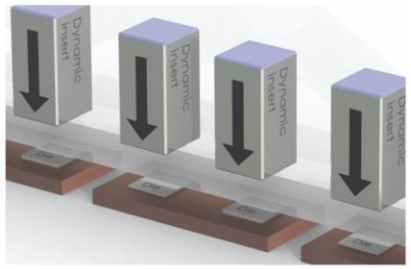



- **5MPa Pressure:** average shear strength is 8,71 MPa
- **10MPa Pressure**: average shear strength is 24,68 MPa
- **20MPa Pressure:** maximum increase rate of 65,83%
- Empirical evidence that pressure-assisted sintering will increase the mechanical reliability.

# Sinter Technology

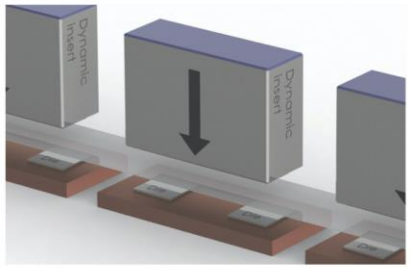
## Dynamic Inserts for Uniform & Controlled Pressure

### Individual, Group or Insert-in-Insert Configurations Possible



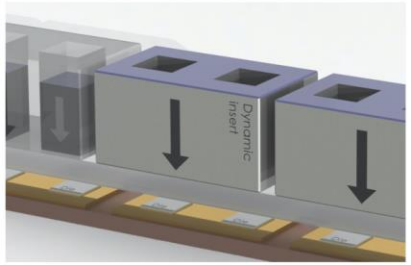

**Individual dynamic insert technology:**

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




**Group dynamic insert technology:**

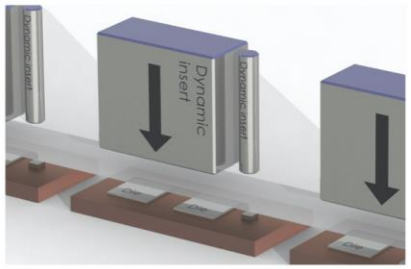
Each insert presses on more than one individual die. Ideal for modules which have multiple dies with same die height.




**Insert in Insert dynamic insert technology:**

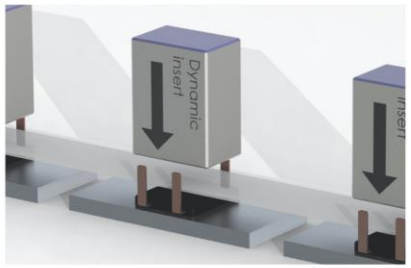
In one sinter cycle we can sinter multiple areas and levels. I.e. die to dbc and dbc to heatsink.

### Combinations and Design Flexibility for Emerging Applications



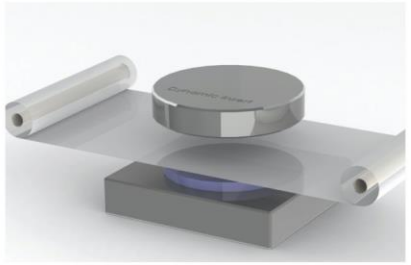

**Combination group and Individual dynamic insert technology:**

I.e. in case thermistors need to be sintered in one cycle together with IGBT/FRD dies.




**Package sintering to heatsink with individual dynamic insert technology:**

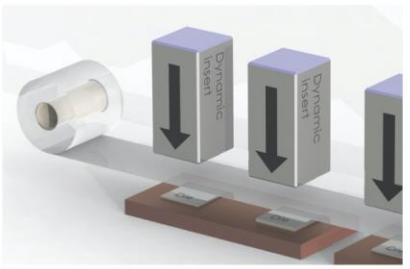
Each insert presses on one individual package with exact pressure control.



**Flat tool with sintering:**

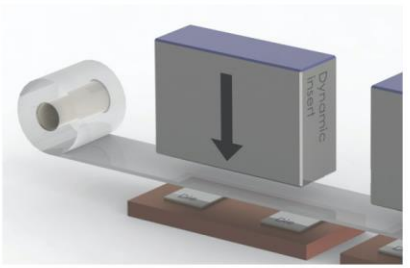
For large area sintering without multiple different heights (I.e. wafers and thyristors).

### Single, Double of Thick Film Configurations



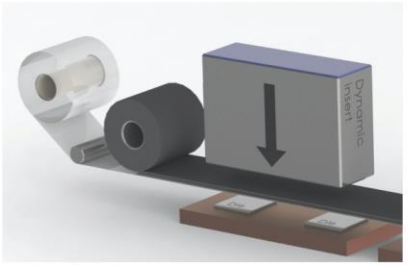

**Standard film configuration:**

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.

# Transfer Molding

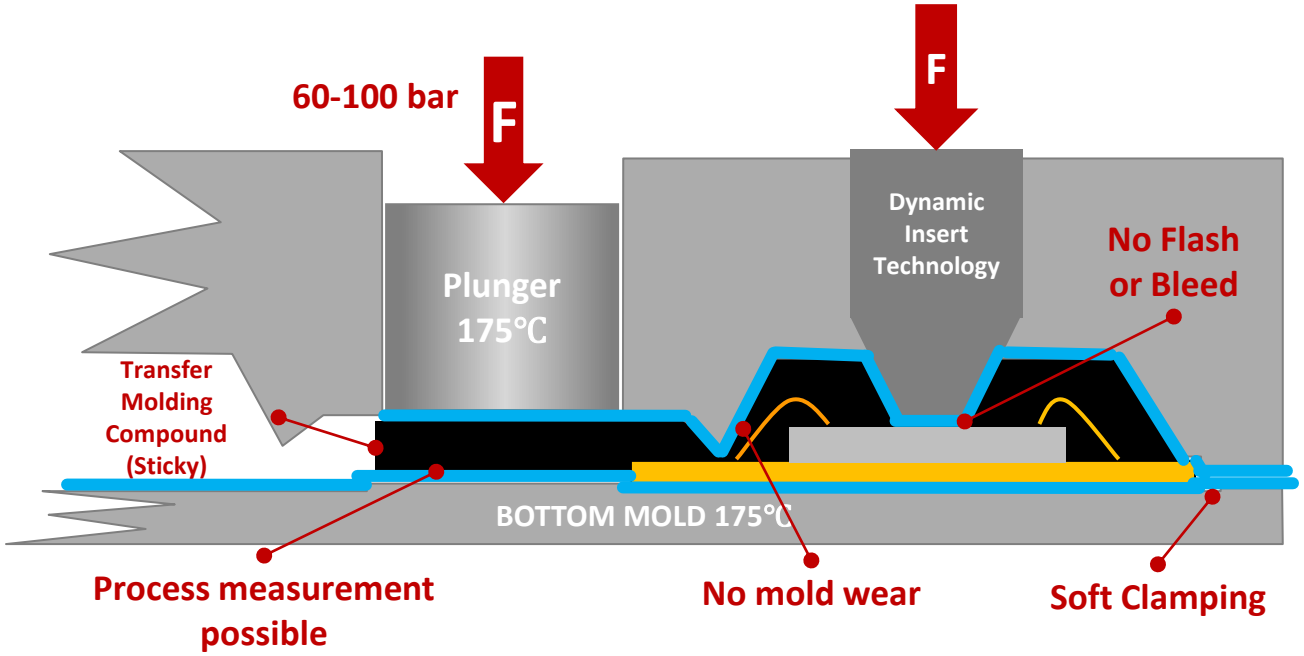
## **Film Assist Molding** Technology with **Dynamic Insert Technology**

