Optimizing Power Electronics Reliability: Advanced Thermal Management & Wire Bond Lifetime Testing

SPEAKER

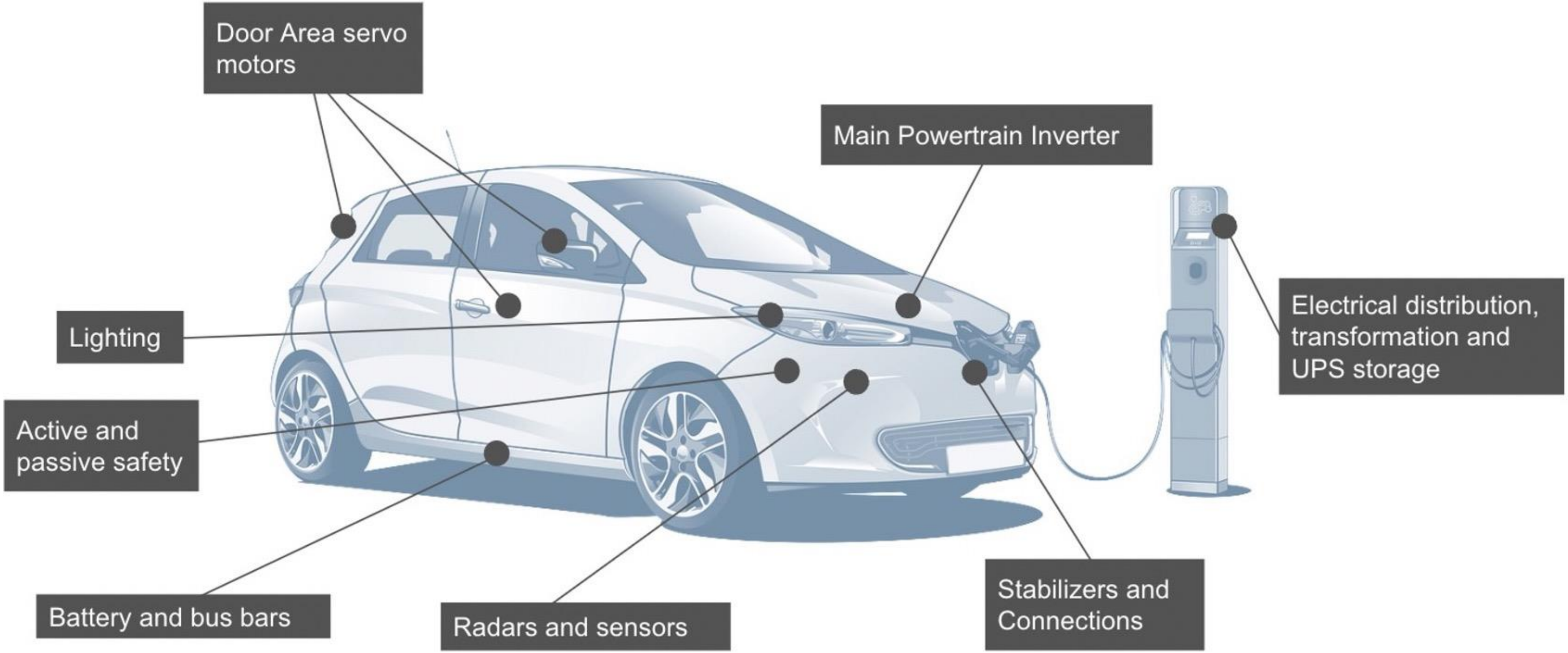
Jeff Berlin

EV & Electronics Specialist at TEC Associates

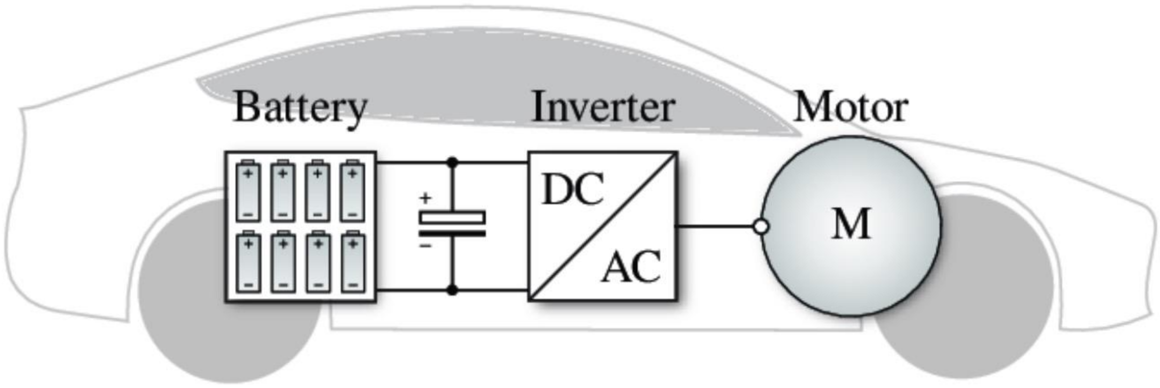
Jeff@tecreps.com | www.tecreps.com

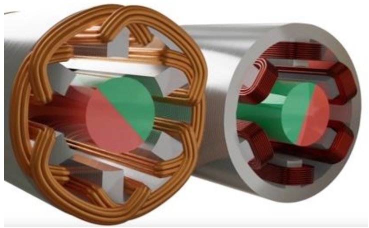
Jeff Berlin supports advanced manufacturing technologies across the automotive, semiconductor, and power electronics sectors. With a background in high-reliability interconnects and packaging processes, he brings deep expertise in thermal management, wire bonding, and lifetime testing solutions for next-generation power modules.

Electrical Systems in Electric Vehicles



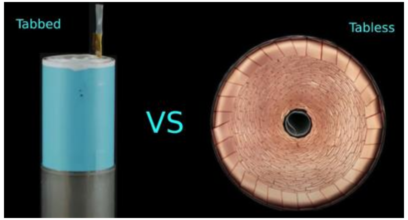
Powertrain in Electric Vehicles



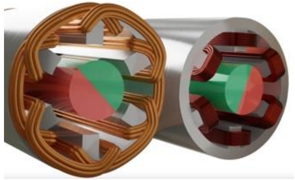


Areas of Improvement

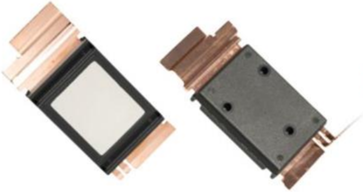
Batteries

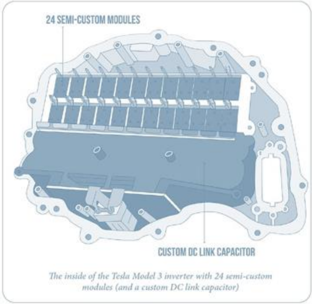


Motors



Power Electronics





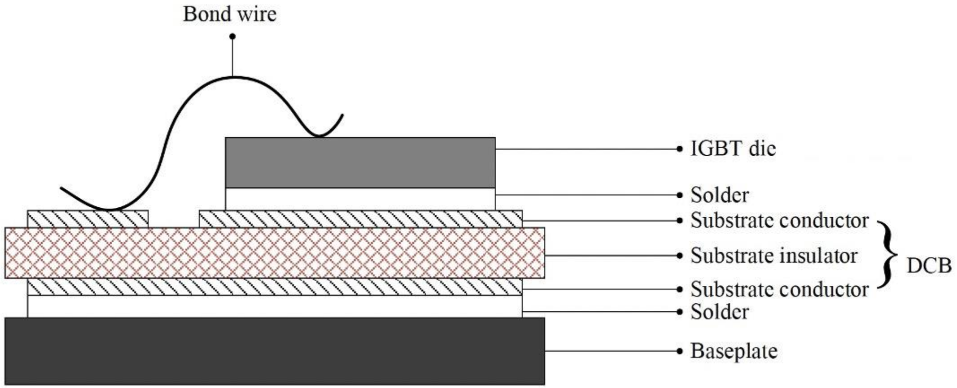
The inside of the Tesla Model 3 inverter with 24 semi-custom modules (and a custom DC link capacitor)

Ag/Cu Pressure Sintering Technology for Power Semiconductors

TEC ASSOCIATES INC.

WWW.AMX–AUTOMATRIX.COM

Traditional IGBT Package Design



The Thermal Management & Reliability Problem:

Solder and many standard epoxy-silver materials are proving increasingly unsuitable for many discrete and small module device applications. They may, for example, be incapable of surviving the ambient conditions seen from longer mission profiles for automotive applications. These mission profiles typically drive longer high-temperature operating life (HTOL) and larger temperature swings in usage (thermally cycling).

Pressure Sintering

Pressure sintering is a heat treatment process applied to powdered materials to enhance their strength, integrity, and conductivity. During pressure sintering, the powdered material is subjected to elevated temperatures (~250C) and high pressures (15mPa) simultaneously. This process helps in densifying the material by eliminating pores, thus improving its overall mechanical, electrical, and thermal properties.

