Fundamentals and Applications of Modern Interconnection Materials for Electronics Packaging

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Speaker:

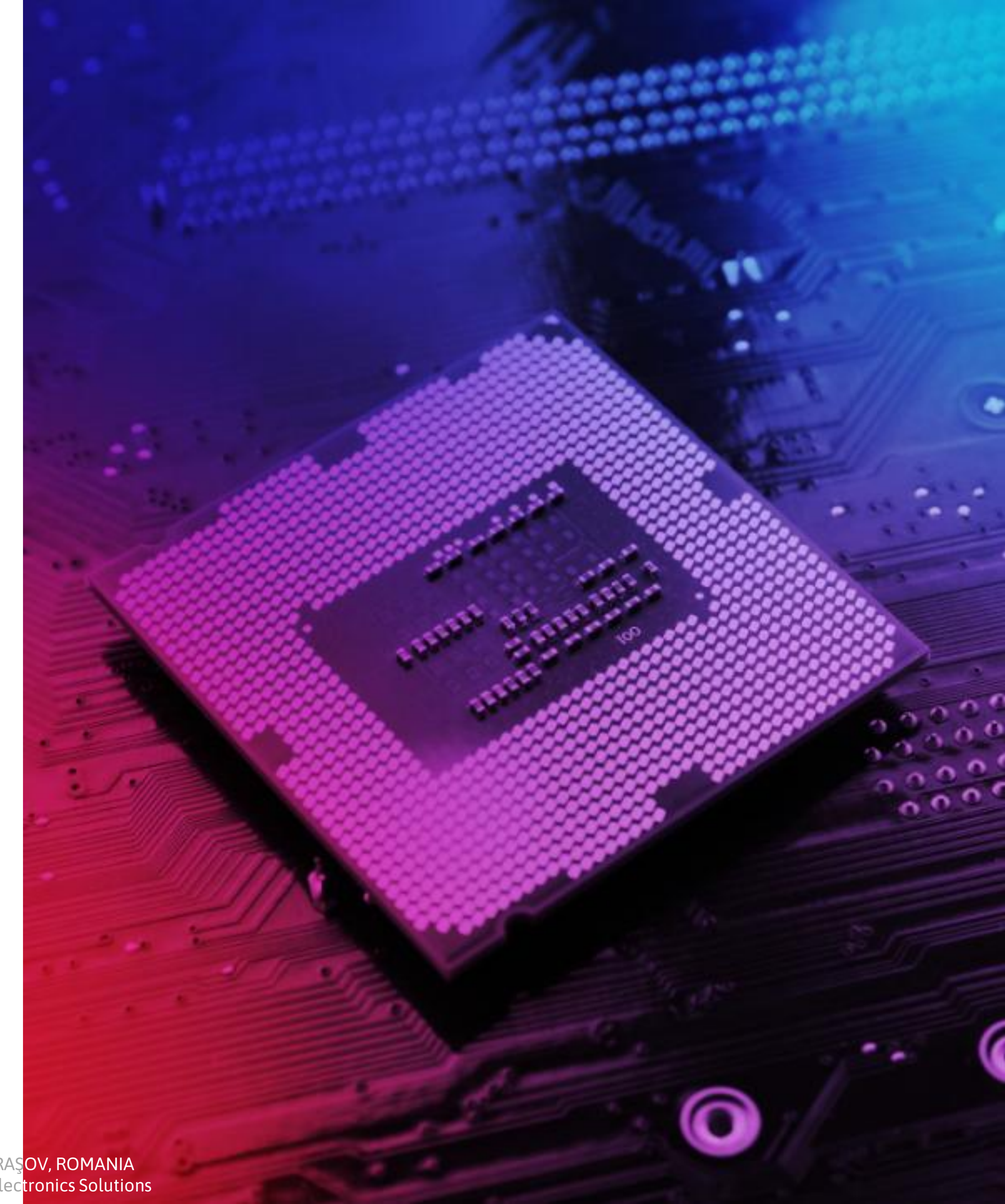
Martin Metzler, Director Technical Business Development Europe

MacDermid Alpha ELECTRONICS SOLUTIONS

Agenda

Fundamentals of Interconnection Technologies

- Differences between soldering, hybrid sintering and sintering
- Overview of material properties



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Differences between soldering, hybrid sintering and sintering

Soldering – History

In the Ancient World

Appx. 3200 BC first known brazing of gold objects, Egypt

Appx. 2000 BC tin is known production of bronze

Around 0 BC: beginning of soft soldering use of tin and lead

The Golden Death Mask of Tutankhamun
appx. 1300 BC

Picture: Michael Reeve, CC3.0
Source: https://commons.wikimedia.org/wiki/File:Tutanchamun_Maske.jpg

Middle Ages

Development of brazing and soft soldering

Soft soldering – lead glazing

Brazing - Armors - Chainmail

Bronze Skean with a handle made of Gold foil (protopalatial , 1800–1700 BC) from Malia, Crete

Picture: Olaf Tausch, CC3.0, Source: https://commons.wikimedia.org/wiki/File:Bronzedolch_Malia_01.jpg?uselang=de

Differences between soldering, hybrid sintering and sintering

Soldering – History

Since 1900

- Development of Welding technology
- Development of new areas of application for soft solders in upcoming electronics

Appx. 1950 beginning of high-volume electronics manufacturing

- Development of mass soldering → first wave/ drag soldering equipment
- Introduction of the Printed Circuit Board – wave soldering
- Late 1950s – Surface Mounted Devices were introduced, SMT – reflow soldering
- 1970 – SMD appear in consumer electronics
- For a long time components have been getting smaller & smaller…mixing technologies
- Soldering with Mini Wave (selective/robotic soldering) and much more…
- 2006 – Lead (Pb) was banned from solders for electronic soldering

Differences between soldering, hybrid sintering and sintering

Soldering – Soft Soldering & Brazing - Differentiation

The **conventional temperature border** between **soft** soldering and **brazing** is 450°C

with actual brazing temperatures often ranging from 600°C to 900°C, or possibly higher, depending on the alloy used

< 450°C → **Soft** soldering → electrical connections

> 450°C → **Hard** soldering (brazing) → mechanical connections - e.g. gas & water piping

Lead-containing alloys

- <85%, low lead containing alloys, with melting points (or melting ranges) from **179-190°C**
- >85%, high lead containing alloys, with melting points (or melting ranges) from **275-312°C**

Lead-free alloys

- most melting points (or melting ranges) from **217-245°C**

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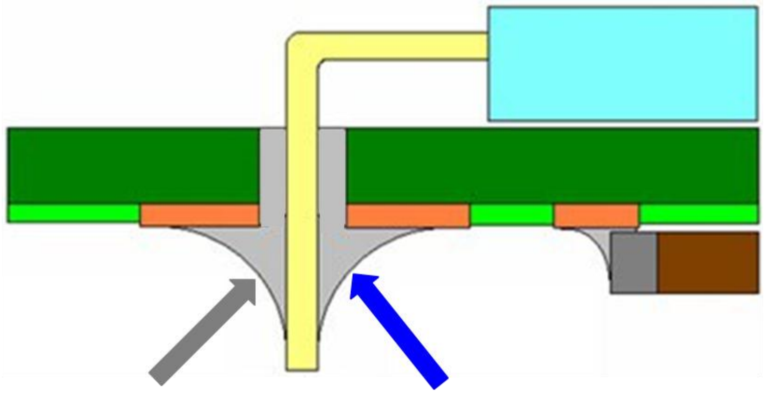
Differences between soldering, hybrid sintering and sintering

Soldering – Basics

What do we need?

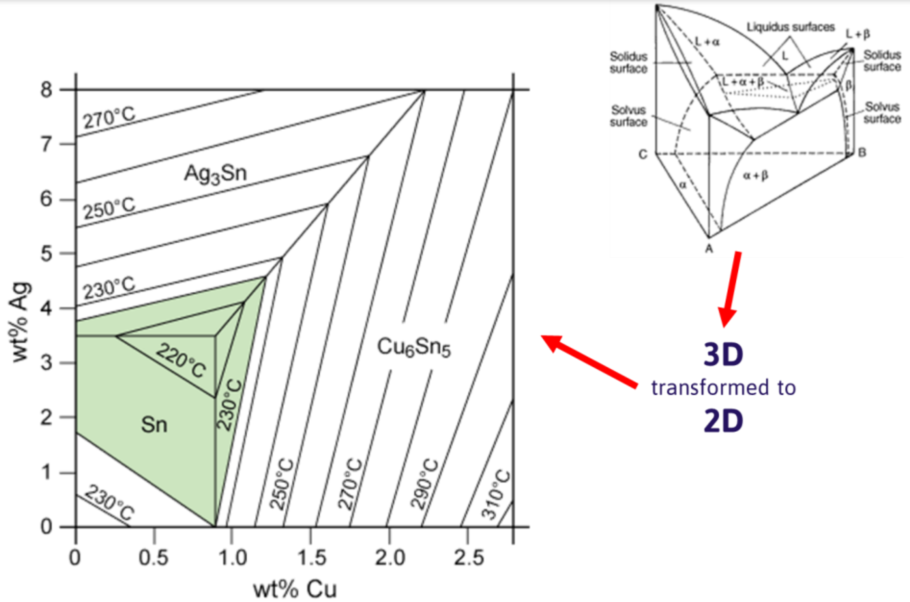


Solder / Alloy

Flux
for clean metallic surface

Energy
= Heat (for liquid solder)

Phase-Diagram for Tin, Silver, Copper



Sn95.5Ag3.8Cu0.7 = **SAC387** Lowest melting point 217°C **Eutectic**	Sn96.5Ag3.0Cu0.5 = **SAC305** Melting range 217-223°C	Sn98.5Ag0.8Cu0.7 = **SACX0807** Melting range 217-225°C

Differences between soldering, hybrid sintering and sintering

Soldering – Intermetallic Compounds

- During soldering processes, it is necessary, that intermetallic layers are created by diffusion processes. These intermetallic layers consist, in this example, of Cu_6Sn_5 and Cu_3Sn

  often called
  IMC = **I**nter**M**etallic**C**ompound
- **Dissolving - not melting!**
- Copper melting point 1085°C
- Tin melting point 232°C
- Growth of the intermetallic layer **continues in solid state** via diffusion

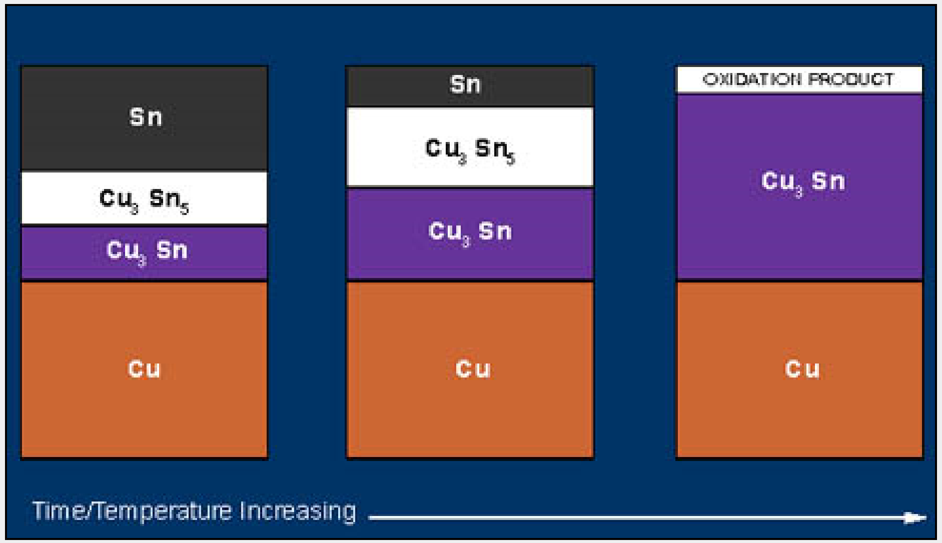
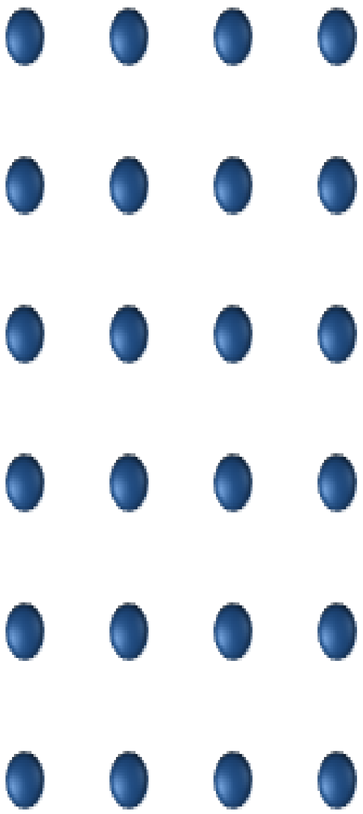


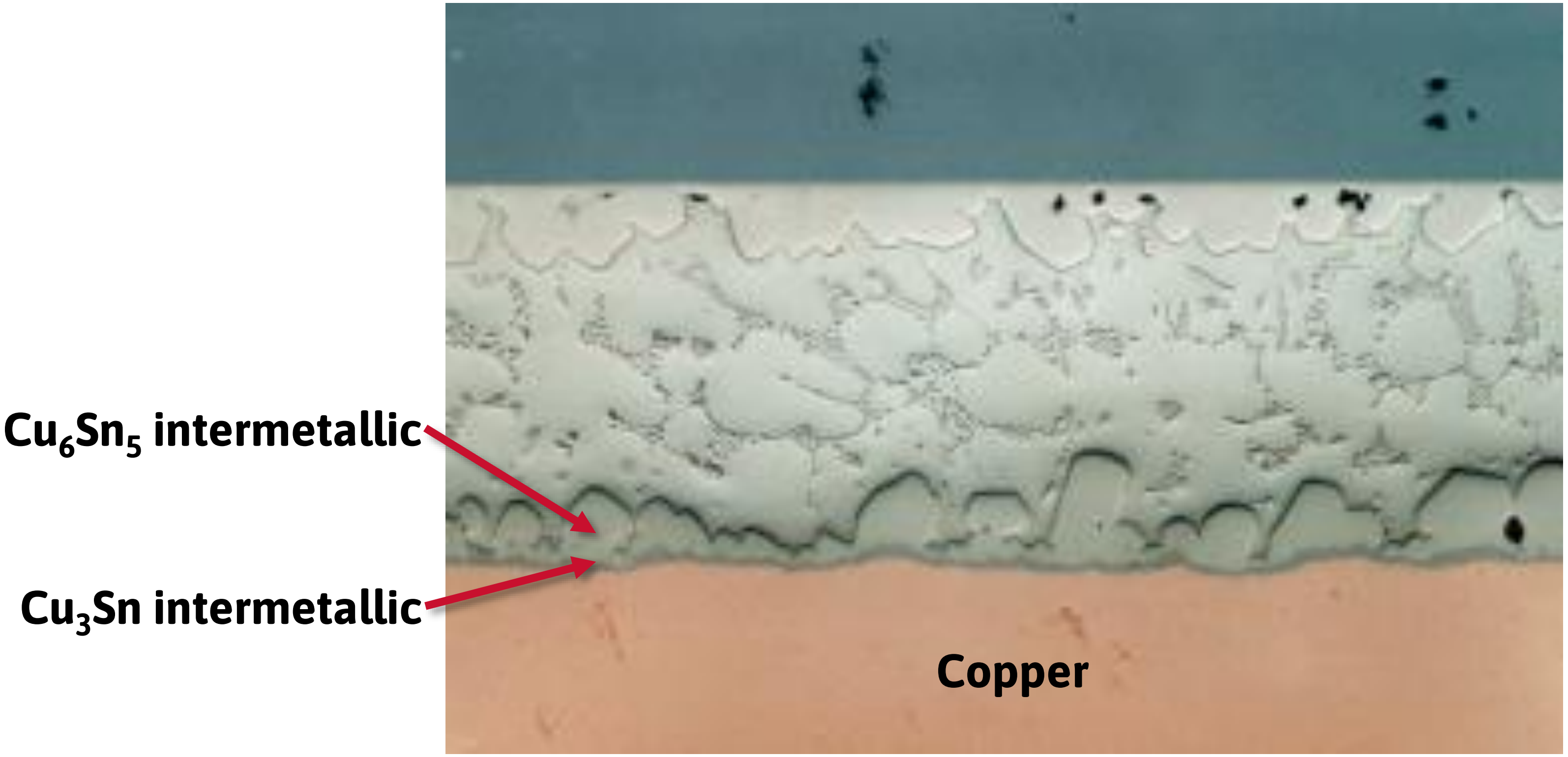
Figure 4 . Intermetallic Growth on Tin Coated Copper Alloy Strip



Animation source: Wikipedia

Differences between soldering, hybrid sintering and sintering

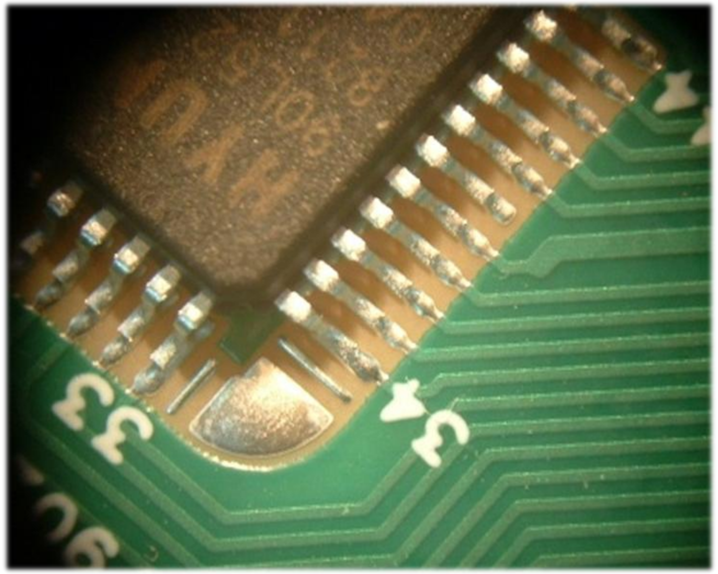
Soldering – Intermetallic Compounds



Intermetallic layers after soldering are typically 0,5-2,5µm

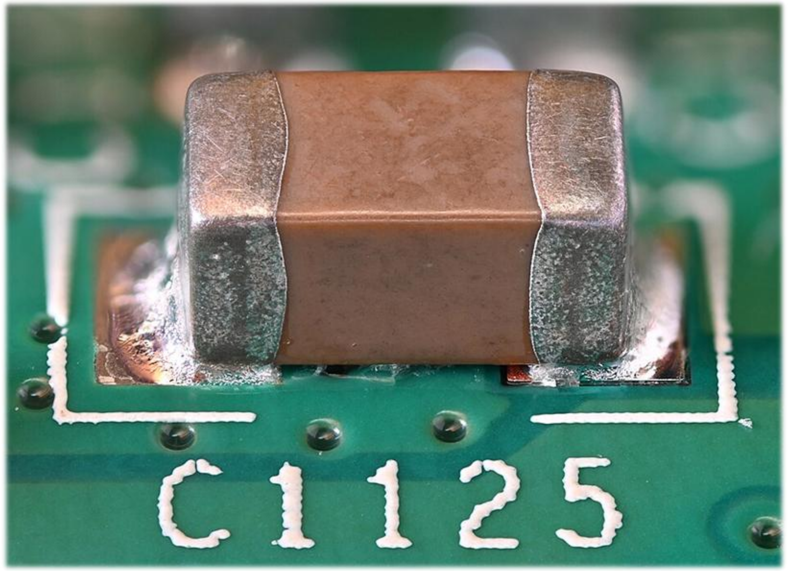
Differences between soldering, hybrid sintering and sintering

Soldering – Examples of Solder Joints



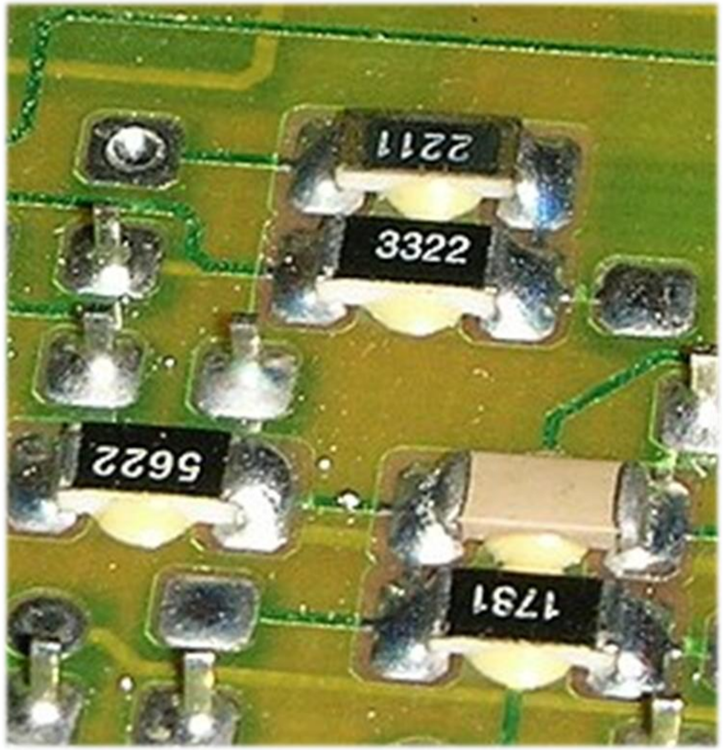
QFP wave soldered with SACX0307 alloy, with solder thief on corner

Source: internal



Chip component, SMD with alloy SAC305 soldered, some time used, brownish solder paste residues

Source: File:Big SMD capacitor 2.jpg - Wikimedia Commons, not changed, Licence: Attribution-ShareAlike 3.0 Unported - Creative Commons



Chip components, SMD technology but wave soldered, with SMD adhesive dots underneath

Source: Surface Mounted Device, soldered.jpg - Wikimedia Commons , not changed, Licence: Attribution-ShareAlike 3.0 Unported - Creative Commons

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Differences between soldering, hybrid sintering and sintering

Hybrid sintering and Sintering – History

- Hybrid Sintering and Sintering have their beginnings in the late 1990s to early 2000s
  - Early research on nanoscale silver sintering was carried out at universities and research institutes.
  - The objective was to develop lead-free, high-temperature joining technologies for power electronics.