- Film Assisted Molding (FAM) is a variation on the transfer molding process. It uses one or two Teflon based films in the mold, which are sucked down onto its inner surface before products are being loaded.
- In combination with Boschman's Dynamic Insert Control Technology (DIT), it enables to produce very specific package designs that couldn't be made otherwise.
- Especially the possibility to create packages with open areas down to 300 micron (versus 500 micron with conventional techniques) in a stable and robust process, offers a lot of interesting opportunities.
- Film-Assisted Molding offers a number of advantages over conventional transfer molding. These include the easy release of the encapsulated products from the mold, and the fact that metal surfaces are kept clear of sticky molding compound; so less maintenance and thus a higher running efficiency and output.
- Another advantage is that the film functions as a soft cushion resulting in less wear of mold parts, i.e. a longer service life.
- The Dynamic Insert Technology has the following advantages: can compensate height and tilt tolerances up to +/- 100 micron, closed loop controlled low Pressure on every single die.
- The Dynamic Insert Technology enables a flash and bleed free exposed area and delivers a very consistent and high quality

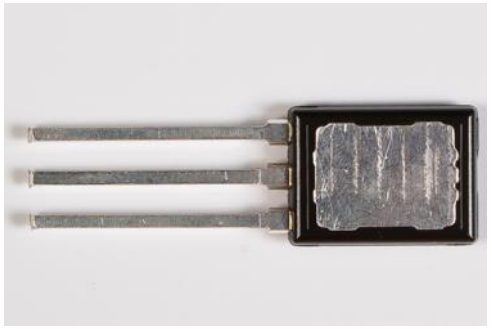
# Advanced Transfer Molding

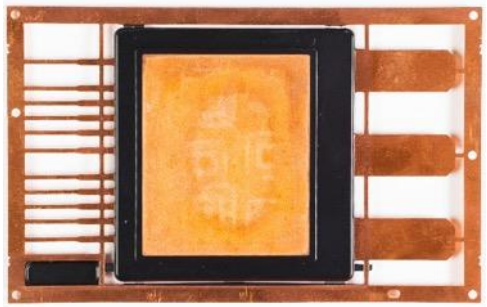
## Film Assist + Dynamic Insert Technology

