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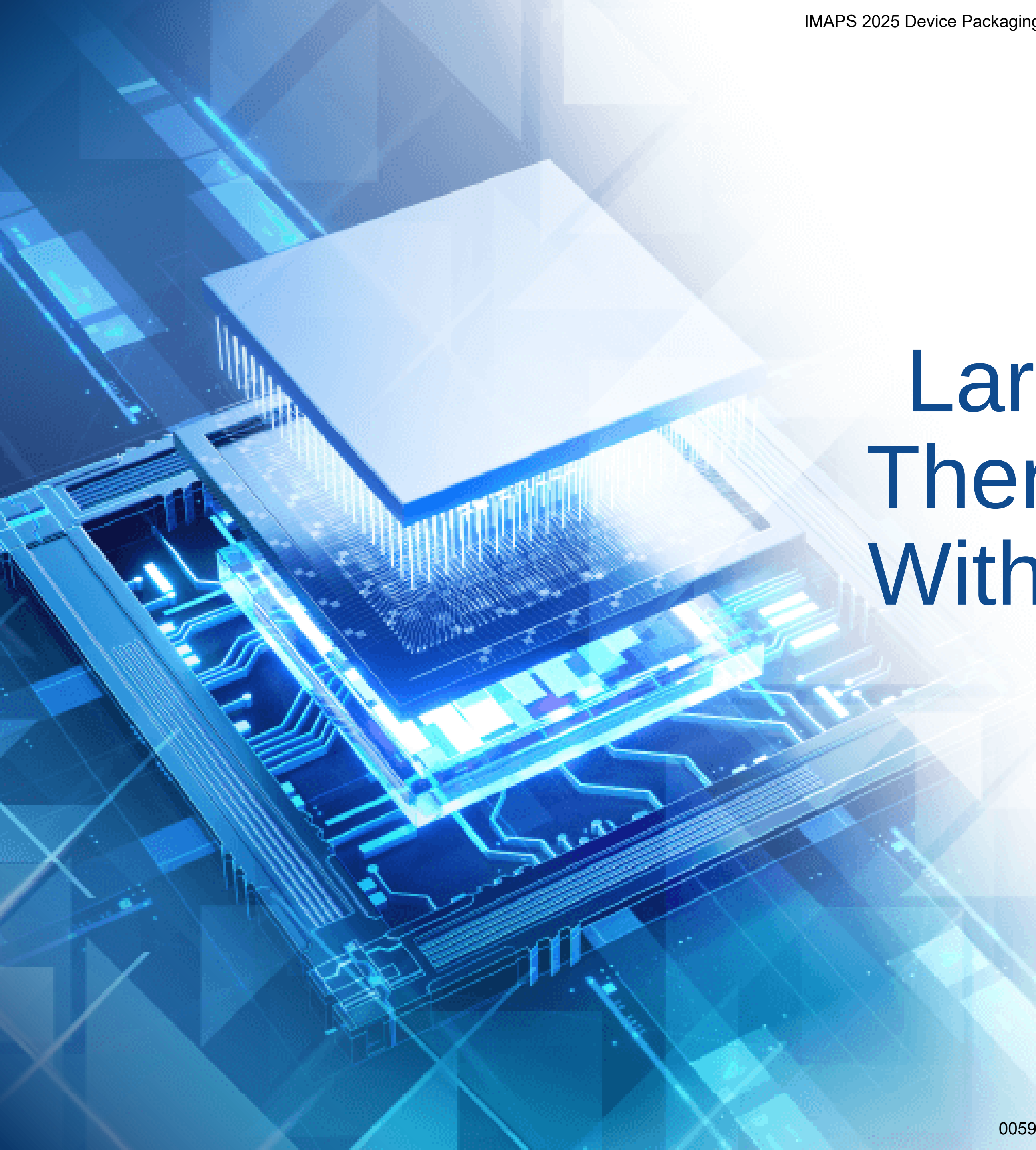

Large Body Lidded FCBGA Thermal Performance Study With Indium-Silver Alloy TIM

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FCBGA Development

Agenda

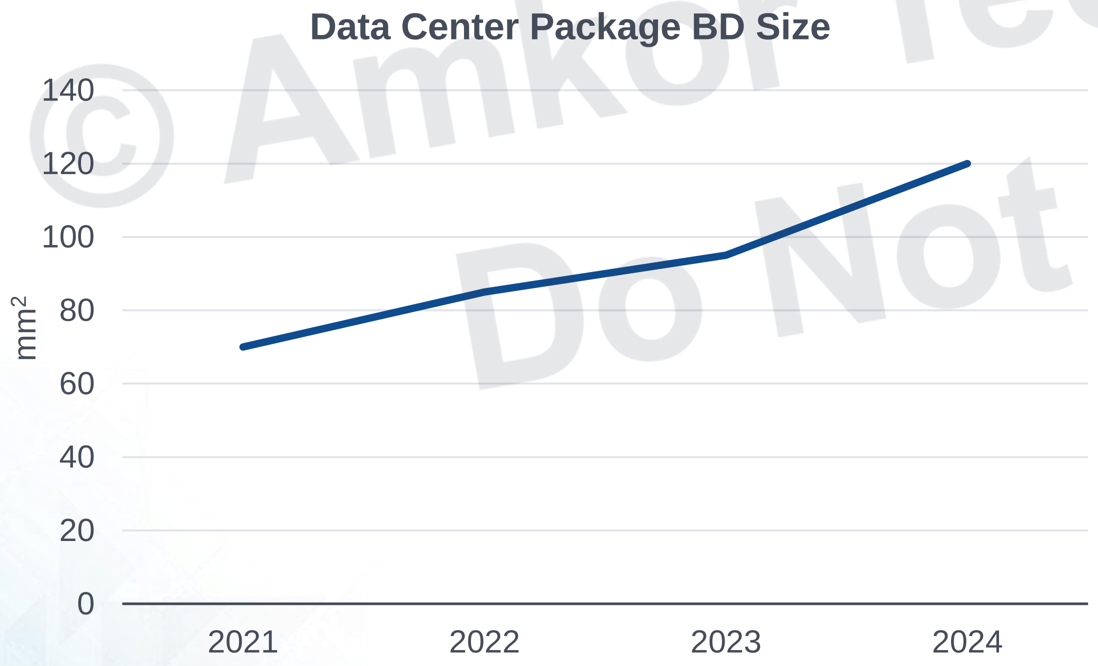
1. Data Center Thermal Management Challenge
2. TIM (Thermal Interfacial Material) for Packaging
3. Indium-Silver Alloy TIM in Assembly
4. Indium-Silver Alloy TIM Thermal Performance Study
5. Summary and Conclusion

Data Center Thermal Management Challenges

Data Center Packaging Trends

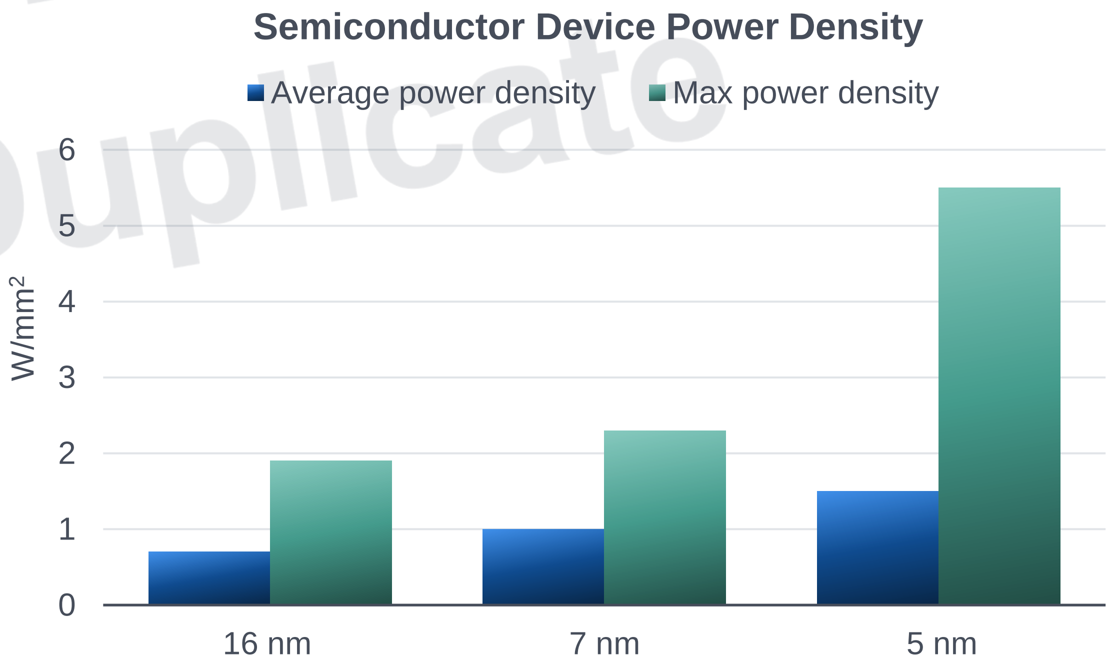
Large Body Die (BD)