Hybrid-Sintering

- Sintering, there were very high process requirements (pressure, temperature, surfaces).
- 2010 – Reduction process pressure, compatibility to multiple surfaces, higher production flexibility.
- 2012-2016 – First hybrid-system as a combination of Silver particles + organic matrix system
- 2017 – Series applications for Power Devices
- 2020 – Trend to low sintering temperature (<180°C)

Sintering

- 2000 – Industrial partners such as MacDermid Alpha began industrial development and manufacturing.
- 2010 – Silver sintering established in high-performance and high-temperature applications
  - Scale-up of production capacities
  - Adaptation to new applications such as large area sintering (2016)
- Today – development lower sintering temperature (<200°C) and new particle system like copper

Differences between soldering, hybrid sintering and sintering

Hybrid sintering

Hybrid Silver-Sintering Die Attach

Two attachment (bonding) mechanisms: Chemical and Silver-sintering

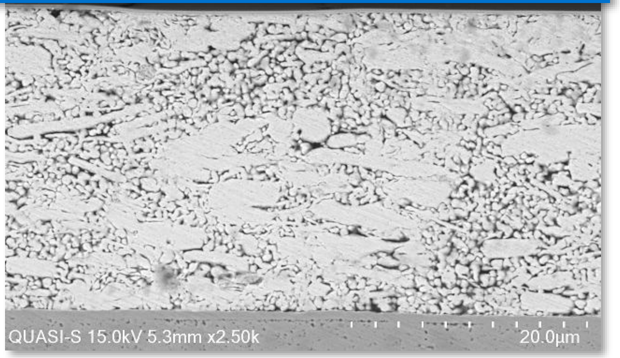
The fusion of Ag particle under heat and time

Process of attaching a die to a substrate/ Lead-frame

! NOT an Electrically Conductive Adhesive (ECA)

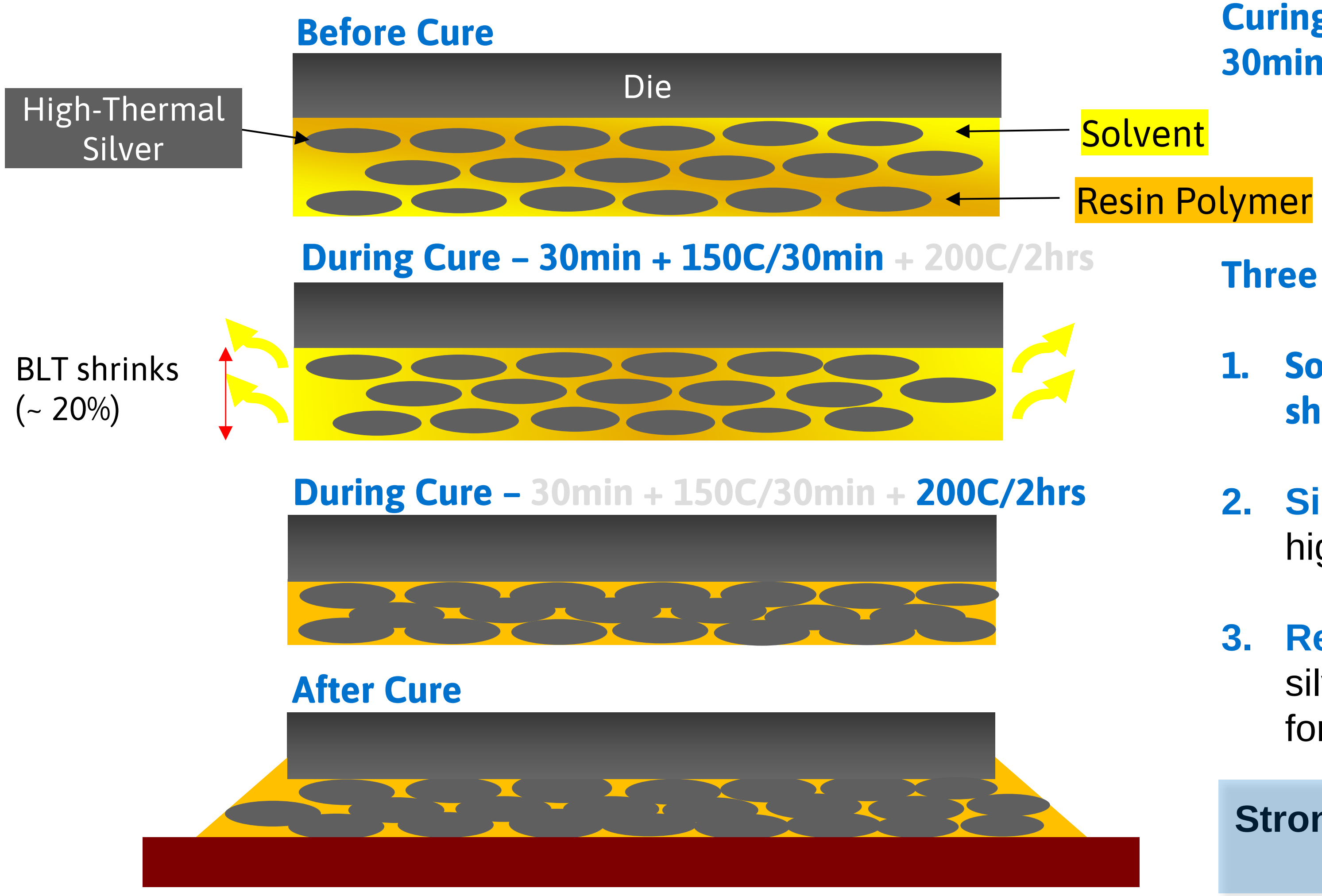
Hybrid Silver-Sintering Material Composition

- **Silver** µm dimensions, various morphologies
- Thermoset **Resin**
- Diluents **(Solvent)**



Differences between soldering, hybrid sintering and sintering

Hybrid sintering



Curing condition, as example:
30min + 150C/30min + 20min + 200C/2hrs

Three key processes occur during curing

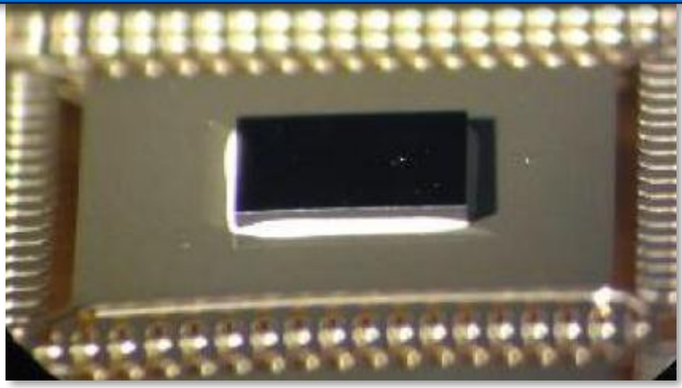
1. **Solvent evaporates** (increasing %Ag) and **BLT shrinkage** occurs
2. **Silver sinters** as the temperature rises, forming high-conductivity sintered-silver joints
3. **Resin** flows into gaps and back-fills area between silver particles, then cures (**cross-links**) thereby forming strong joints between die backside and LF

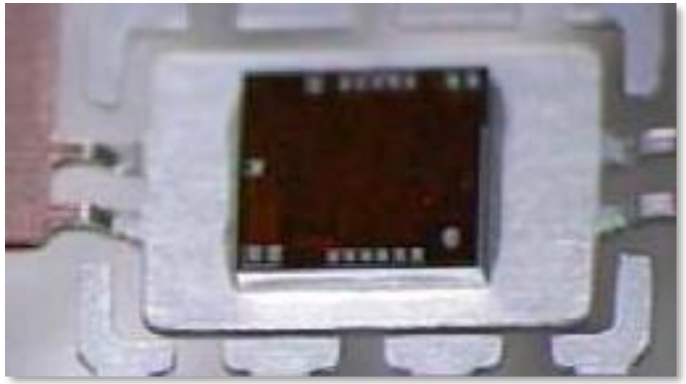
Strong joints formed between Ag particles, DA to die backside, and DA to LF surface

Differences between soldering, hybrid sintering and sintering

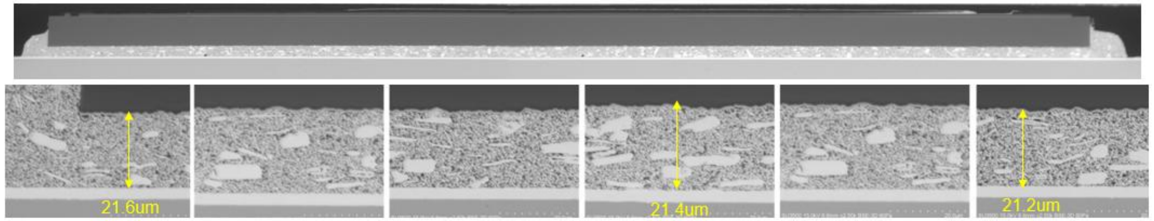
Hybrid sintering - Examples of Joints

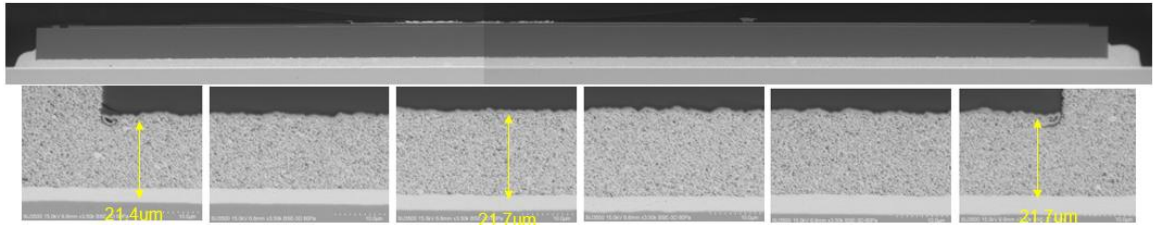
Side-view of attached dies	Cross-section (different filler types)





Examples with thin die ~60µm





Differences between soldering, hybrid sintering and sintering

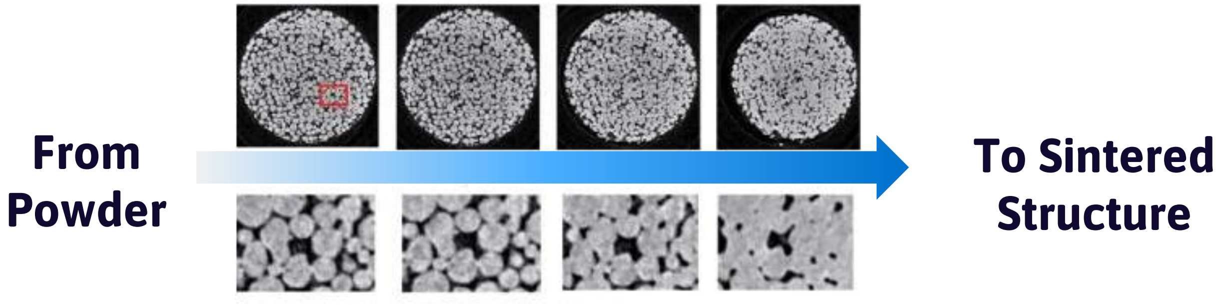
Sintering

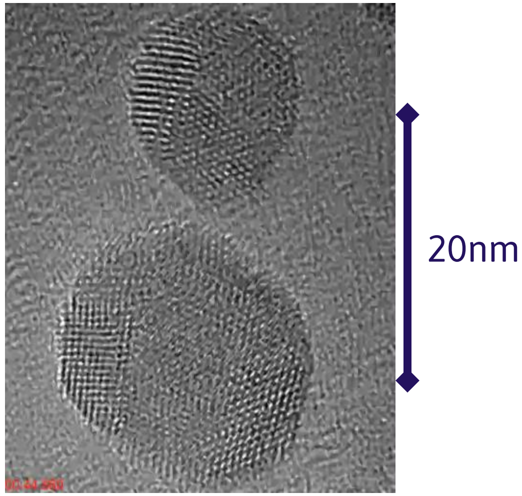
Sintering is a method used to create objects from powders.

It is based on **atomic diffusion**. Heated to a temperature below the melting point, the atoms in the powder particles diffuse across the boundaries of the particles, fusing the particles together and creating one solid piece.

Material transfer is affected by the **change in free energy** across the curved surface. If the size of the particle is small, these effects become very large in magnitude. The change in energy is much higher when the radius of curvature is less than a few micrometers.

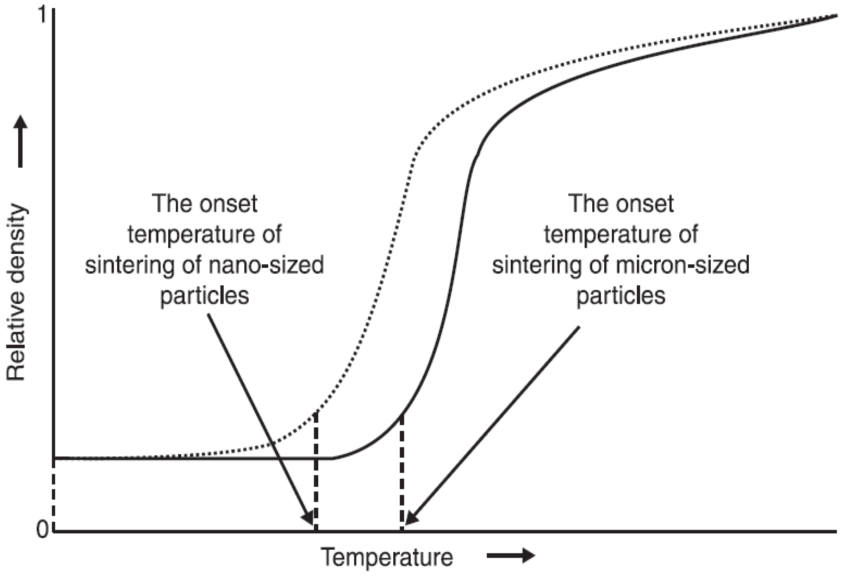
Nano scale powder e.g. Argomax® sinters at T>190°C (typical processing temp 230-250°C) with low applied pressure – a benefit of the nano sized particles.



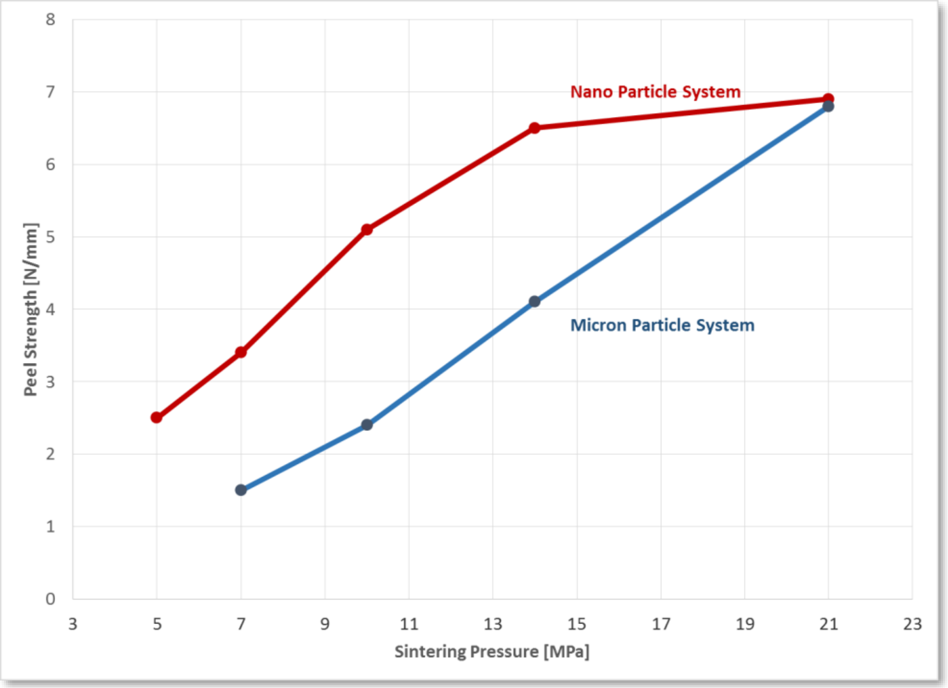


Differences between soldering, hybrid sintering and sintering

Sintering



Wang, Z.Z., and H. Fang. 2010. "Sintering of ultrafine and nanosized particles." In *Sintering of advanced materials*, 434-473. Wooodhead Publishing Limited.



