DfR Solutions
reliability designed, reliability delivered

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

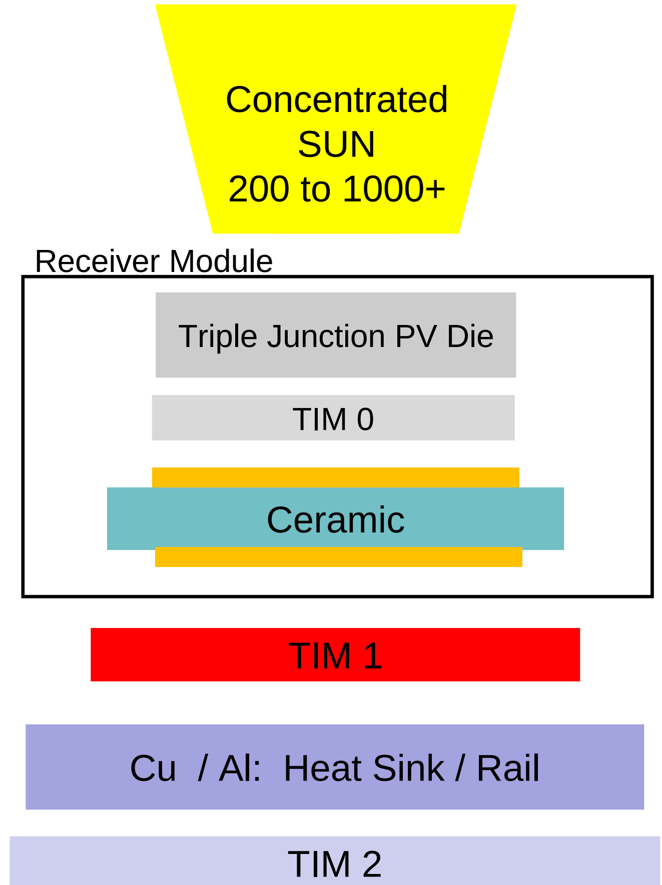
E / T Conductive Die Attach Epoxy

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

Tj,max <100C 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

Aluminum Heat Sink (Back Panel / Rail)

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Typical CPV Receiver - Thermal View

Thermal Conductivity (W / mK)	Layer	CTE (ppm / C)
	Concentrated SUN 200 to 1000+	
	Receiver Module:	
50 / 60	Triple Junction PV Die	5.0 / 6.0
4.0 / 7.0	TIM 0	☺
46	Ceramic	5.5
1 .0 / 4.0	TIM 1 (TC -40C to 110C)	☹
210 / 360	Cu / Al: Heat Sink / Rail	16 / 24
1 .0 / 4.0	TIM 2	☺
	Aluminum Heat Sink (Back Panel / Rail)	

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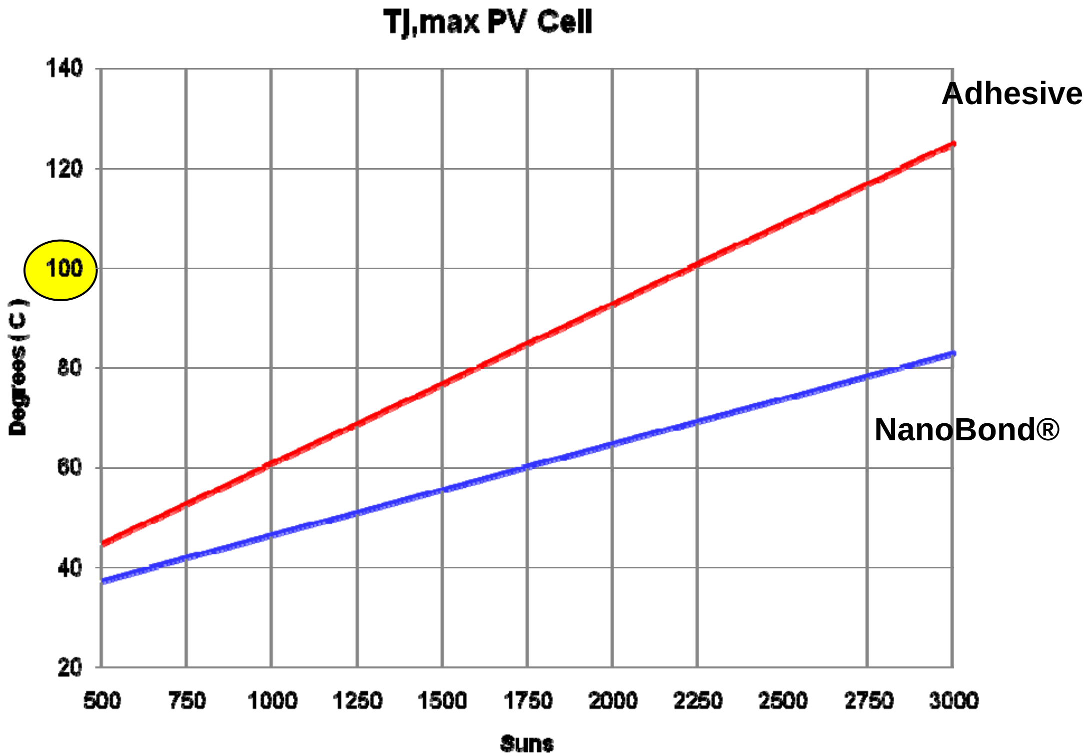
CPV Cell Performance NanoBond vs. Adhesive

