iNEMI®
International Electronics Manufacturing Initiative

Impact of Green Mold Compounds on First- and Second-Level Interconnect Reliability

Welcome

Advancing manufacturing technology

Agenda

- **iNEMI Overview – Grace O’Malley, iNEMI**
- **Part 1: Impact of Green Molding Compounds on Solder Joint Reliability – Geert Willems, imec**
- **Part 2: Early Fatigue Failures in Copper Wire Bonds Inside Packages with Low CTE – Bart Vandevelde, imec**
- **Potential Next Steps**
- **Contact Details**

About iNEMI

Mission: Forecast and Accelerate improvements in the Electronics Manufacturing Industry for a Sustainable Future.

5 Key Deliverables:

- Technology Roadmaps
- Collaborative Deployment Projects
- Research Priorities Documents
- Proactive Forums
- Position Papers

3 Major Focus Areas:

- Miniaturization
- Environment
- Medical Electronics

International Electronics Manufacturing Initiative (iNEMI) is an industry-led consortium of around 107 global manufacturers, suppliers, industry associations, government agencies and universities. A Non Profit Fully Funded by Member Dues; All Funding is Returned to the Members in High Value Programs and Services; In Operation Since 1994.

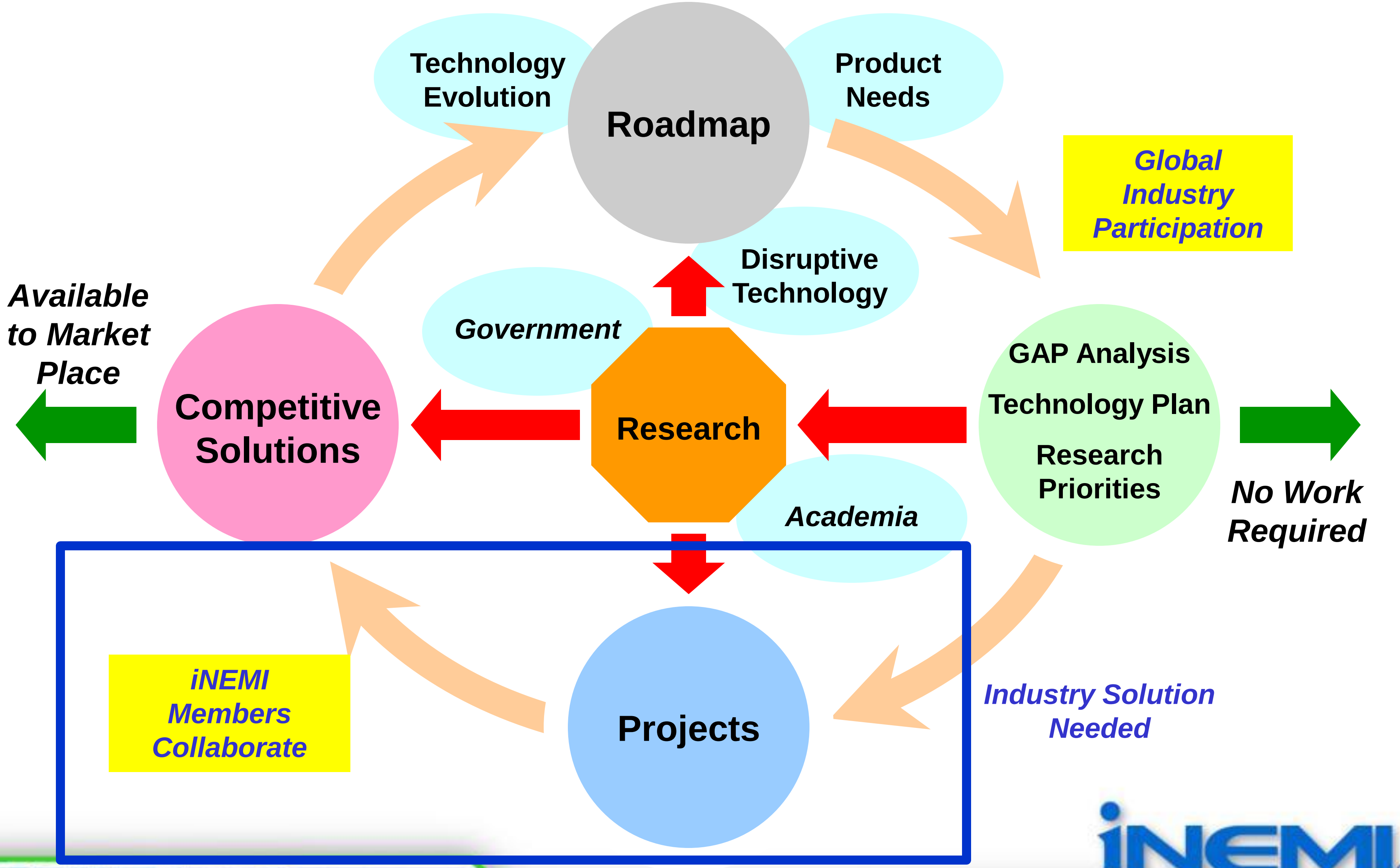
Visit us at www.inemi.org

International Membership Across The Total Supply Chain

The International Membership	Incorporated Location; Number of Members			
INEMI Member Business Type	**North America**	**Asia Region**	**Europe**	**Totals**
OEM	14	3	2	19
ODM/EMS (inc. pkg. & test services)	5	6	1	11
Suppliers (materials, software, services)	9	18	12	39
Equipment	8	0	2	10