- Increasing yearly with multi-dies and dense interconnection



Power Density

- Decreasing node size with increasing power density

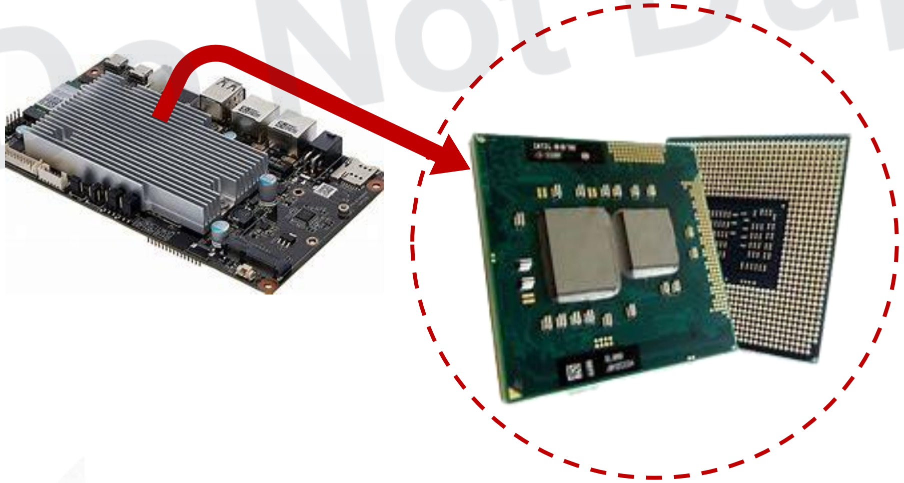


Data Center Power Flow and Cooling Systems

Power In → **Power Out (Heat) & Cooling (Cost)**

Power Management

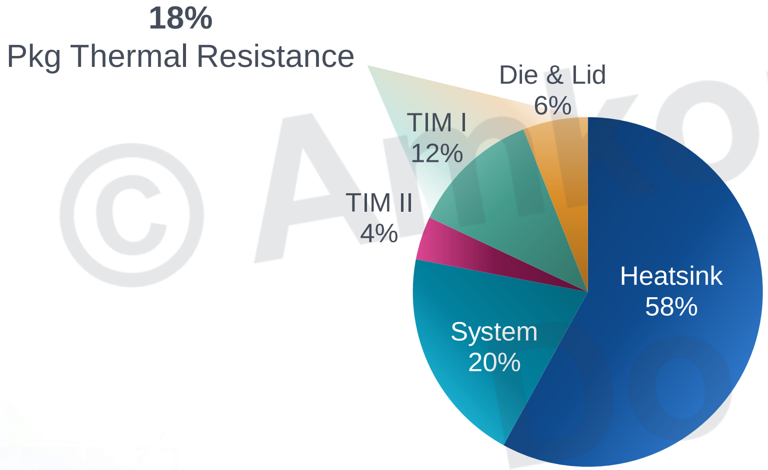
Thermal Management

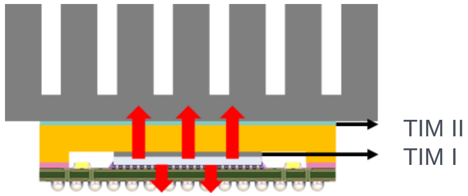


Package Thermal Resistance – Cooling Systems Trends

- Package thermal resistance becomes an important factor in high-power package with advanced cooling systems – TIM I is critical

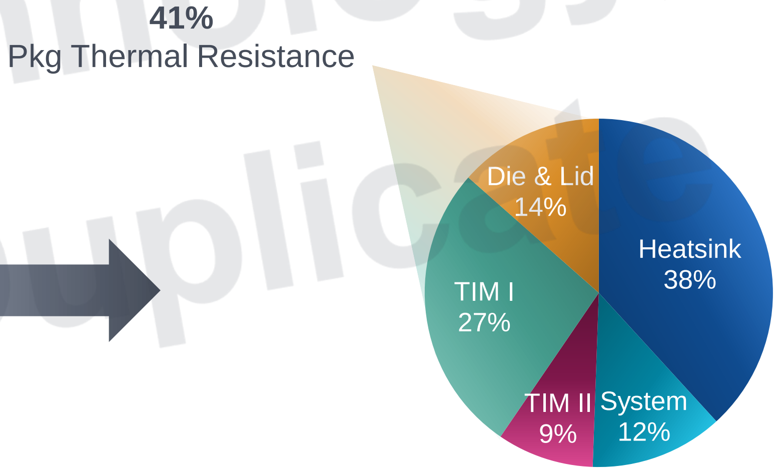
Aired Cooled Systems



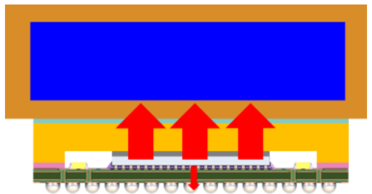


Some heat flows to PCB

Advanced Cooled Systems (Liquid Cooling)



Source: serverthehome.com



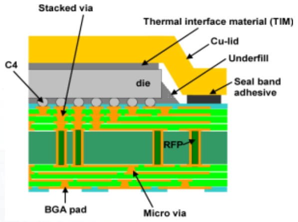
Most of the heat flows to package top

TIM (Thermal Interfacial Material) for Packaging

TIMs Comparison for TIM I

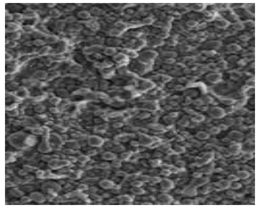
- Limited thermal conductivity and assembly contact thermal resistance values of polymer TIMs are challengeable with high-power large die packages
- Interfacial thermal contact resistance is critical for high-power package thermal dissipation
  - Graphite film has a higher interfacial thermal resistance of packaging
  - Sintered Ag paste has a higher modulus, which limits its reliability performance

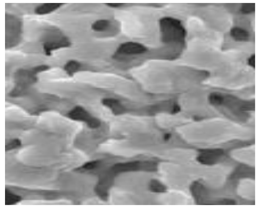
	Polymer TIM k < 5 W/mK	Polymer TIM k < 10 W/mK	Graphite Film k > 10 W/mK	Sintered Ag (Ag) k > 25 W/mK	Indium Alloy TIM k > 60 W/mK
Benefits	▶ Widely used ▶ Cost effective	▶ Better thermal performance	▶ Good stability in accelerated tests	▶ Same process as polymer TIM ▶ Better Θ_{JC}	▶ Excellent Θ_{JC} ▶ Large dies OK
Challenges	▶ High contact R ▶ BLT quality with large dies		▶ High contact R ▶ Not lower Θ_{JC}	▶ NG for reliability	▶ BSM required ▶ High cost

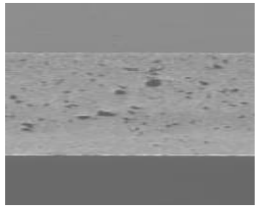


$$R_{TIM1} = \frac{BLT}{k * A} + \boxed{R_{Contact}}$$

k : TIM1 bulk thermal conductivity
A : Die area

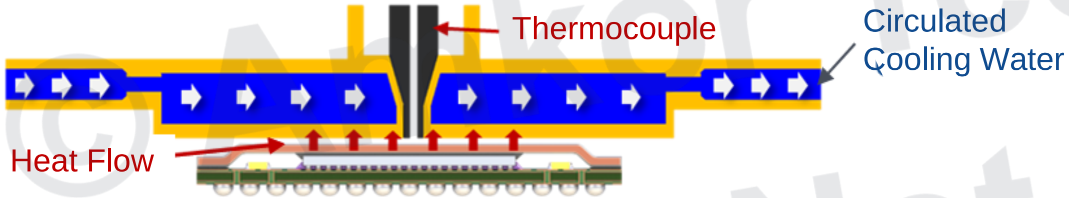






Indium-Silver Alloy TIM Performance: Junction Temp (Tj)

- With a higher input power, In Ag alloy TIM showed a much lower Tj relatively
  - Providing a high thermal bulk conductivity and low interfacial thermal resistance in the package
  - Expecting 2x longer semiconductor lifetime