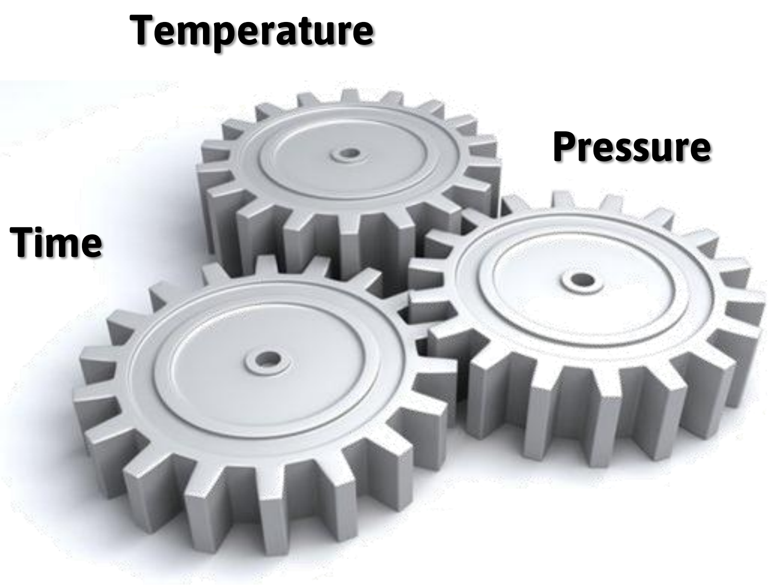
Test vehicle with sintered ribbon Ag/Ag for 1min@250°C

Nanosized particles sinter at lower temperatures/ pressures (compared to µ-scale)

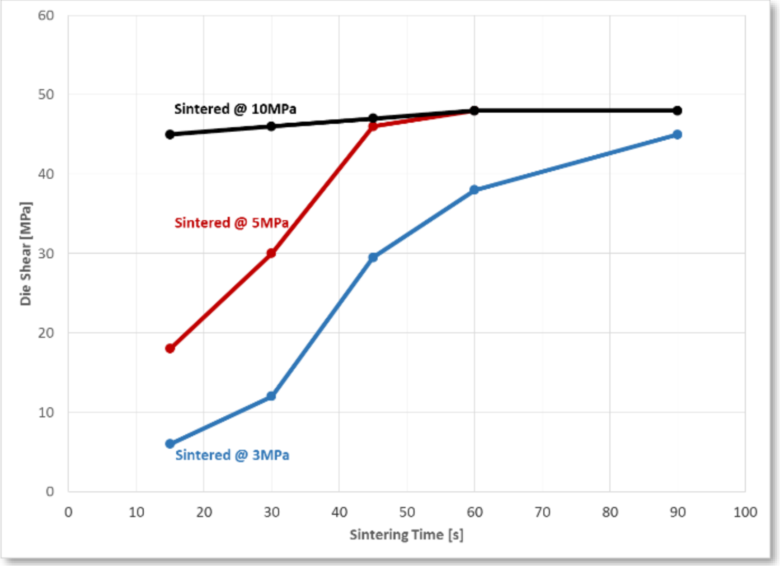
Differences between soldering, hybrid sintering and sintering

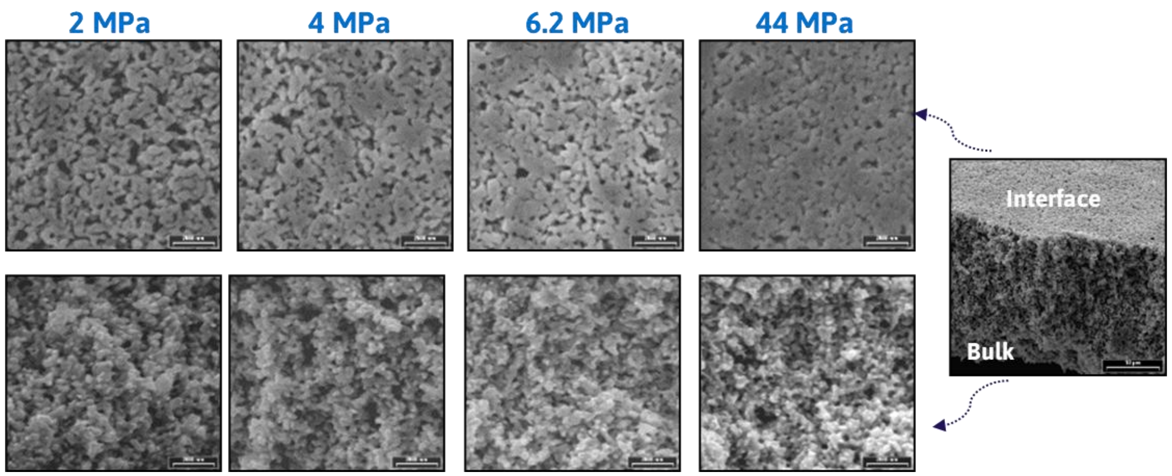
Sintering

Sintering is a function of:



Silver nano-particle system sintered at 250°C

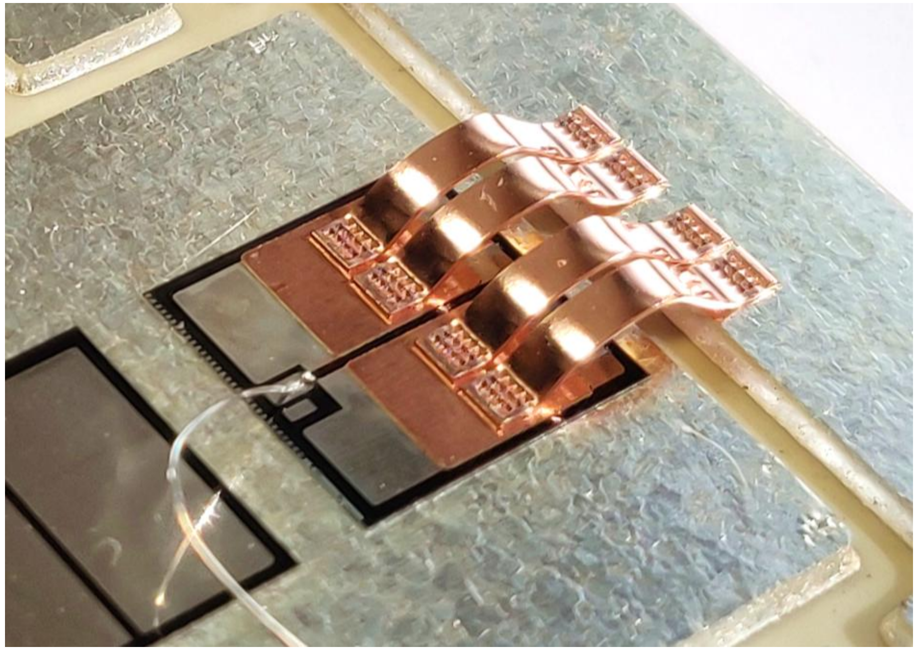




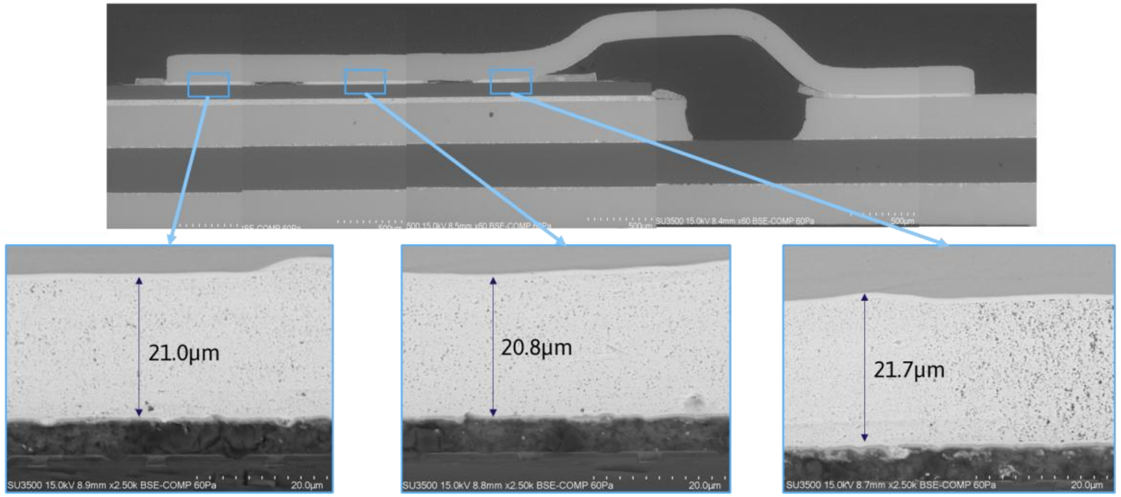
Differences between soldering, hybrid sintering and sintering

Sintering

Side-view, internal test vehicle



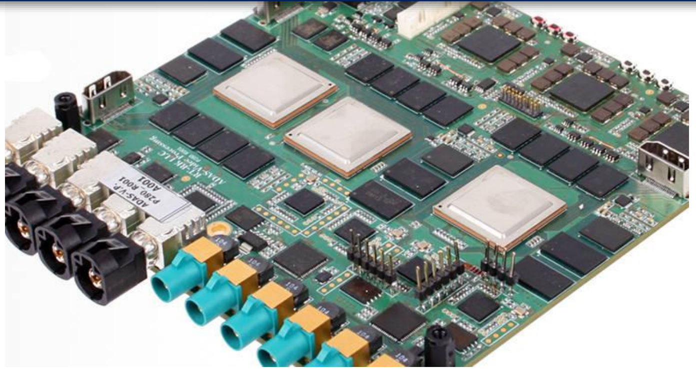
Cross-section (example with topside attach)



Differences between soldering, hybrid sintering and sintering

Technology boundaries

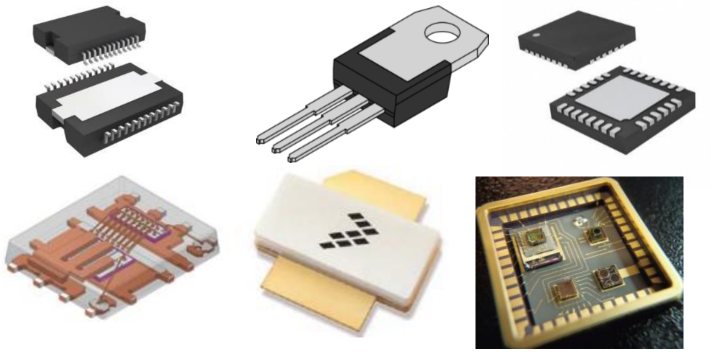
Example
PCB Board for ADAS application



Source: https://static.electronicsweekly.com/wp-content/uploads/2016/11/07154435/Alpha-AMS.jpg

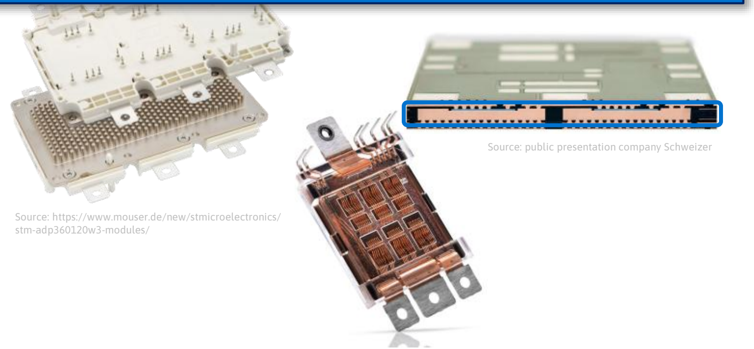
- Complex multilayer PCBs
- Different connection technologies e.g. Leads, BGA-spheres, Pin-in-Paste
- Wide range of used components
  - Std SMD: R/C, QFP, QFN, BGA, …
  - Micro controller and RAM
  - Special connector type

Example
Standard Die Attach application



- Single leadframes, structured ceramic substrate
- Bare-Die applications for IC, Si, SiC and GaN
- Stacking of component and leadframes
- Molded or hermetically sealed devices

Example
Power Electronics for Automotive



Source: https://www.mouser.de/new/stmicroelectronics/stm-adp360120w3-modules/

Source: public presentation company Schweizer

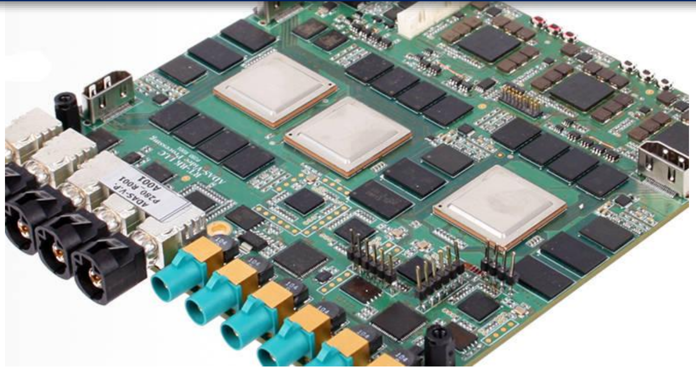
Source: https://www.danfoss.com/de-de/about-danfoss/our-businesses/silicon-power/danfoss-dcm-power-module-technology-platform/

- Single layer ceramic or leadframe substrates
- Bare-Die applications for Si, SiC and GaN
- Single special components
  - PT elements, PTC or NTC
  - Resistors

Differences between soldering, hybrid sintering and sintering

Technology boundaries

Example PCB Board for ADAS application	Example Standard Die Attach application	Example Power Electronics for Automotive



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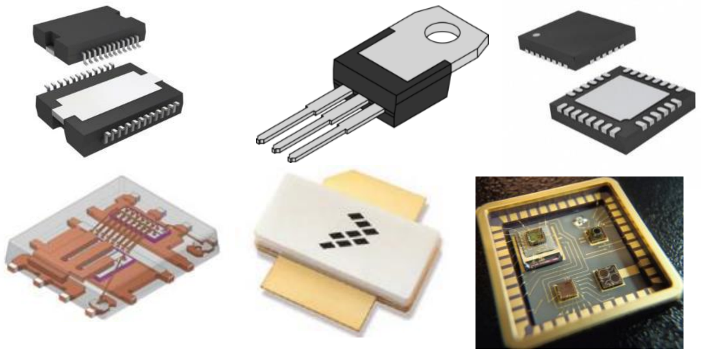

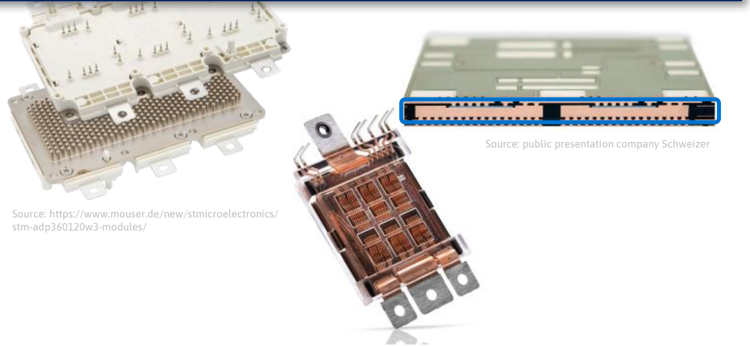

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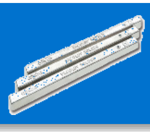
Source: public presentation company Schweizer

Source: https://www.danfoss.com/de-de/about-danfoss/our-businesses/silicon-power/danfoss-dcm-power-module-technology-platform/

Primary connection technology

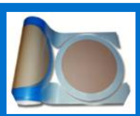



Soldering



Hybrid Sintering




Sintering



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Differences between soldering, hybrid sintering and sintering

Material Properties

Property	Solder (SnPb, SnAgCu)	Hybrid Sintering	Sintering (Silver)
Joining Mechanism	Melting of Sn, diffusion and solidification (metallurgical bond)	Partial sintering + curing of organic matrix	Solid-state diffusion/ full sintering of silver particles
Process Temperature	180–250 °C (depending on alloy)	150–220 °C	220–250 °C (sometimes higher)
Applied Pressure	None	Pressureless	5–40 MPa (depending on paste type)
Electrical Conductivity	15–20 µOhm.cm	10-30 µOhm.cm	1-5 µOhm.cm
Thermal Conductivity	30–60 W/mK	100–210 W/mK	200–300 W/mK
Max. Operating Temperature	< 150 °C	200–250 °C	> 250 °C, up to 300 °C+
Mechanical Stiffness	Relatively ductile	Medium – partially elastic due to resin content	Very stiff
Thermal Cycling Reliability	Good at moderate temperatures	Very good – hybrid structure absorbs stress	Excellent – high fatigue resistance
Wettability / Surface Compatibility	Very good on Cu, Ni, Au, Sn	Good depending on solvent and resin system	Diffusion open surfaces
Main Advantages	Easy processing, low cost	Good balance between processability and performance	Highest thermal & electrical performance
Main Limitations	High-temperature stability, creep resistance	Slightly lower conductivity and stability	Complex process, sensitive to cleanliness

Process in Detail

- Soldering: classical technologies, strengths & limitations
- Hybrid Sintering: principles, material combinations, process window
- Sintering: mechanisms, requirements, reliability

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Process in Detail - Soldering

Concept of wetting

Wetting principal

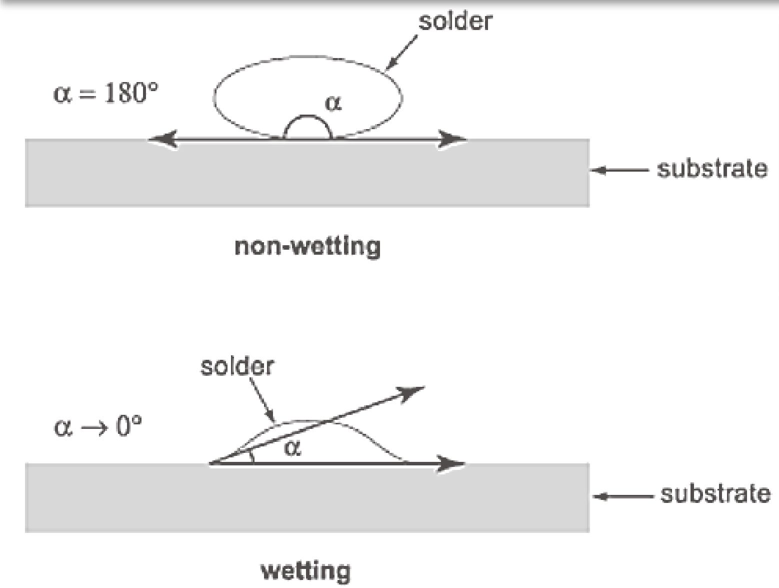
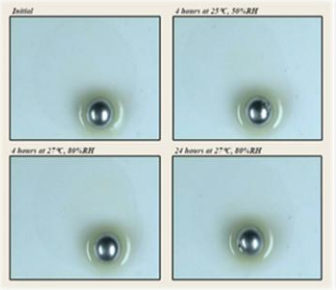


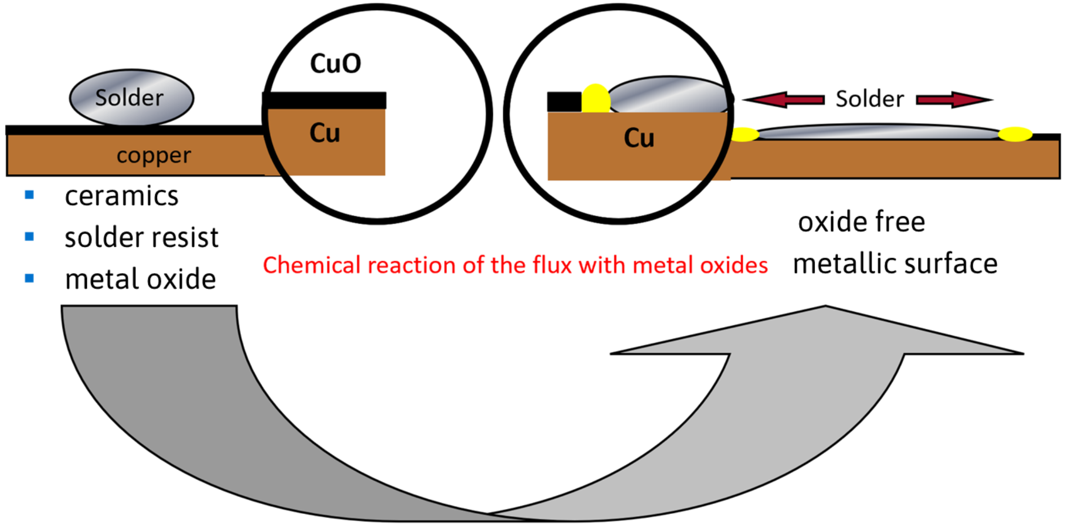
Image source: Martin Tarr www.ami.ac.uk



No Wetting

Good Wetting

Effect of flux/ activator



A solder joint can only be formed properly if the surface is clean and free of oxidation and if reoxidation is prevented during the process.