Universities & Research Institutes	8	3	2	13
Organizations	11	1	2	14
Totals	**55**	**31**	**21**	**107**

- ✓ **Total <u>Global</u> Supply Chain Integration**
- ✓ **70% Growth in past 3 years**

Methodology



Technology Evolution

Roadmap

Product Needs

Global Industry Participation

Disruptive Technology

Government

Available to Market Place

Competitive Solutions

Research

GAP Analysis

Technology Plan

Research Priorities

No Work Required

Academia

iNEMI Members Collaborate

Projects

Industry Solution Needed

PART I:

IMPACT OF GREEN MOLDING COMPOUNDS ON SOLDER JOINT RELIABILITY

GEERT WILLEMS

BART VANDEVELDE, STEVEN THIJS

IMEC – CENTER FOR ELECTRONICS DESIGN & MANUFACTURING

EDM
Electronics Design & Manufacturing

imec

CONTENT

1. Towards “Green”, low CTE molding compounds
2. The impact of green molding compounds
   1. Solder joint fatigue
   2. What lifetime is required?
   3. What does literature tell us?
   4. Failure experience
3. FE study of TSOP, QFN and BGA with GMC
4. Recent experimental results
5. Impact on Assembly
6. Conclusions

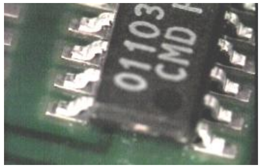
1. MOLDING COMPOUNDS

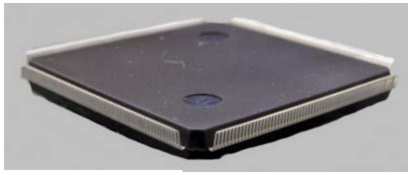
Plastic molding compounds are used to encapsulate the IC/leadframe or IC/substrate assembly in plastic IC packaging:

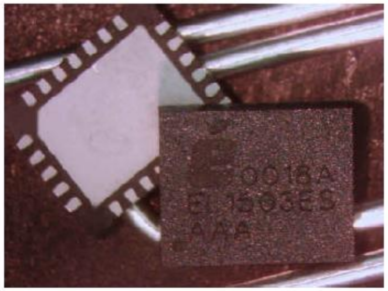
Leaded packages: SOIC, QFP, TSOP,...

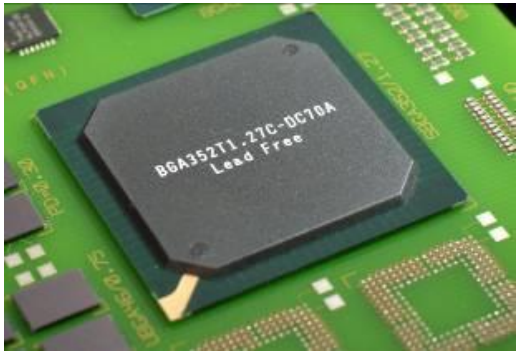
Leadless packages: QFN, MLF, LPP,...

Area array packages: PBGA





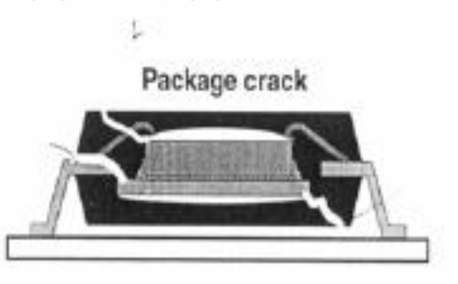


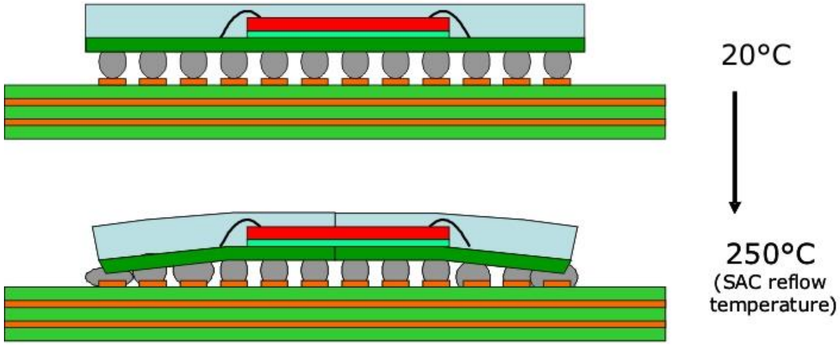


I. MOLDING COMPOUND

Molding compound requirements:

