

Ensuring and Predicting the Reliability of Concentrated Photovoltaics (CPV): Interconnect Structures

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Reliability Challenges in CPV Interconnects

- Current material selection for CPV interconnects are insufficient
 - Filled epoxy is cheap 'temporary' solution
 - Poor thermal conductivity prevents migration to higher concentration levels, greater efficiencies
 - Inappropriate above 1000 Suns
 - Insufficient reliability to meet 25-year lifetime
- Extensive life requirements, short product development cycle demands 'proof-of-concept' before hardware build
 - Waiting till test to validate reliability requirements is high risk proposition
 - Requires reliability prediction of interconnect structures in the concept and design stages
- New materials by Indium Corporation and new reliability algorithms by DfR Solutions provide direct solutions to these industry-limiting issues

Typical CPV Receiver - Material Stack-Up

Material Comments

Fresnel Lens,
Cassegrain Mirror
Parabolic Mirror

III- IV, 10 x 10 x 0.2 mm
Metalized Backside

E / T Conductive Die Attach Epoxy

24x24 x0.38mm:
Alumina, BEO, ALN
Cu Ni Au Both Sides

Non Conductive Adhesive

Heat Spreader

Non Conductive Adhesive

Design Comments

200 to 1000+ Suns

$T_{j,max} < 100^{\circ}\text{C}$ to Meet
25 Year Life and Efficiency

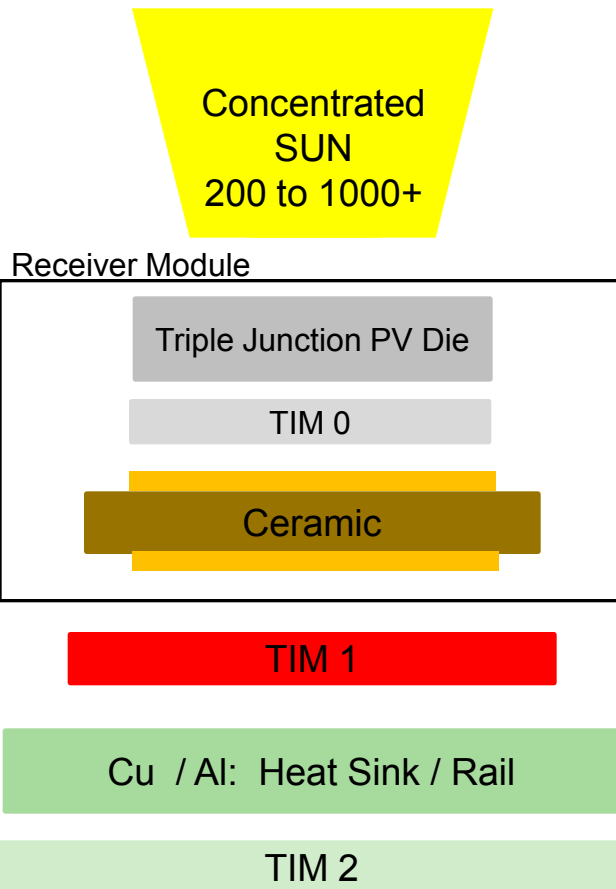
Better Thermal Conductivity
Can Improve Efficiency

Good CTE Match to Die
OK Thermal Conductivity
Electrical Insulator – High Pot Test