Process in Detail – Soldering

Process differentiation

- Where is the energy for heating and melting the alloy coming from?
- How is the chemistry or atmosphere for cleaning and activation applied?
- Which component types and range needs to be soldered?

Solder Pastes

- Solder paste is a mixture of:
  - Alloy as powder in different particles sizes
  - Flux for cleaning and activation
- Flux system are available in different activity classes
  - No-Clean
  - Clean
  - Clean, water soluble
- Convection and contact heating, Vapor phase
- Wide range of components, connectors other parts in SMT and THT

Tackiness by the used flux system

Solid solders, only alloy

- Solder alloy in different shapes:
  - Preforms, wires, bars and pellets
  - Spheres
- For Cleaning and activation an additional applied flux is mandatory, or
  - No-Clean
  - Clean
  - Clean, water s
- Soldering atmosphere is able to reduce the oxides
- Convection and contact heating, Vapor phase, selective or wave soldering
- THT, simple components for SMT or electronic packaging

No tackiness, fixtures needed

Solid solders, alloy and flux

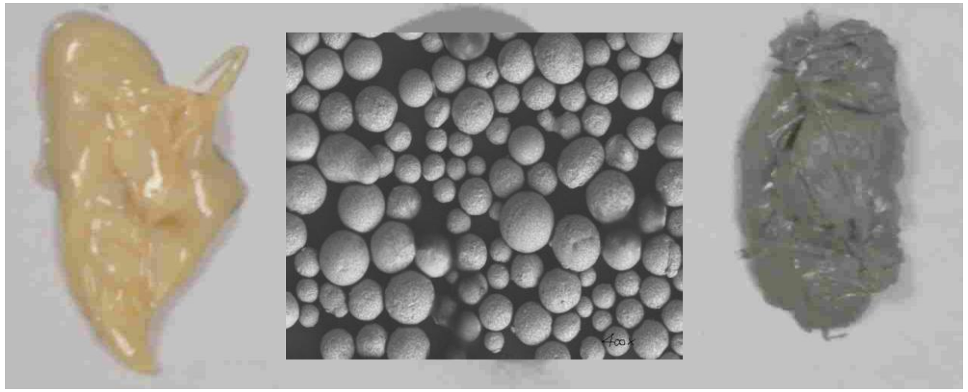
- Solder alloy in different shapes:
  - Coated preforms
  - Cored wire
- For Cleaning and activation, the flux is embedded into or coated on the shape of the solder allo
  - No-Clean
  - Clean
- Convection and contact heating, Vapor phase, selective or wave soldering
- THT, simple components for SMT or packaging needs

No tackiness, fixtures needed

Process in Detail – Soldering

Materials

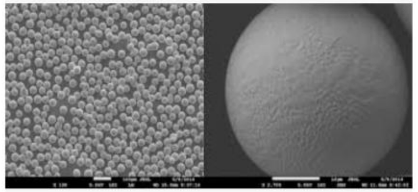
FLUX + POWDER = PASTE



Key solder paste Specifications:

- Alloy Type
- Flux Type
- Mesh (Powder) Size
- Metal Loading ~ Viscosity

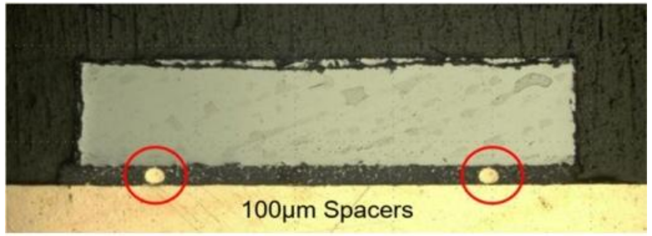
Solder Paste
- Alloy Powder
  - SnPb
  - Pb-Free
- Paste Flux
  - Activator
  - Solvent
  - Rheology Modifier
  - Plasticiser
  - Thickener



Process in Detail – Soldering

Materials

Preforms	Wires, bars and pellets	Spheres



Process in Detail – Soldering

Equipment Overview

Soldering process based on Solder paste

SMT Wertheim

REHM

Vitronics Soltec, ITW

Soldering process based on Formic Acid

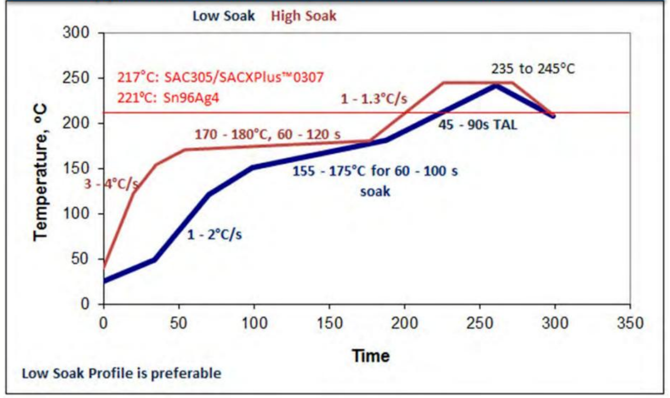
ATV Technologies

PiNK Thermosysteme

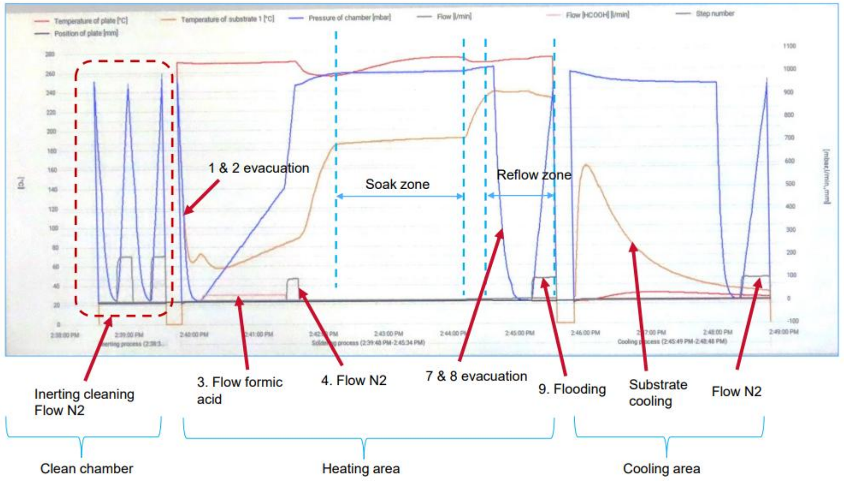
Centrotherm

REHM

Typical Reflow Profile
Applicable to SAC305, SACX Plus 0307 & Innolot



- Heating technologies differ between the two processes
  - Hot air/ reflow for typical solder paste
  - Radiant heat, contact heat, or a combination of both for formic acid
- New trend that formic acid is used with special equipment also on classic reflow process
  - Concentration of formic acid to be considered
  - Cleanliness of atmosphere, O2-concentration



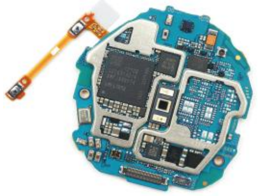
Heller Industries
Other development ongoing

Process in Detail – Soldering

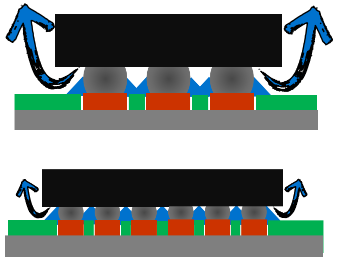
Challenges for solder paste application for new package designs

Package development and influence on flux evaporation

https://www.techinsights.com/blog/apple-iphone-15-pro-teardown

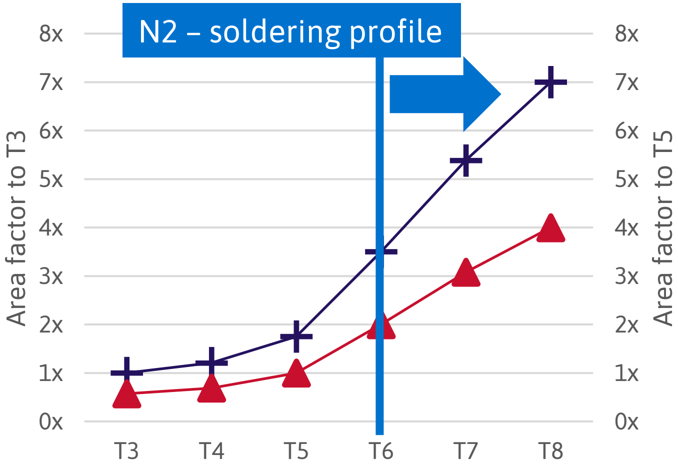


https://www.eeweb.com/wp-content/uploads/Jan112021Figure-1Wearable.jpg



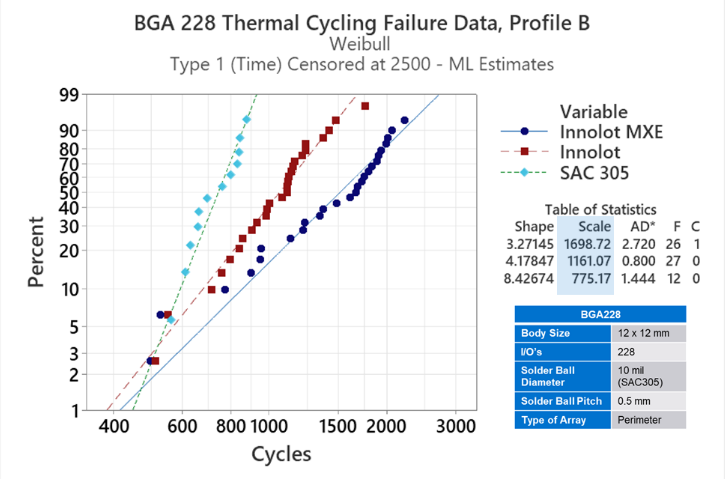
- Increase of I/O counts and density
- Reduction of I/O height, thinner gap between substrate and packaging, low standoff height
- Increase of area ratio to gap height, reduction of I/O distance to substrate. Influencing evaporation of flux

Surface area of used powder



- Higher density cause smaller printing apertures
- For high yields during printing finer powder types are necessary
- Increase of surface area is directly link to the usage activity class of flux

Reliability (thermal cycling -40/150°C)

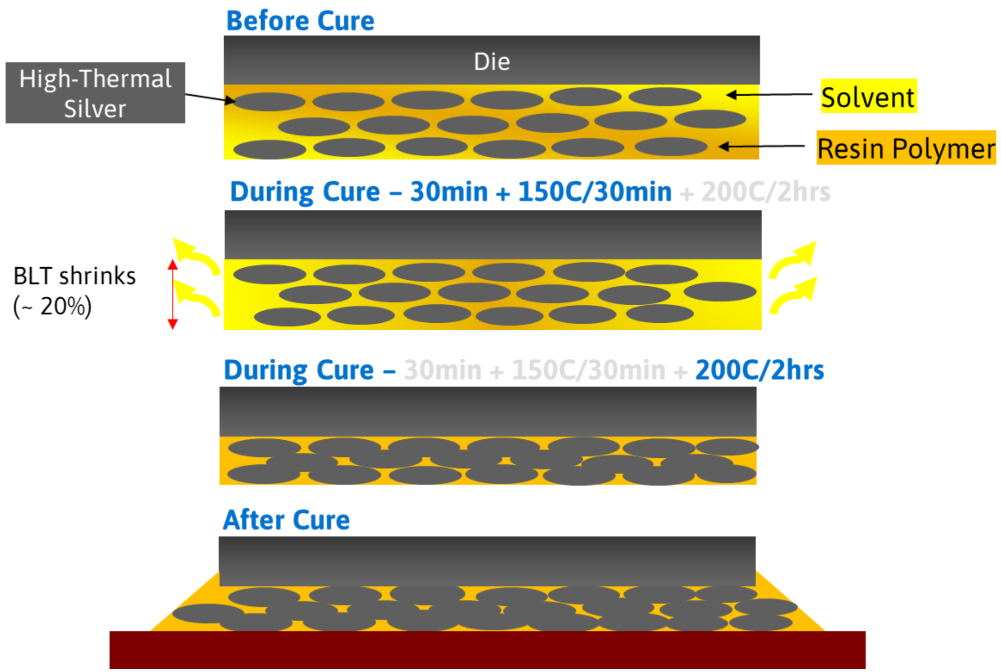


- Higher application and I/O temperature have impact on homologous ratio: > $0{,}5xT_{melt}$ increase of diffusion, recrystallisation and creeping
- new alloy have higher resistance on creep

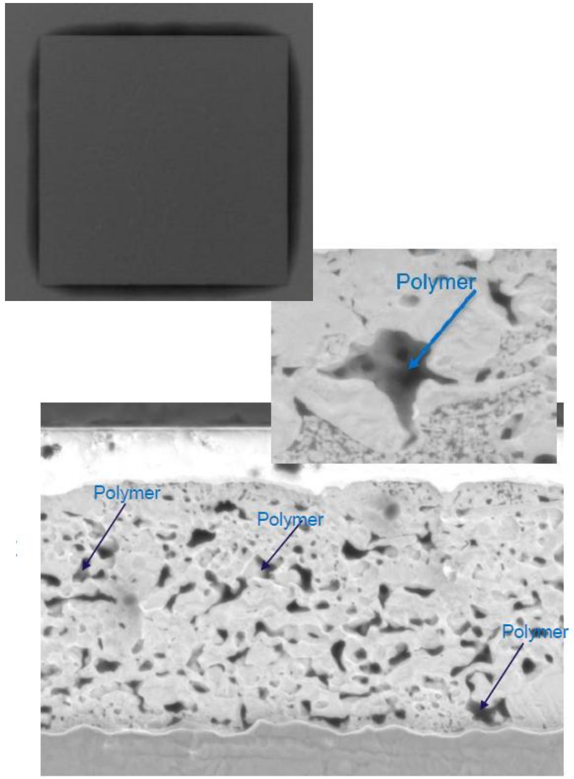
MacDermid Alpha ELECTRONICS SOLUTIONS

Process in Detail – Hybrid Sintering

Principles

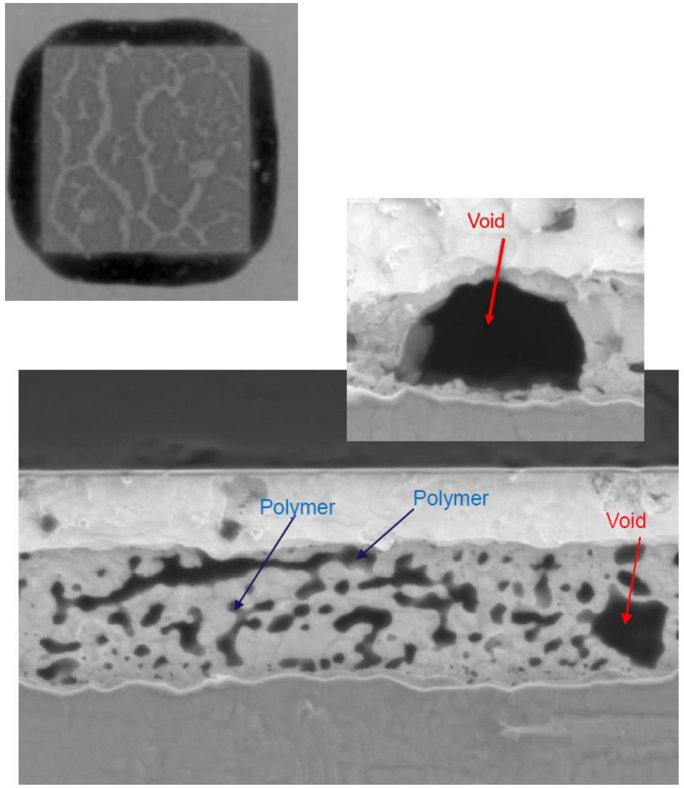


Good voiding (XRay)



Cloudy with some Ag flakes peeking from behind, Structure looks more 3D

High voiding (XRay)



Clear, dark, black area indicating it is a void and not polymer

MacDermid Alpha ELECTRONICS SOLUTIONS

Process in Detail – Hybrid Sintering

Material combinations

Metallized surface,
Ag, Au, Pd, Cu, NIP, PPF

Bare Silicone,
metallized

	COMMERCIAL PRODUCTS							New Products		
Type	>100W (Highest Thermal)				>75W (Low stress)			Low Temperature Sintering		High Thermal, Tight Tolerance
Properties	800HT2V	800HT2V-P1	850HT1	800HT2VX	800HT5	800HT6B	800HT7A	840-3LT	840HT5	800HT2VX-LV
Target Package	High thermal conductivity	High thermal Printable	Highest thermal conductivity	High thermal, Ultra fine Pitch assembly	Low-stress Small and medium die sizes			Low temp Sintering die attach		High thermal, Ultra fine Pitch assembly
Die size (mm)	~ 6 x 6		~7x7	~6 x 6	2 x 2 ~ 6 x 6		~ 7 x 7	Up to 6 x 6		~6 x 6
Die backside	Metallized			Metallized	Metallized or bare Si			Metallized	Metallized, bare Si	Metallized
Viscosity (cps)	17,000	45,000	20,000	58,000	13,000	10,000	17,500	22,500	24,500	50,000
Thixotropic Index	5.9	6.0	5.5	5.5	5.5	5.0	6.0	6.5	4.5	6.0
Modulus 25°C (GPa) 260°C	9.1 1.9	8.0 0.9	17.5 8.0	11.7 2.7	9.5 0.9	9.6 1.4	4.9 0.5	13.3 2.8	15 5.5	11.7 2.7
Vol. Resistivity (ohm.cm)	0.00002	0.00002	0.00001	0.00001	0.00002	0.000025	0.00003	0.00003	0.00009	0.00001
Bulk Thermal Conductivity (W/mK)	170	>100	210	>175	75	85	75	>130	>100	>175
Cure Profile	150°C / 30 min + 200°C / 120 min OR 150°C / 30 min + 250°C / 120 min							30 min to 175C + 175°C / 120 min		150°C / 30 min + 200°C / 120 min

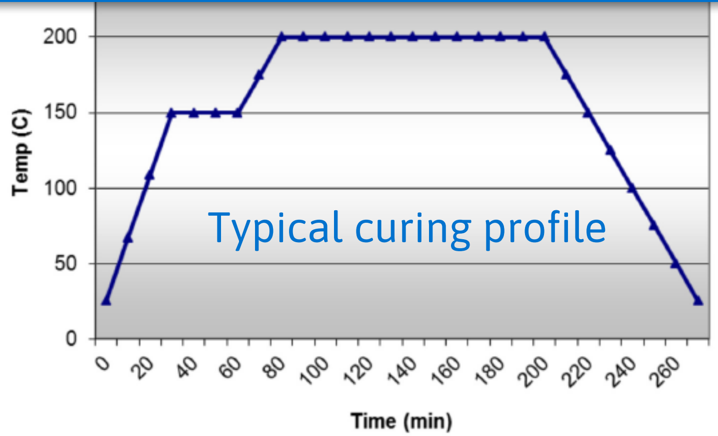
MacDermid Alpha
ELECTRONICS SOLUTIONS

Process in Detail – Hybrid Sintering

Process window

Before curing	Curing

- **Pot life:**
  - Hybrid-Sintering materials are a mixed polymer which need to be stored at -40°C to stop cross-linking
  - Formulation have pot life between 24-48h, viscosity increase can be measured
- **Stage time:**
  - Open time before curing
  - It is recommended to place the die directly after dispensing into the paste
  - After placement stage times up to 8h can be applied