- Compatibility with silicon die & first level interconnect (wire bond, flip chip, die attach)
- Thermal, mechanical, moisture robustness
- Leadframe – substrate matching (warpage)
- Electrical properties
- Thermal conductivity
- Flame retardant
- Manufacturability
- Cost
- …



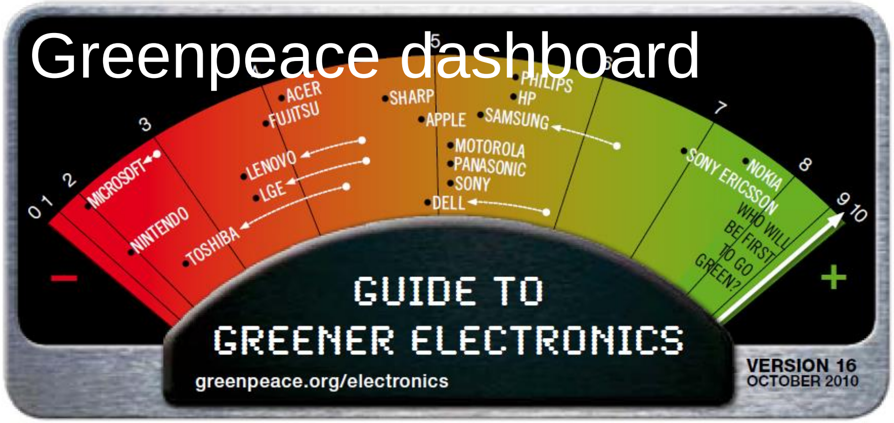


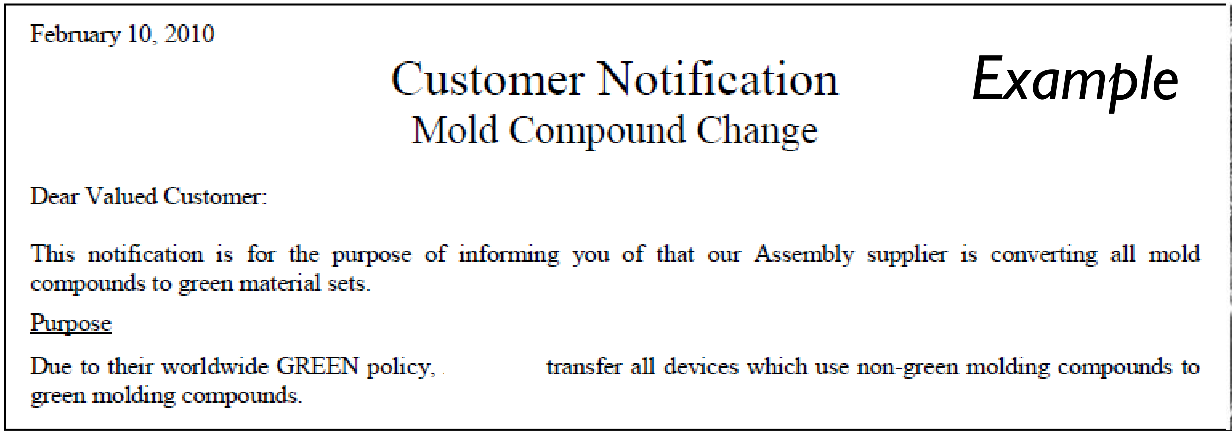
1. GREEN MOLDING COMPOUND

Driven by:

- Need for reduced moisture sensitivity (lead-free)
- “Going Green” trend: Halogen-free plastics
- Die stress: new IC-dielectrics
- Cost

→ Electronic component manufacturers introduced highly SiO_2 filled (85%) “Green mold compounds”


Greenpeace dashboard


February 10, 2010

Customer Notification

Mold Compound Change

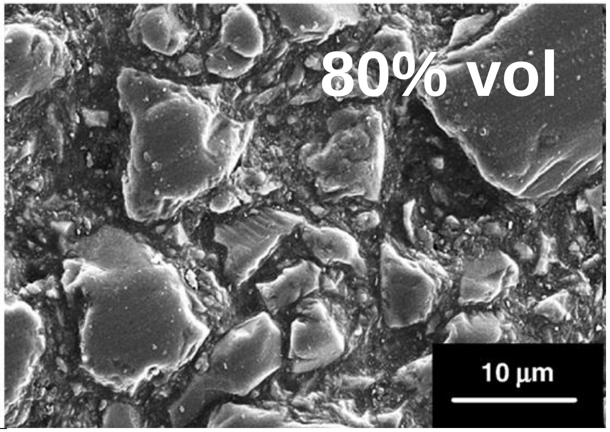
Example

Dear Valued Customer:

This notification is for the purpose of informing you of that our Assembly supplier is converting all mold compounds to green material sets.