1 Sun = 85 mW/mm2 x 500 = 425 mW/mm2
Die Surface Area = 100mm2
Power Incident Die Surface = 42.5W
Conversion Efficiency = 35%
Pdc = 14.9 W
Pdiss = 27.6 W – Thermal Management

Tj,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

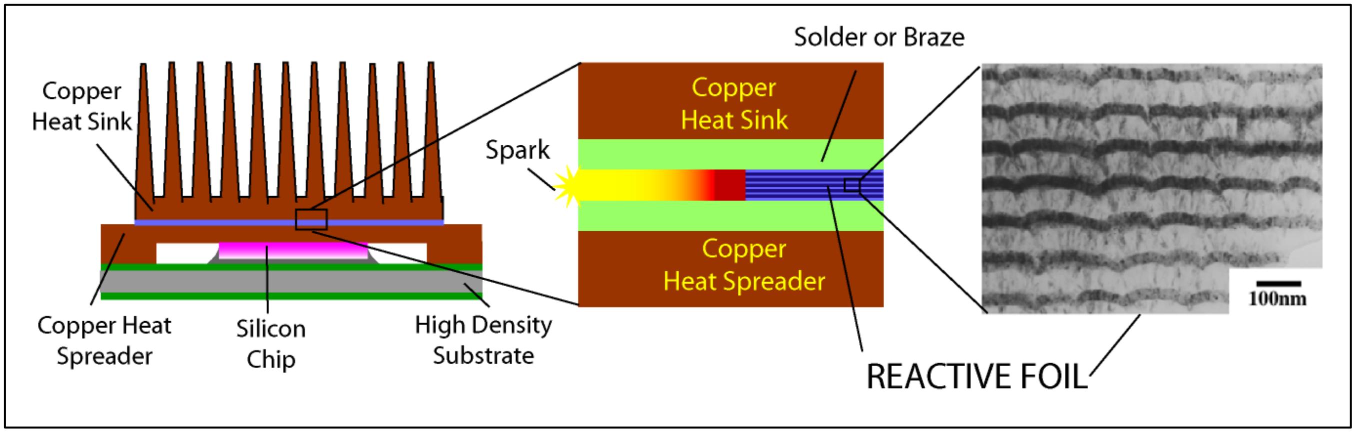


Delta Tj,max Increase vs. Suns
- Lower Tj,max - Increase Lifetime
- Or More Sun Headroom