- 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

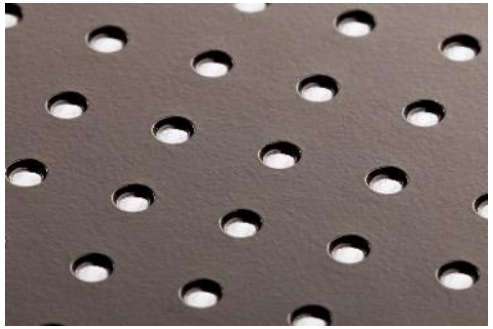


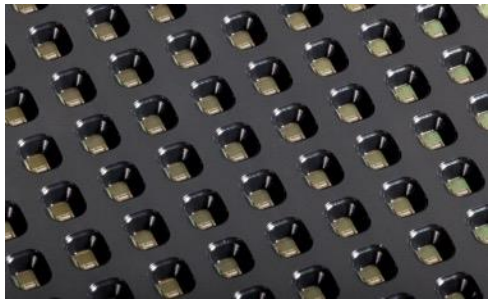

**POWER**

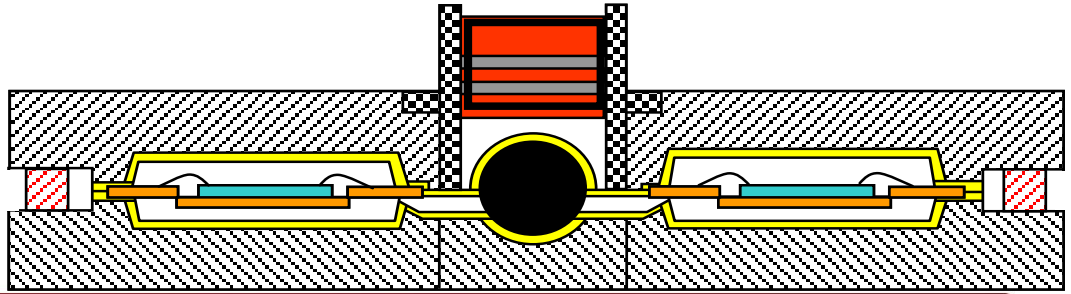




**MEMS & SENSORS**

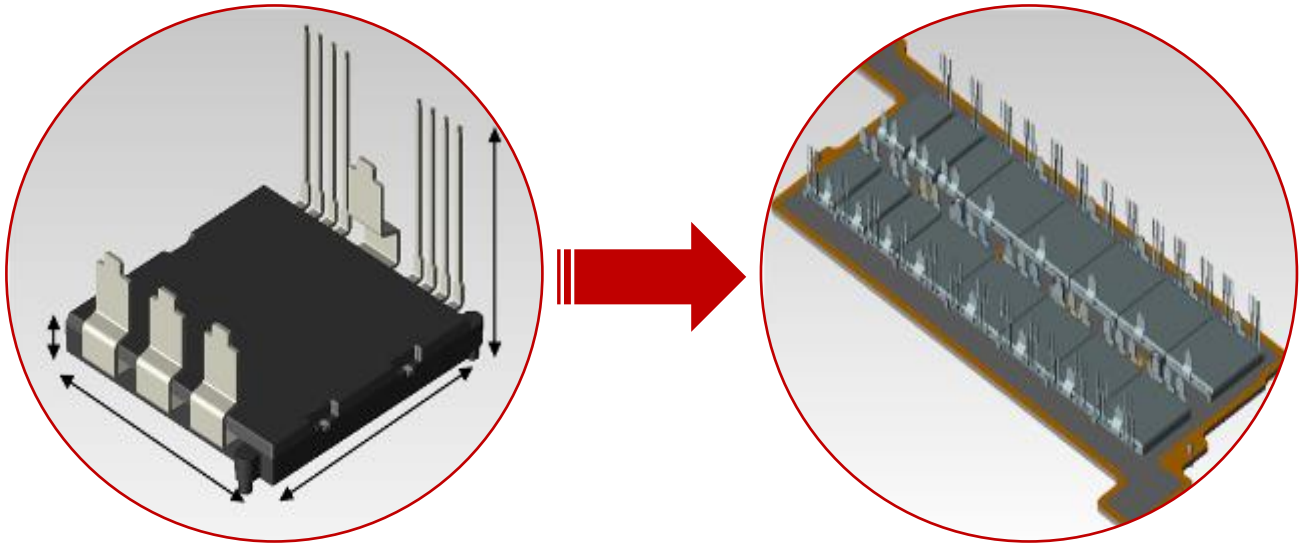






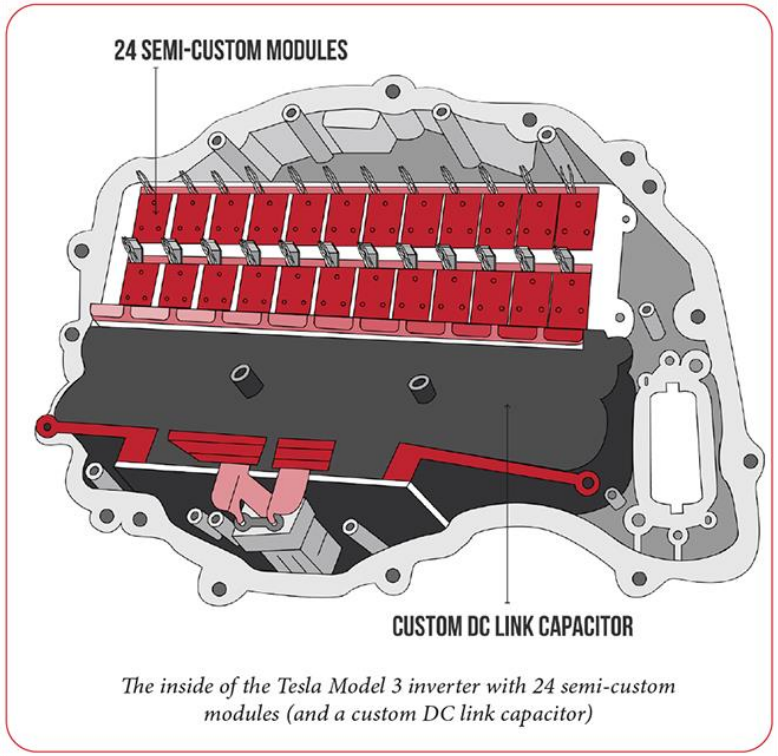
# Power Electronics Supply Chain

## Shifting Landscape



**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)

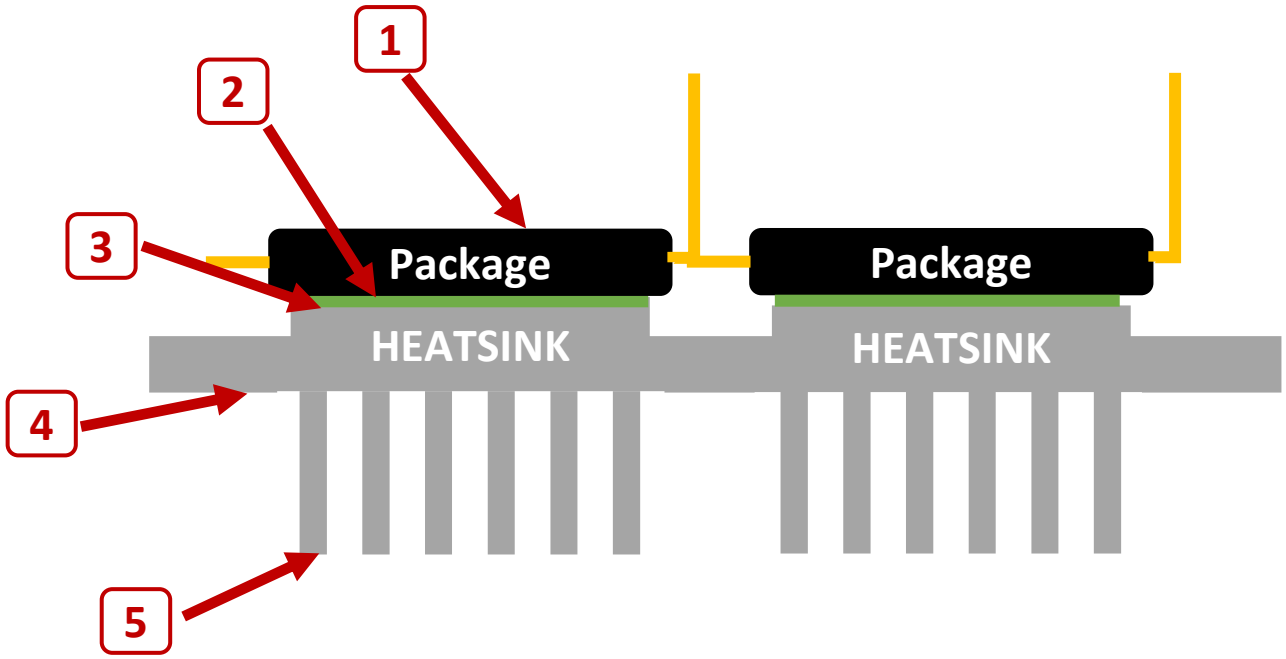



*The inside of the Tesla Model 3 inverter with 24 semi-custom modules (and a custom DC link capacitor)*