Silver (Ag) sintering is currently the most popular in commercial applications, and provides:

I. Best Thermal Conductivity > 250 W/mK
I. Best Electrical Conductivity ~ 2 (μΩcm)
II. Enhanced Reliability (Life Cycle Testing)
III. High re-melting temperature >400°C

Figure 1a: SEM images of the nanoscale silver paste before sintering.

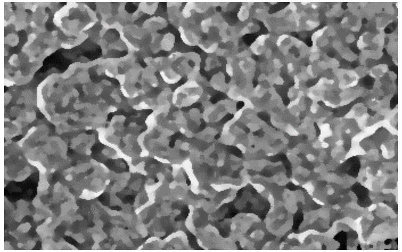
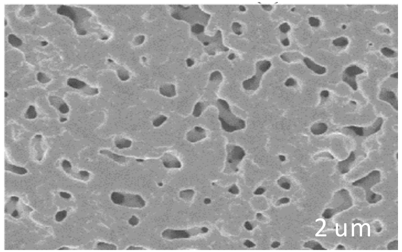


Figure 1b: SEM images of the nanoscale silver paste after sintering on substrate at 280°C.



Pressure Sintering

AG PRESSURE SINTERING

Silver (Ag) Sintering: Advantages of Pressure Sintering vs Soldering

I. Monometallic Interconnection
II. Porosity <10% (depending on the force applied)
III. High re-melting temperature >400°C
IV. High ductility on micro scale
V. Better results in life cycle testing

SEM inspection after ion milling cross section

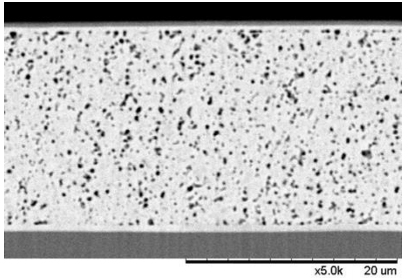


Figure 2a:
Ag Layer 15MPa Pressure Sintering
Porosity <10%,

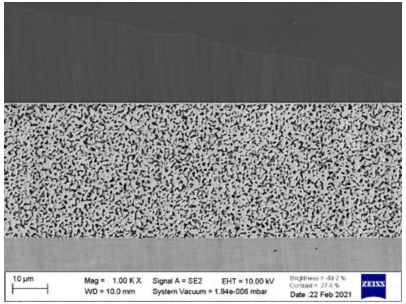


Figure 2b:
Ag Layer Pressure-Less Sintering
Porosity >25%

Material	DENSITY g/cm3	ELECTRICAL RESISTIVITY	THERMAL CONDUCTIVITY	MELTING POINT
Ag (Silver)	10.49	1,6 (µΩcm)	420 (W/mK)	962°C
Pressure Sintering	~8,9	~2 (µΩcm)	~300 (W/mK)	
Pressure-Less Sintering	~6.5-7,4	~10-14 (µΩcm)	~58 - 100 (W/mK)	

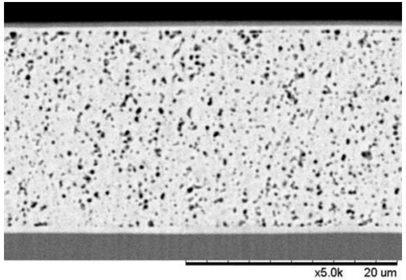
Pressure Sintering Materials

AG/CU PRESSURE SINTERING

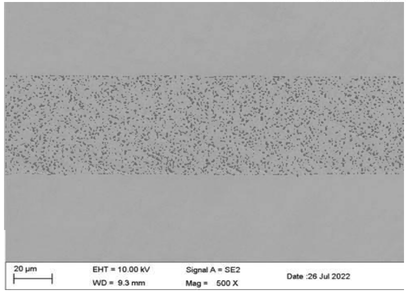
- Silver (Ag) Sintering - currently the most popular sintering material
- Copper (Cu) Sintering - copper sintering is a new/next generation material

Material	MELTING POINT (C°)	ELECTRICAL RESISTIVITY	THERMAL CONDUCTIVITY	Price / g
Ag (Silver)	960°C	1,6 (μΩcm)	420 (W/mK)	$ 0.72
Cu (Copper)	1080°C	1,7 (μΩcm)	401 (W/m∘K)	$ 0.10

SEM inspection after ion milling cross section



AMX Figure 3a :
Ag Layer 15MPa Pressure sintering



AMX Figure 3b:
Cu Layer 20MPa Pressure sintering

Reliability Implications of Pressure Sintering

AG PRESSURE SINTERING

Silver (Ag) Sintering: Pressure Sintering vs Soldering Advantages

I. High Remelting Temperature >400°C
II. Higher Thermal Conductivity
III. Higher Shear Strength Results
IV. Longer Lifetime / Reduction in Failure Timeline (Power Cycling Test)
100% Operating After 50K+ Power Cycles
vs Soldering Joint - 15% Failure After 2500 cycles

V. Minor Variation After Thermal Cycling -55ºC / +150ºC (10000x Air-to-Air)
VI. No Variation After Hot temperature Storage +150°C (1000Hrs)
VII. No Variation After Low Temperature Storage -50°C (1000Hrs)

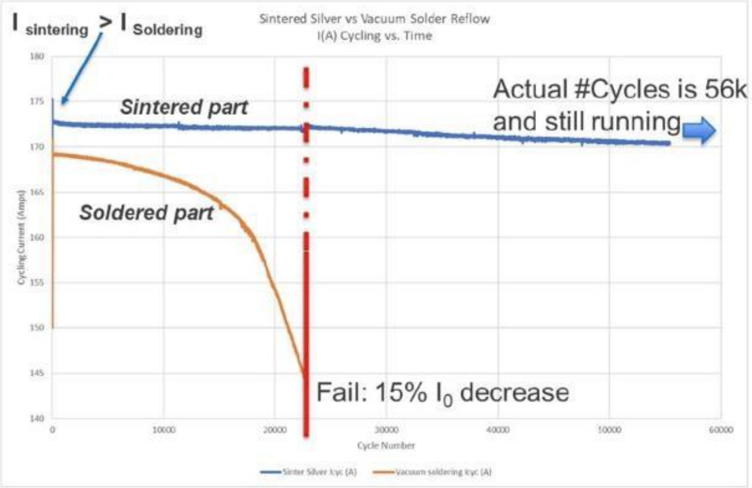


Table 01 - Failure Analysis
Source – Mac Dermid Alpha

Equipment Involved in Pressure Sintered Device Manufacturing

Typical Assembly Workflow (representative pictures)

Manufacturing Challenges in Advanced Packaging

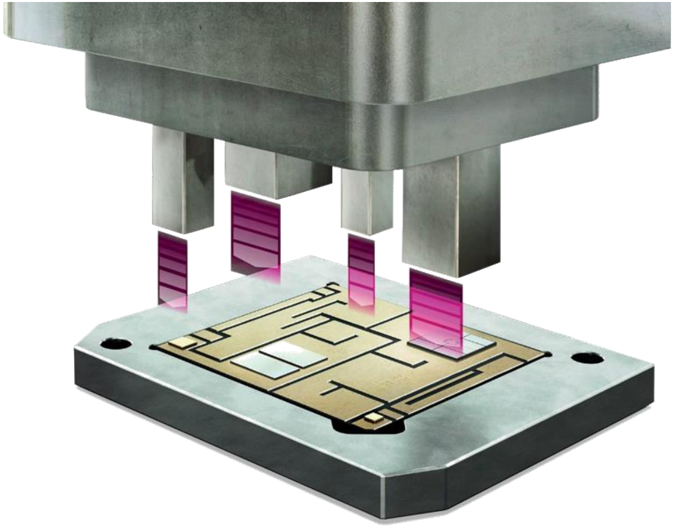
Controlling Applied Pressure Across Complex Designs

- Variations in Component Size Requires Different Applied Pressure for Each Component
- Variation in Die Height Due to Sinter Paste Volume Requires Independent Force on Each Component
- Substrate Tilt & Warpage Requires Angle Compensation

Manufacturing Challenges in Advanced Packaging

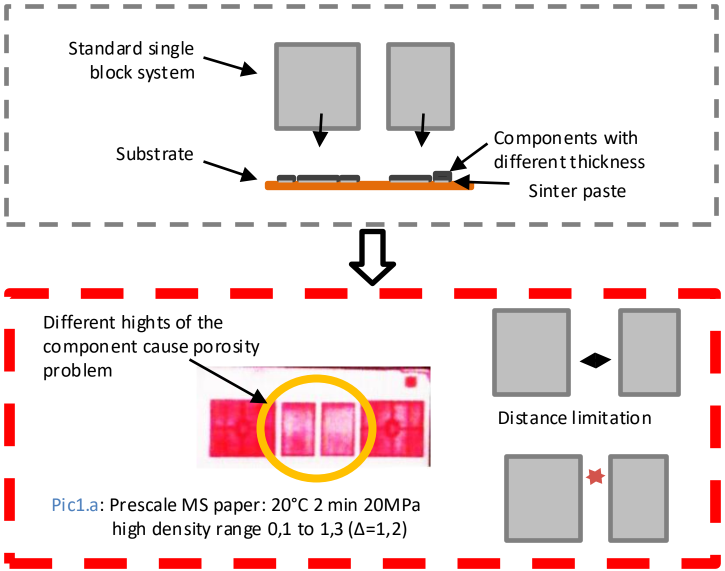
“Micro-Punch” Solution

“Micro-Punches”, Capable of Pressing Individually on all Devices in a Modern Power Package, with a Dedicated Pressure, and Angle Compensation