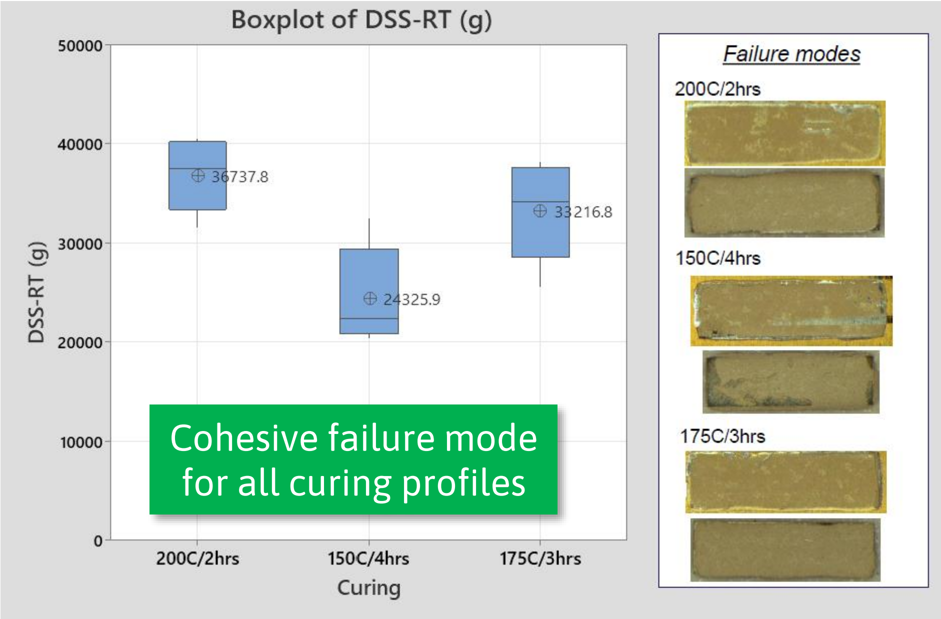
- **Curing profile** typically in peak between 200-250°C for standard materials, low temperature material starting at 175°C
- If the modulus need to be adapted due to sensitive dies lower curing temperature with longer curing time are possible

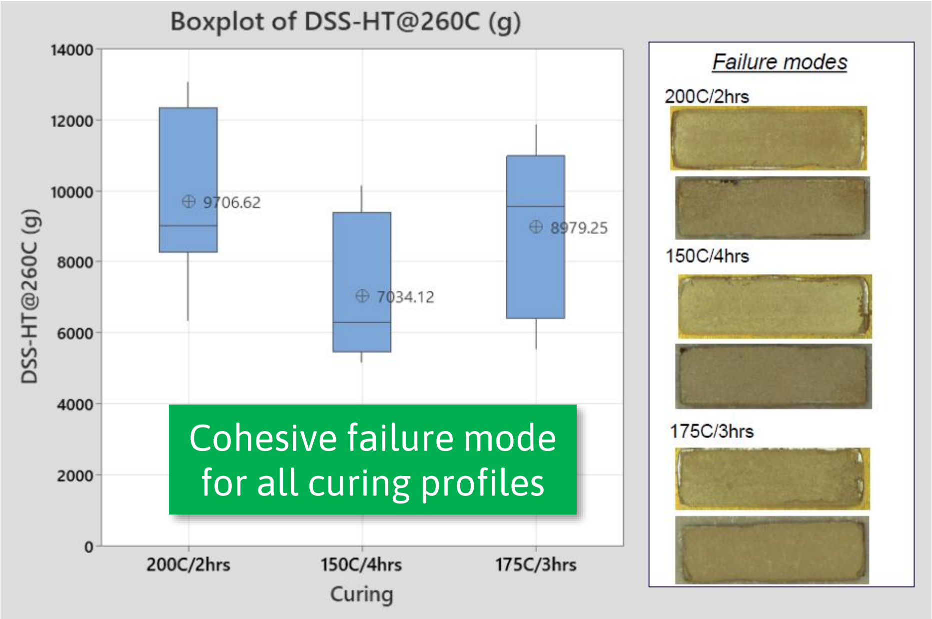
Process in Detail – Hybrid Sintering

Process window

- Example for lower curing temperature

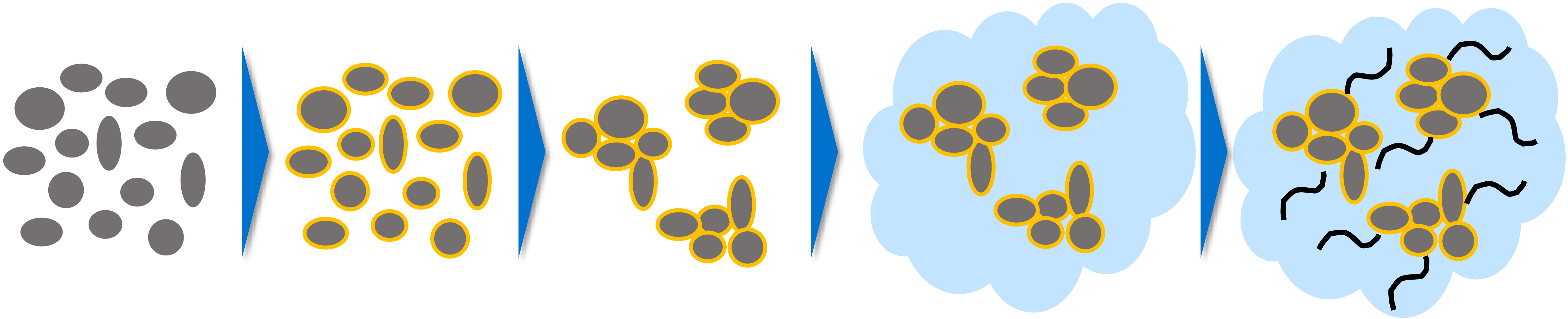
	Curing 1: 200C/120min	Curing 2: 30m+150C/4hrs	Curing 3: 175C/3hrs
Bef Cure	0.00void%	0.00void%	0.00void%
Aft Cure	0.00void%	0.00void%	0.00void%





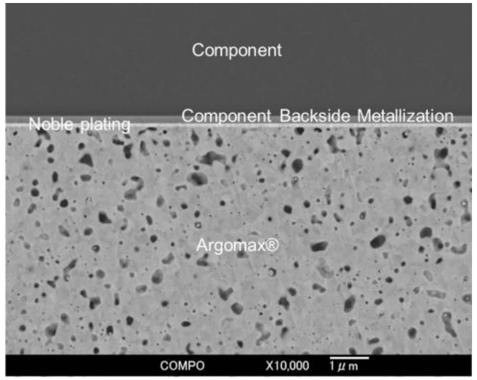
Process in Detail – Sintering

Mechanisms



Raw powder out of liquid | Organic coating on powder | Formed agglomerates | Embedding into vehicle | Adding surfactants, modification of paste behaviour

- Nano-scale or micro-scale powder have very high surface/ free energy, the coating secures to particles from direct sintering after the precipitation.
- To make the powder printable various chemistries are added like: solvent, surfactants, rheologic modifier.
- Evaporation of solvents during drying, it is very important that the paste is dry for sintering.
- The coating will burn away during the sintering process and the particles start to sinter.



Argomax® structure after sintering

Process in Detail – Sintering

Requirements

Material overview MacDermid Alpha

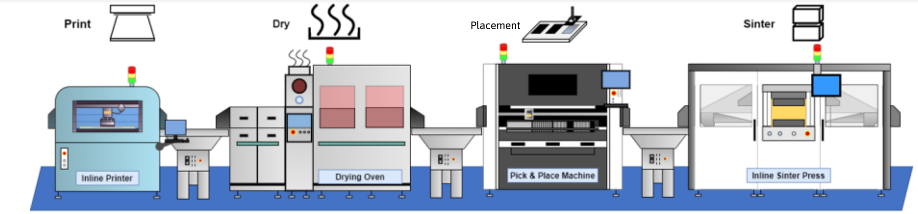
		Application				Delivery			Placement in Paste			Surface		
Product Name	Form	Die Attach	Package Attach	Large Area Lamination	Wafer	Print	Dispense	DTF	Wet	Dry	% Metal Loading	Ag / Au	Cu	
Argomax 2010C	Paste	√				√				√	69-71	√		Printing on Ag
Argomax 2020	Paste	√				√				√	76-79	√		
Argomax 2040	Paste	√				√	√ dot		√		67-69	√		
Argomax 2047	Paste		√			√			√	x - can be used	69	√		
Argomax 2048	Paste		√				√ ribbon		√	x - can be used	80-82	√		Ribbon Dispensing on Ag
Argomax 2141	Paste		√				√ ribbon		√	x - can be used	76-80	√		
Argomax 5022	Paste	√	√			√				√	72-75		√	Printing on Cu
Argomax 5040	Paste	√				√	√ dot		√	x - can be used	70		√	
Argomax 8010	Film Sheet			√							98	√		Films and Engineered Film products
Argomax 8020	Film Sheet	√						√			98	√		
Argomax 8022	Film Sheet	√						√			98	√		
Argomax 8021	Film Sheet	√						√			98	√ (Au +)		
Argomax 8031	Film Sheet	√			√						98	√		
Argomax 8050	Film Sheet	√						√ - tack Agent			98		√	

Process in Detail – Sintering

Requirements

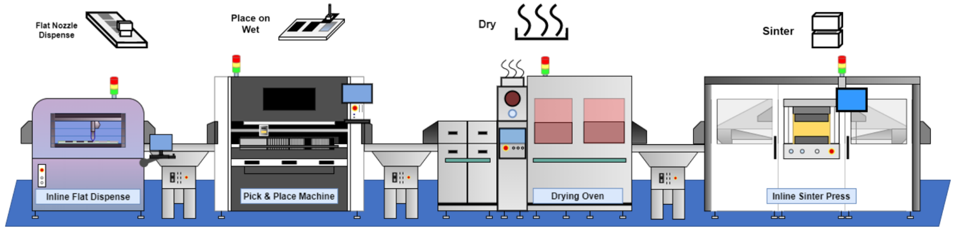
Potential process flows MacDermid Alpha

Printing



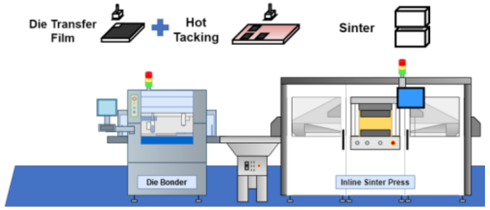
- Traditional sintering process
- Requires a drying step
- Requires hot tacking or tacking agent during placement

Dispensing



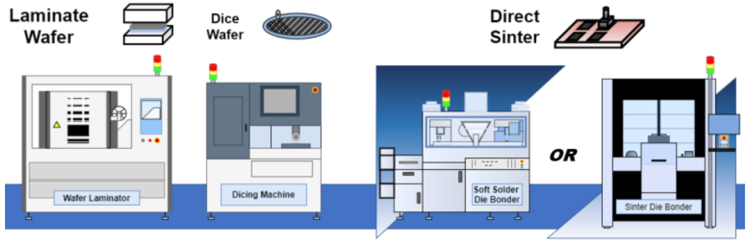
- Paste dispense (flatbed, dot, line, jet)
- Placement on wet
- Die-attach, package attach, lead frame…

Direct Transfer Film



- Unique process that does away from the printing steps
- All processes are in dry, no drying requires
- DTF process includes a Hot-Tacking step fixing the die

Wafer Lamination



- Applying Argomax® on a wafer
- Dies prelaminated with Argomax® ready for pick/place process

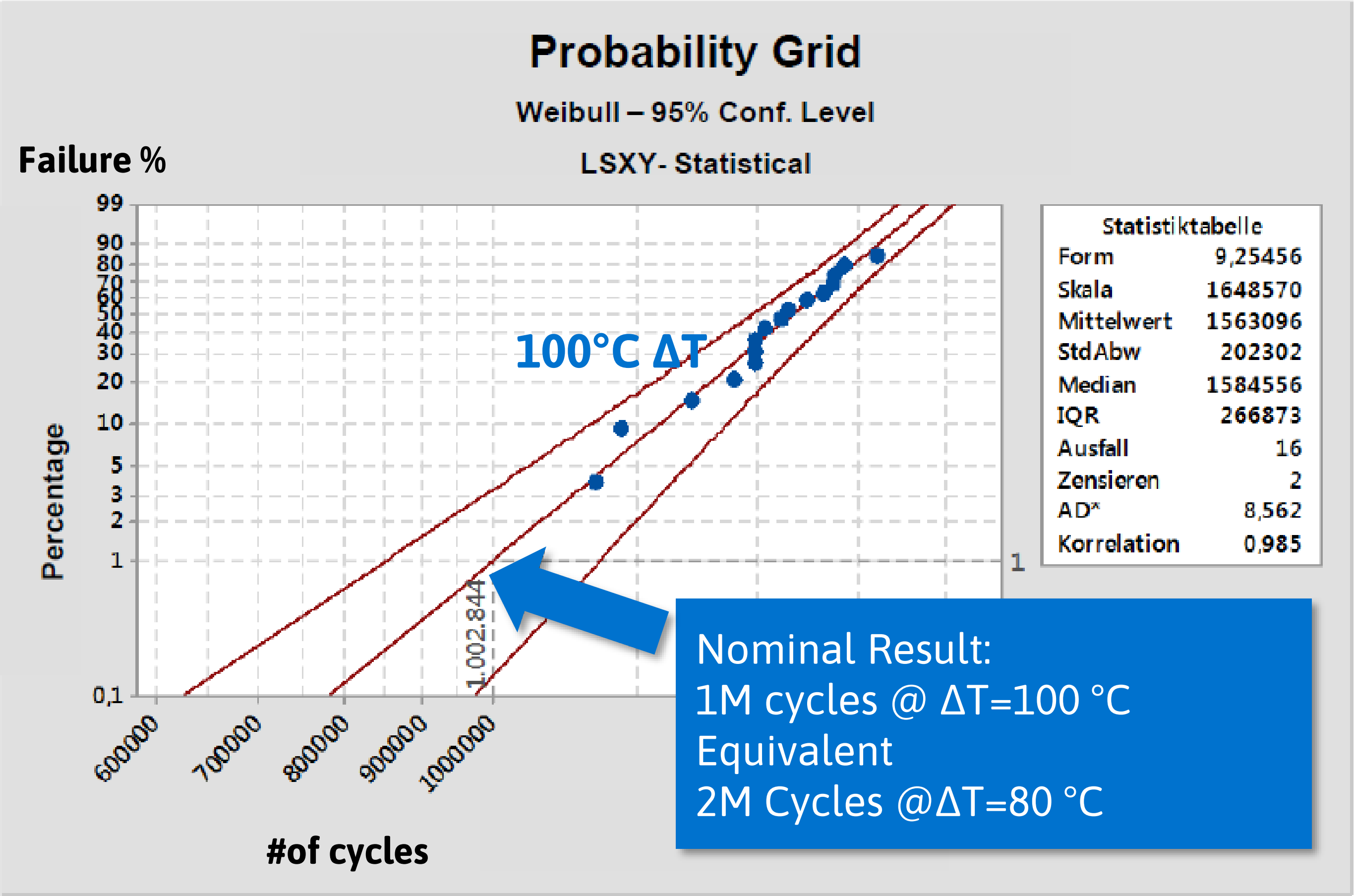
Process in Detail – Sintering

Requirements

- **Surfaces**
  - Sintering relies on atomic diffusion between the bulk material and the bonding surfaces.
  - Clean, oxide free, active, no passive surfaces are required.
  - Difficult surface conditions can be handled by adjusting the paste properties. Risk for higher contaminations after the sintering process.
- **Components**
  - Noble surfaces are easier to sinter, easier to store.
  - Pressure and heat resistance required. Different tool technologies can be used to find optimum in the process.
- **Sinter paste**
  - For which application method the material is used?
  - Dry or wet placement?
  - Smaller area or large area attach?
  - Bare-die or package application?

Process in Detail – Sintering

Reliability – application for Si bare-dies



Traditional soldering approach:
150k Power Cycles @ ΔT =80°C

Sintering approach:
1M Power Cycles @ ΔT =100°C

Increase of lifetime by factor 6,5x with higher ΔT by 20K

Process in Detail – Sintering

Reliability – application for package attach

- **Reliability testing:**
  - Method air-to-air thermal shock testing
  - According AQG324

Lowest value of the storage temperature [a]	$T_{stg,min}$	$-40°C^{0}_{-10}$
Highest value of the storage temperature [a]	$T_{stg,max}$	$+125°C^{+15}_{0}$
Temperature slope: mean linear value for 10% to 50% [b]	$\Delta T/t_{slope(10/50)}$ *target value:*	> 6 K/min *8-10 K/min*
Temperature slope: mean linear value for 10% to 90% [b]	$\Delta T/t_{slope(10/90)}$ *target value:*	> 1 K/min *4-5 K/min*
Minimum dwell time for highest/lowest temperature	t_{dwell}	> 15 min
Minimum number of cycles without failures	N_C	> 1000

[a] Note: If a lower or a higher temperature is defined in the datasheet for T_{stg}, this value should be used for the test.

[b] The mean linear slopes for the temperature shock are defined in accordance with JESD22-A104F:2020

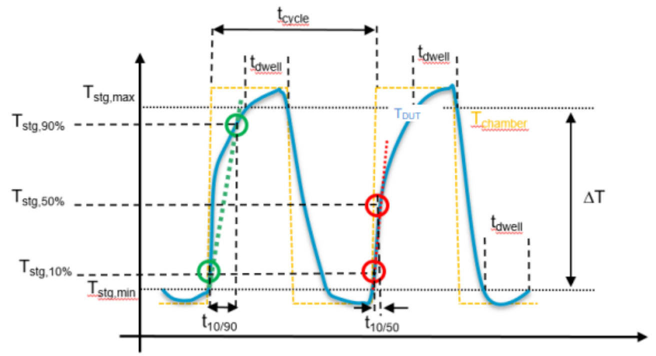
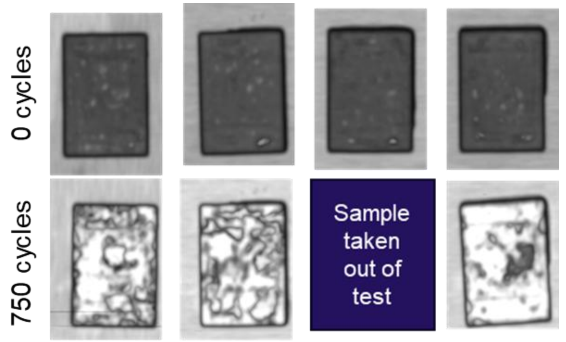


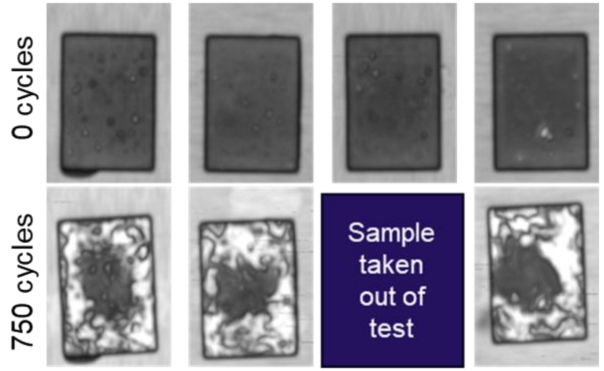
Figure 8.1: Example for TST temperature curve

CSAM

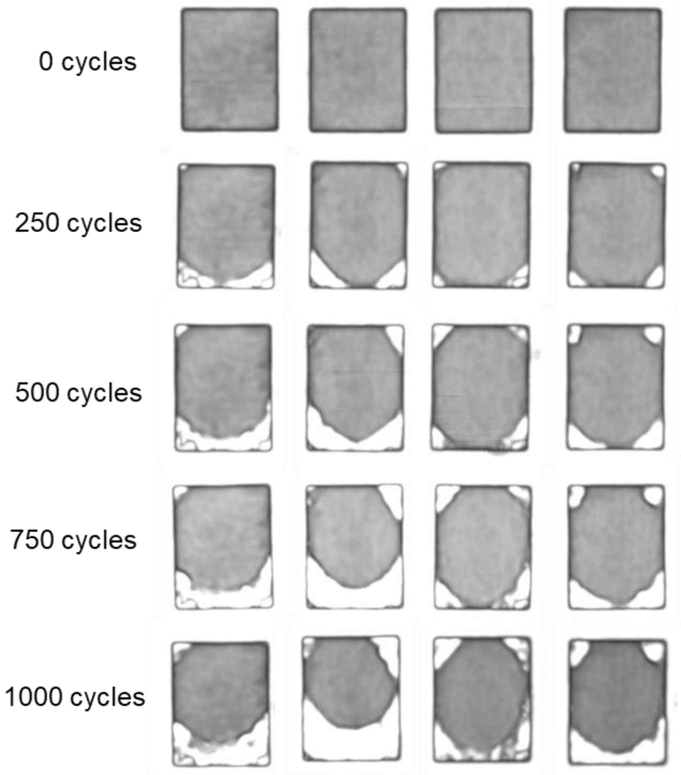
- **Soldering:**
  - Alloy 1 - modules show 100% delamination of attachment layer



  - Alloy 2 – modules show small remaining contact area of attachment layer. But already in functional area, Rth influence!