# PAS / Process Flow

# Challenge: Z-tolerance stack

## Tolerances determine required tooling solution




1. Package thickness and warpage variations
2. Paste thickness variations
3. Pedestal height and flatness variations
4. Coolerplate thickness and flatness variations
5. Pin finn height and flatness variations

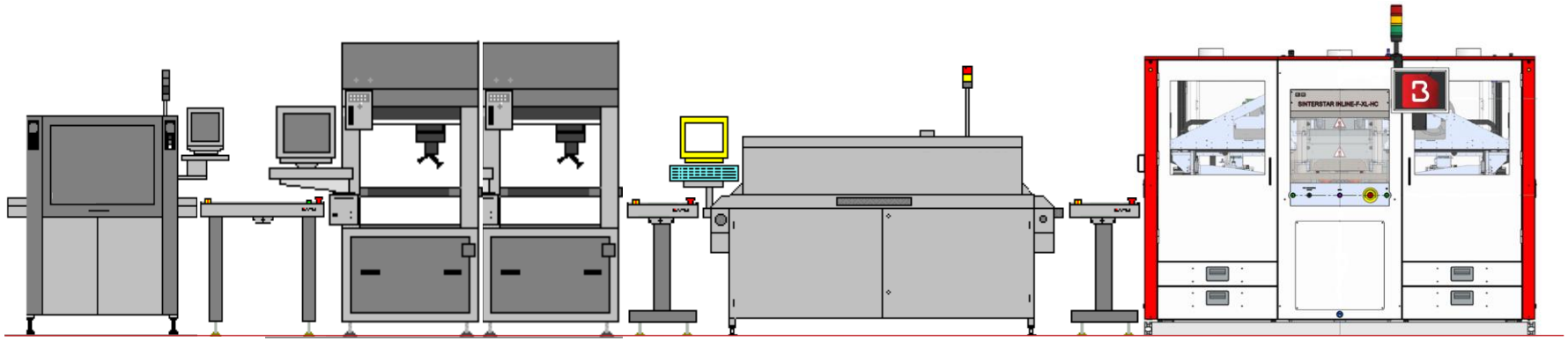
Subject to design, individual dynamic inserts should be used to balance top and bottom pressure for each package to ensure uniform pressure on all individual packages is applied.

By default Boschman uses Top Dynamic Insert Technology for compensating package to package and pedestal to pedestal differences within one Cooler plate assembly.

Optionally Bottom Dynamic Insert Technology can be required for compensating additional (e.g. pin finn area) height variations

# Package to Heatsink Sinter Process Flow

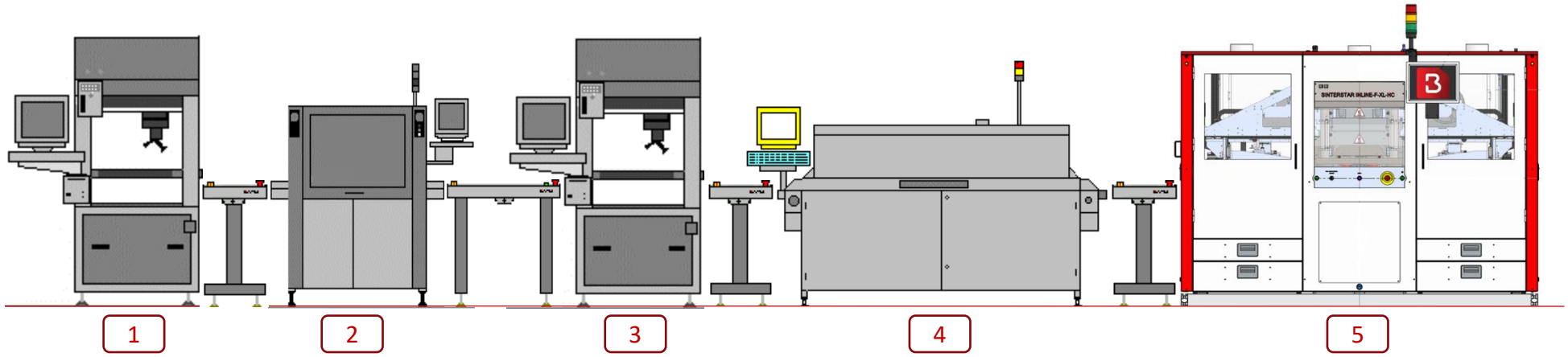
## Package Attach Sintering - Simplified