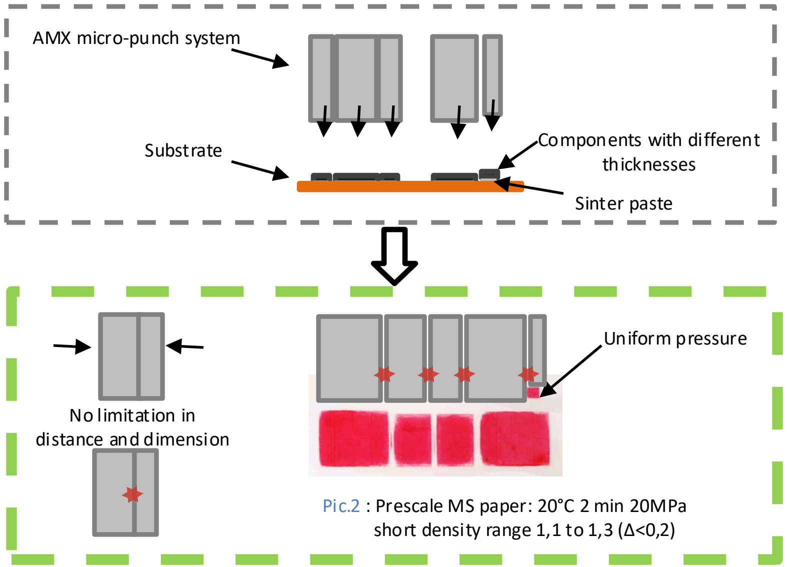
”Micro-Punch” Solution

Standard Multi-Punch Systems



Pic1.a: Prescale MS paper: 20°C 2 min 20MPa
high density range 0,1 to 1,3 (Δ=1,2)

“Micro-Punch System"

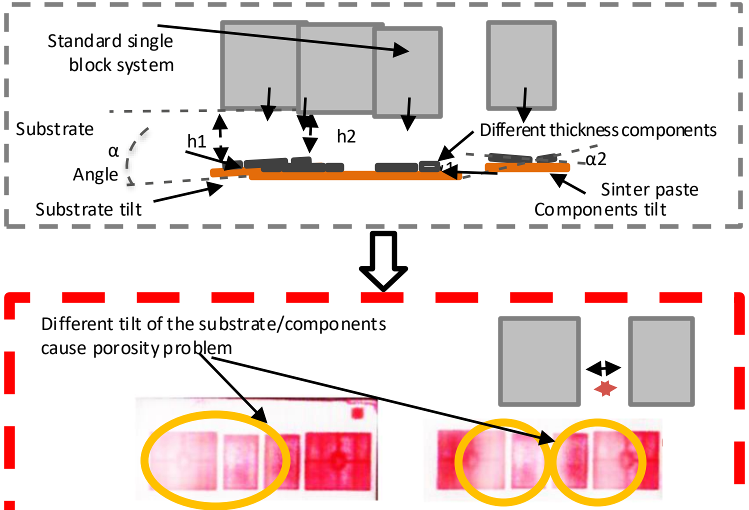


Pic.2 : Prescale MS paper: 20°C 2 min 20MPa
short density range 1,1 to 1,3 (Δ<0,2)

- No Limitation in Die Thickness Difference - No Limitation in Die Distance & Dimension
- Can Compensate Uneven Die Thickness & Printing

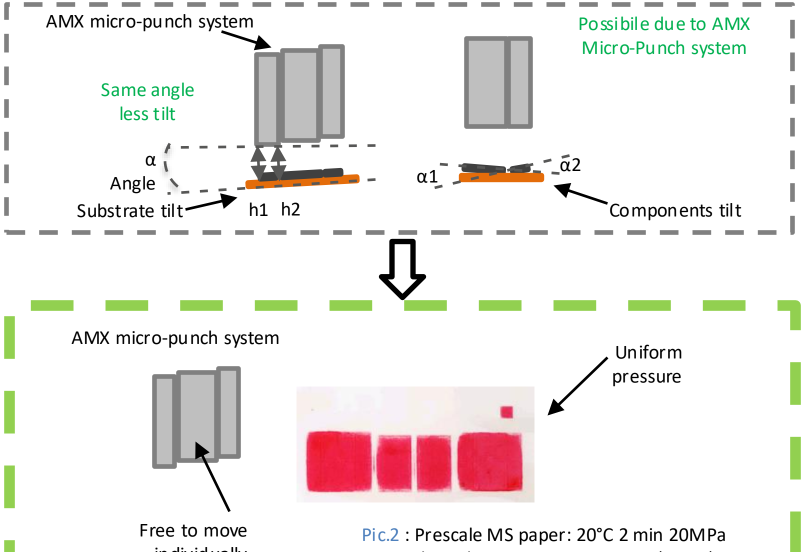
"Micro-Punch" Solution

Standard Multi-Punch Systems



Pic2.a: Prescale MS paper: 20°C 2 min 20MPa
high density range 0,1 to 1,3 (Δ=1,2)

"Micro-Punch System"



Pic.2 : Prescale MS paper: 20°C 2 min 20MPa
short density range 1,1 to 1,3 (Δ<0,2)

Best Bonding Results In Case of Bad Placement or Native Warpage

Advancements in SiC Power Module Designs

Advanced Package DIE Level Sintering – DSC (Double Sided Cooling) Packages

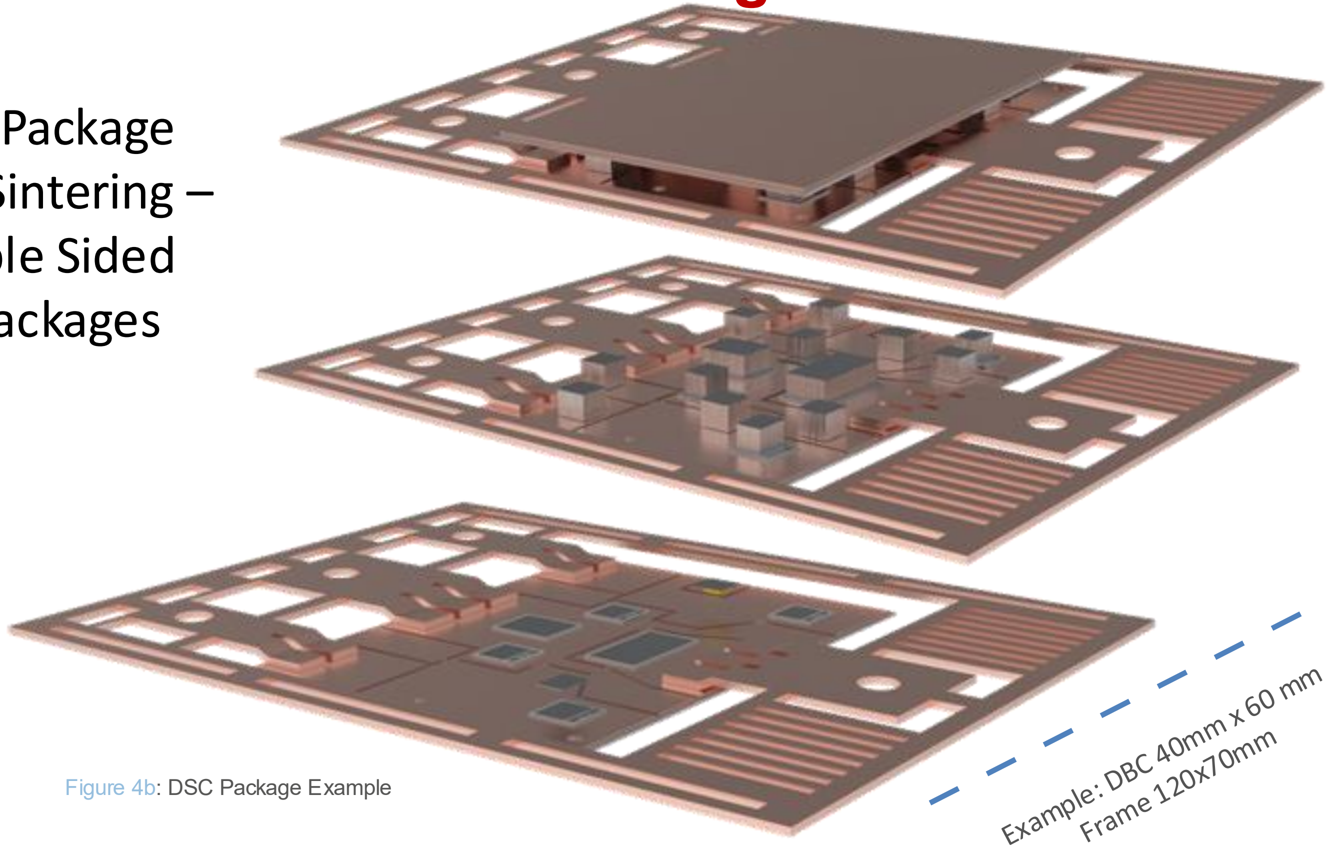


Figure 4b: DSC Package Example

Advancements in Inverter Assembly – Large Area Sintering

Sintering of Power Modules On Heatsinks

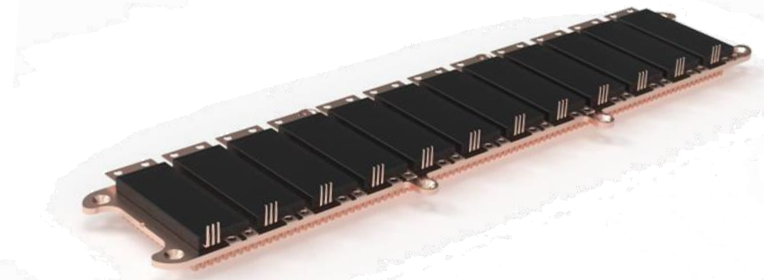


Figure 4a: Modular Solution Heatsink (AMX Representative Illustration)
A series of modular packages (typically 6 or more), working in parallel