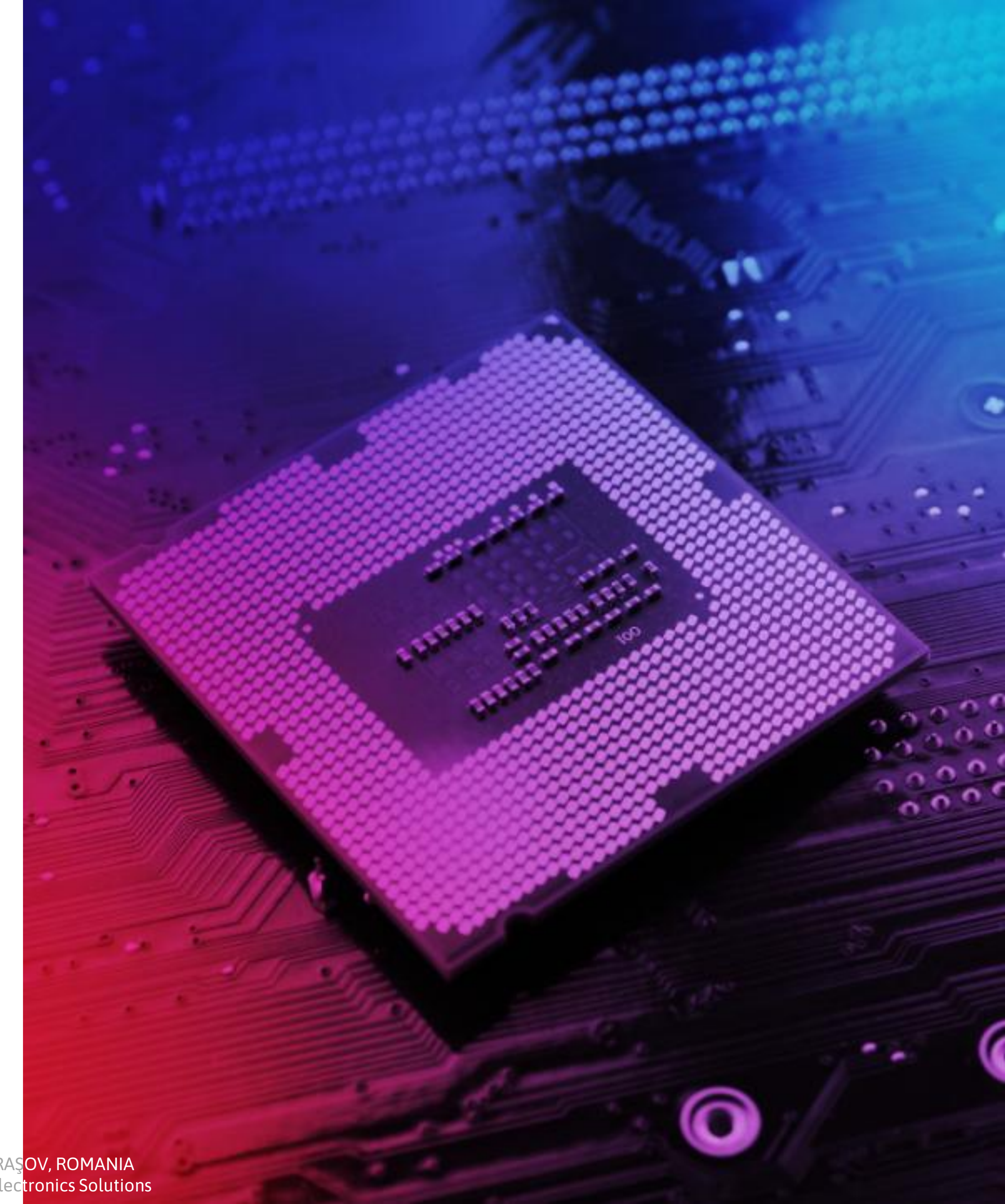
- **Sintering:**
  - Sintering reach the 1000cyles in thermal shock
  - Delamination visible but with less influence on Rth



MacDermid Alpha
ELECTRONICS SOLUTIONS

Application Examples & Case Studies

- Trends in reliability and miniaturization
- Automotive and industrial applications
- Power electronics



Application Examples & Case Studies

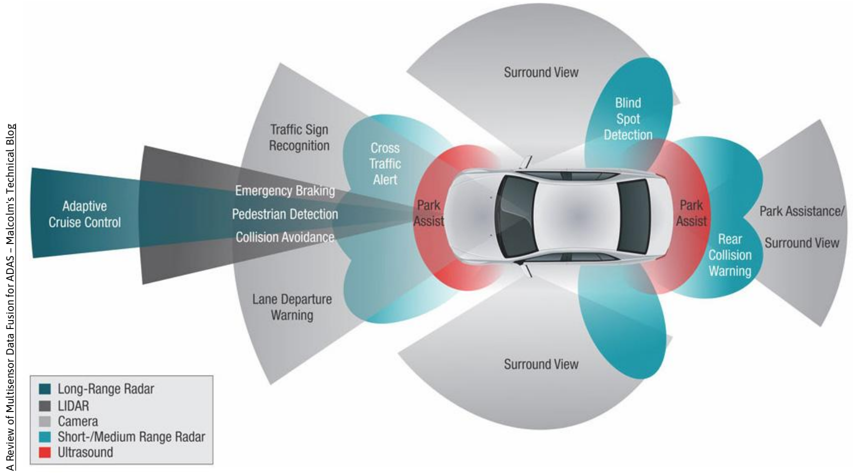
Trends in reliability and miniaturization

- Connectivity: Comfort and Entertainment
  - Display panels, lighting, V2X
- ADAS: Computing for safety
  - Vehicle architecture, Autonomous driving (L3-5), safety sensors
- Shared: New Mobility habits
  - Interior monitoring systems, societal shifts
- Electrification: CO2 reduction
  - DC chargers, Inverters, Powertrain domain controllers

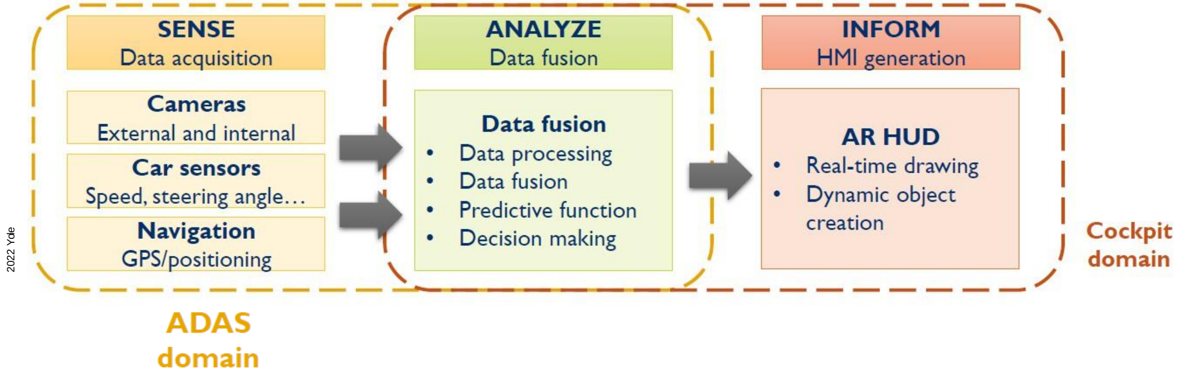
Connectivity: Single ECU model


2005 Lexus


2022 Rivian



ADAS: Increased sensors and computing power

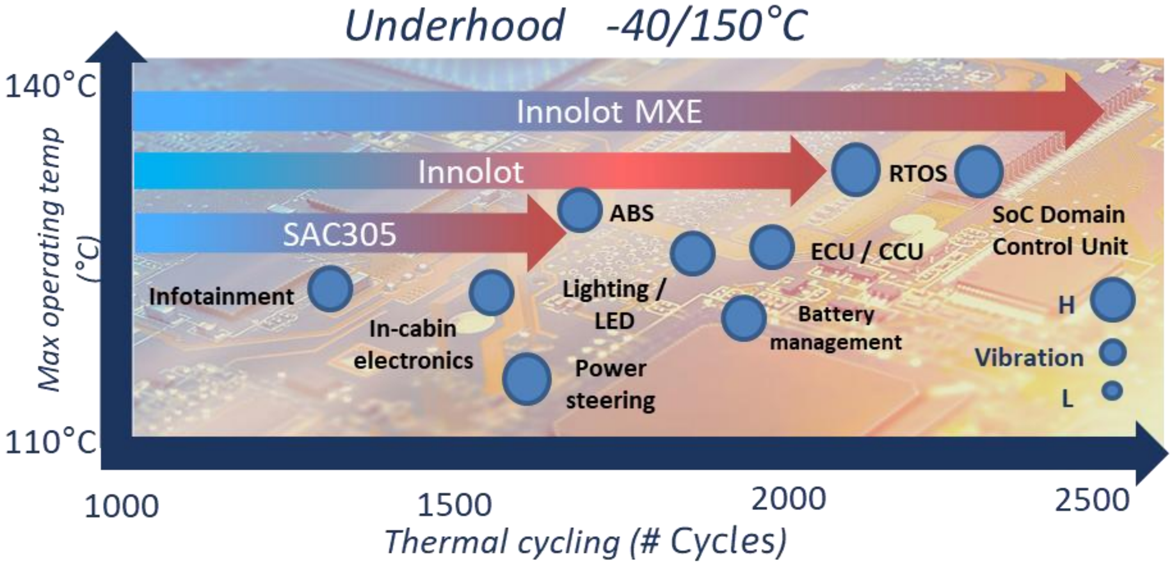


Application Examples & Case Studies

Trends in reliability and miniaturization

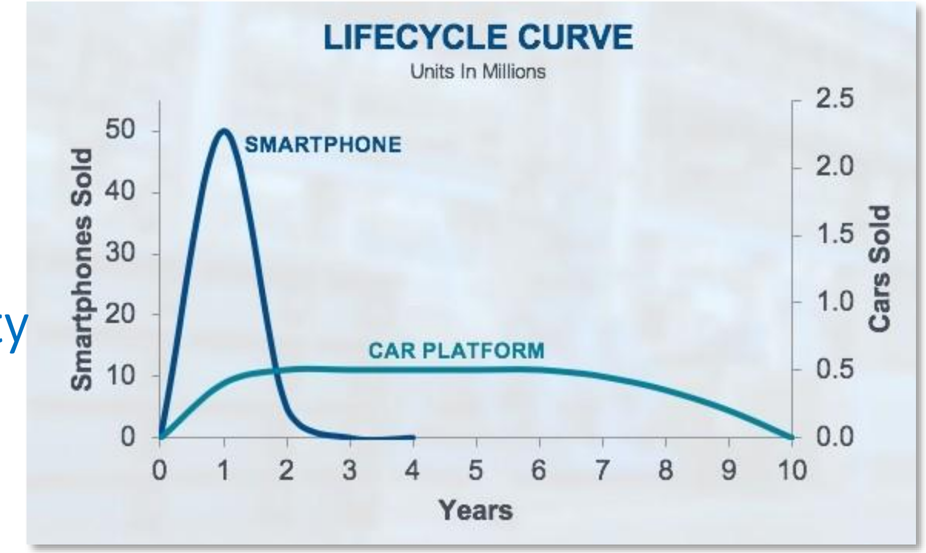
- Decreasing Process nodes
- Increased I/O
- Decreasing standoff height
- Harsh operating conditions

Increased Solder Strain



	Mobile IC	Automotive IC
Process	28nm → 7nm	180nm → 7nm
Voltages	0.5V → 1.8V	1V → 60V
Temperature	0-40°C	-40°C → 150°C
Operation Lifetime	1-3 yrs	10-15 yrs
Target field Failure	<10%	Target 0%
Reliability factor	Drop Shock	Therm. cycles, Vibr.

Board Level Reliability

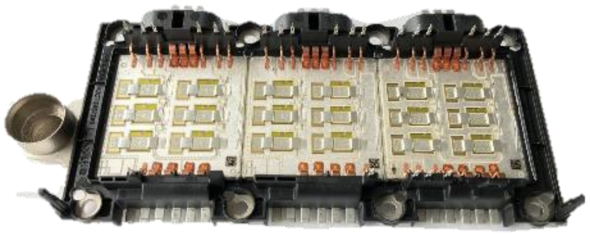
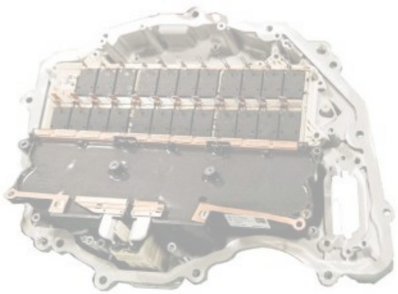


https://www.linkedin.com/pulse/exploring-automotive-adas-processor-packaging-prasad-dhond/

MacDermid Alpha ELECTRONICS SOLUTIONS

Application Examples & Case Studies

Automotive, Power Electronics and Industrial applications

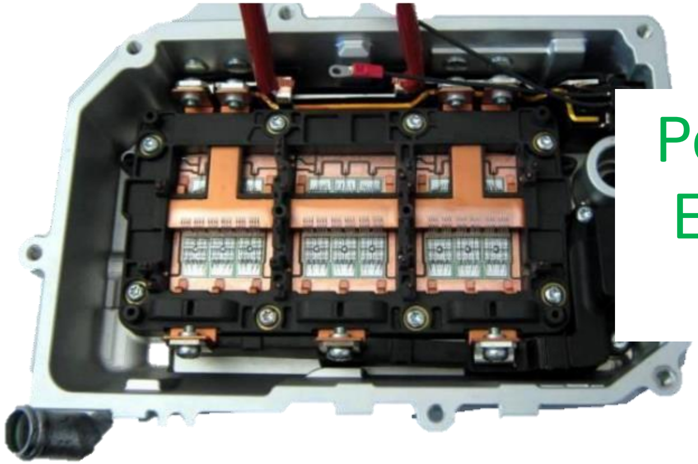
Case 1	Case 2
High Voltage Si Power Module Approach	High Voltage "SiC Mini Modules" Approach
	
How silver sintering help to **increase power** density, **reduce weight** and **increase reliability**?	How silver sintering help to **reduce thermal resistance, weight** and **increase reliability**?

All data in this presentation is publicly available information on Internet, teardown reports + MacDermid Alpha proprietary tests results

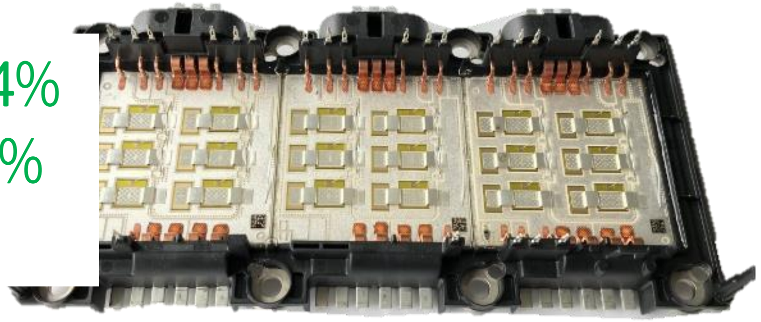
Application Examples & Case Studies

Automotive, Power Electronics and Industrial applications

Traditional Approach	New Approach
Gen 2 – Wire bonding, Si Dies and Solder Die Attach	Gen 2.8+ – Si Dies, Fully sintered Top & Die Attach



Power Density: +84%
Endurance: +1300%
Weight: -33.8%



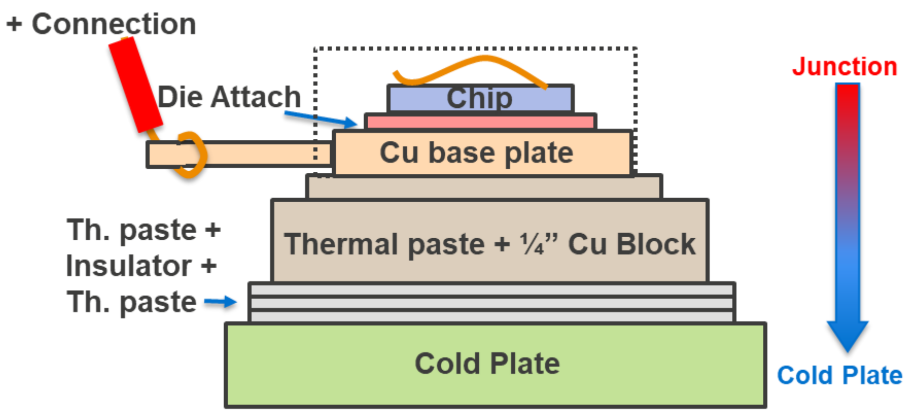
Power Density = 21.2kW/ Liter
150k Power Cycles @ Δ T =80◦C

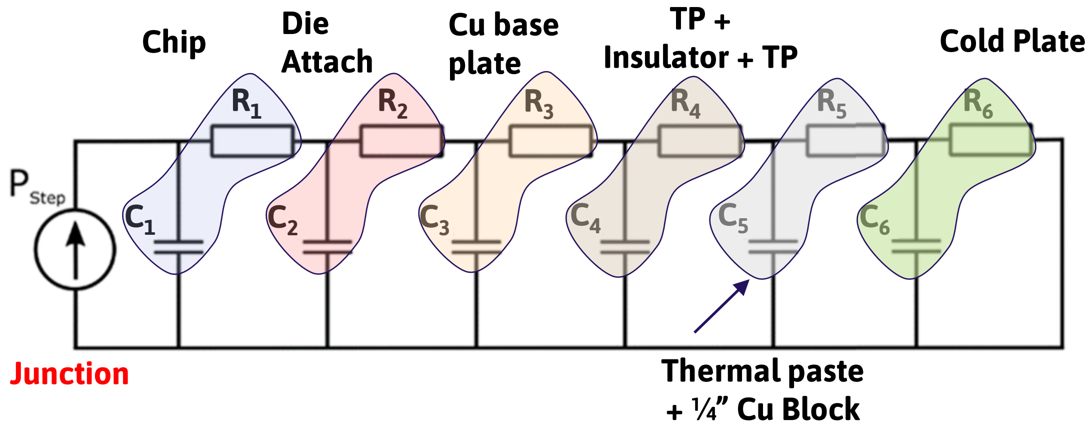
Power Density = 38.9 kW/ Liter
2M Power Cycles @ delta Δ T =80◦C