# Possible process flow

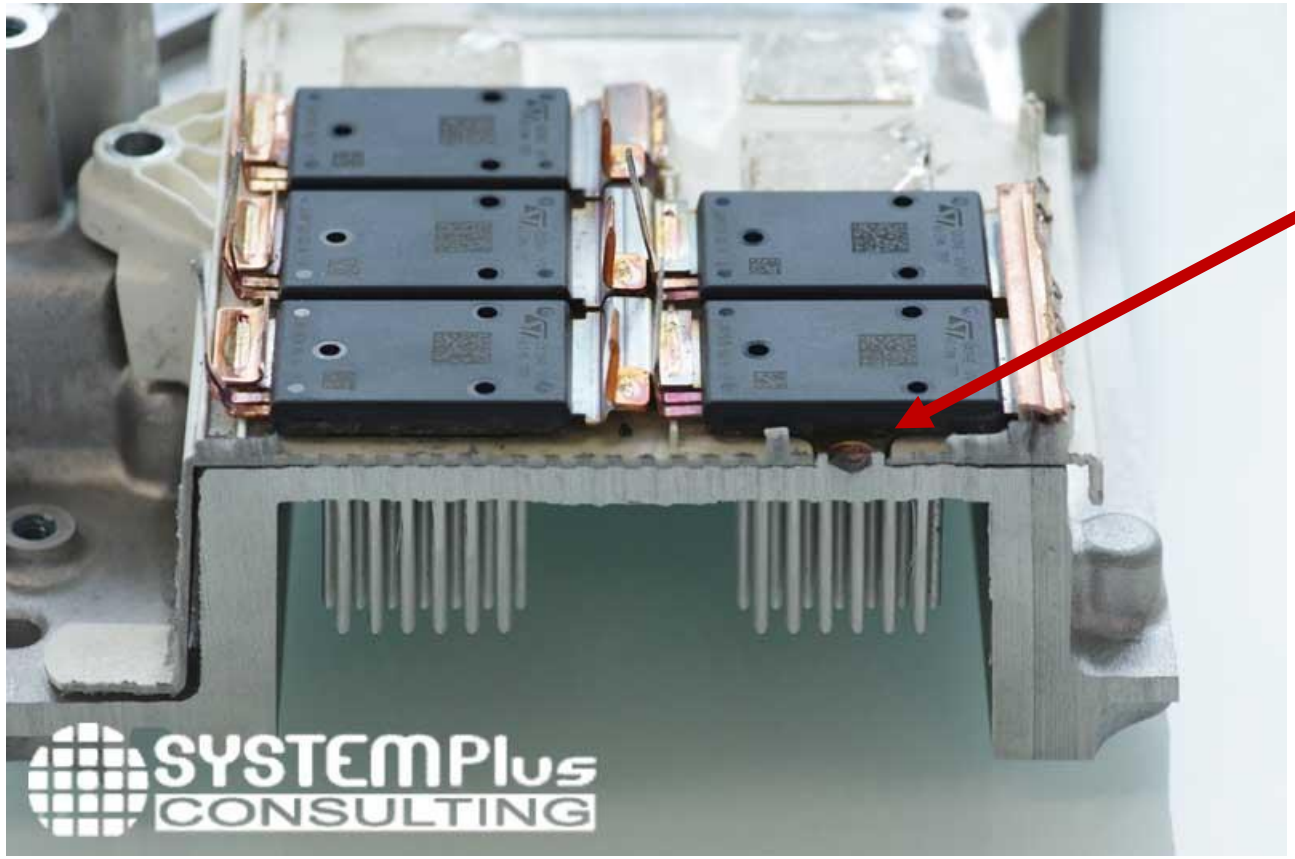
## Complete process flow

1. Placement of heatsinks in carrier
2. Paste application (Flatbed Dispense or Screen Printing -TBD) on heatsinks
3. Placement of Packages on Heatsinks
4. Paste drying
5. Sintering



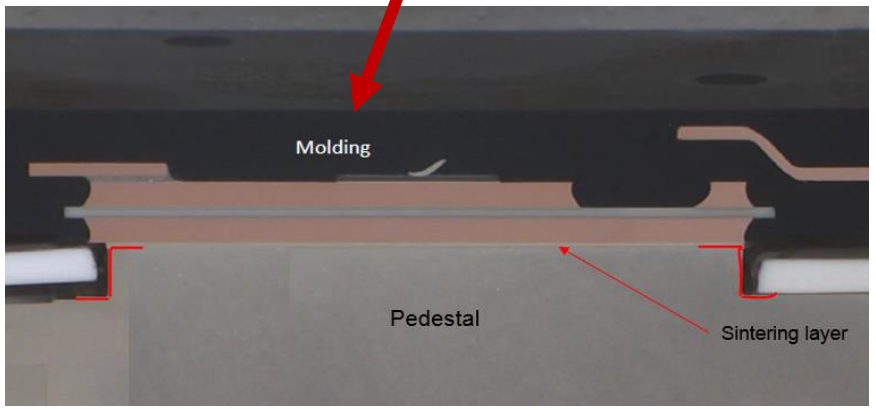
# Examples

# Example: Tesla




Sinter the package into the (inverter) housing.

Cross section



# Boschman Advanced Packaging

## Assembly Lab & Analytical Capabilities

For the Package Development and Assembly Services we have a 280m$^2$ micro-assembly lab, with all required equipment to build proto-types and small series in house:



# Perfecting the Package

## Innovative Final Assembly Stages for Power Module Manufacturing

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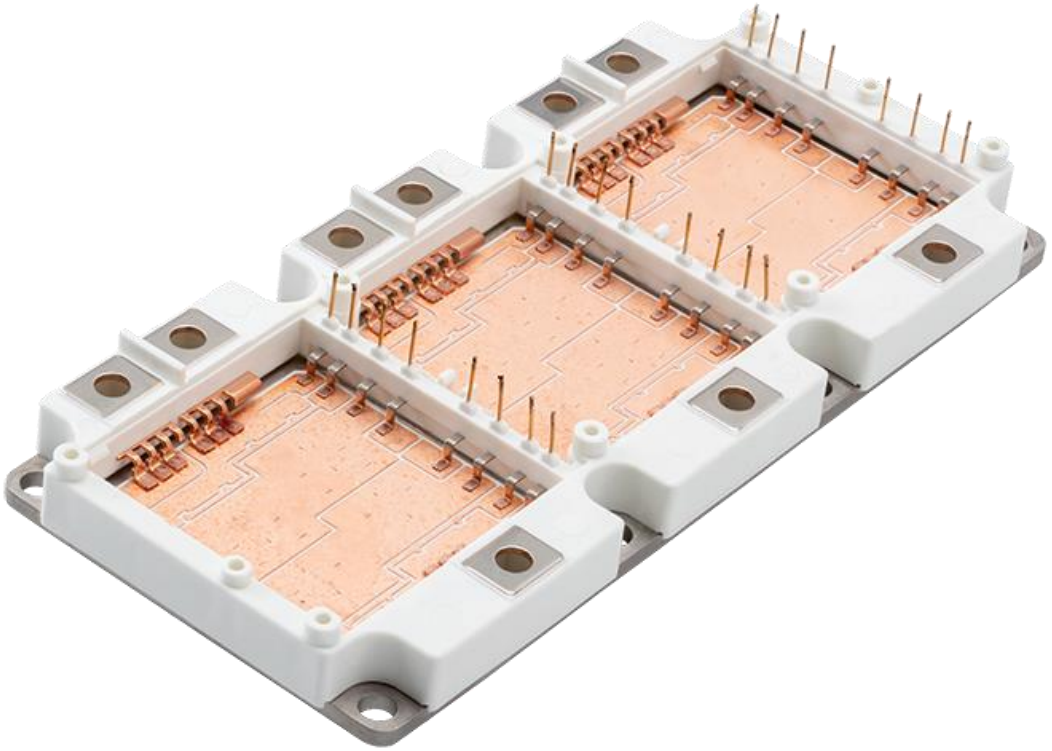
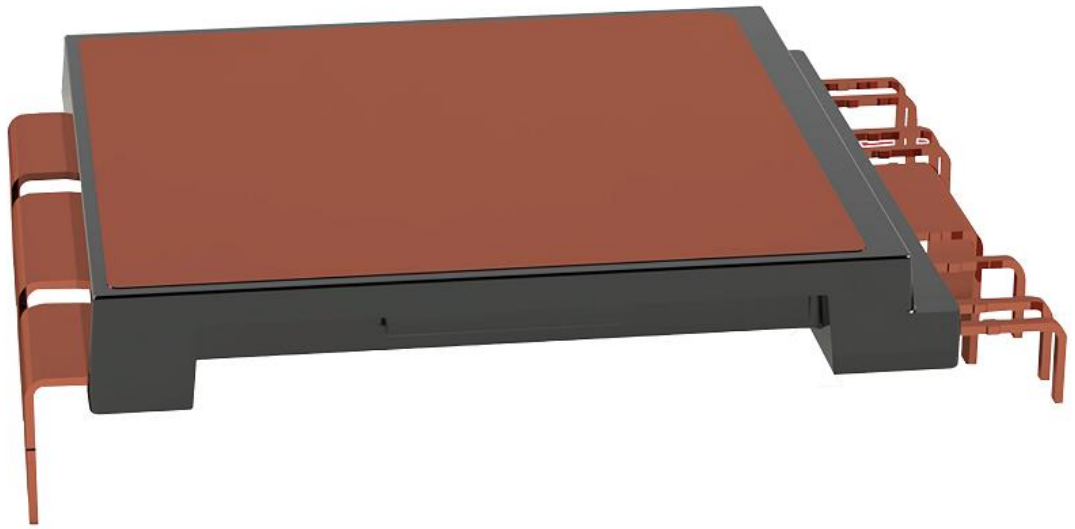
# From Casing to leadframe based Power Module