Absorb CTE Mismatch
 Al_2O_3 / Cu or Al

Good Thermal Conductor

Thermal Path to Baseplate

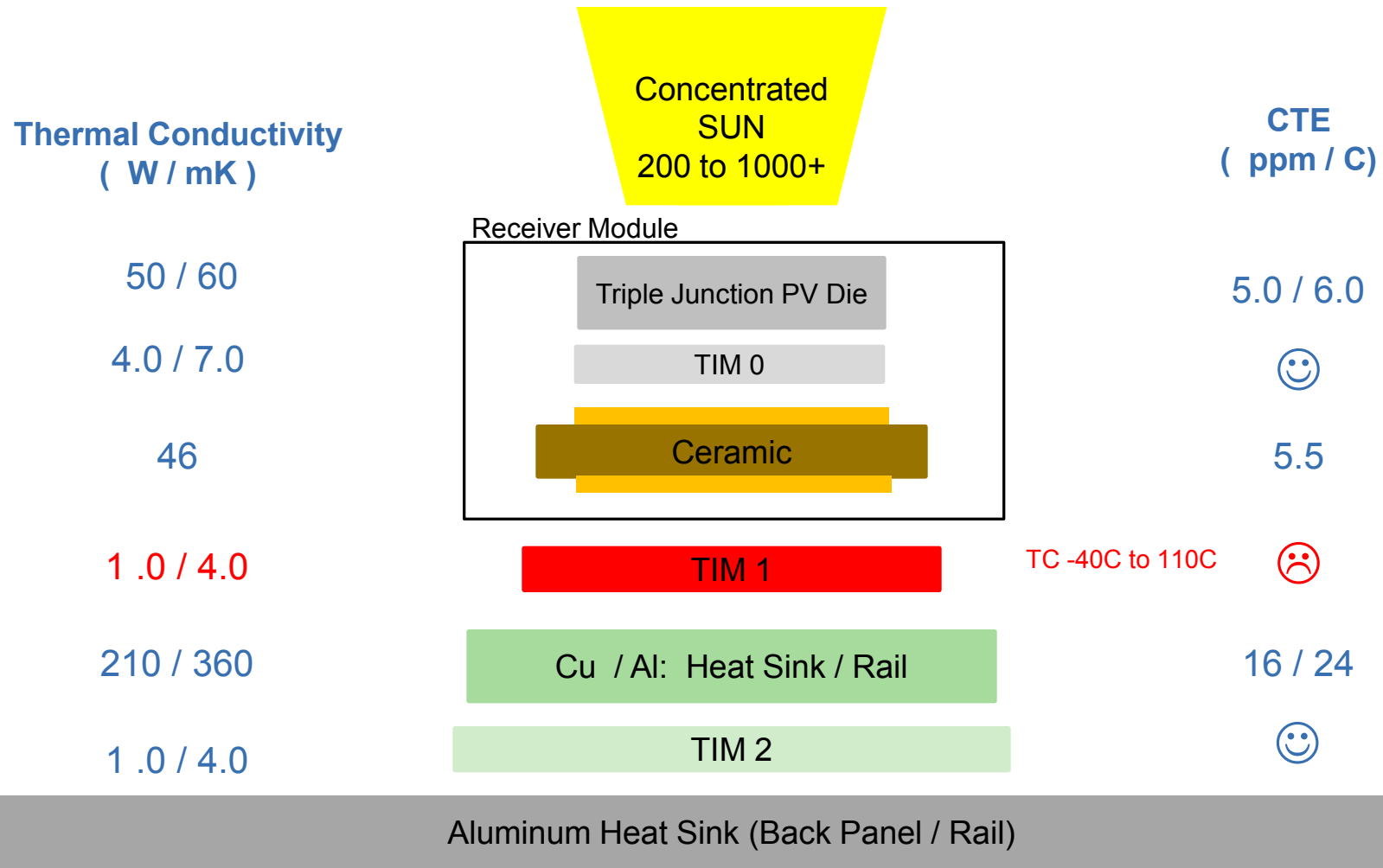


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Typical CPV Receiver - Thermal View



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CPV Cell Performance NanoBond vs. Adhesive