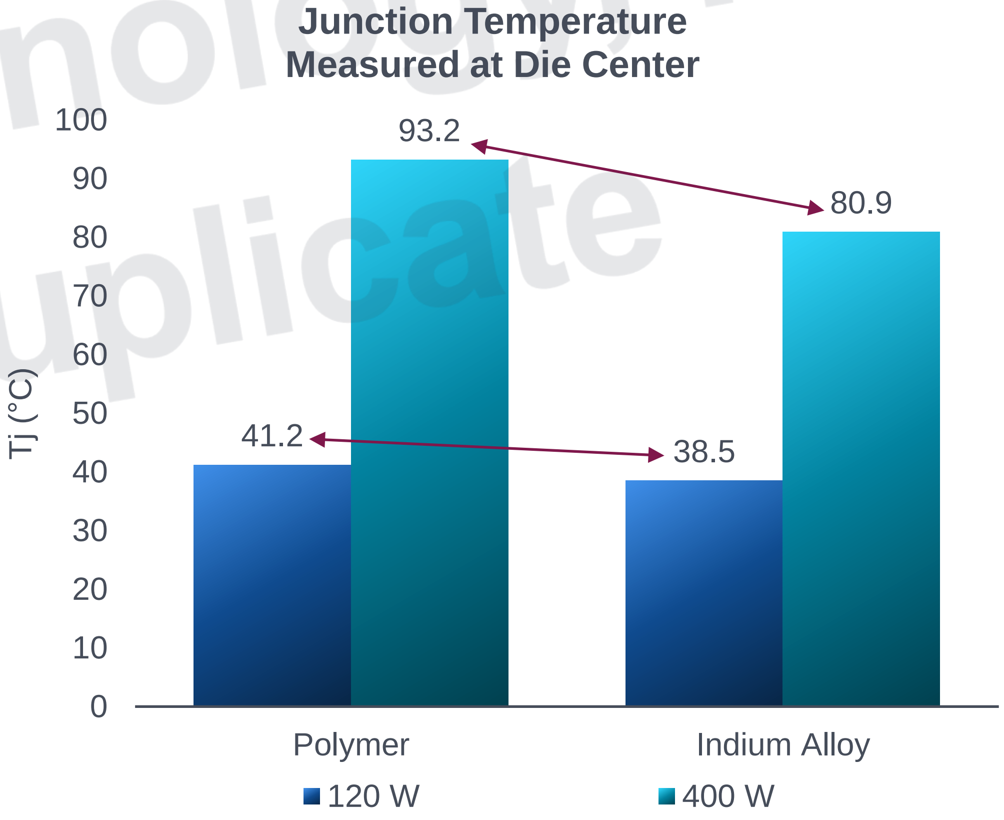


Cold Plate Apparatus

$$R_{TIM\ 1} = \frac{BLT}{k * A} + \boxed{R_{Contact}}$$

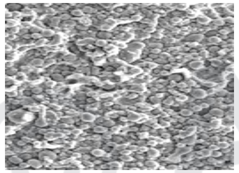
k: *TIM 1 bulk thermal conductivity*

A: *Die area*


Junction Temperature Measured at Die Center

TIM I Solution for Various Applications

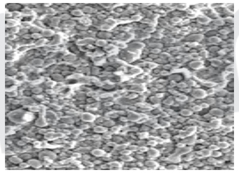
- Amkor provides various TIM solutions according to power consumption
- Indium-Silver alloy TIM offers the highest thermal conductivity
- As a result, Indium-Silver alloy TIM is used in HPC, AI and network applications



TC <5 W/mK

Polymer TIM

Low Power
<0.25 W/mm^2



TC <10 W/mK

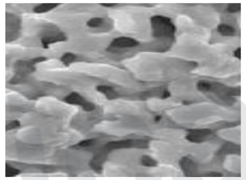
High-k Polymer

Mid-range Power
<0.35 W/mm^2

TC <15 W/mK

Graphite Film

Mid-range Power
<0.45 W/mm^2



TC <25 W/mK

Sintered Ag

Mid-range Power
<0.45 W/mm^2

TC >70 W/mK

Solid Metal

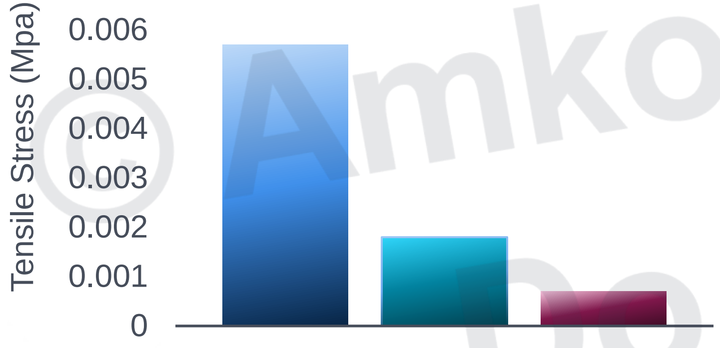
High Power
>0.45 W/mm^2

Indium-Silver Alloy TIM in Assembly

Thermal Tensile Stress Simulation for In Ag Alloy TIM

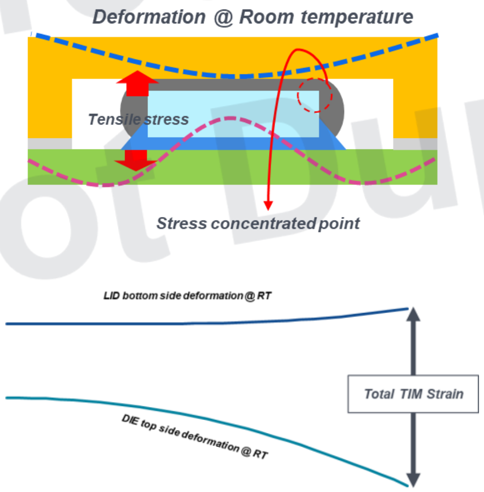
- Thinner Indium-Silver alloy TIM BLT shows a higher tensile stress relativity
- Larger BD also shows a higher tensile stress

Variable: TIM BLT After Lid Attachment

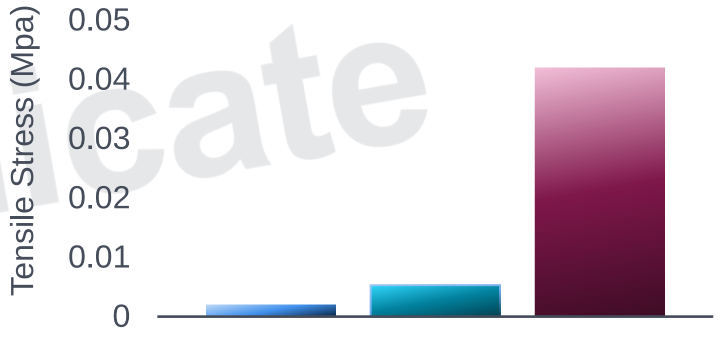


BD Size	52.5 BD	52.5 BD	52.5 BD
Die Size	15 x 15	15 x 15	15 x 15
TIM Thickness	110 µm	150 µm	200 µm

Tensile Stress at RT After Lid Attachment



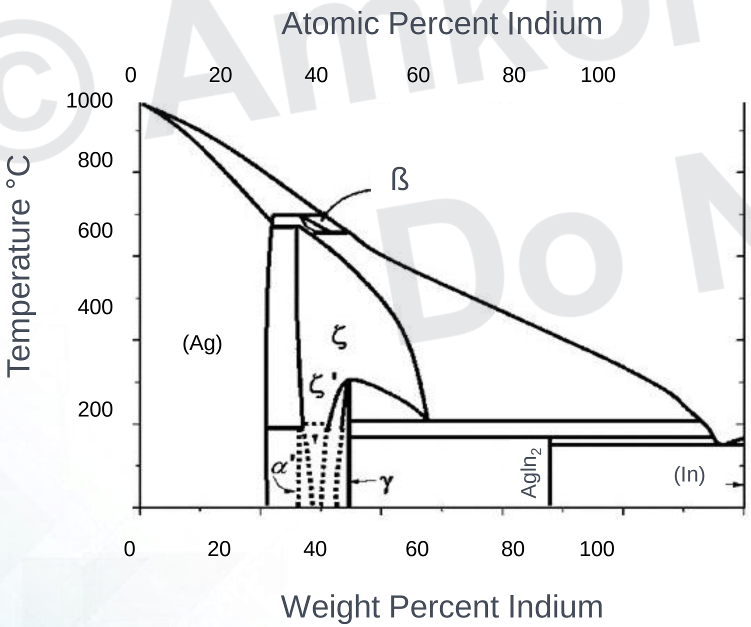
Variable: BD Size After Lid Attachment



BD Size	35 BD	52.5 BD	70 BD
Die Size	15 x 15	15 x 15	15 x 15
Substrate	6L Sub	6L Sub	6L Sub