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

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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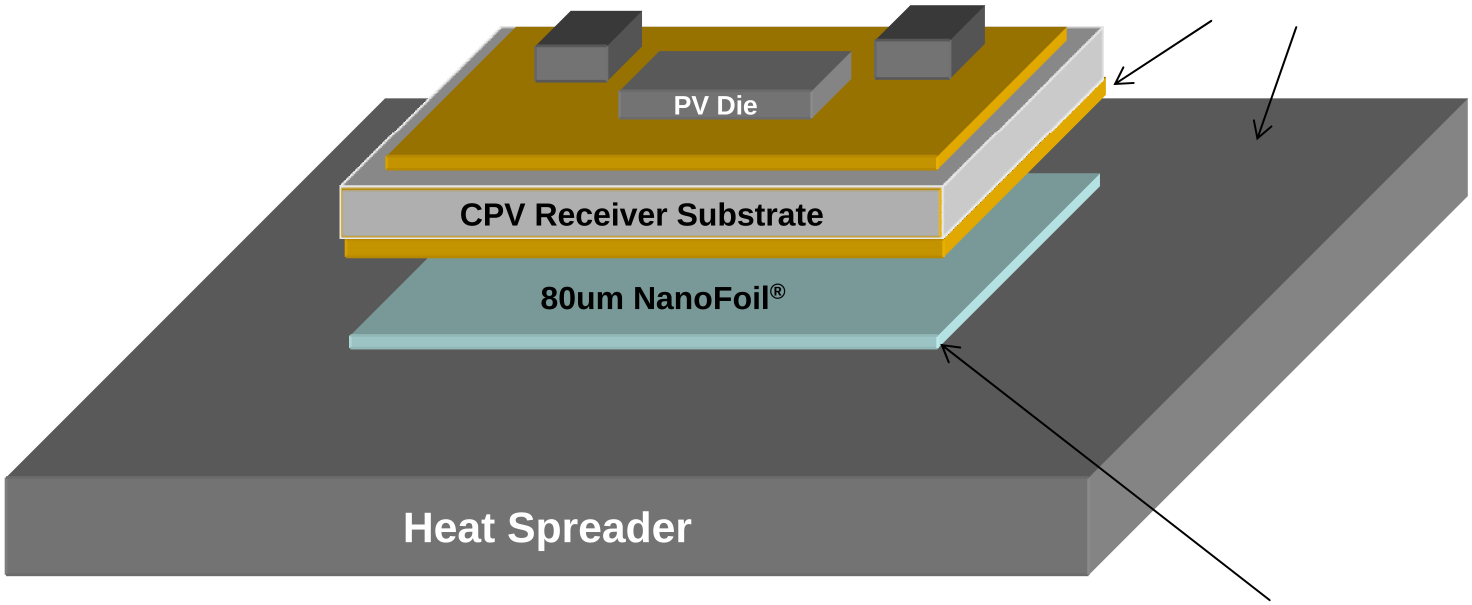
NanoBond® Configuration for CPV Receiver Modules

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 Tjmax
- Increased Efficiency
- Improved Lifetime

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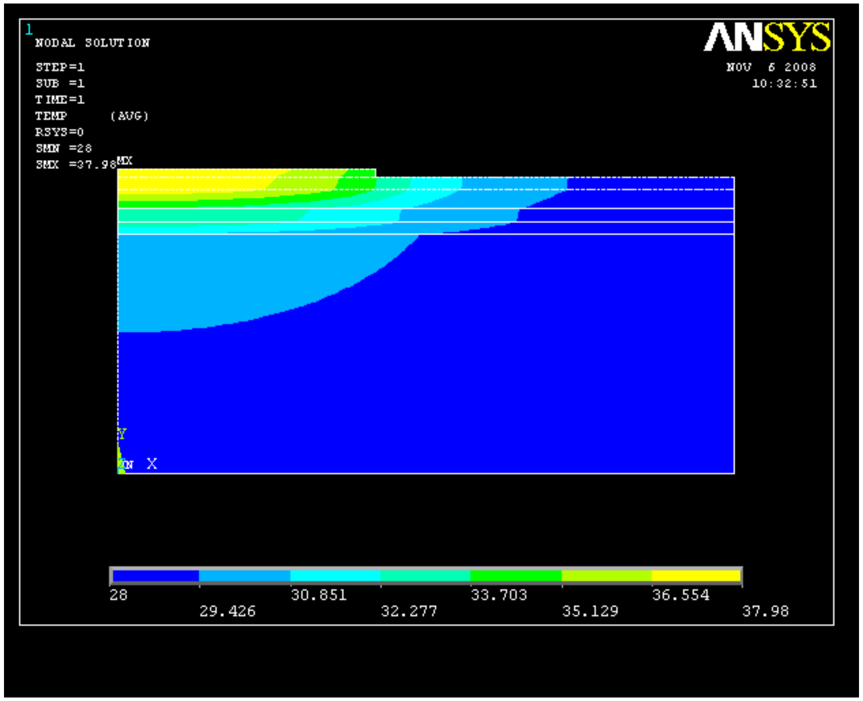
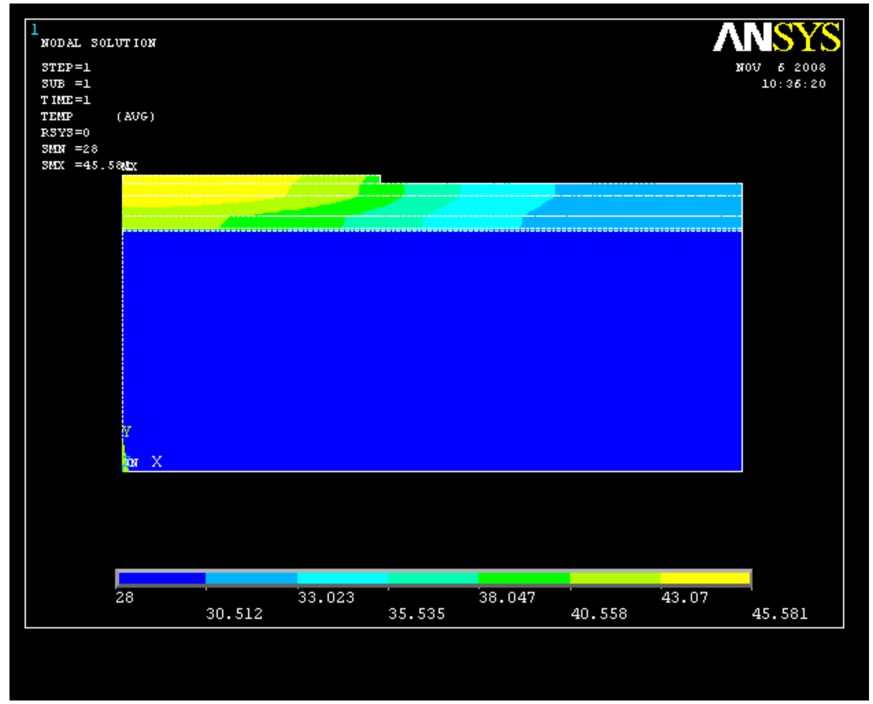
Solder vs. Adhesive Thermal FEA Model – 30W Heat Flow