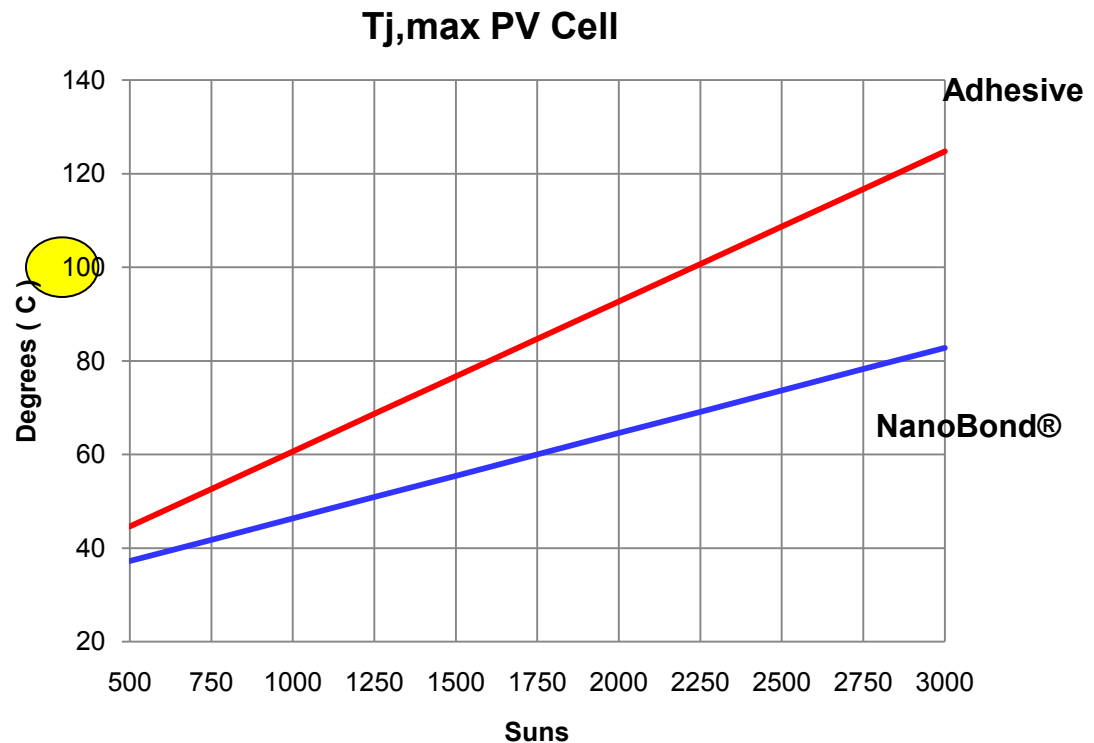
1 Sun = 85 mW/mm² x 500 = 425 mW/mm²
Die Surface Area = 100mm²
Power Incident Die Surface = 42.5W
Conversion Efficiency = 35%
P_{dc} = 14.9 W
P_{diss} = 27.6 W – Thermal Management

T_{j,max}

Conversion Efficiency ~ 0.5% / 10° C
Maintain < 100°C to Meet 25 Year Life Time

Sun Concentration Levels

Typically ~ 500 X (Suns)
CPV Roadmaps – X will Continue to Increase



Delta T_{j,max} Increase vs. Suns

- Lower T_{j,max} - Increase Lifetime
- Or More Sun Headroom

DNI 850 W/m²
Efficiency 35%
Base Plate Held 28C

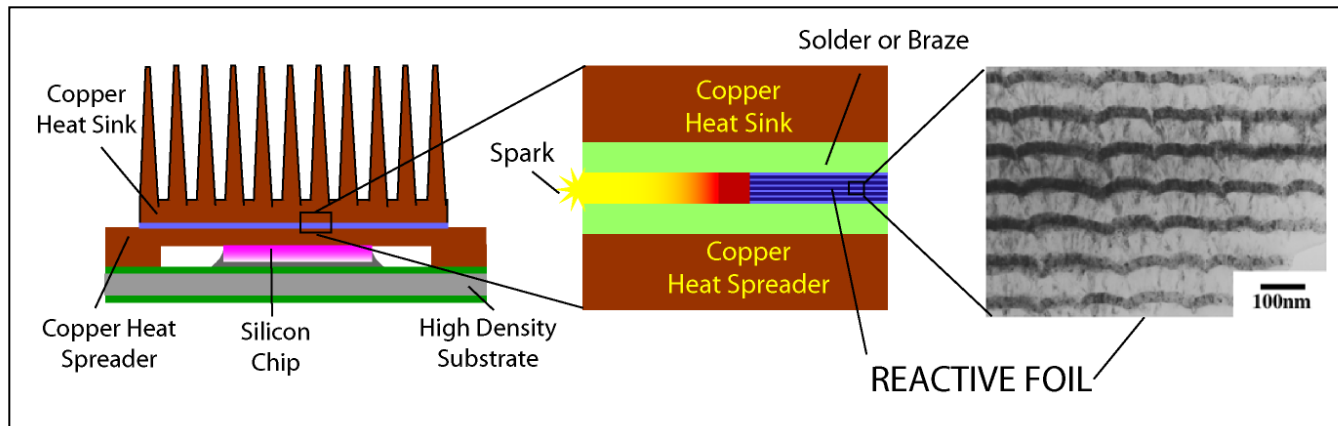
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NanoBond® Soldering Approach