Indium-Silver Alloy TIM for Semiconductor Packages

- Higher thermal bulk conductivity (k)
  - Pure Indium and In3Ag In Ag alloy TIMs have a lower liquidus temperature, making them suitable for FCBGA board assembly
- Lower thermal contact resistance at the interfacial layers relatively
- In10Ag and In7Ag are suitable for FCBGA applications that require multiple reflows



$$R_{TIM\ 1} = \frac{BLT}{k * A} + R_{Contact}$$

k: TIM 1 bulk thermal conductivity

A: Die area

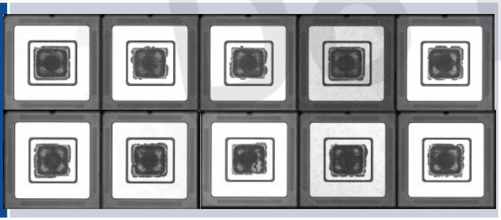
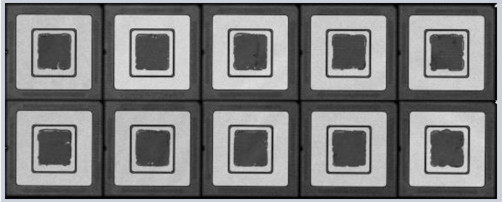
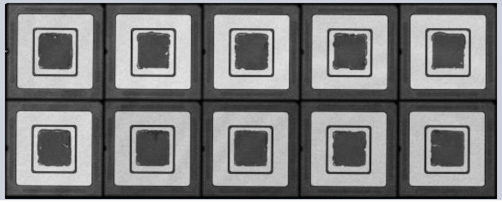
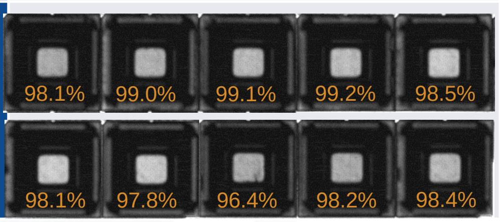
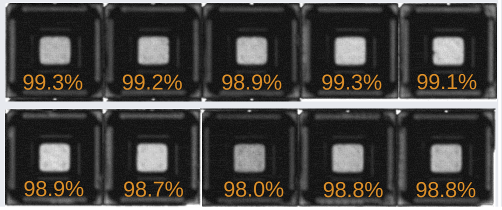
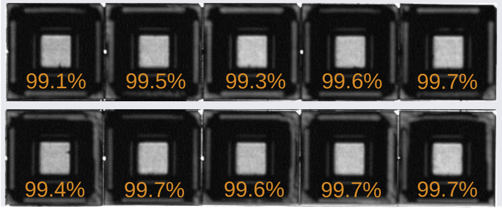
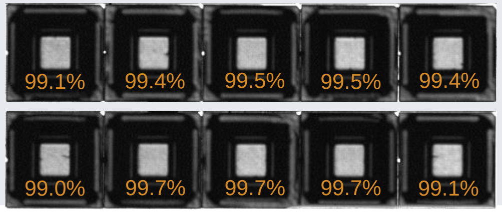
Alloy		Pure In	97In3Ag	93In7Ag	90In10Ag
Solidus Temp.	(°C)	156	143	143	143
Liquidus Temp.	(°C)	156	143	190	237
Tensile Strength	(PSI)	386	1200	1330	1364
Elongation	(%)	67	50	33	9.45
Youngs Modulus	(PSI x 10^6)	1.7	1.8	1.9	2.2
Thermal Conductivity	(W/mK)	86	84	75	71

Source: Indium Co. February 2024

Experimental Data: Pre-Conditioning & TCK 1500x Data

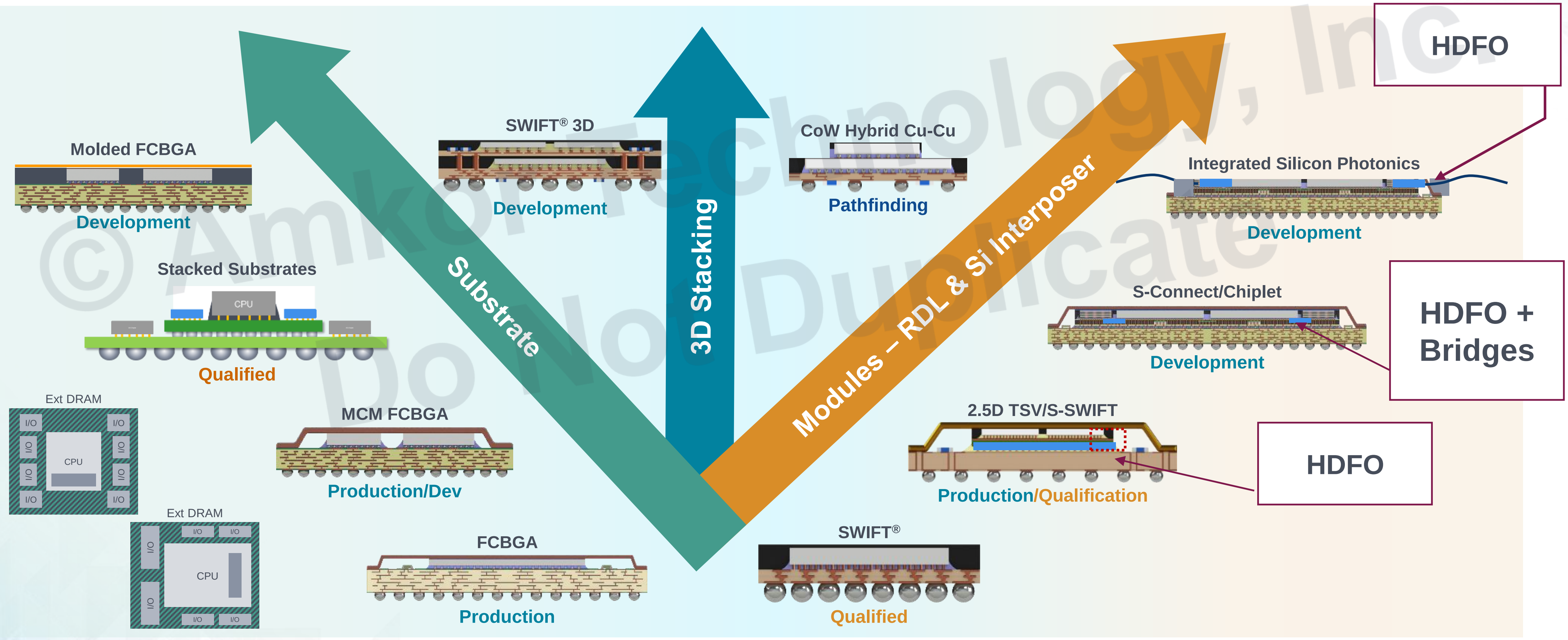
- Stress induced micro-voids appeared at the die corners, where tensile stress concentration is higher
  - In10Ag exhibited TIM BLT degradation due to stress-induced micro-voids
  - In7Ag did not show degradation at TCK 1500x

TIM Coverage	In10Ag	In7Ag
Min.	96.4%	99.0%
Max.	99.3%	99.7%
Average.	98.6%	99.5%

Composition	In10Ag		In7Ag	
R/Out	Post TCK 1500X			
Loading	Group 1	Group 2	Group 1	Group 2
C-Scan				
T-Scan TIM Coverage	 98.1% 99.0% 99.1% 99.2% 98.5% 98.1% 97.8% 96.4% 98.2% 98.4%	 99.3% 99.2% 98.9% 99.3% 99.1% 98.9% 98.7% 98.0% 98.8% 98.8%	 99.1% 99.5% 99.3% 99.6% 99.7% 99.4% 99.7% 99.6% 99.7% 99.7%	 99.1% 99.4% 99.5% 99.5% 99.4% 99.0% 99.7% 99.7% 99.7% 99.1%

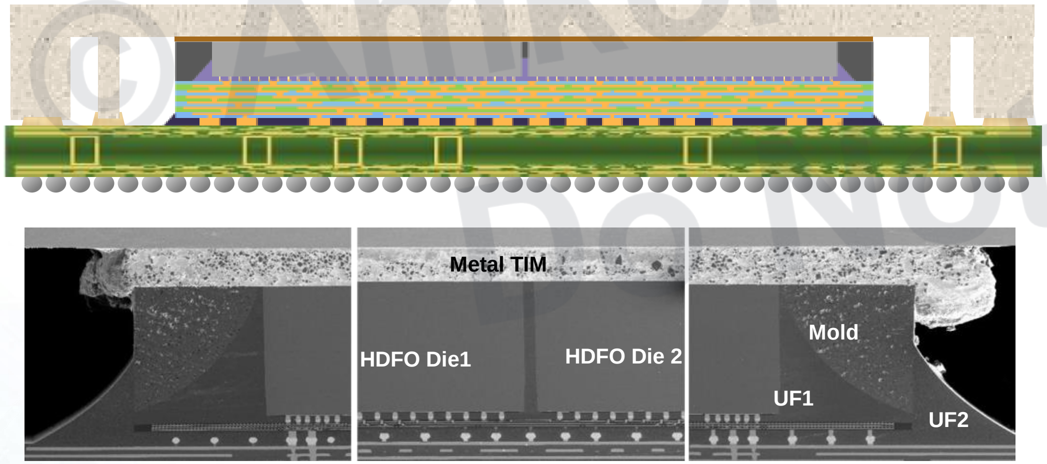
Heterogeneous Integrated Packages: HDFO/Bridges