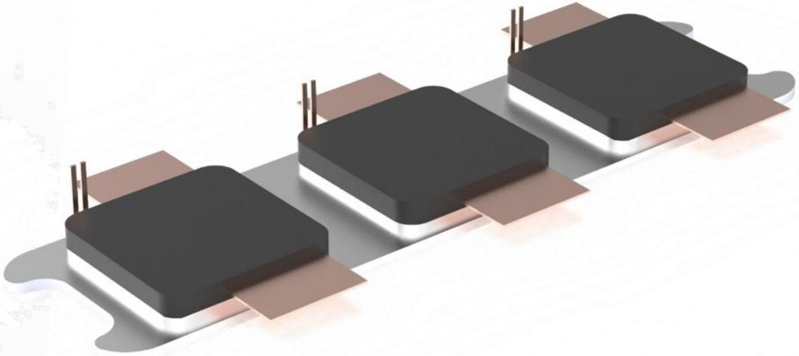


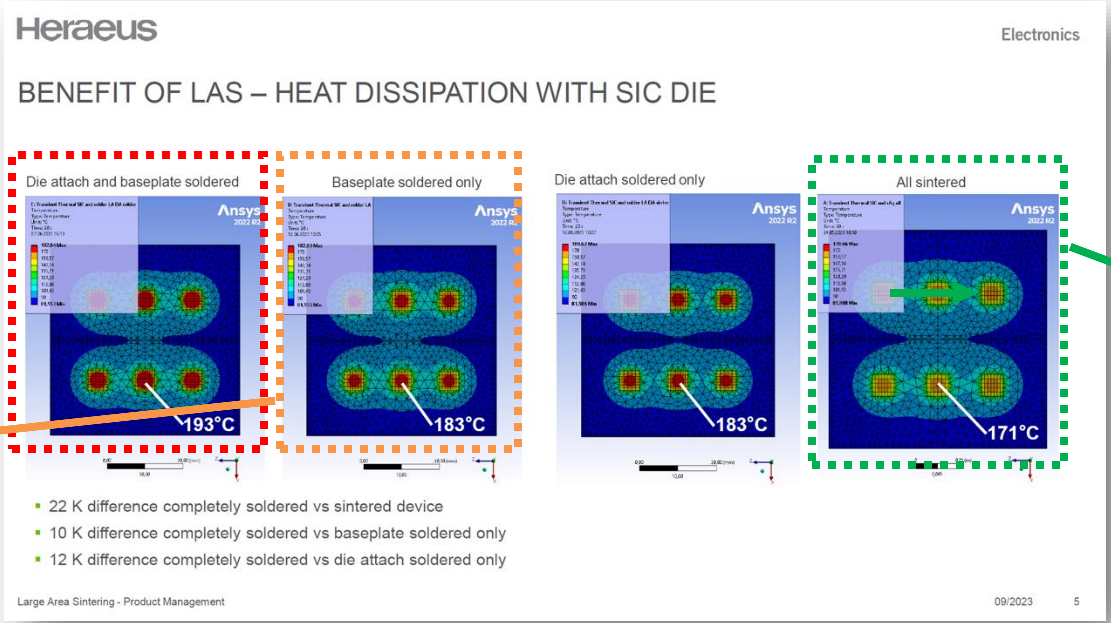
Figure 4b: Modular Solution Heatsink (AMX Representative Illustration)
3 Half Bridge Power Packages

Thermal Implications of Pressure Sintering

Pressure Sintering vs Traditional Soldering

Hansis Simulation (Source: Heraeus Electronics)

SiC Soldered / Baseplate Soldered
A: SiC to AMB Soldered
B: AMB to Heatsink Soldered

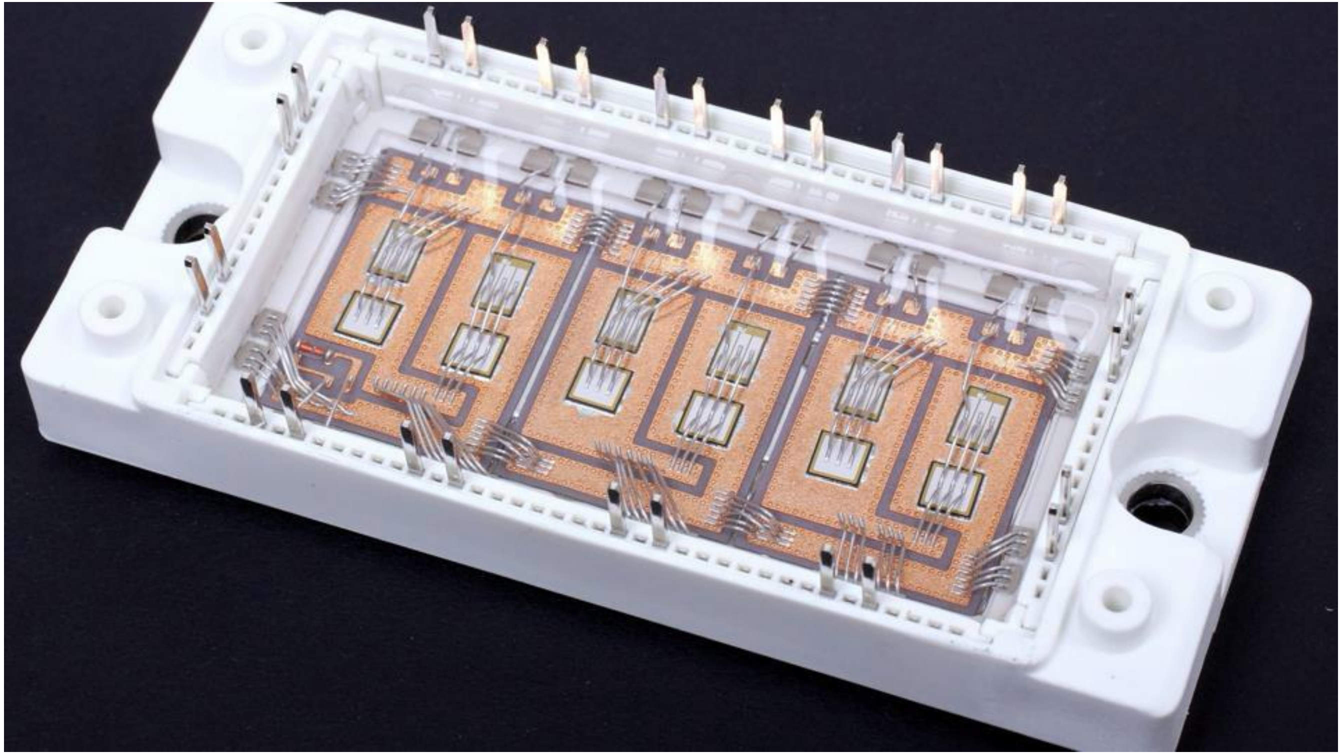


SiC pressure sintered / Baseplate soldered
A: SiC to AMB Pressure Sintered
B: AMB to Heatsink Soldered