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# Trim and Form Process

- **Dambar Trimming**

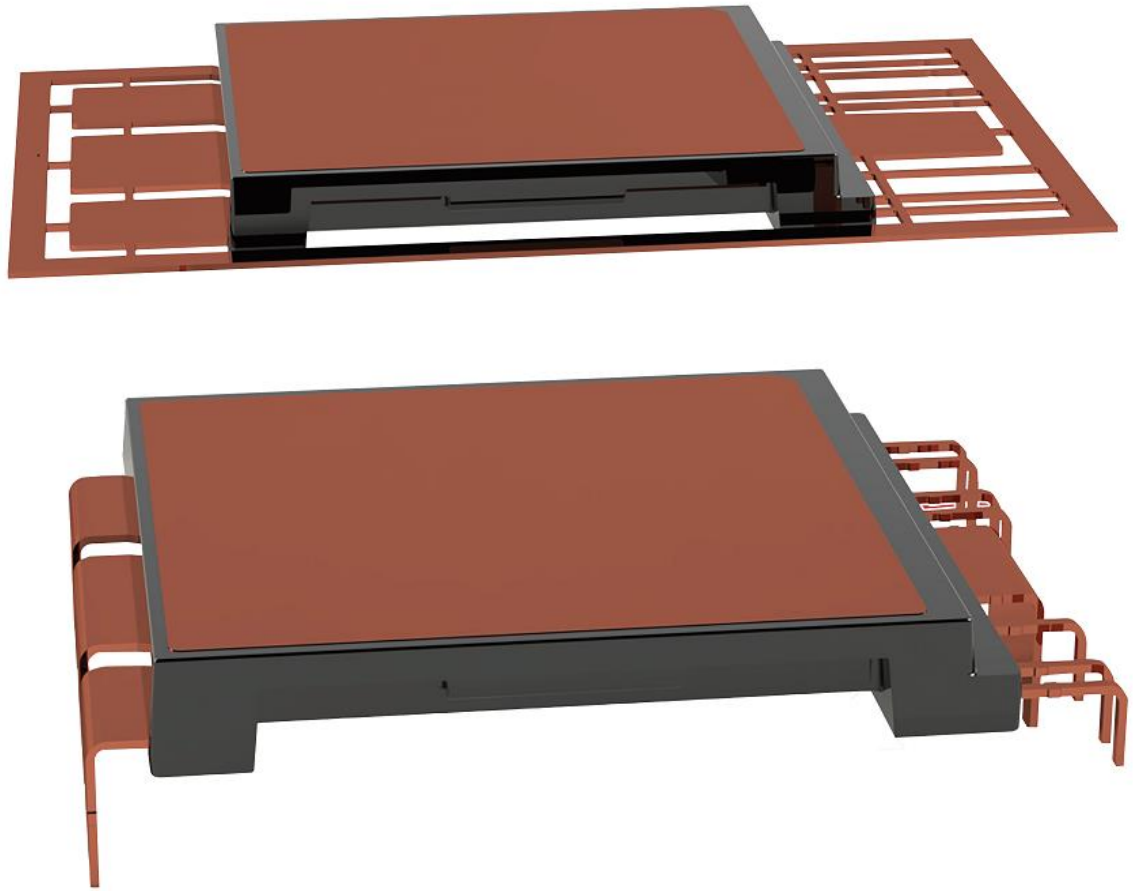
Removing dambar with Trimming Tool

- **Signal / Power Leads Forming**

Forming Leads with Forming Tool

- **Singulation**

Removing excess leadframe with Trimming Tool



TFA

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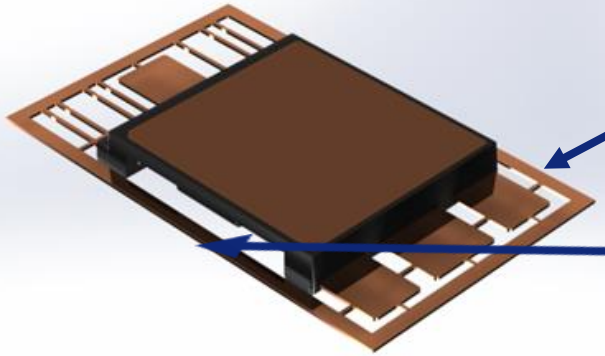
# General considerations: Trimming and Forming process