- Reliable interconnections and efficient thermal dissipation methods are needed

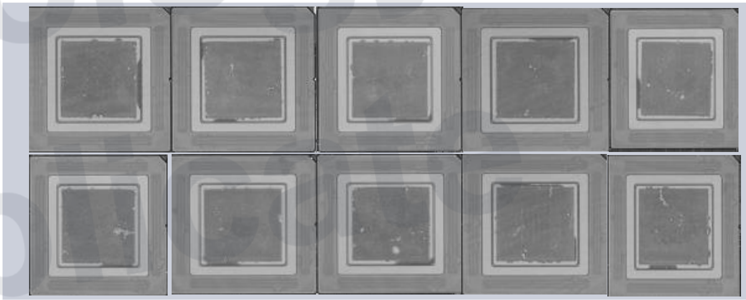
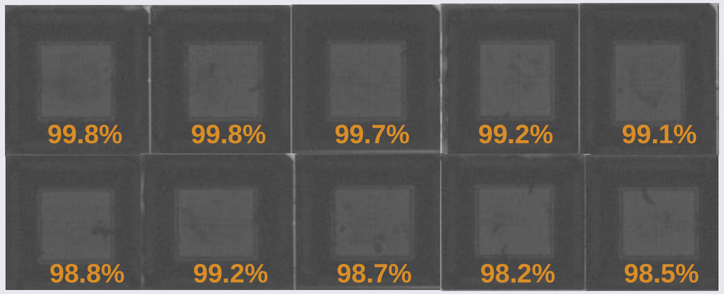


HDFO (SWIFT®) fcLBGA Indium-Silver Alloy TIM

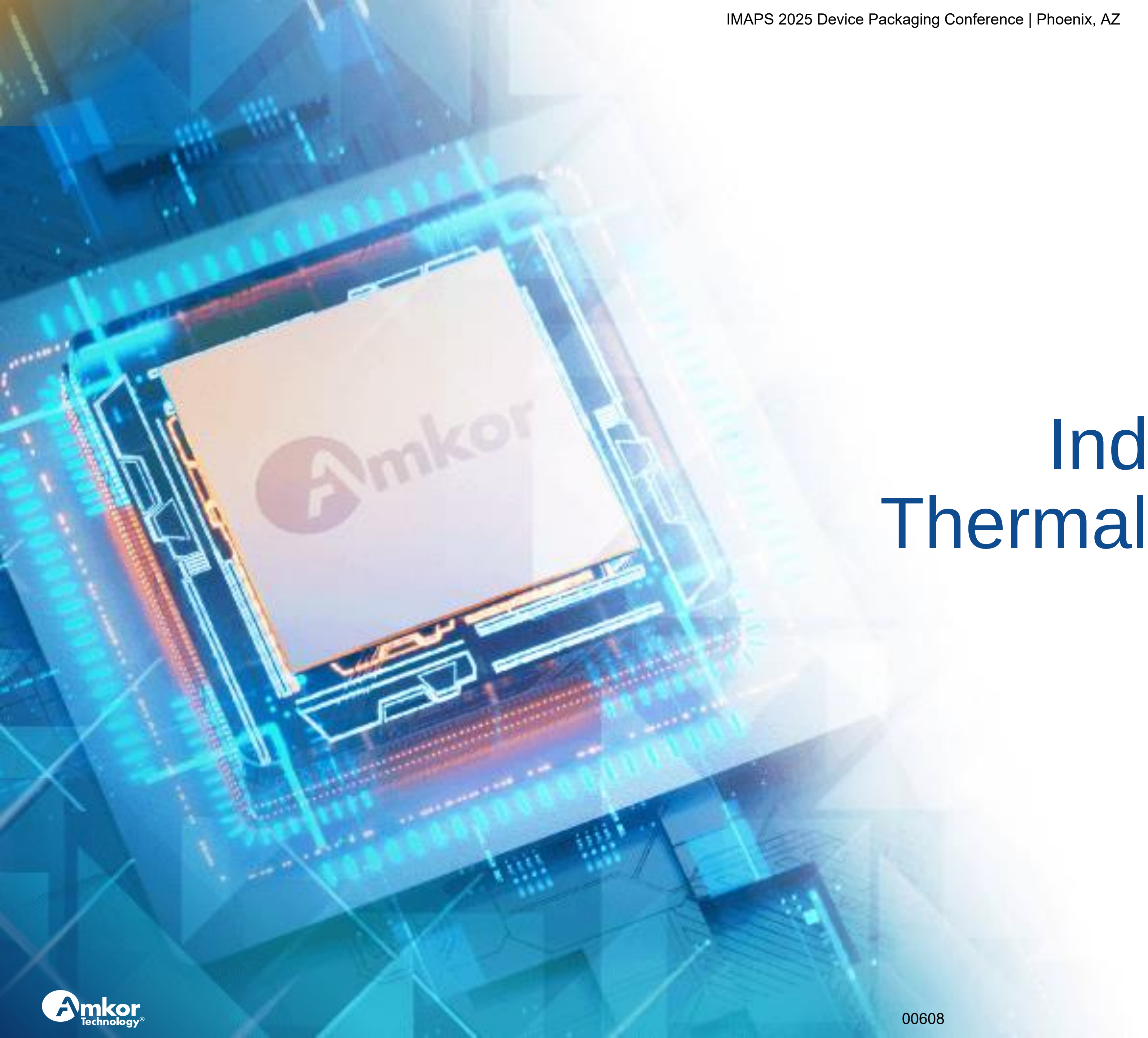
- Heterogeneous integrated HDFO module applied to lidded FCBGA
  - TIM: In7Ag
  - TIM BLT: 200 µm
  - TIM coverage criteria: >90% at EOL
    - > 98% at EOL
    - > 94% at MSL4 + TC condition K 1000x



Vertical view after metal TIM lid attach

Image	EOL
C-Scan	
T-Scan TIM Coverage	

TIM coverage at EOL

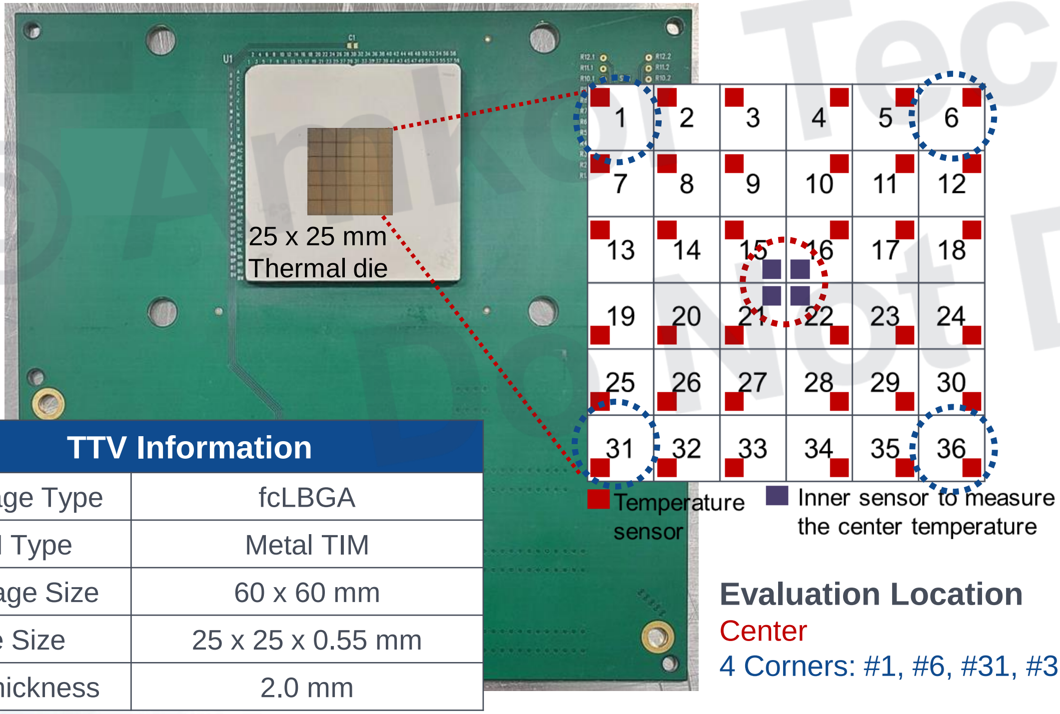


Indium-Silver Alloy TIM Thermal Performance Study

Θ_{JC} and Junction Temperature Measurement

- Indium-Silver alloy TIM's performance was evaluated using 60 x 60 mm lidded FCBGA TTV with water cooling systems: Input power at 400 W