- A foil with thousands of nanoscale layers of aluminum and nickel.
- Heat generated by intermixing of aluminum and nickel layers.
- Foil acts as a controllable, rapid, local heat source.
- Heat of mixing melts the adjoining solder layers.
- Melted layers lead to formation of metallic bond



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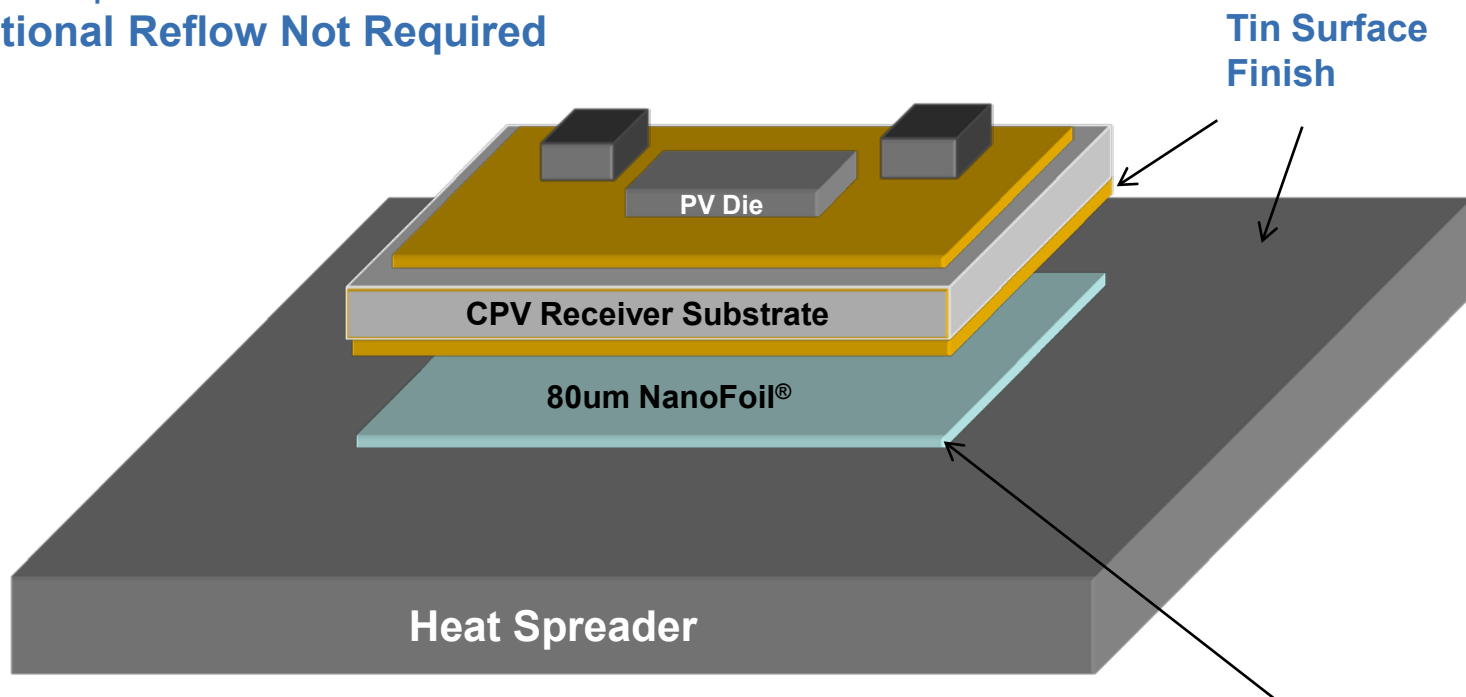
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NanoBond® Configuration for CPV Receiver Modules

Tin Surface Finish

- Bottom of CPV Module
- Top of Heat Spreader
- **Conventional Reflow Not Required**