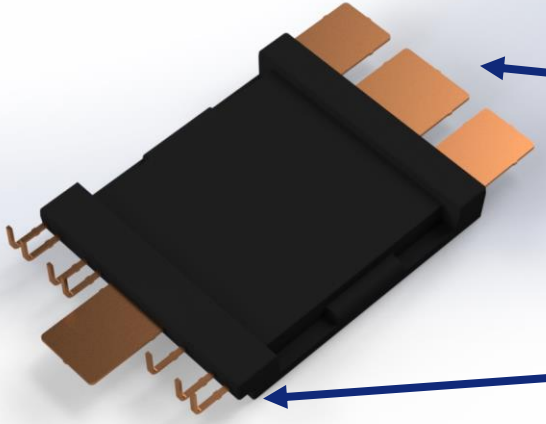


**Dambar cutting / de-junk**

- 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



**Final leadlength cut**

- avoid cutting burrs
  - might effect the forming process
  - avoid cupper smearing / contaminations of tools

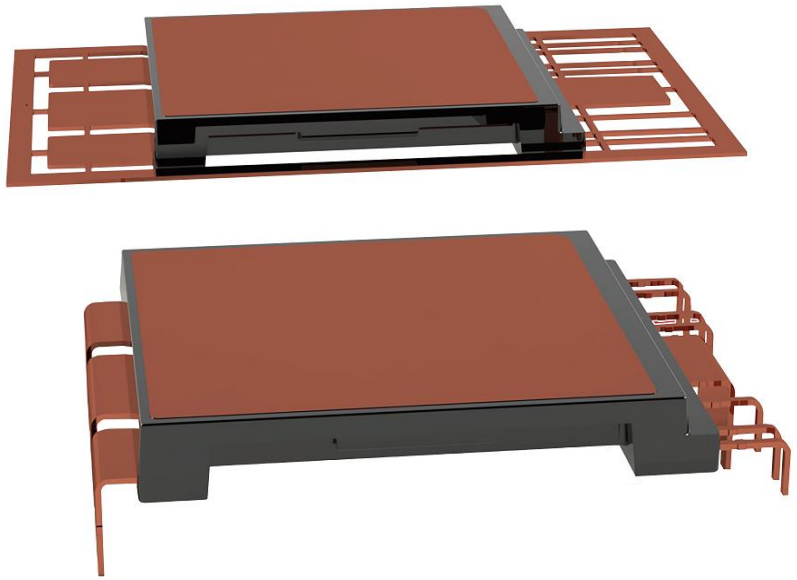
**Forming process**

- shape requirements /forming process (avoid scratches / roller forming)

# Trim and Form Tooling

**Trimming and Forming of power leads (Cu leads/ thick Cu) requires force and stroke controlled process**

- Servo driven force and stroke controlled presses
- Tools designed with hardened  steel and carbide re-grindable parts to ensure lowest cost of ownership
- Easy accessible tools for maintenance and tool change within 15 minutes

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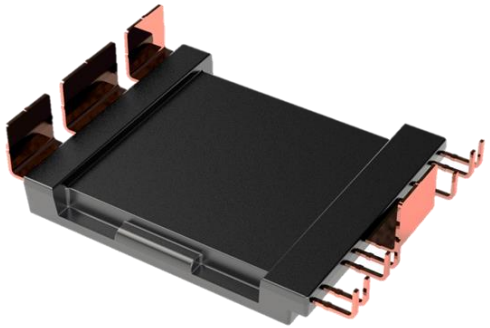
# Automation solution for Power Module Trim and Form


## TFA Flex Line



**High press force and up to 3 force controlled presses**

**High productivity up to 1200 Power M odules per hour**

**Product change within 15 minutes**

**Flexible integration with other process steps**

**Loading and offloading options**

Magazines
Trays
In-line
AGV's
Transport belt

**Optional items**

Barcode / DMC reader
Laser marking
Laser cleaning
Product inspection
MES integration

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**Fully servo driven system: No air supply or hydraulics required**

# Flexible product handling

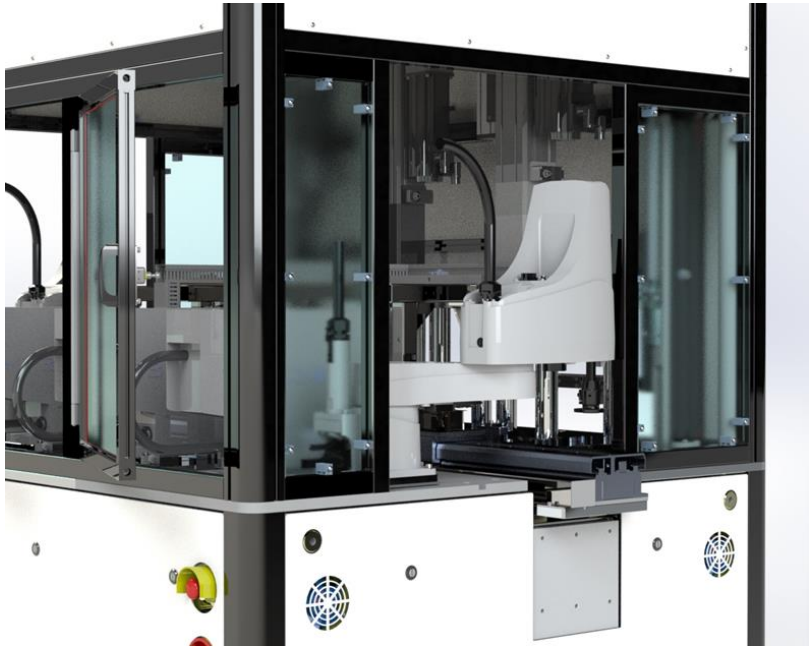
**Enables handling of different power modules in one system**

**Scara robot for loading and offloading**

- Flexible handling of the Power modules

**Product change within 15 minutes**

- Tools easy accessible for maintenance or product change
- Product related parts are easy changeable:
- Tools, product carriers, robot grippers and system program
- RFID for tool recognition