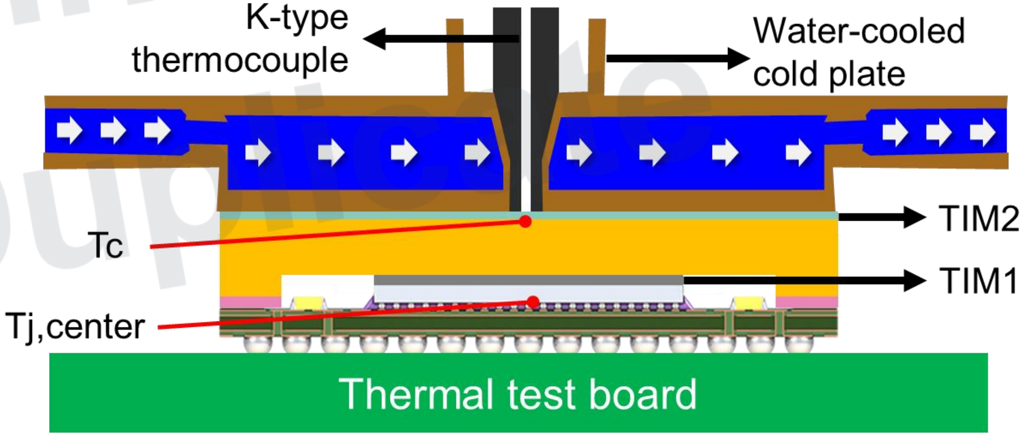
60 BD on Board



TTV Information	
Package Type	fcLBGA
TIM Type	Metal TIM
Package Size	60 x 60 mm
Die Size	25 x 25 x 0.55 mm
Lid Thickness	2.0 mm

Evaluation Location
Center
4 Corners: #1, #6, #31, #36

Side View of Water-Cooling System



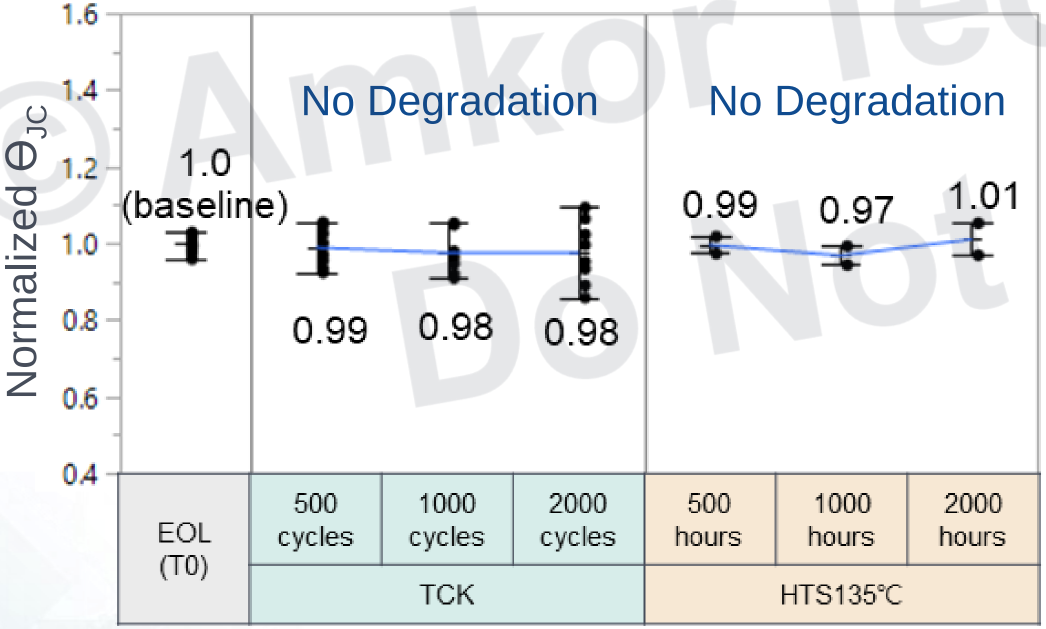
$$\Theta_{JC} = \frac{(T_J - T_C)}{Power}$$

Indium-Silver Alloy TIM Performance After Reliability Tests

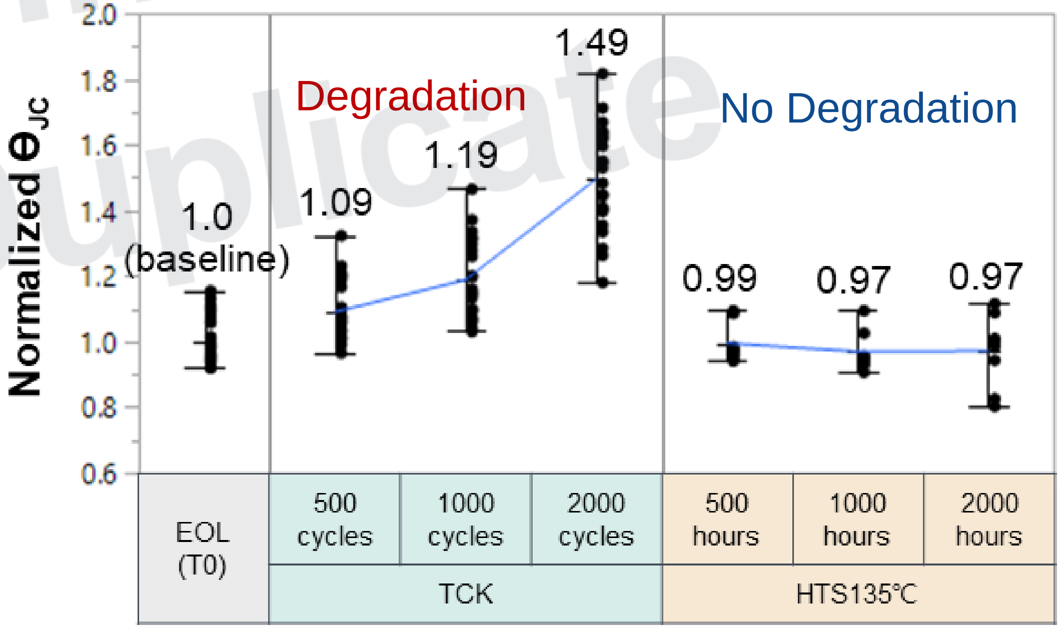
- Center: No degradation performance after TCK and HTS T2000
- Corner: Degradation after TCK, but not after HTS

- Θ_{JC} measurement result (Read out: every 500 cycles/hours)

Center



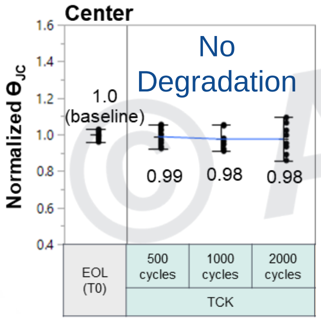
Corner

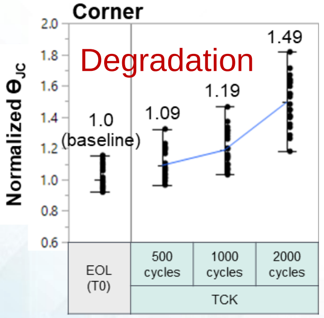


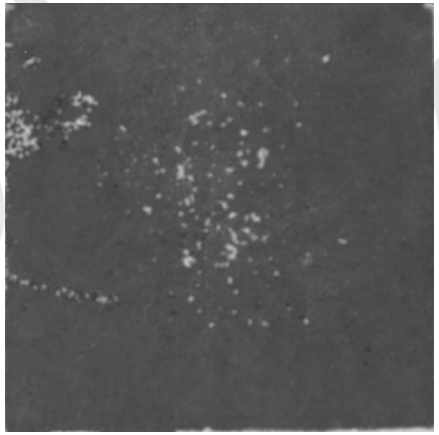
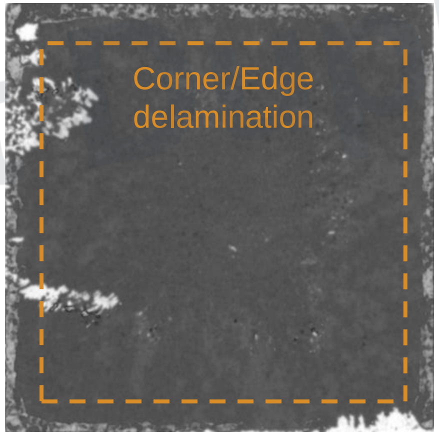
Indium-Silver Alloy TIM Coverage After TCK Test

- TIM coverage is higher than 90% of die size after board level TCK test
  - Center: Small voids disappeared
  - Corner: Delamination at die back side