Cu vs. Al Heat Spreader

- Cu is Better TCE Match to Receiver Module
- Also Better Thermal Conductor

NanoFoil® Replaces TIM1 Adhesive

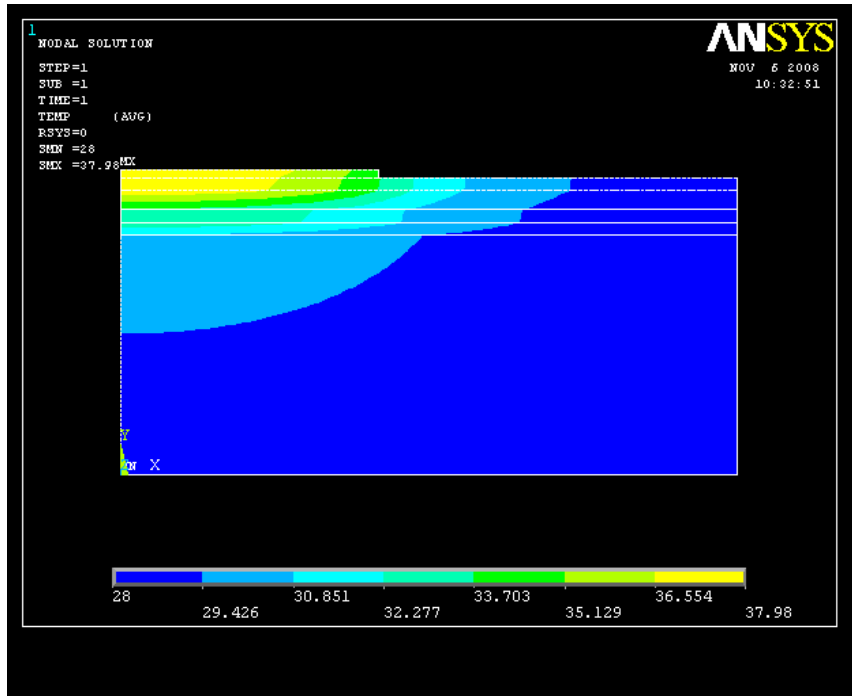
- Lower T_{jmax}
- Increased Efficiency
- Improved Lifetime

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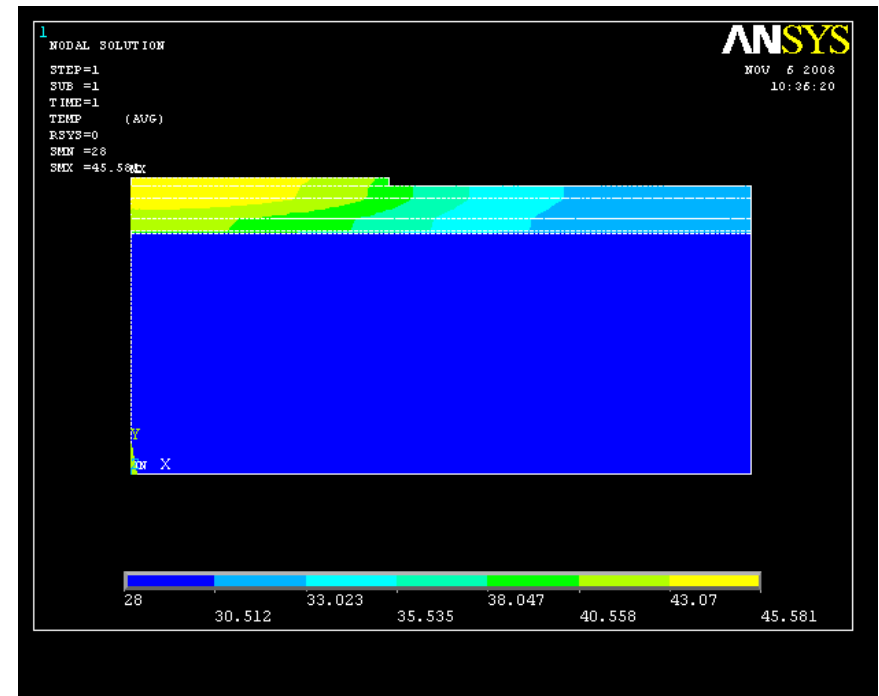
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Solder vs. Adhesive Thermal FEA Model – 30W Heat Flow