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

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

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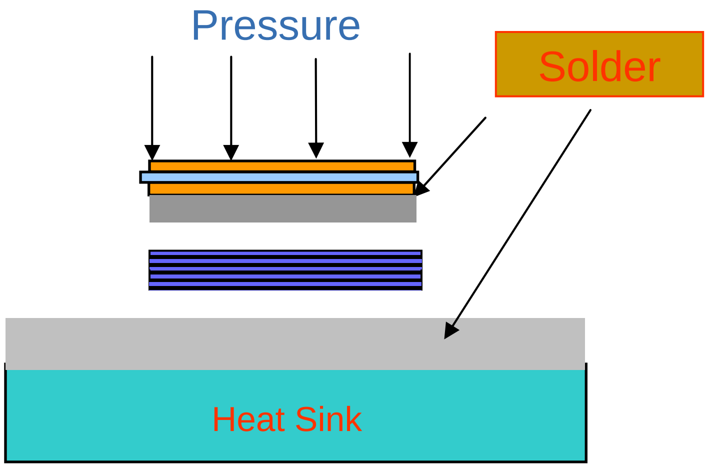
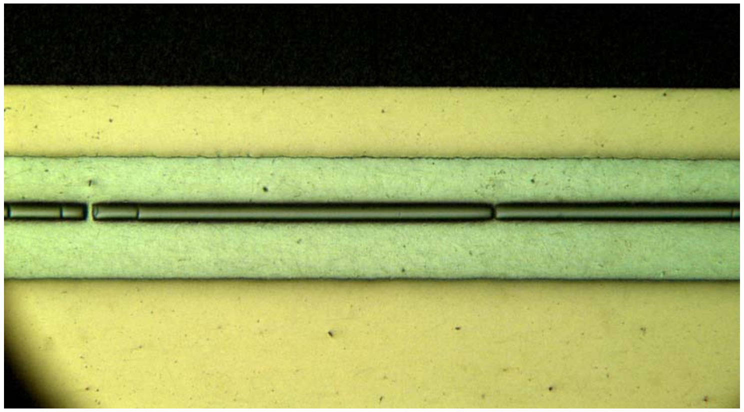
NanoBond®
Solder Solution





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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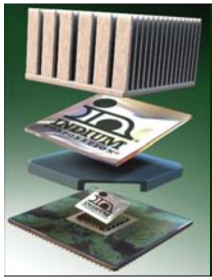
Laser Flash Analysis