Application Examples & Case Studies

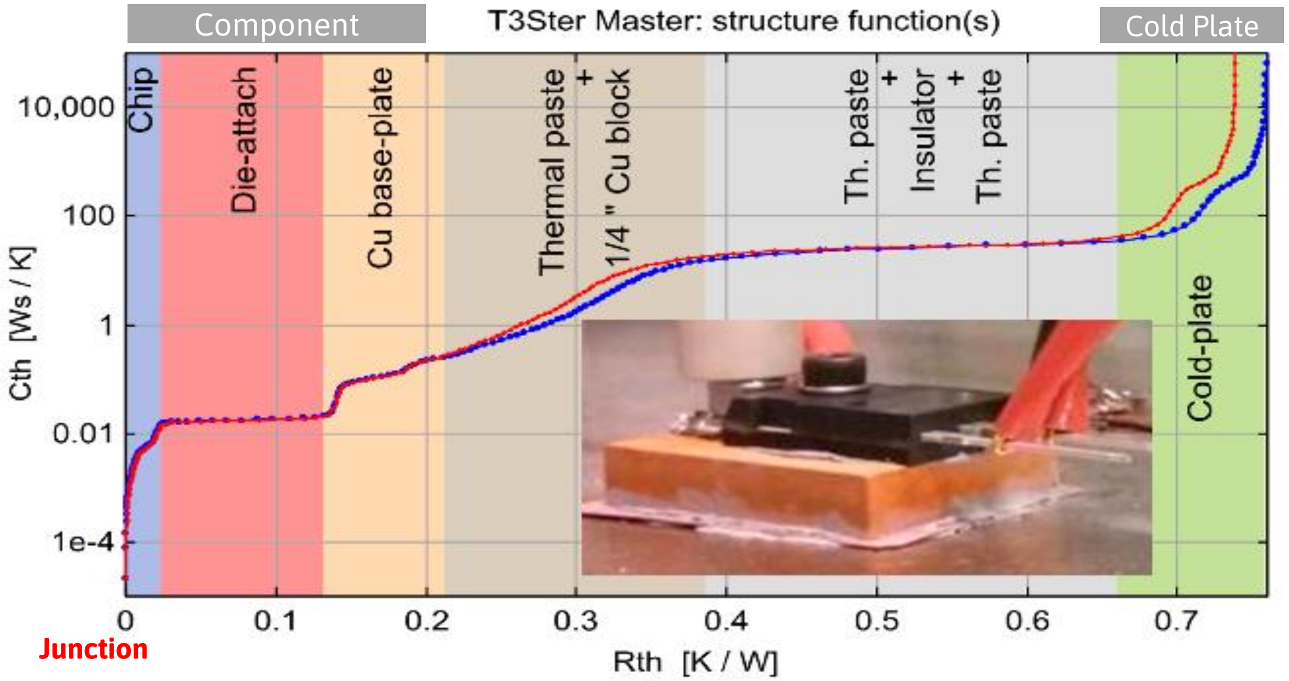
Automotive, Power Electronics and Industrial applications

Power Cycling and Thermal resistance (Rth) Measurements:





Before Power Cycles (Rth) T=0Cycles



Cauer Network for thermal modelling

$R_{1,2,3,...}$ & $C_{1,2,3...}$ are dependent on dimensions and material of each layer

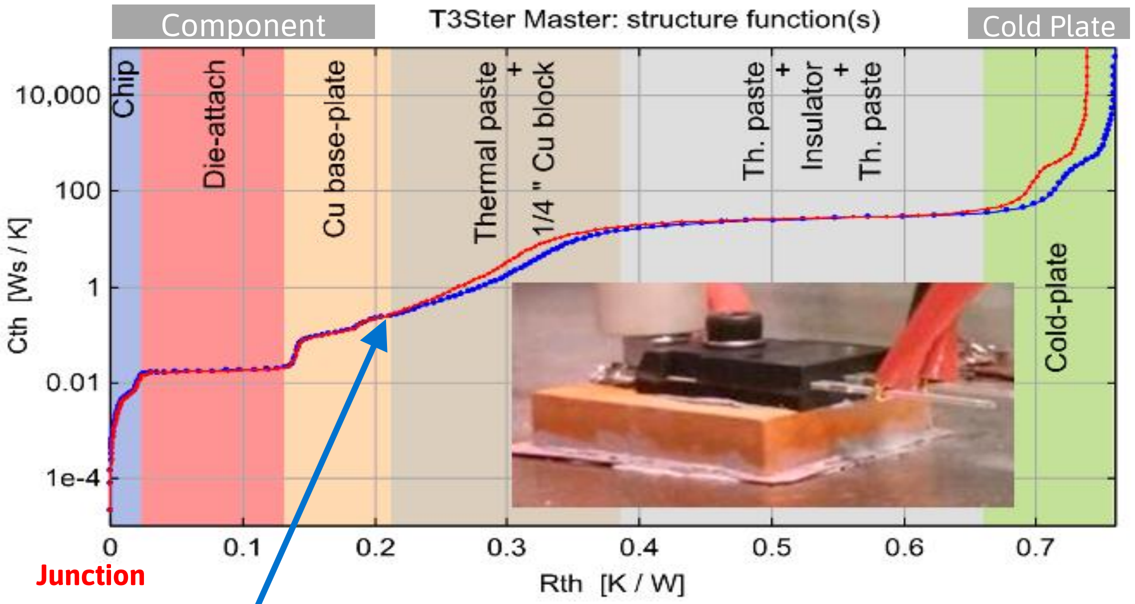
Courtesy from Siemens – Mentor Graphics (Zoltan Zarkany, Marta Rencz)

Application Examples & Case Studies

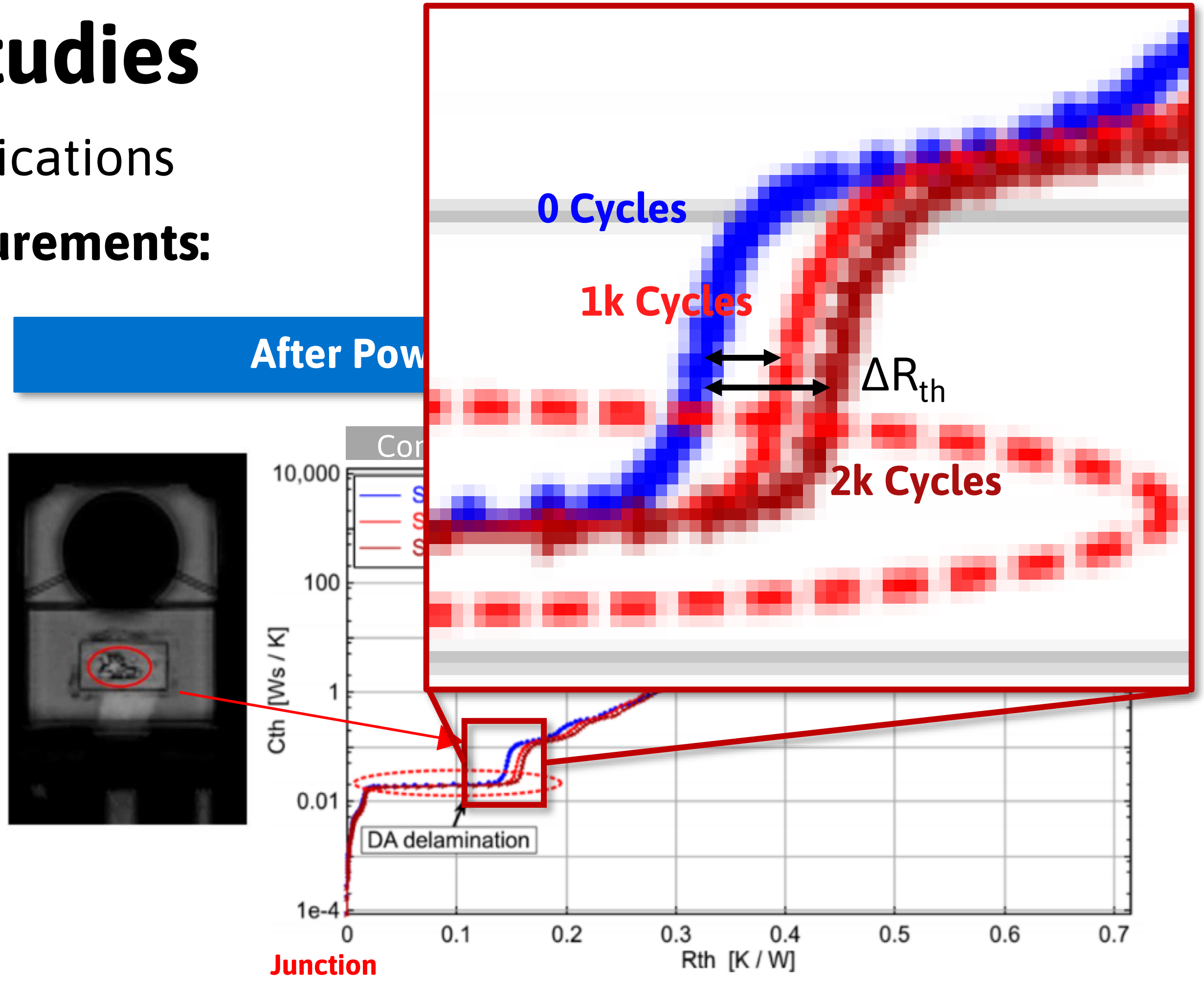
Automotive, Power Electronics and Industrial applications

Power Cycling and Thermal resistance (Rth) Measurements:

Before Power Cycles (Rth) T=0Cycles



After Pow



Usage of two different thermal insulator materials to find where the component finishes

Delamination (Material separation) causes increase in Rth

Courtesy from Siemens – Mentor Graphics (Zoltan Zarkany, Marta Rencz)

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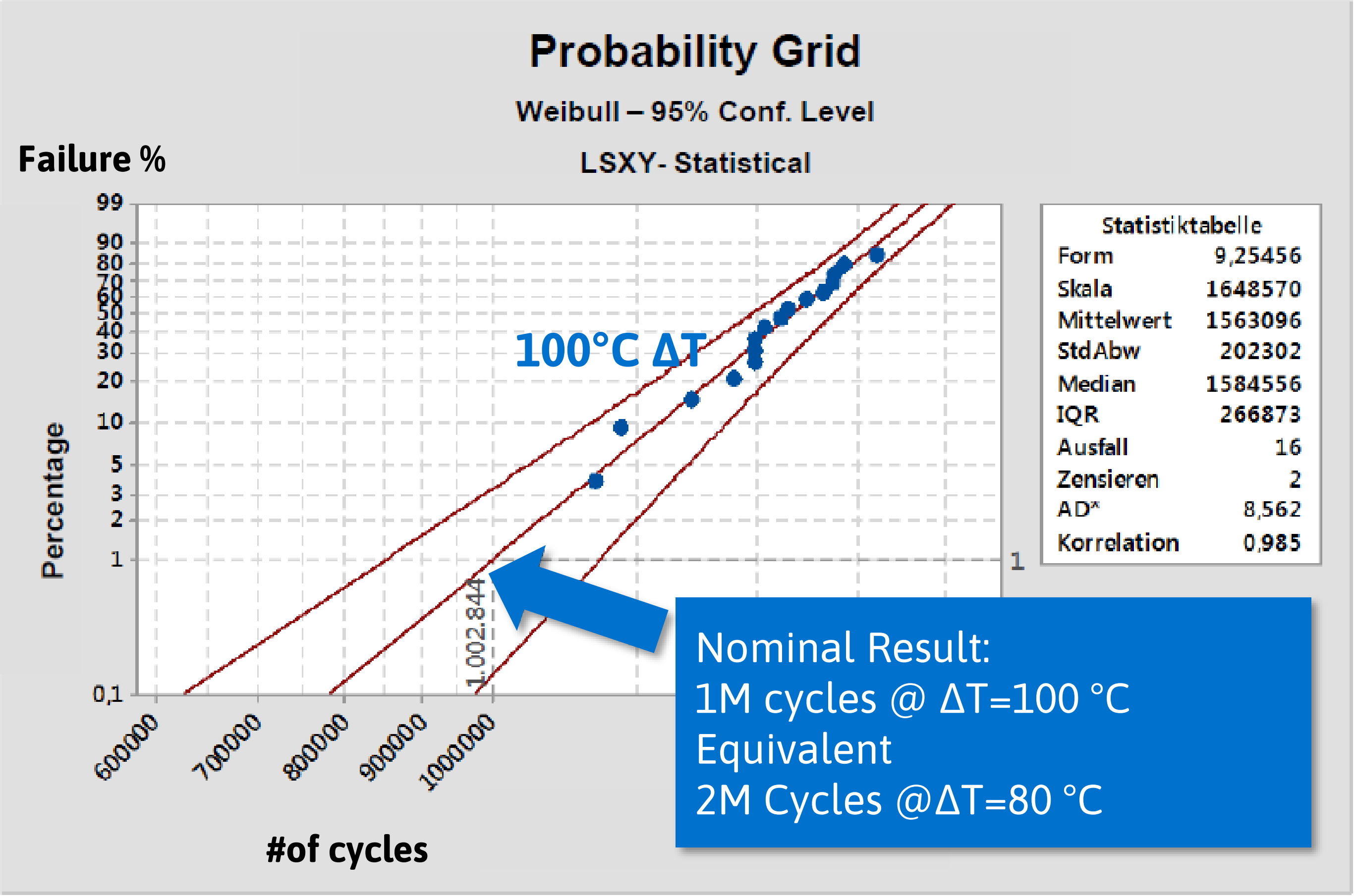
Application Examples & Case Studies

Automotive, Power Electronics and Industrial applications

Power Cycling and Thermal resistance (Rth) Measurements:



Traditional soldering approach:
150k Power Cycles @ ΔT =80°C

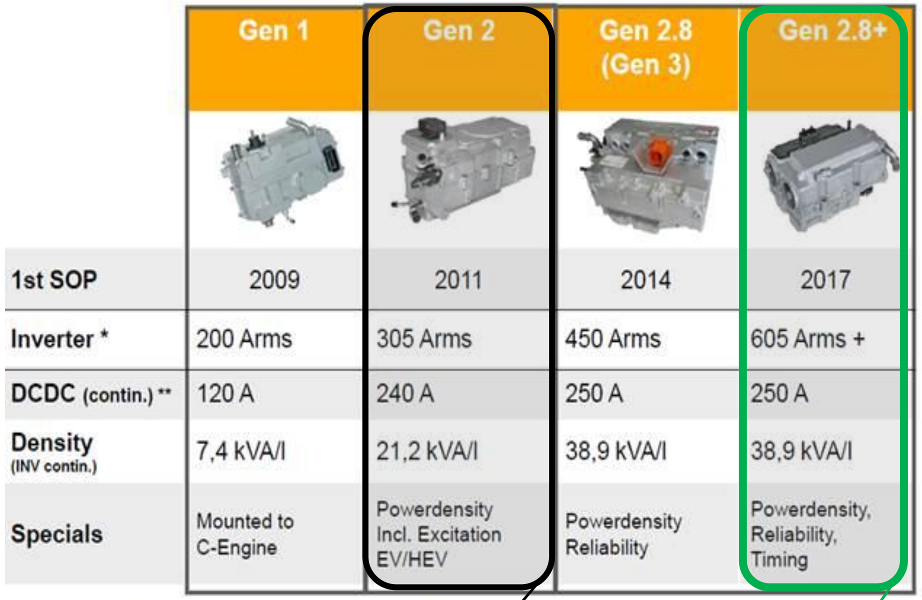
Sintering approach:
1M Power Cycles @ ΔT =100°C

Increase of lifetime by factor 6,5x with higher ΔT by 20K

Application Examples & Case Studies

Automotive, Power Electronics and Industrial applications

Superior Performance With Lower TCO (Total Cost of Ownership):



	Traditional			New
	Gen 1	Gen 2	Gen 2.8 (Gen 3)	Gen 2.8+
1st SOP	2009	2011	2014	2017
Inverter *	200 Arms	305 Arms	450 Arms	605 Arms +
DCDC (contin.) **	120 A	240 A	250 A	250 A
Density (INV contin.)	7,4 kVA/l	21,2 kVA/l	38,9 kVA/l	38,9 kVA/l
Specials	Mounted to C-Engine	Powerdensity Incl. Excitation EV/HEV	Powerdensity Reliability	Powerdensity, Reliability, Timing

* @450V, 10sec, 7l/min, 65°C, f_switch = 10kHz, cosPhi = 0,8, mod = 1,0; **: @14V, 65°C

System weight in kg

Vitesco Power Module	Traditional	NEW	Improvement
Effective Current (A)	215.0	462.0	+215%
Performance Peak (kW)	96.5	208.0	+215%
Performance Peak (HP)	129.3	278.7	+215%
Weight (Kg)	11.6	7.7	-33.8%
Power Density (kW/Kg)	8.3	27.0	+325%
Potential Weight Savings (70% Al)*	19.50 USD	12.89USD	-6.61USD

Considering 2 std systems to achieve same power, economy is at least 26USD*.

New Approach can also deliver:

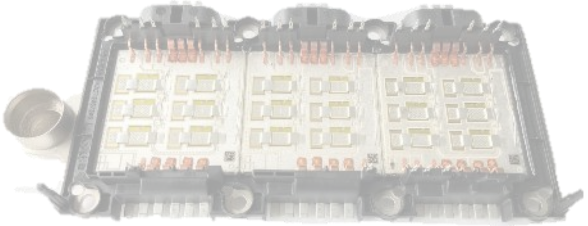
- Extended range for EVs
- Smaller cooling system cost $$

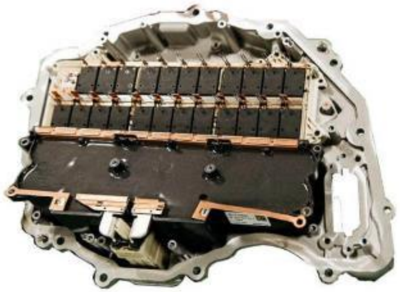
*Considering 70% weight coming from Al: 1kg= $2.40

Application Examples & Case Studies

Automotive, Power Electronics and Industrial applications

Case 1	Case 2
High Voltage Si Power Module Approach	High Voltage “SiC Mini Modules” Approach





How silver sintering help to **increase power** density, **reduce weight** and **increase reliability**?	How silver sintering help to **reduce thermal resistance, weight** and **increase reliability**?