- $T_{jmax} = 38C$
- BLT=250um
- $K=25 \text{ W/Km}$



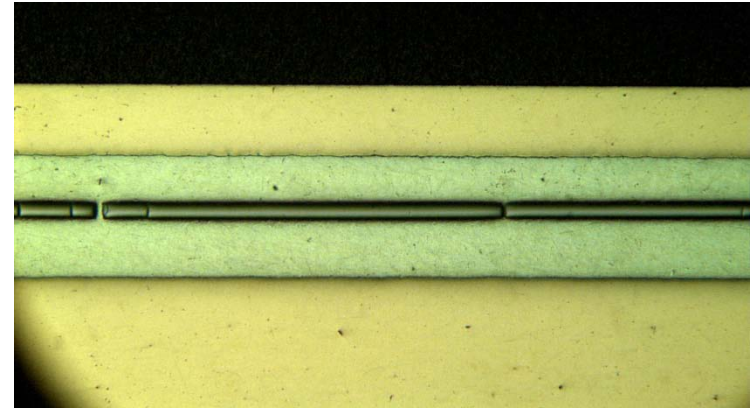
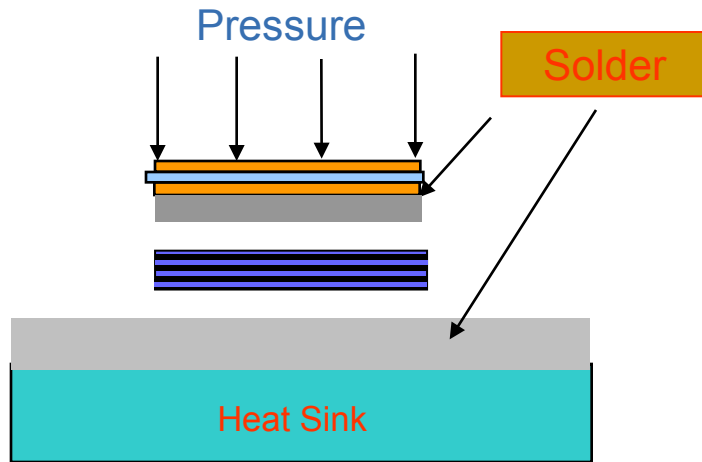
- $T_{jmax} = 46C$
- BLT=50um
- $K=1 \text{ W/Km}$

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NanoBond® Solder Solution



Post 1000 Cycles

NanoBond® Solder Bond

- Cu Heat Sink and Receiver Module
- >1000 cycles completed, no degradation
- -25 to +125C (8.5C per minute ramp)

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Laser Flash Analysis

Bonding Method	Bondline Thickness (μm)	Original Bond		After 540 cycles		After 940 cycles	
		*Thermal Cond. (W/Km)	*Thermal Resist. (Kmm ² /W)	*Thermal Cond. (W/Km)	*Thermal Resist. (Kmm ² /W)	*Thermal Cond. (W/Km)	*Thermal Resist. (Kmm ² /W)
NanoBond Screen printed DBC	447	42.2	10.6	42.3	10.6	41.0	10.9
NanoBond Spray coated DBC	467	30.7	15.2	32.4	14.4	32.0	14.6
Epoxy1 (3M)	50	0.85	58.96	0.81	61.9	0.76	65.86
Epoxy 2 (Epo-Tek)	50	2.83	17.6	Bonds started falling apart at 400 cycles	-	--	-

- Bond size 24 mm x 24 mm
- DBC material properties have been corrected using laser flash
- Copper thickness 1.6 mm

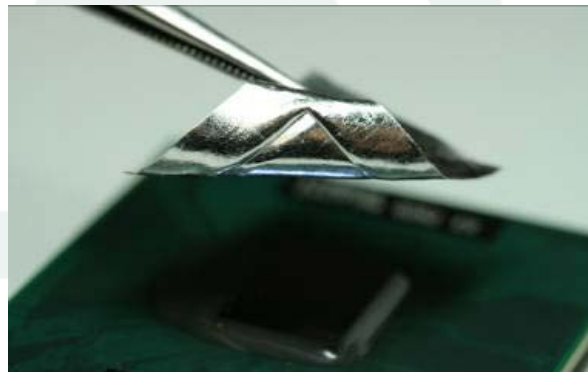
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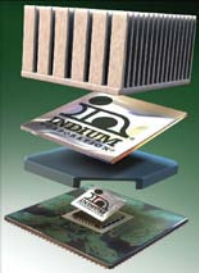
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Heat-Spring®: What is it?