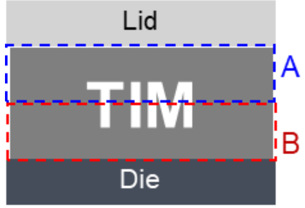
- Θ_{JC} result





Rel.	**TCK**	
Cycle	0 cycle	2000 cycles
SAT image C-SCAN		
Coverage%	97%	92%

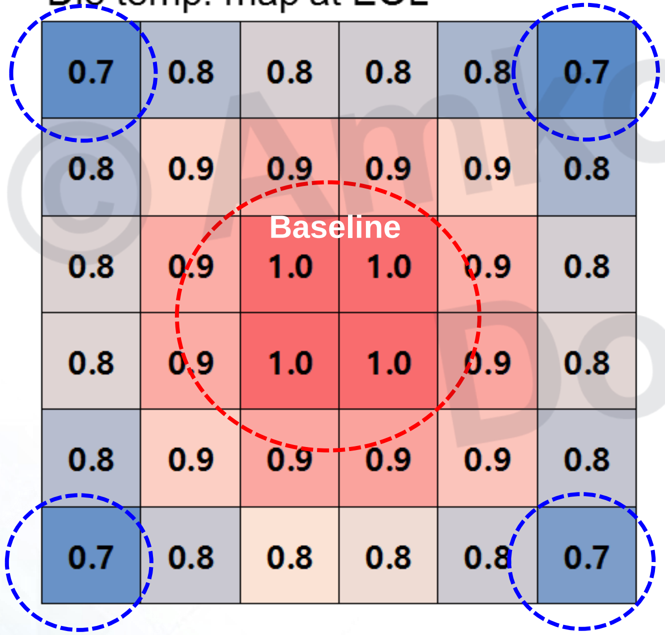
Rel.	**TCK 2000 cycles**
SALI Mode (**A Layer**)	
SALI Mode (**B Layer**)	



Junction Temperature After TCK

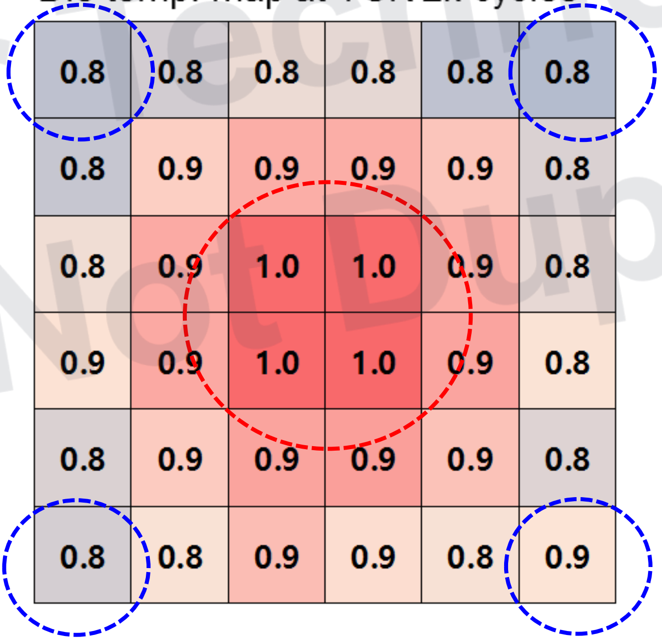
- Die corner temperature after TCK 2K cycles is higher than EOL
  - But corner temperature is **still lower** than center hot spot
- Die center temperature after TCK 2K cycles shows no difference

Die temp. map at EOL



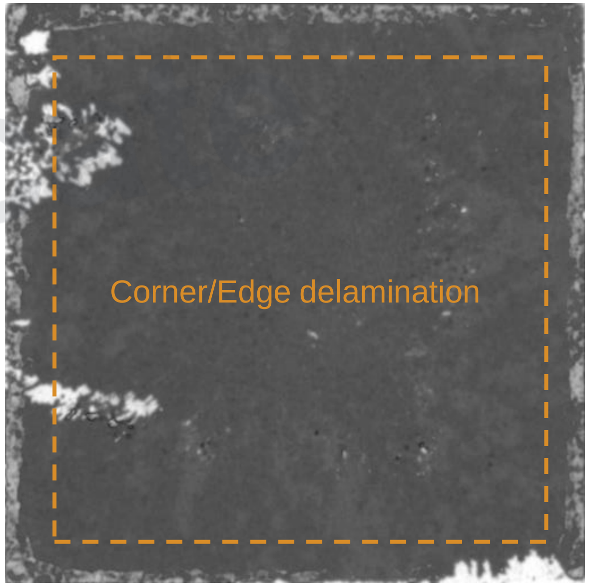
0.7	0.8	0.8	0.8	0.8	0.7
0.8	0.9	0.9	0.9	0.9	0.8
0.8	0.9	1.0	1.0	0.9	0.8
0.8	0.9	1.0	1.0	0.9	0.8
0.8	0.9	0.9	0.9	0.9	0.8
0.7	0.8	0.8	0.8	0.8	0.7

Die temp. map at TCK 2k cycles



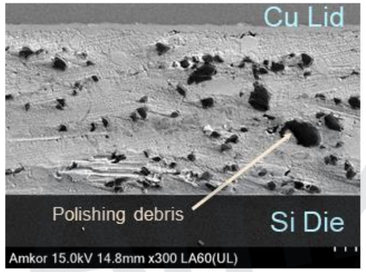
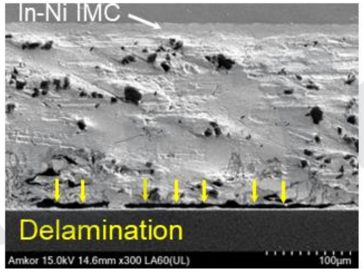
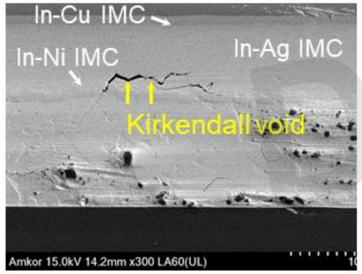
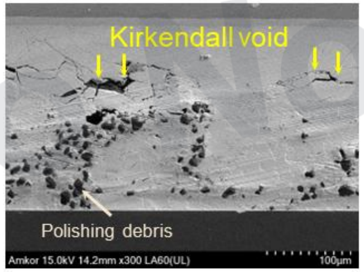
0.8	0.8	0.8	0.8	0.8	0.8
0.8	0.9	0.9	0.9	0.9	0.8
0.8	0.9	1.0	1.0	0.9	0.8
0.9	0.9	1.0	1.0	0.9	0.8
0.8	0.9	0.9	0.9	0.9	0.8
0.8	0.8	0.9	0.9	0.8	0.9