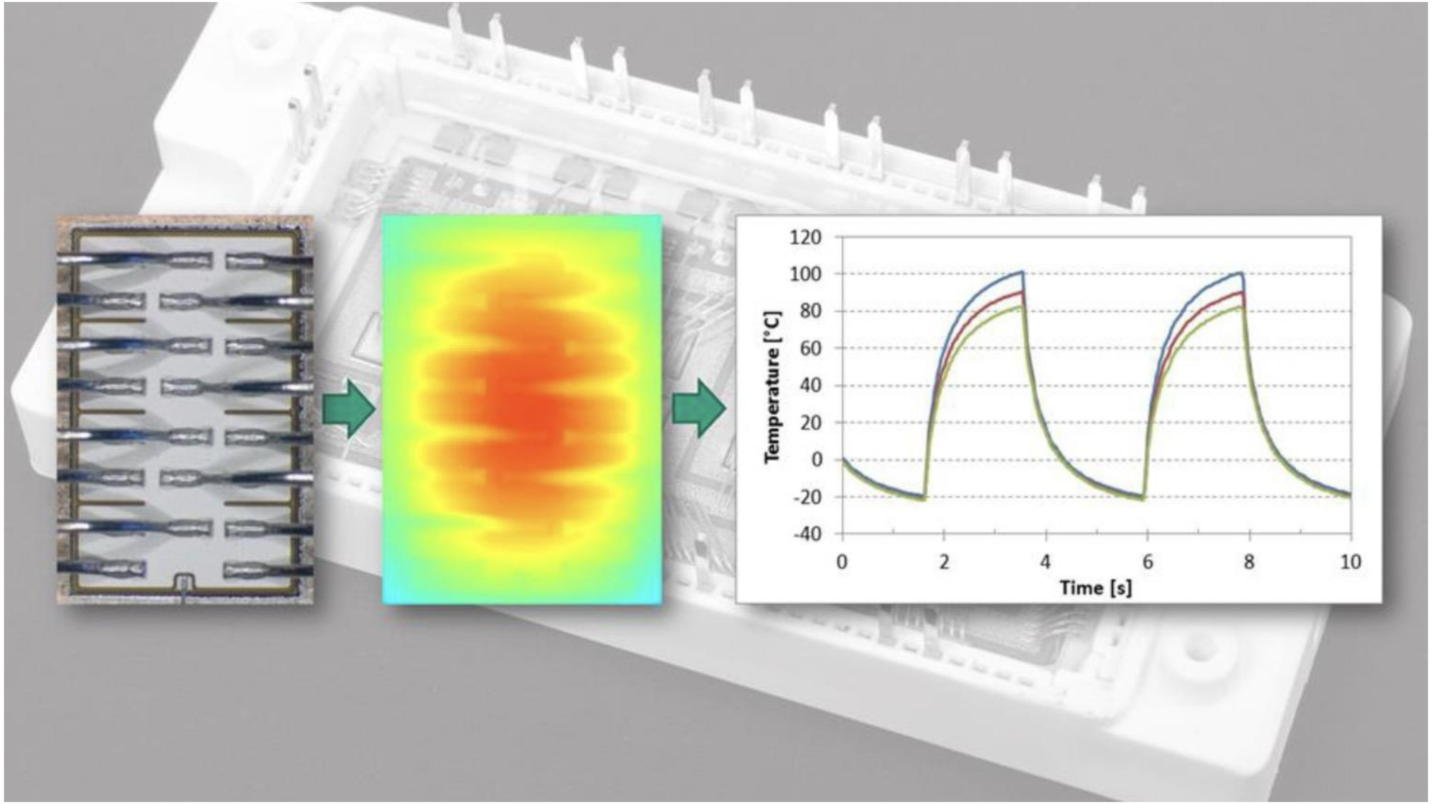
Fully Pressure Sintered:
A: SiC to AMB Pressure Sintered
B: AMB to Heatsink Pressure Sintered

BAMFIT: Mechanical Fatigue Evaluation for Power Module Wire Bonds

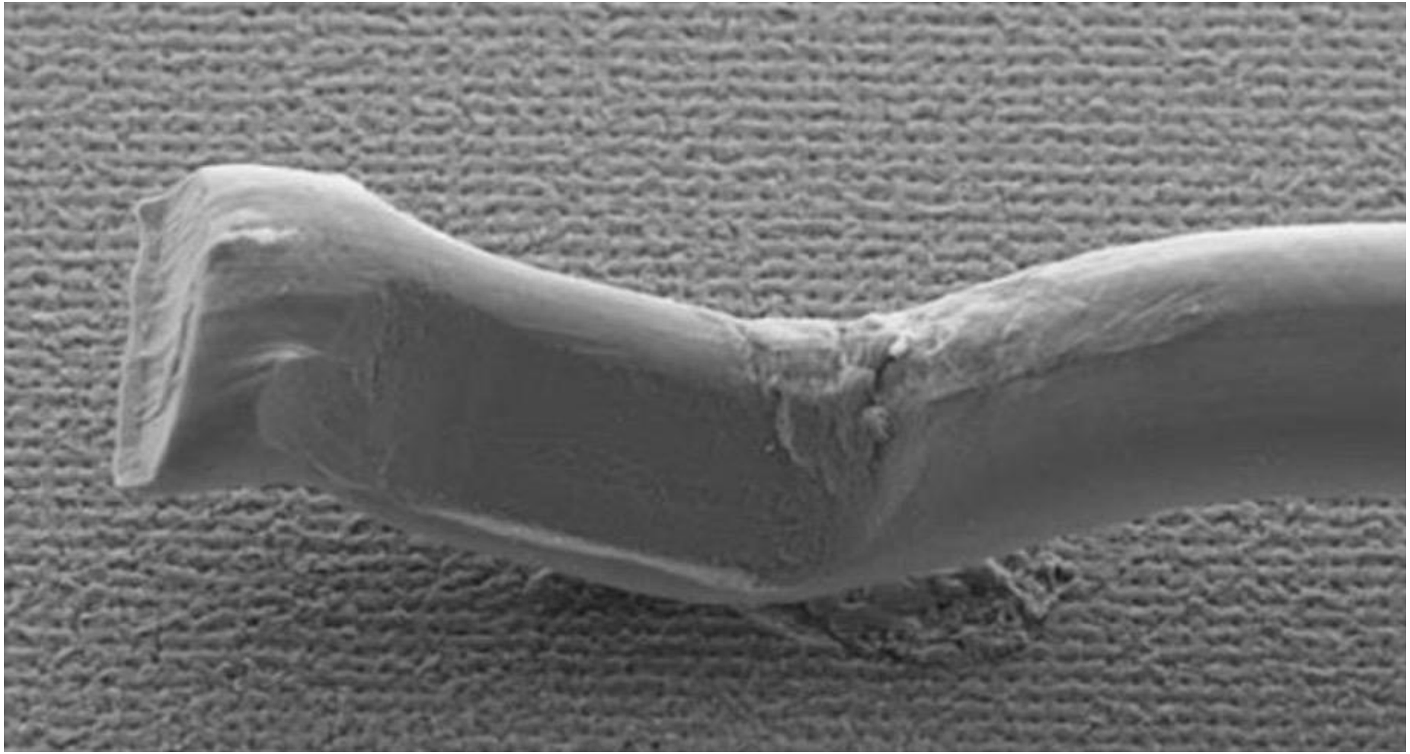
Wire Bond Reliability Under Real-World Mission Cycles



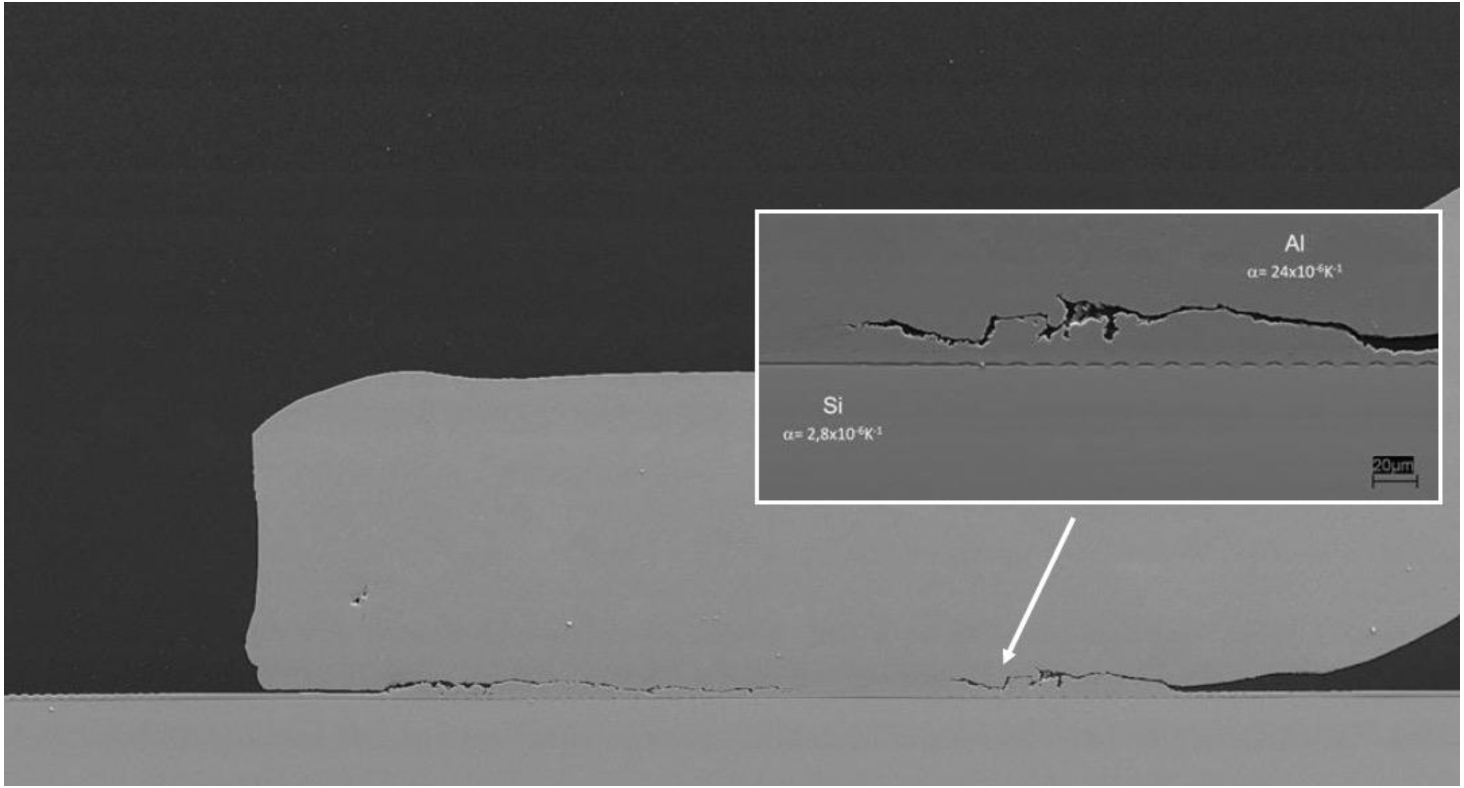
Why Traditional Shear Testing Falls Short in EV Power Modules