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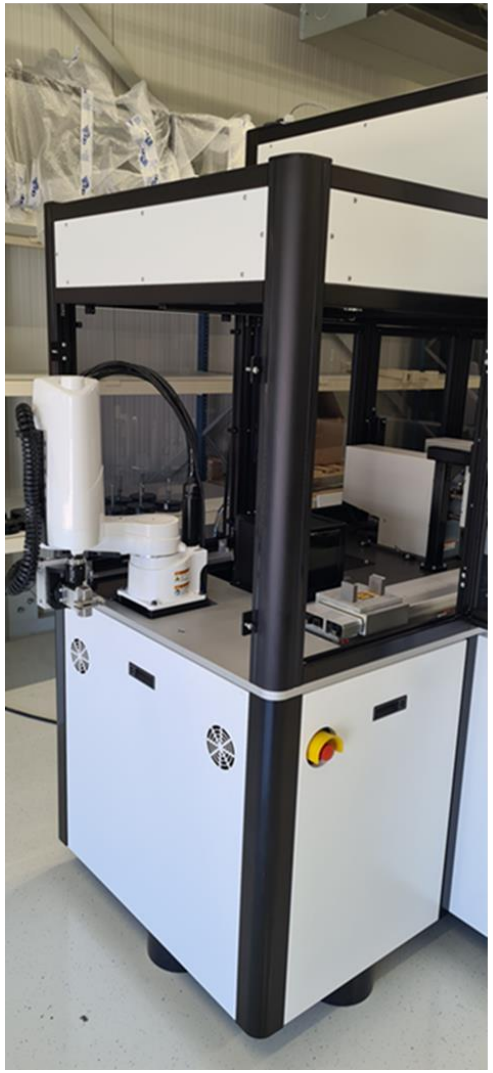
# Flexible Loading and Offloading options

- In-line
- Transport belt
- Magazines
- Trays
- AGV's
- SMEMA compatible



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# Optional Items

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


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# Data collection / tracability per individual Power Module

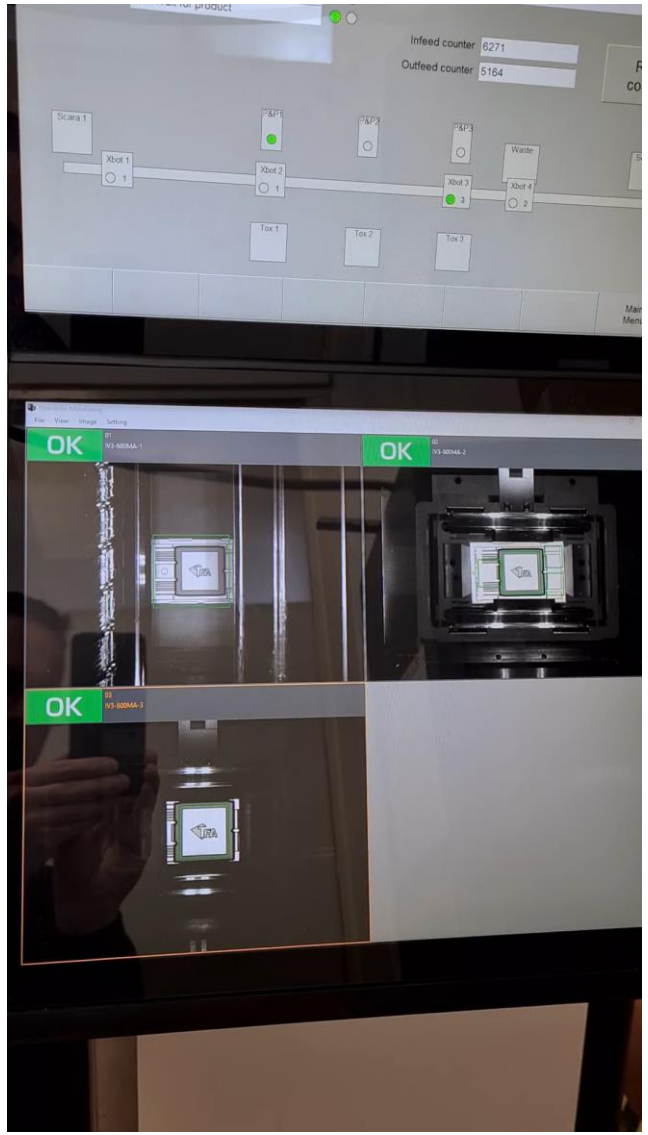
- DMC / Barcode reader
- Laser marking to mark DMC / Barcode on individual Power Module
- Location of power module during all production steps
- Press force and stroke
- **Vision sensors (3) between presses to control process steps:**

- Position of power module on internal linear transport system
- Control trimming process before approval for next process step
- Control forming process before approval for next process step

- **Automatic optical inspection for final product:**

- Pin positions
- Pin angles
- Overall dimensions

**All process data saved for data collection / host communication**

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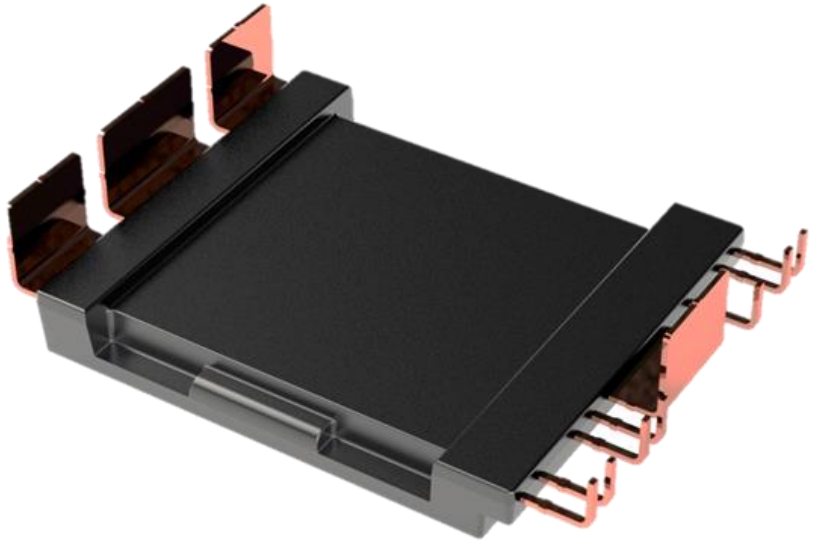
# Power Module Prototype Support

- Package and leadframe design support
- Protoype tooling for manual production and product qualification
- In-house engineering and manufacturing
- Sample production
- Quality measurements



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# Strategic partnership
# Boschman Advanced Packaging Technology

**Partnership to ensure a total solution for Power Module Development and Production**

- Package developement
- Assembly services
- Pressure sintering Equipment & Tooling
- Transfer Molding Equipmenet & Tooling
- Trim and Form Equipment & Tooling


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advanced packaging technology

# Thank you for your attention!

## For more information:


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# from idea to industrialization

**package development**
by boschman

**assembly services**
by boschman

**production equipment**
by boschman

## questions or support?


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