Bonding Method	Bondline Thickness (µm)	Original Bond		After 540 cycles		After 940 cycles	
		*Thermal Cond. (W/Km)	***Thermal Resist. (Kmm2/W)**	*Thermal Cond. (W/Km)	***Thermal Resist. (Kmm2/W)**	*Thermal Cond. (W/Km)	***Thermal Resist. (Kmm2/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

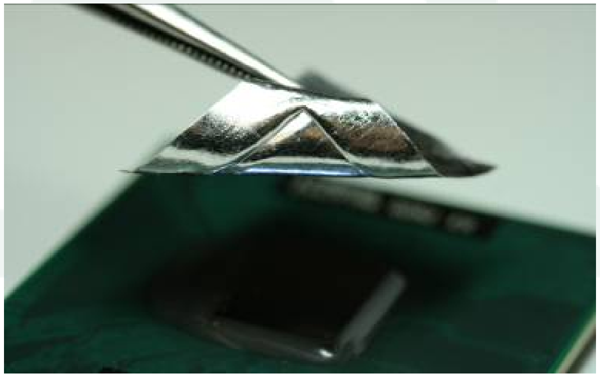
•DBC material properties have been corrected using laser flash

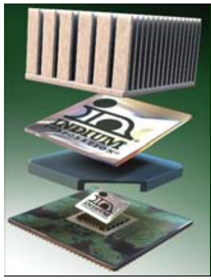
•Copper thickness 1.6 mm



Heat-Spring®: What is it?

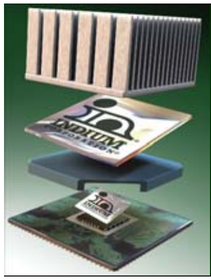
- **Material Description**
  - Made from Indium or Indium Tin as standard alloys
  - Custom Alloys available
  - We alter the surface so contact resistance is reduced
  - We use high conductive metal 86w/mk
  - We custom package for your application
  - We standard pack in Tape and Reel
  - We can recycle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