Wire Bond Lift Off Caused By Active Power Cycling (APC)

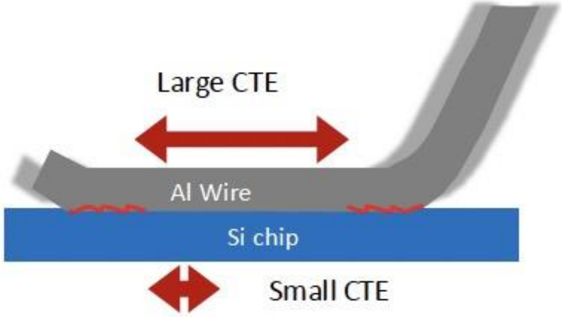


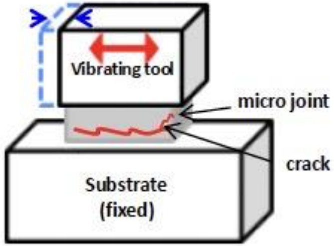
Crack Propagation in the Wire Bond Interface During APC



Alternative: Accelerated Mechanical Fatigue Testing

Thermal cycling → Fatigue failure ← Mechanical cycling

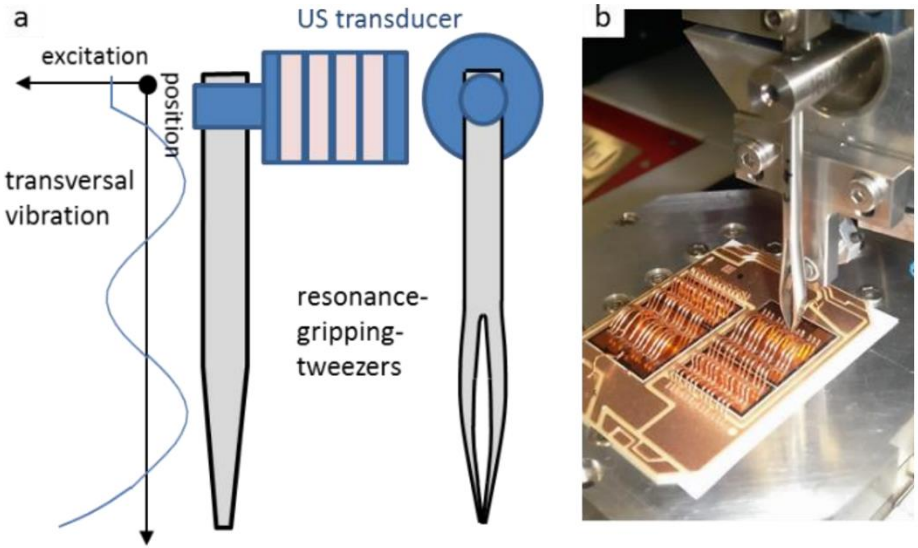


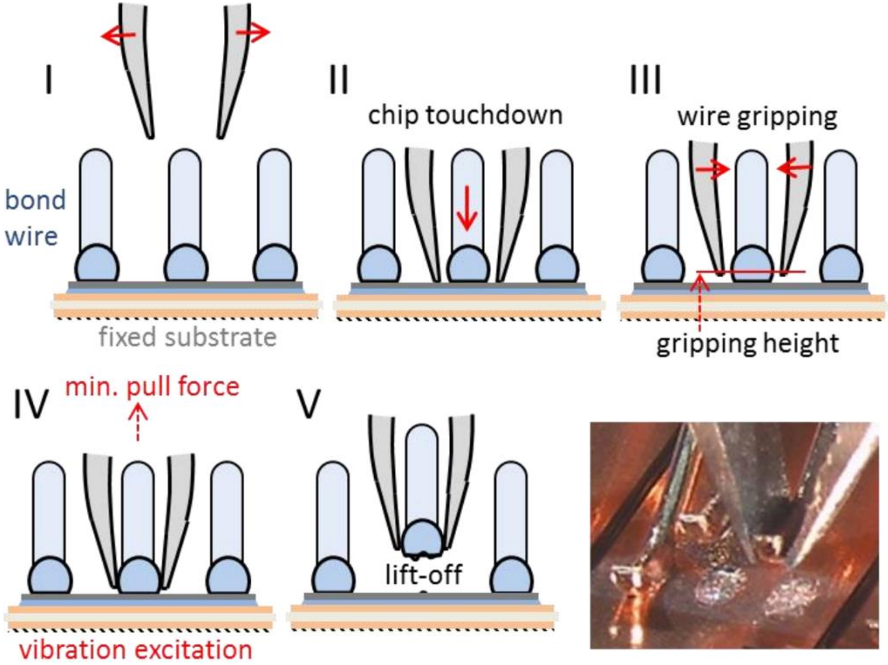


- Thermal cycles create interfacial stress → fatigue failure
- Equivalent shear stress can be introduced by cyclic mechanical loading
- Testing can be done much faster
- Developed by Khatibi and Czerny, TU Vienna; Patent pending DE 102016107028

General – Accelerated Life-Time Test

BAMFIT…Bondtec Accelerated Mechanical Fatigue Interconnect Testing

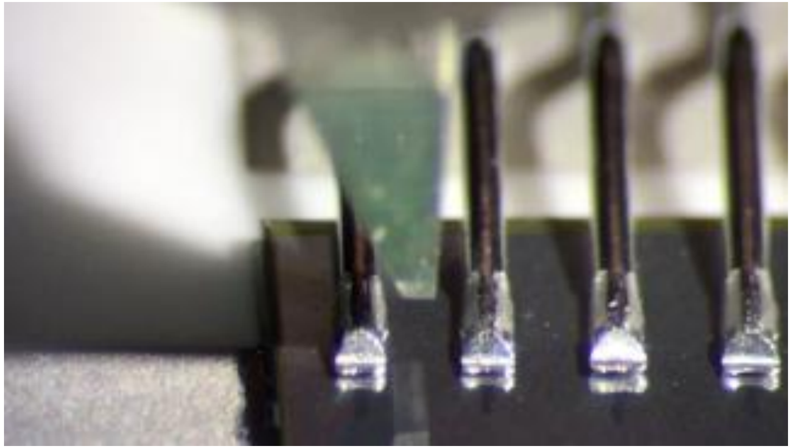


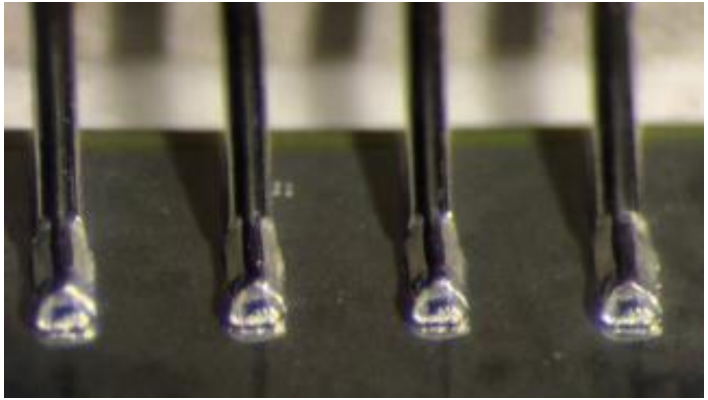


Shear Testing & Bamfit Testing Example

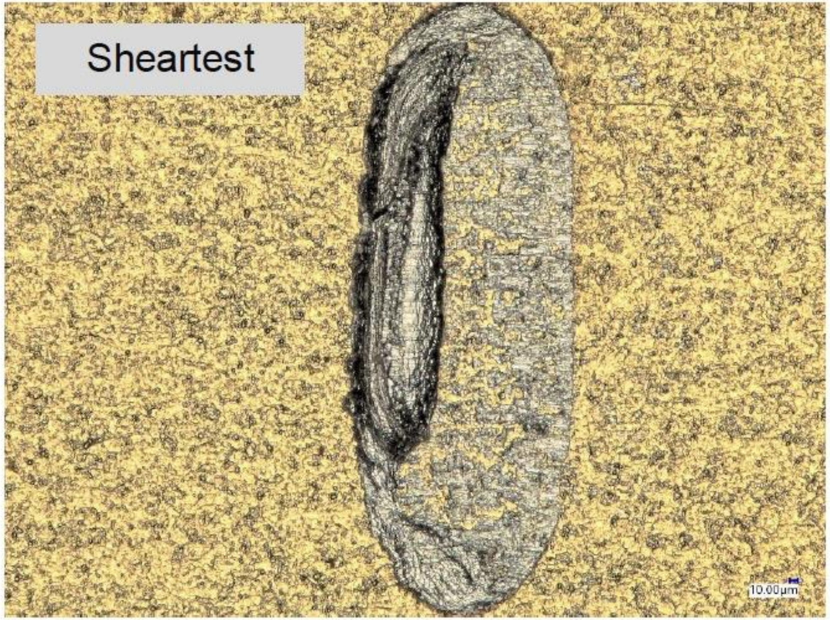
Process parameter development:

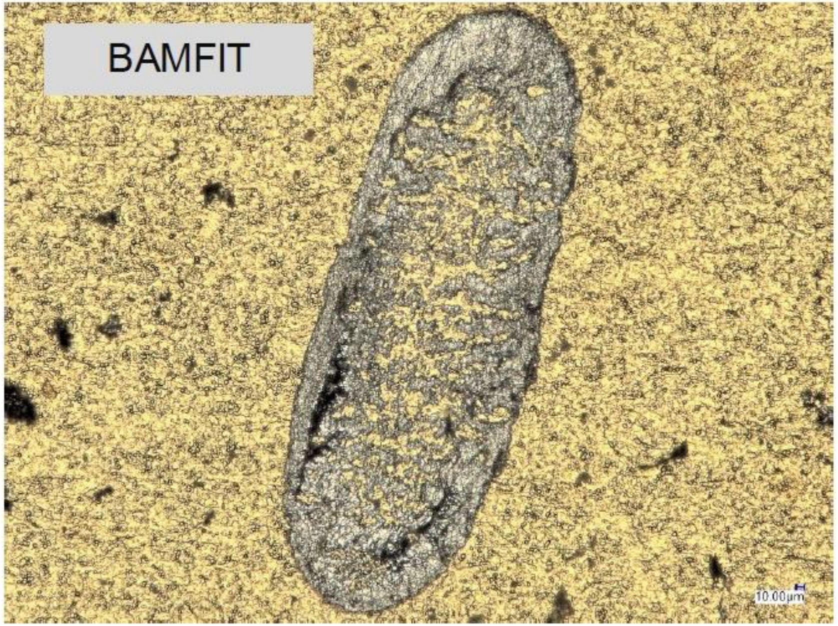
- 2 Sets of parameters for optimized bonding
- Set A = 110 digits Ultrasonic
- Set B = 160 digits Ultrasonic