- **Material Description**

- Made from Indium or Indium Tin as standard alloys
- Custom Alloys available
- We alter the surface so contact resistance is reduced
- We use high conductive metal 86w/mk
- We custom package for your application
- We standard pack in Tape and Reel
- We can recycle it and reclaim it
- We can offer you a credit on un-used material
- It's a “green” TIM



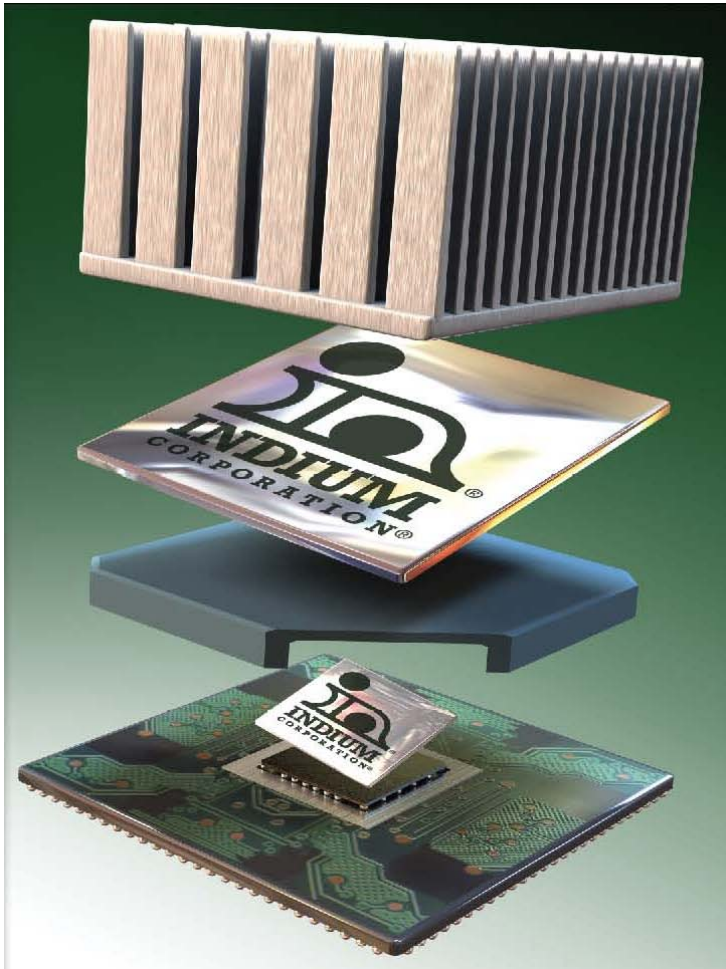


Soft Metal TIM Attributes

- **High thermal conductivity
86W/mK**
 - Low bulk resistance—insensitive to BLT
 - Heat spreading
- **Conformability**
 - Plastic deformation provides low contact resistance path, especially after time zero (burn-in period)
 - Inherent gap filling for co-planarity issues:
 - HSD: +/- .003"
 - HSG: +/- .010"
 - Complies with CTE mismatch
- **Stability/ Advantages**
 - No out-gassing
 - No bake-out or pump-out
 - Easy to handle
 - Reclaimable/ recyclable
- **Thickness**
 - HSD pattern, minimum thickness before Patented Heat-Spring Process is 75um, after the HSD process thickness will increase 75um.
 - HSG pattern, minimum thickness before Patented Heat-Spring process is 150um, after HSG is 300um
 - HSG pattern can be applied to a 250um preform and after HSG process will be 500um thick.
 - Max Thickness is well over .25 inches if necessary.



Stack-up Pictorial



TIM1: Indium Solder Preforms, or conceptual Liquid Metal.

TIM1.5: Heat-Spring®, Liquid Metal

TIM2: Heat-Spring®, Liquid Metal

Burn-in and Test: Heat-Spring® and Aluminum Indium Clad preforms.