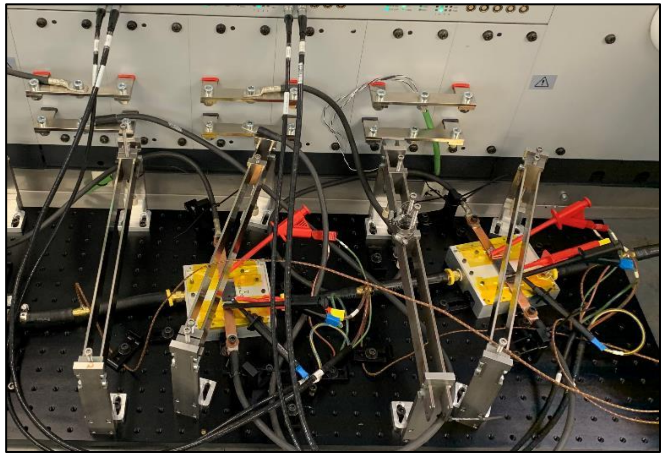
All data in this presentation is publicly available information on Internet, teardown reports
+ MacDermid Alpha proprietary tests results

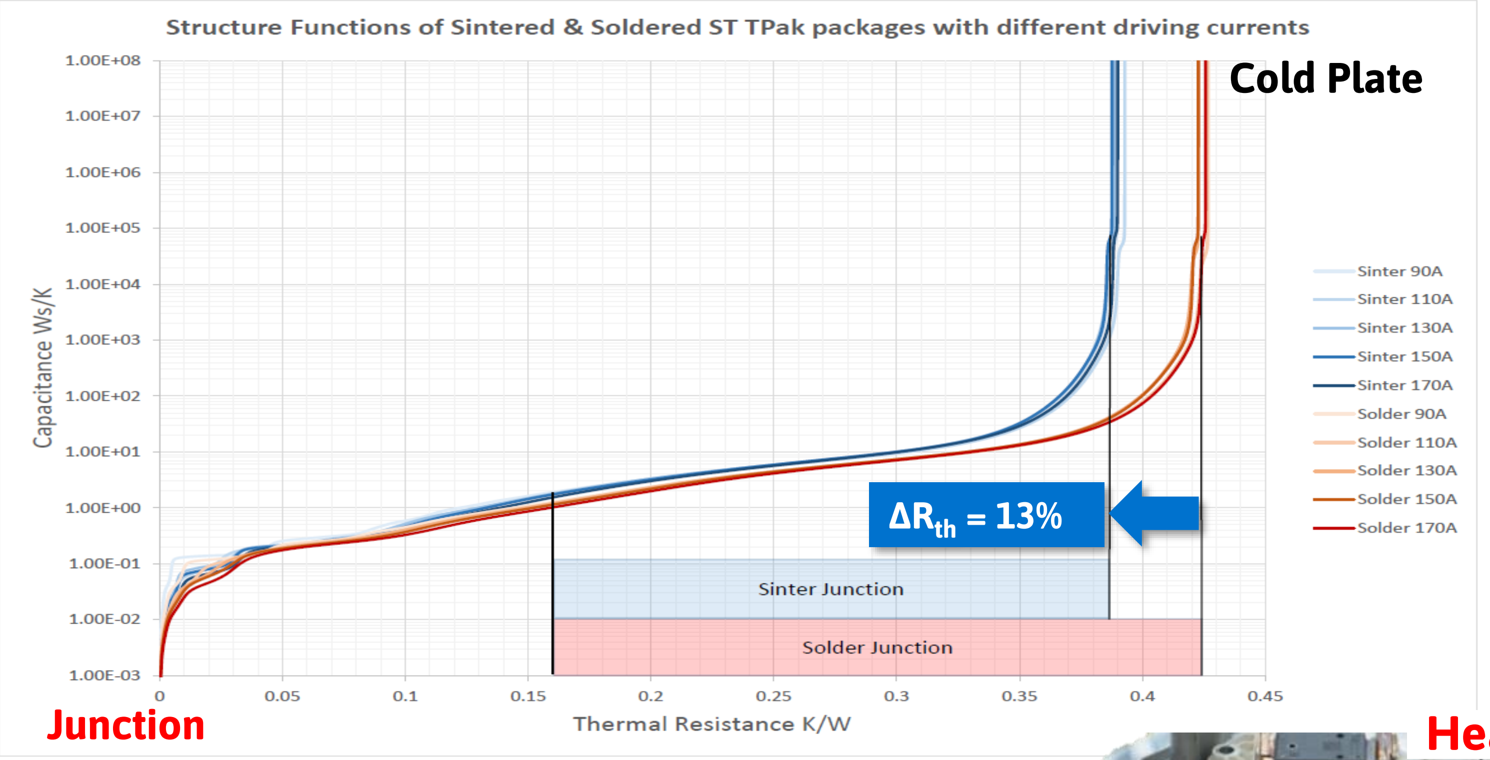
Application Examples & Case Studies

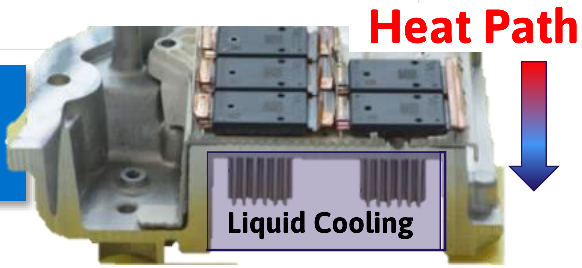
Automotive, Power Electronics and Industrial applications

Sintering Vs. Soldering : R_{th} Measurement:

DUT (Devices Under Test)





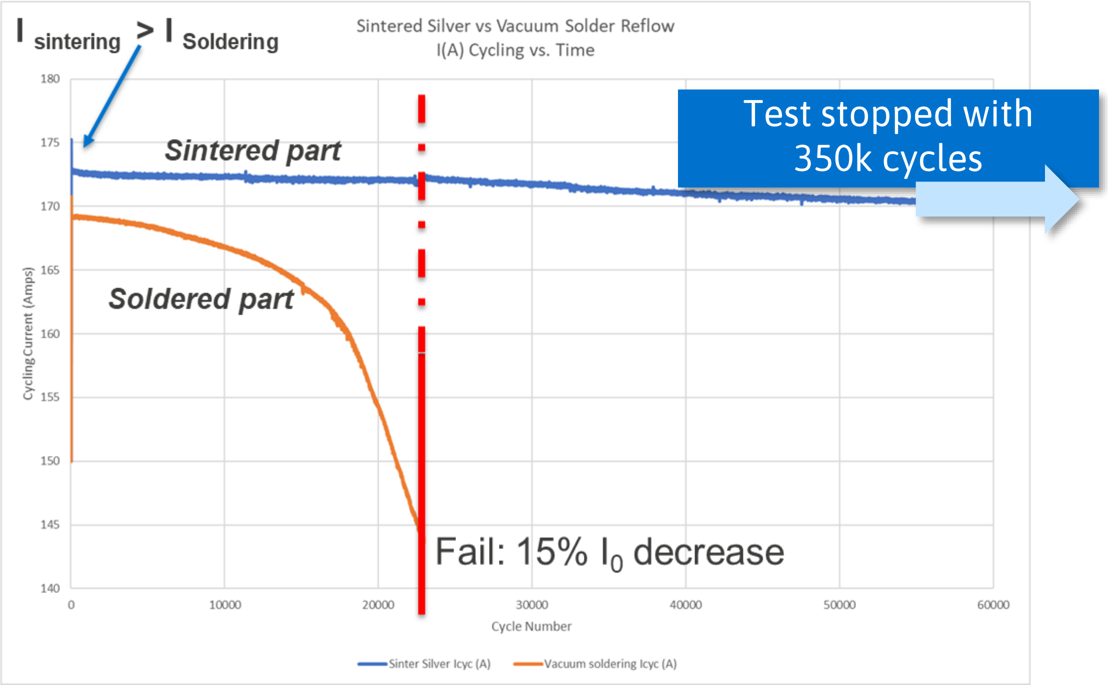


- In other applications sintering reduces overall (junction to heatsink) R_{th} upto 20%!
- Delta R_{th} is reproducible across different packages and across different currents

Application Examples & Case Studies

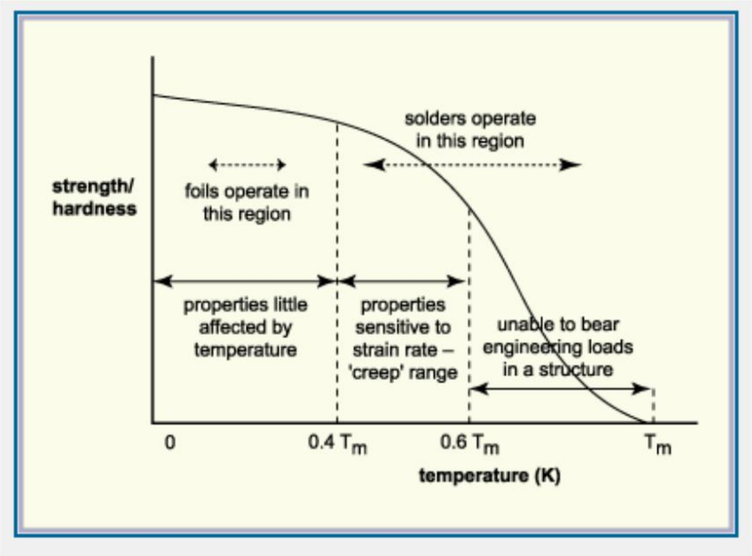
Automotive, Power Electronics and Industrial applications

Reliability: Component to Inverter Attach



Results at end-of-life soldering:

- 56K for Sintering
  @ Δ T =100°C, Δ I (I_0-I_{56k}) : 1.97A
- 22K for Std Soldering
  @ Δ T =100°C, Δ I (I_0-I_{22k}) : 26.1A



Homologous Temperature

Practical Aspects & Discussion

- Selecting the right interconnection technology
- Selection of suitable test methods
- Common failure modes and mitigation strategies

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Practical Aspects & Discussion

Selecting the right interconnection technology

- **PCB Assembly**
  - Very high thermal cycling requirement (>2000cycles)
    - Application >120°C
      - Innolot MXE
  - High thermal cycling requirement (>1500cycles)
    - Application >120°C
      - Innolot
    - Application <120°C
      - SAC305
  - Low thermal cycling requirement (1000cycles)
    - Application <120°C
      - SAC305
      - Application 100-120°C
      - Reduced Silver contents
- **Discrete package**
  - Regulatory Lead-free
  - Reflow resistance
  - Thermal conductivity
    - Low
    - Mid
    - High
- **Power Electronic Package**
  - Low cost
    - Soldering
      - Solder paste
      - Preform
  - High Performance
  - High Reliability

Practical Aspects & Discussion

Selecting the right interconnection technology

PCB Assem

Power Electronic

- There can be **no clear** and simple **recommendation** for material selection **in general**.
- Depending on the **area of application**, **properties may** be **weighted differently** in the processing of a material. Alternatively, the components to be used may already specify a material group.
  - For example, soldering is basically the only option for PCB assembly, and questions regarding alloy service life, electrochemical service life, sizes and designs of components, connectors, etc. must be clarified.
  - “Simple” chip assembly, on the other hand, is easier to decide on. Factors such as service life, thermal performance and costs play an important role here.

Innolot MXE | Innolot | SAC305 | SAC

Practical Aspects & Discussion

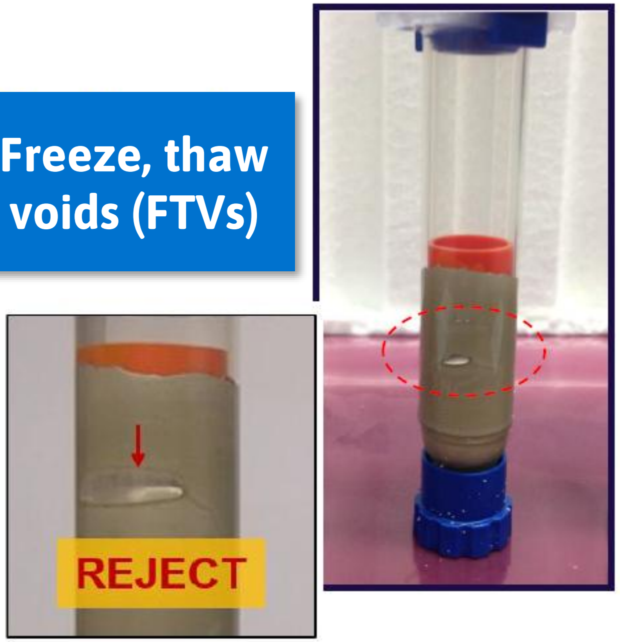
Selection of suitable test methods - Example

Technology	Prozess/ Initial	Focus reliability	Examples, acceptance criteria
Soldering	**X-Ray** analysis **IMC**-thickness by cross section **Wetting** by pictures **Shear Test** for chip components	**TCT** or TST **SIR Testing** **Dye and Pry** (BGA) Corrosion Power Cycling	Contact resistance value ≤ 10–20 % IMC-growth (definition of value) Crack propagation
Hybrid-Sinter	**BLT**-measurement **X-Ray** analysis **Shear test** at RT/ HT260°C **Cross section** with SEM	TCT or **TST** **HTS** (aging of binder) **Power Cycling**	No Delamination in SAM Thermal resistance, ΔRth ≤ 10 % Change of porosity
Sintering	**SAM** **Shear test** at RT/ optional HAT **Cross section** with SEM	**Power Cycling** TCT or **TST** **HTS, with humidity**	Thermal resistance, ΔRth ≤ 5-10 % Shear force

Practical Aspects & Discussion

Common failure modes and mitigation strategies – Example Hybrid-Sintering

Freeze, thaw voids (FTVs)



Possible cause:

- Thermal Shock of the syringe
- Introduction of voids (since the syringe and material expand at different rates)

Can lead to:

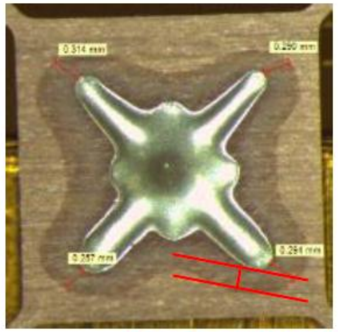
- Inconsistency issues
- Voiding under die

Solution:

- Syringes obtained from freezer should be held by the *flanges*

Practical Aspects & Discussion

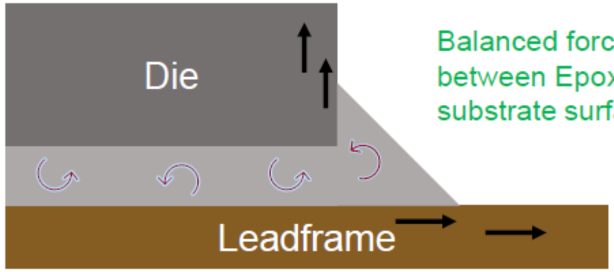
Common failure modes and mitigation strategies – Example Hybrid-Sintering



Capillary effect

Resin/Epoxy bleed out

Ideal situation

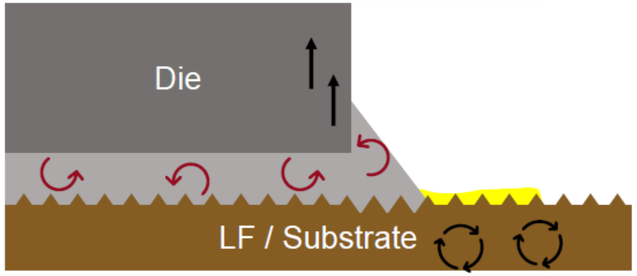


Balanced forces between Epoxy and substrate surface

Low energy surface

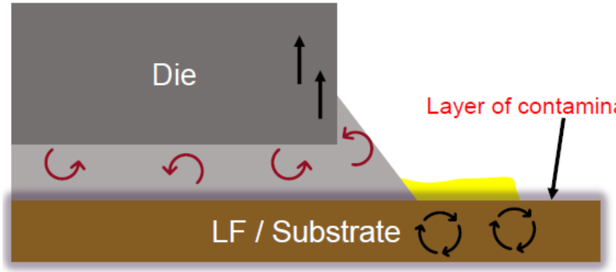
Resin Bleed Out is a **surface phenomenon** whereby fractions of the organic resin or reactive diluents migrate along the surface of the substrate or up the side of the semiconductor chip **due to surface energy difference between the resin & the substrate**.

Roughened surface



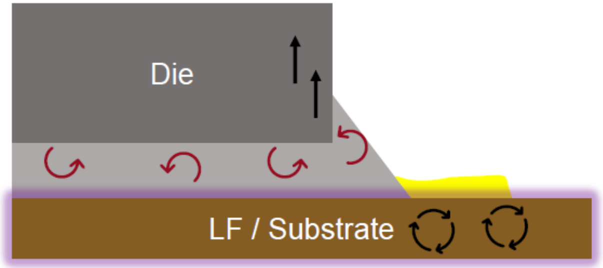
High energy surface

Contaminated surface



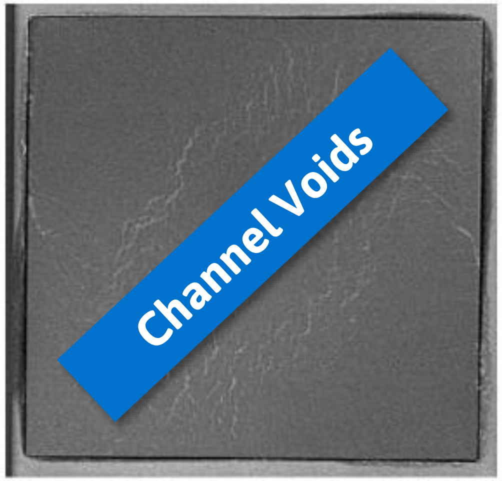
Layer of contamination

Activated surface

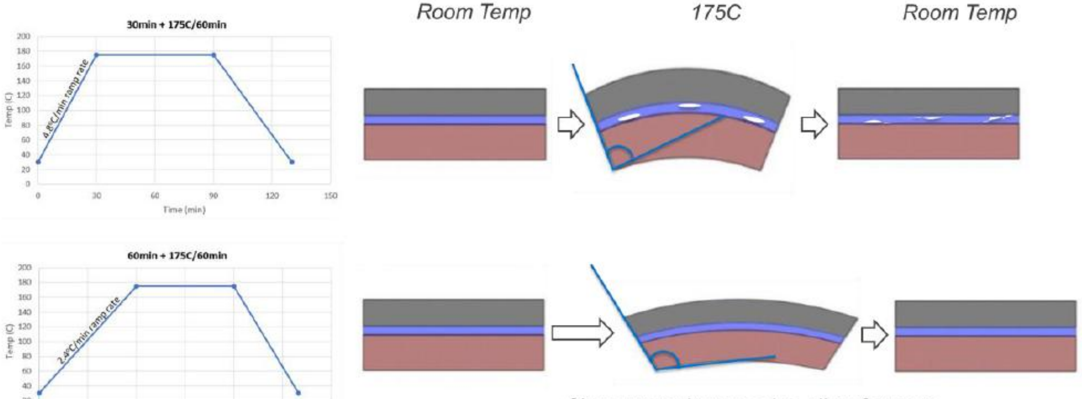


Practical Aspects & Discussion

Common failure modes and mitigation strategies – Example Hybrid-Sintering



Material	CTE, ppm/°C
ceramic	9.5-11.5
tantalum	6.5
glass, borosilicate	3.24-4.5
silicon	2.6-3.0
gold	14.1
FR-4 PCB	18
polyimide/glass PCB	12
polyimide/Kevlar PCB	7
copper lead frames	16-17
Kovar® lead frames	5.1-5.5
filled epoxy resins (<T_g)	18-25



Slower ramping speed to allow for more time to better release stress to the die before DA material gels/cure at 175C.

Possible Cause:

- Low Bondline Thickness (BLT) insufficient coverage, creating stress in package during cure
- Need further curing optimization for large die package (due to CTE mismatch)

Solution:

- Slow down the curing ramp up time
- e.g. 60min ramp to 150C + 150C/30min + 200C/2hrs

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Contact us

Martin Metzler

Director, Technical Business Development

martin.metzler@macdermidalpha.com

macdermidalpha.com

www.linkedin.com/in/martin-metzler-a73901291/

Thank you for your attention!