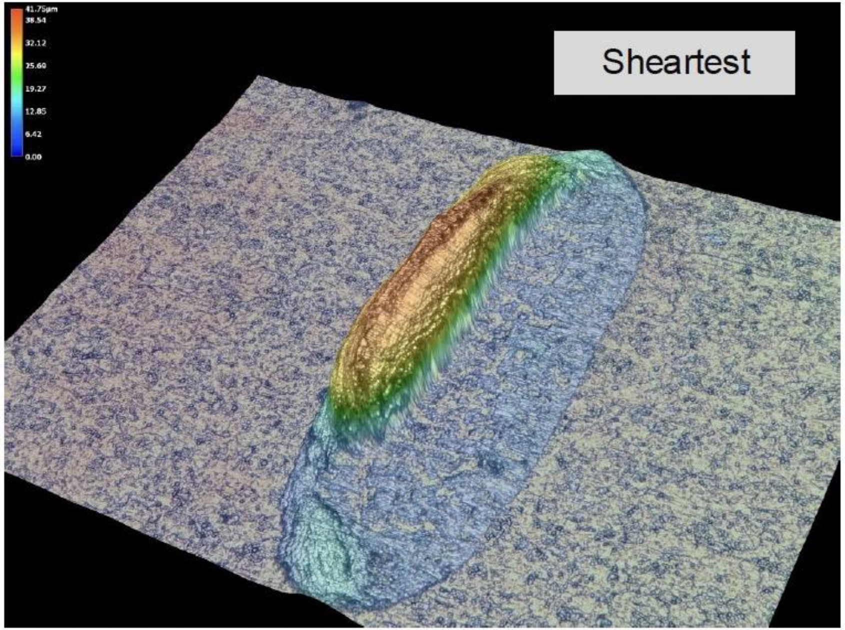


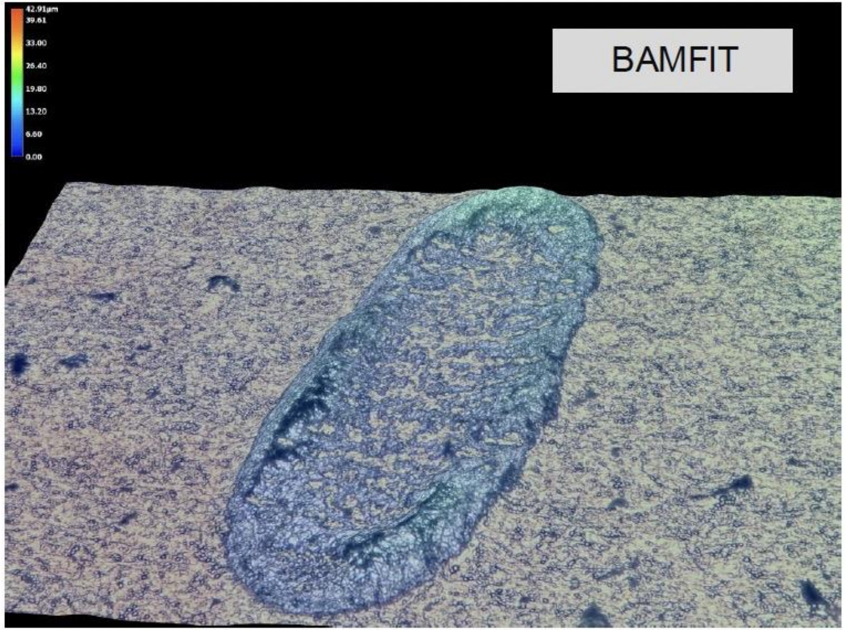
Low Ultrasonic Power Testing Data



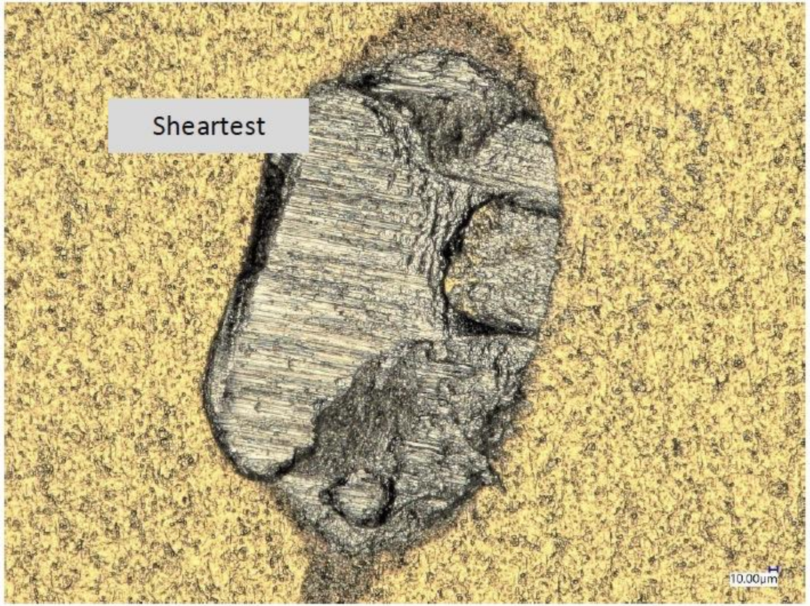


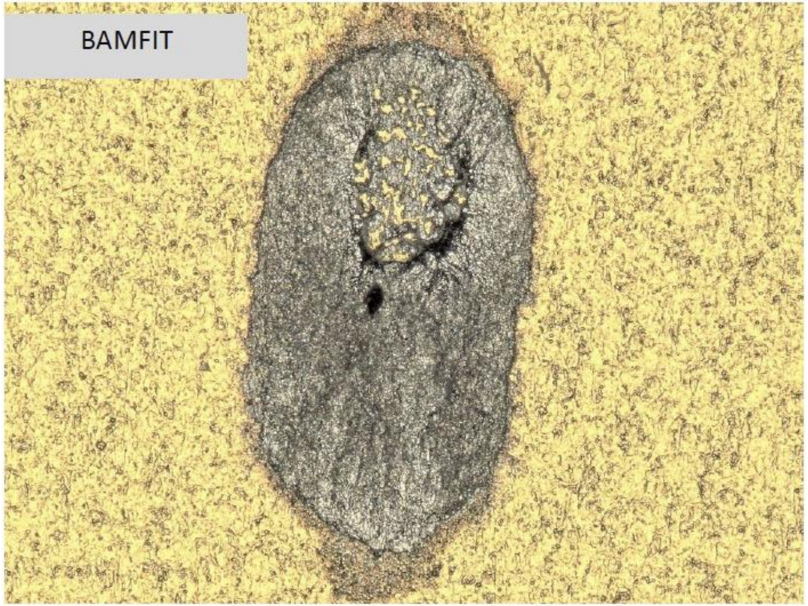
Low Ultrasonic Power Testing Data



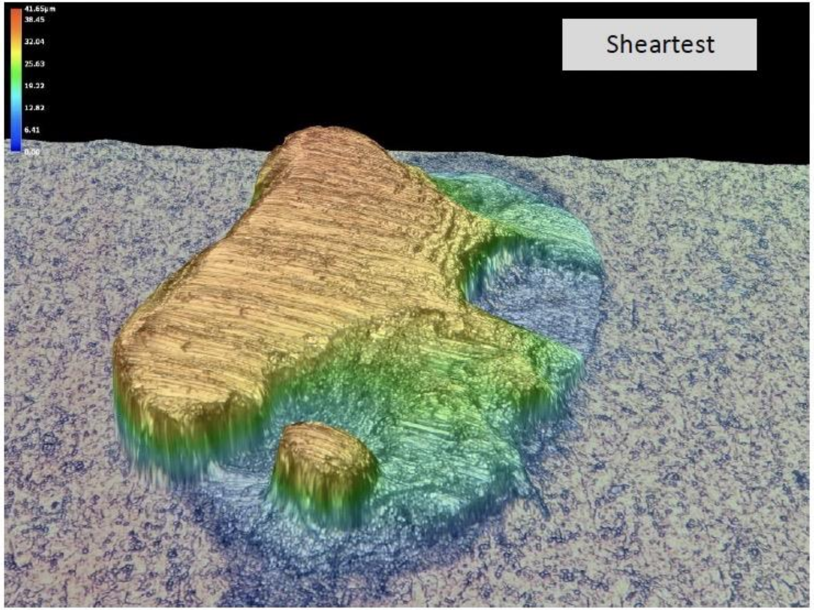


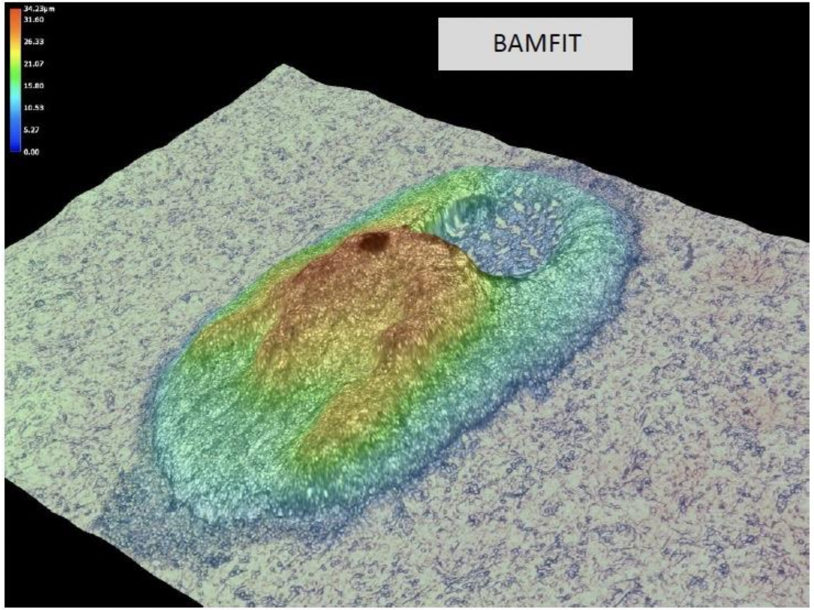
High Ultrasonic Power Testing Data



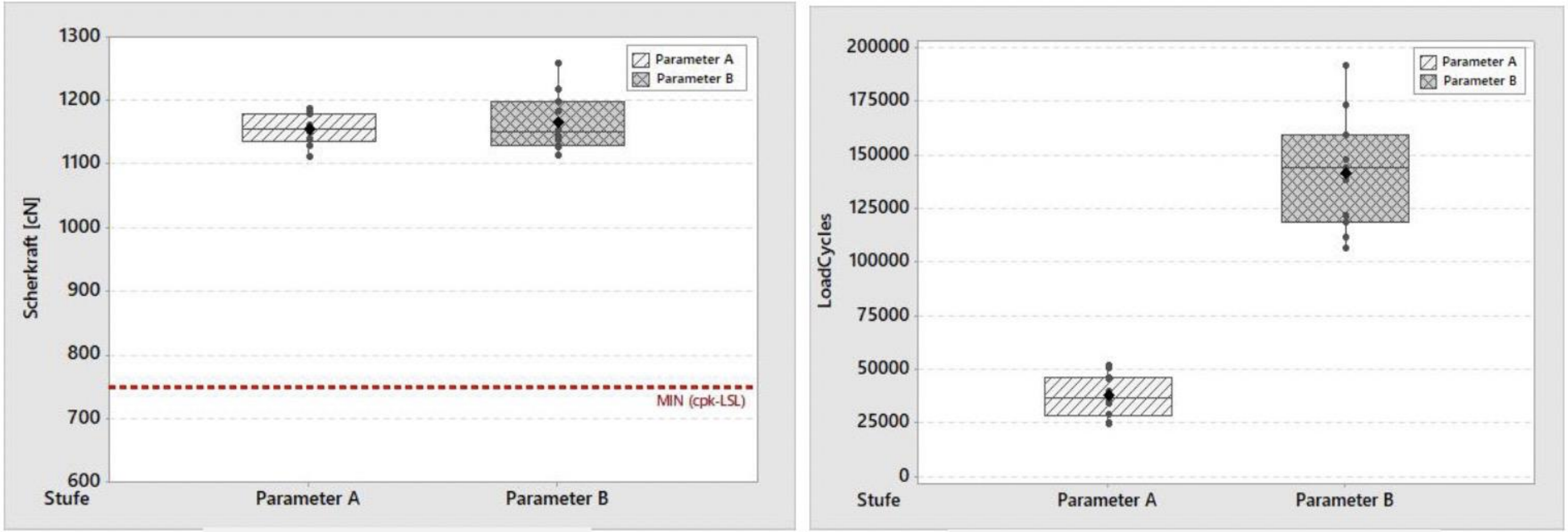


Low Ultrasonic Power Testing Data





BAMFIT: More Informative Than Shear Test Alone

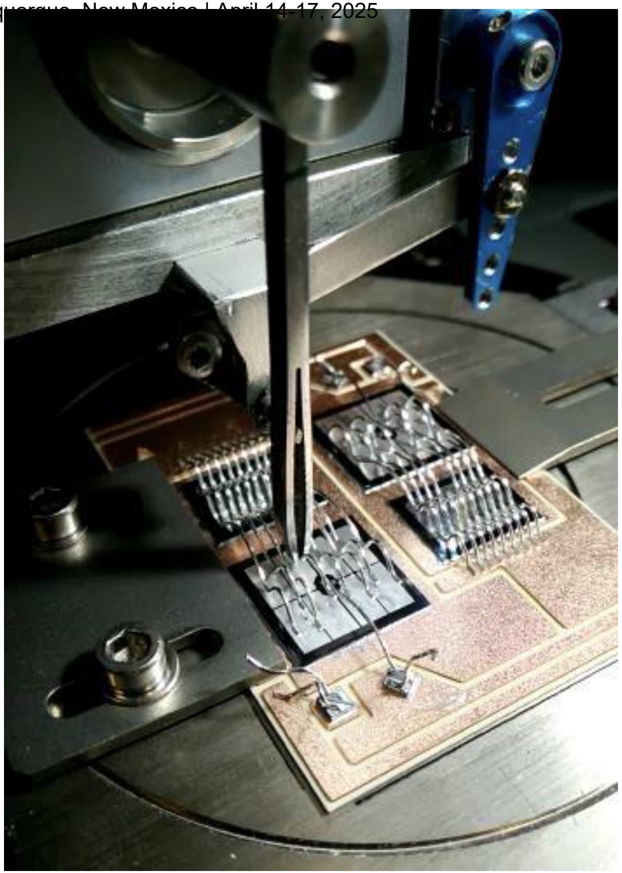


Shear test: very similar

BAMFIT: shows big difference

Production Monitoring: The Big Advantage - Speed

Tests Can be Done In Minutes instead of Months!



Summary: Pressure Sintering – Advanced Die Attach for High Thermal and Mechanical Stress

- Replaces traditional solder in power modules with sintered metal layers.
- Provides superior thermal conductivity, electrical performance, and mechanical resilience.
- Supports long-term reliability over EV and industrial mission cycles.
- Enables robust packaging of SiC devices, large-area modules, and double-sided cooling structures.

Summary: BAMFIT – Accelerated Mechanical Fatigue Testing for Wire Bonds

- Addresses the limitations of traditional shear testing, which doesn't replicate real-world fatigue.
- Applies cyclic mechanical loading to simulate thermal and power cycling fatigue.
- Rapidly reveals bond interface degradation—minutes vs. months.
- Ideal for process optimization, production monitoring, and early failure detection in mission-critical applications.

Optimizing Power Electronics Reliability: Advanced Thermal Management & Wire Bond Lifetime Testing

Thank you!

QUESTIONS?