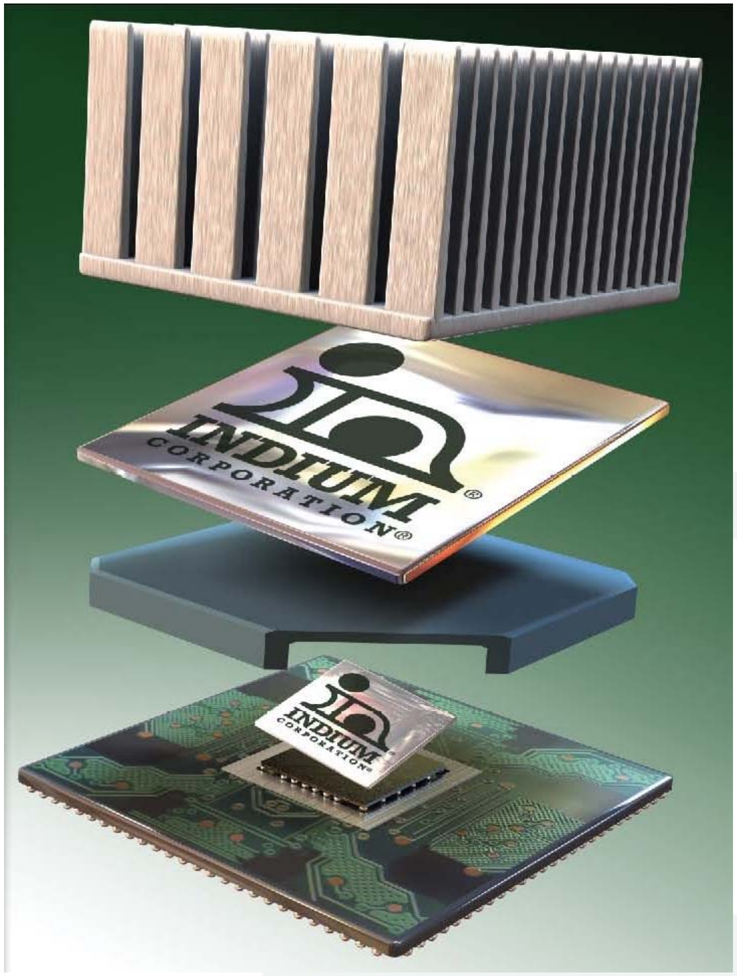


Soft Metal TIM Attributes

- **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

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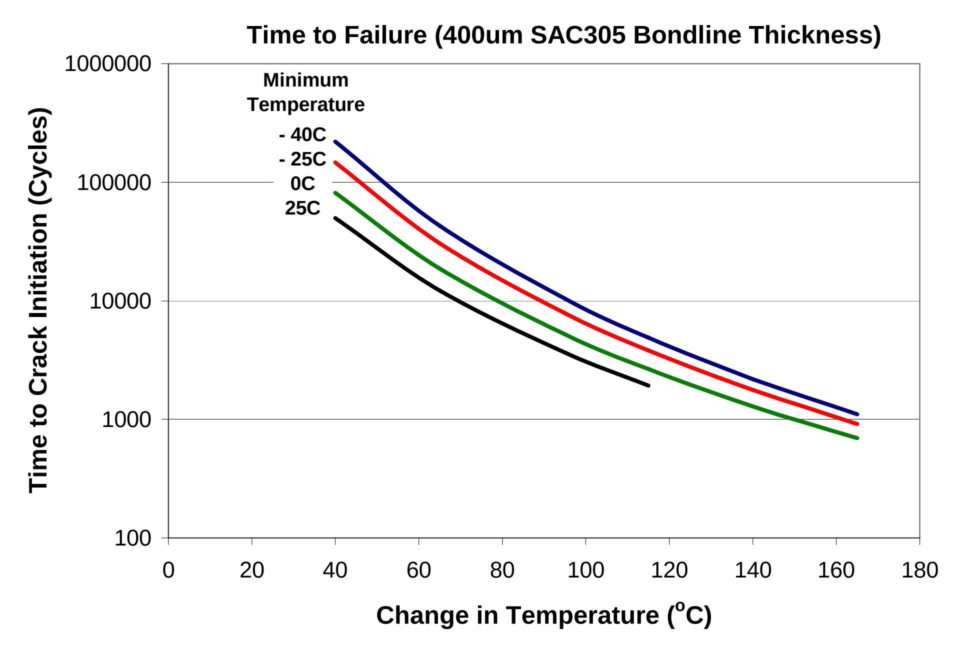
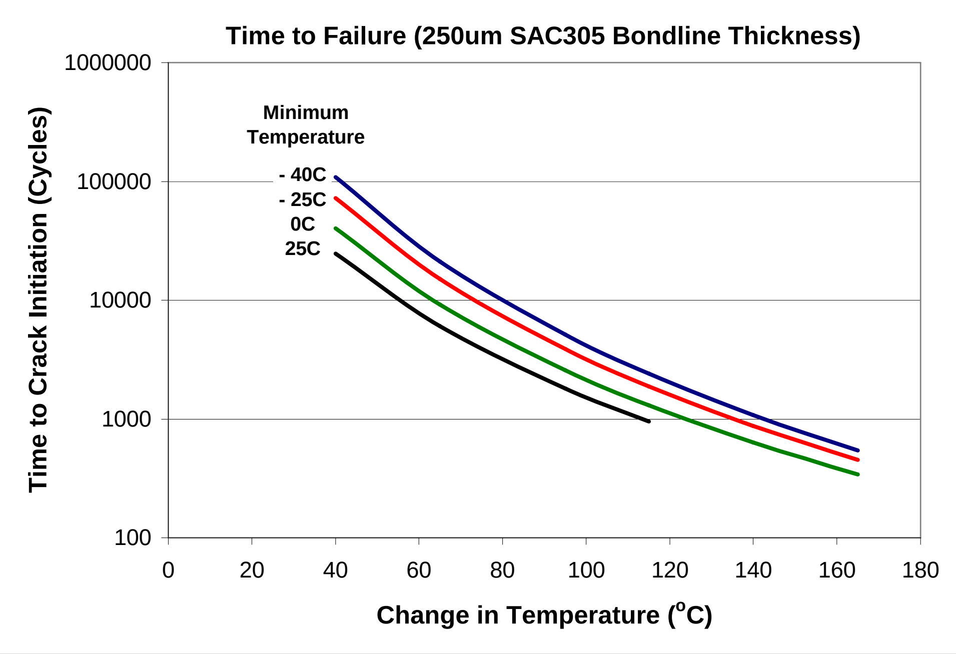
Reliability Prediction: Results





- 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

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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

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