Interconnect Reliability Prediction

Overview

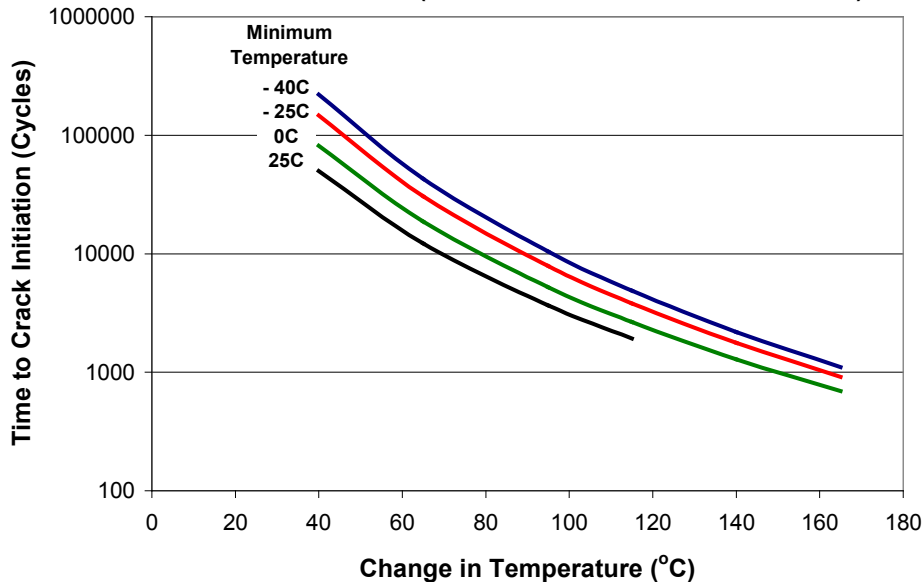
- DfR has extensive experience in developing material degradation algorithms for electronics applications
- These models have been adapted to assess cycles to failure for Concentrated Photovoltaic (CPV) modules
- Typical CPV architecture
 - ❑ 25 mm square CPV receiver
 - ❑ DBC on alumina
 - ❑ Heatsinks are copper and aluminum
 - ❑ Solder is SAC305

Model Inputs

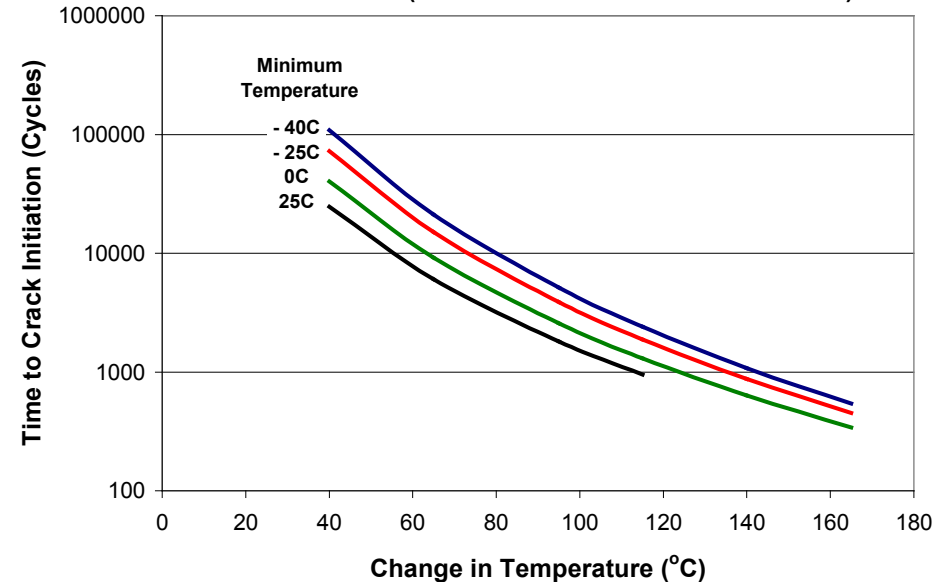
- Environment
 - ❑ Max temperature
 - ❑ Min temperature
 - ❑ Dwell times
- Direct Bond Copper (DBC) Architecture
 - ❑ Thicknesses
- Interconnect Material
 - ❑ Composition (SAC305, etc.)
 - ❑ Material Properties
- Heatsink Material
 - ❑ Composition (Cu, Al, etc.)
 - ❑ Material Properties

Reliability Prediction: Results

Time to Failure (400um SAC305 Bondline Thickness)



Time to Failure (250um SAC305 Bondline Thickness)



- Clearly demonstrates influence of minimum temperature (mountain vs. desert), change in temperature, and bondline thickness
- Allows for tradeoff analysis and rapid assessment of existing interconnect materials and architecture

Summary

- DfR and Indium provide a turn-key solution for the reliability assurance of CPV modules
- New materials and technology for radical improvement in interconnect robustness
 - Commercially available NanoBonding and Heat Spring
- Interconnect reliability algorithm adapted to assess cycles to failure for Concentrated Photovoltaic (CPV) modules