SAT image after TCK 2k cycles

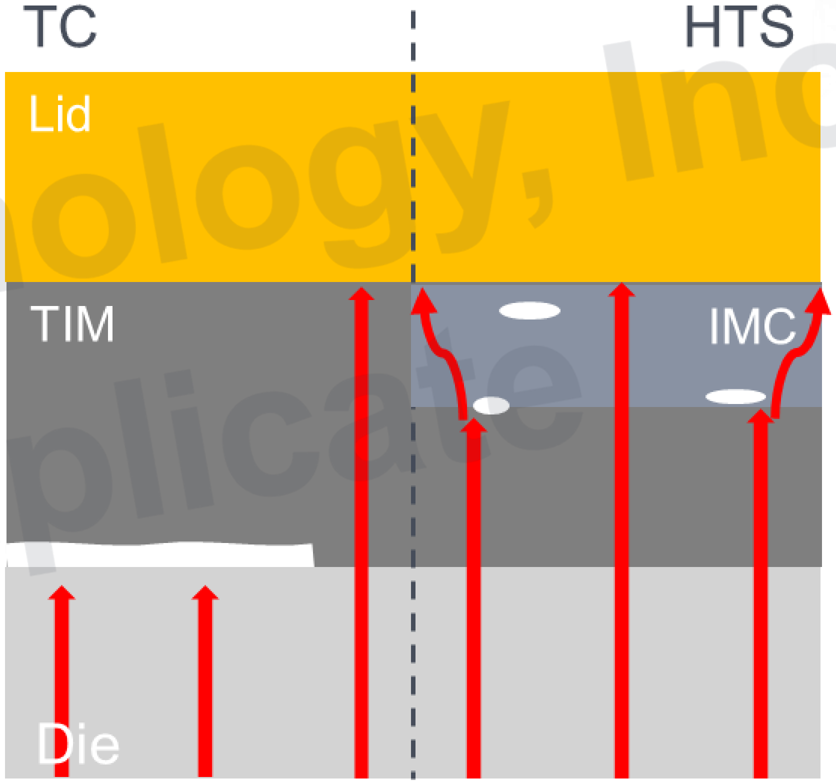


Indium-Silver Alloy TIM Heat Flow Mechanism

SEM Images

Rel.	SEM image (Center)	SEM image (Corner)
TCK		
HTS 135℃		

Heat Flow Mechanism

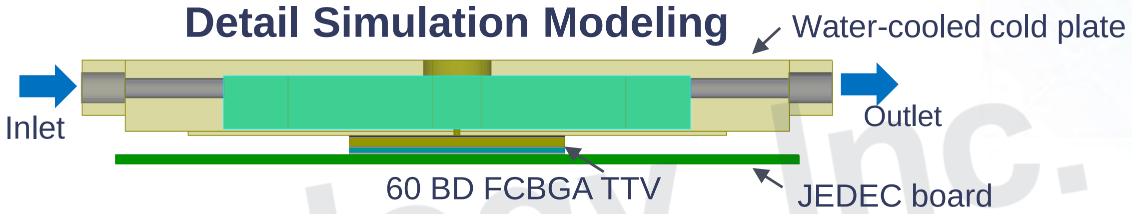


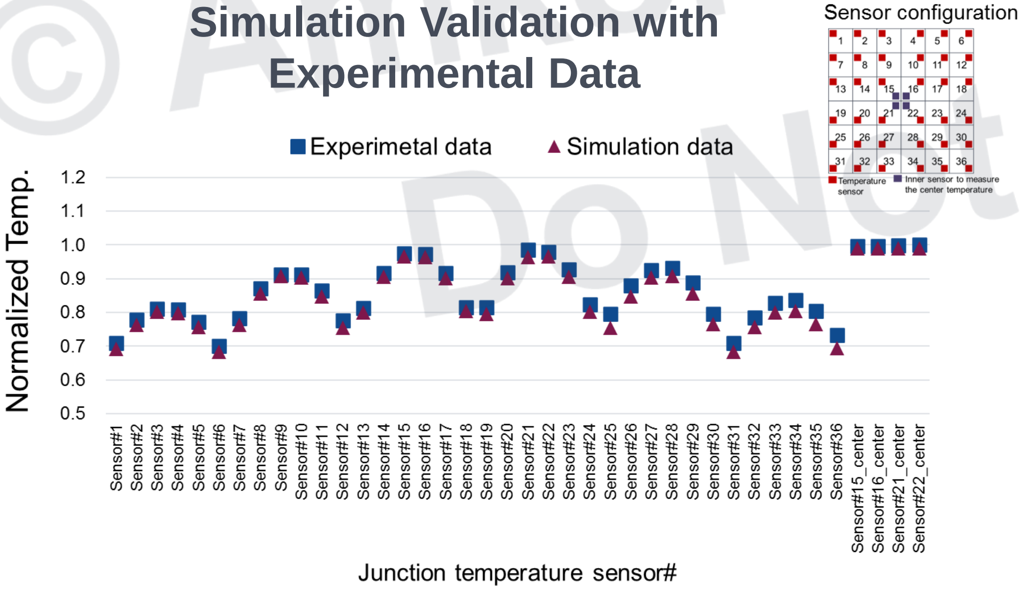
- TCK – Delamination at die back side
- HTS – Kirkendall void in IMC layer

- Delamination can block heat dissipation path
- Heat can flow around voids

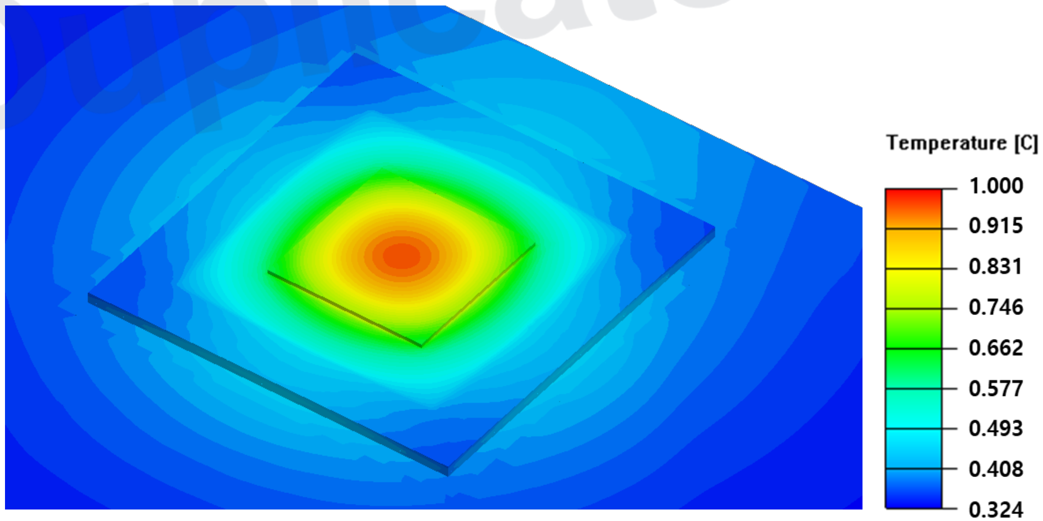
Indium-Silver Alloy TIM Thermal Simulation: Setup

- Boundary condition
  - Water-cooled cold plate
  - Power: 400W
  - Ambient temperature: 23°C
- Simulation shows good correlation of more than 95% with the experimental test data


Detail Simulation Modeling


Simulation Validation with Experimental Data

Temperature Contour of TTV on Board



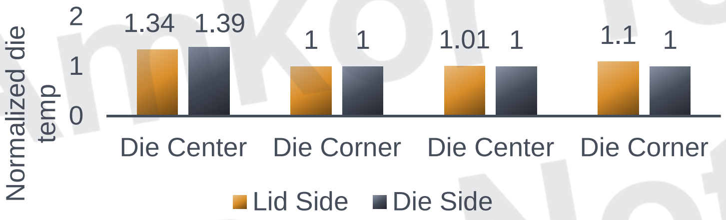
Indium-Silver Alloy TIM Thermal Simulation: Results

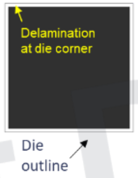
- Large delamination shows 10~40% increase in junction temp
- Partial and small delamination shows max 3% increase in junction temp

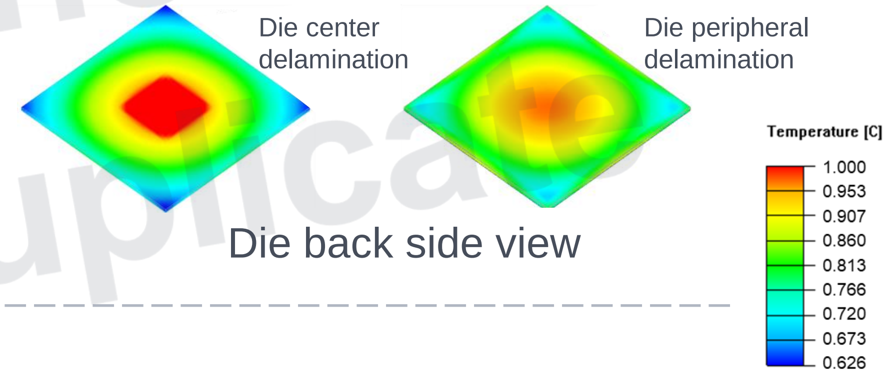
-10% Delamination Scenarios

10% Delamination Area at Die Center

10% Delamination Area at Die Peripheral

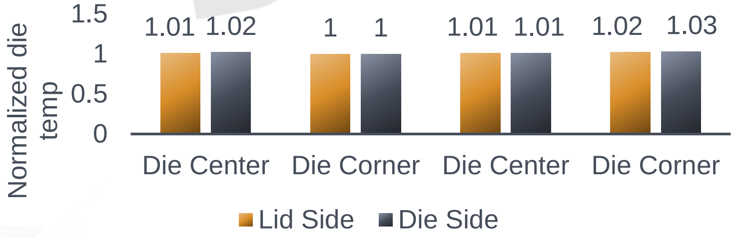


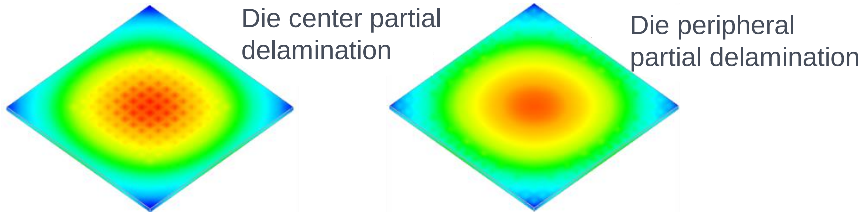




Die back side view

-10% Partial Delamination Scenarios





Die back side view

Summary and Conclusion

Summary

- Semiconductor IC power densities are increasing yearly
  - Requiring a high thermal dissipation of package; low Θ_{JC}
- It's crucial to use a low thermal resistance package with an advanced cooling system in data centers; TIM is key for reducing Θ_{JC}
- Indium-Silver alloy TIM is an effective thermal solution for large body lidded FCBGA products in data centers
  - Higher thermal bulk conductivity
  - Lower interfacial thermal contact resistance of package
  - Demonstrates stable assembly, preconditioning (multiple reflows) and TC condition K results; suitable for FCBGA
- Stable Tj and thermal performance with Indium-Silver Alloy TIM are expected after BLR tests, except for a big defect at die center

Conclusion

- Indium-Silver alloy TIM as TIM I can relatively double the lifetime of semiconductor devices
- Large BD heterogeneous integrated HDFO fcLBGA with Indium-Silver alloy TIM shows good TIM coverage under assembly, preconditioning and thermal cycling condition K

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Thank You