Purpose

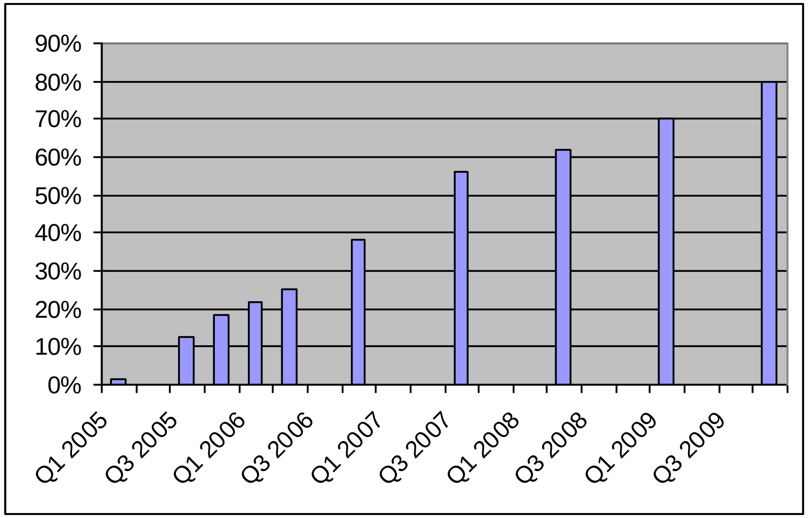
Due to their worldwide GREEN policy, transfer all devices which use non-green molding compounds to green molding compounds.



1. GREEN MOLDING COMPOUNDS

The change-over took place between 2005-2010

(from a leading semiconductor supplier)

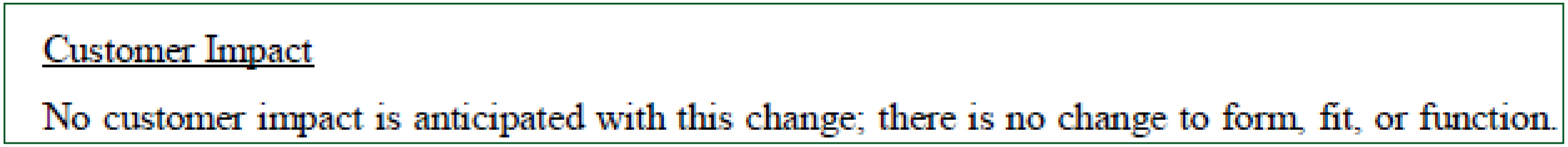


High penetration level of highly filled GMC

All plastic components: SOIC, TSOP, QFN, BGA,...

Customer notification is MISLEADING!

2nd level interconnect reliability has not been considered!?



Customer Impact

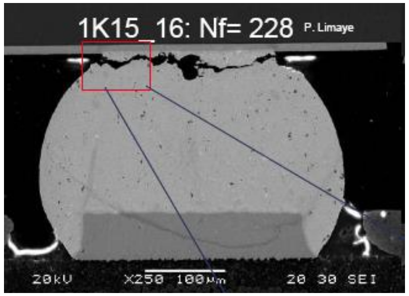
No customer impact is anticipated with this change; there is no change to form, fit, or function.

2. GREEN MOLD COMPOUNDS THE IMPACT

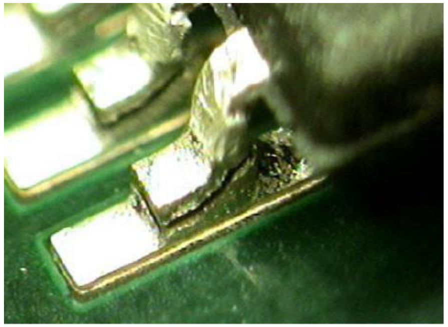
High SiO_2 filling creates molding compound with very low thermal expansion: CTE=6-10 ppm.
For reference: CTE Al_2O_3 = 6.7ppm (ex. CBGA)

In the past it matched the PCB CTE of 15-18ppm

This creates a nearly **tenfold** increase in thermal mismatch between component and PCB.

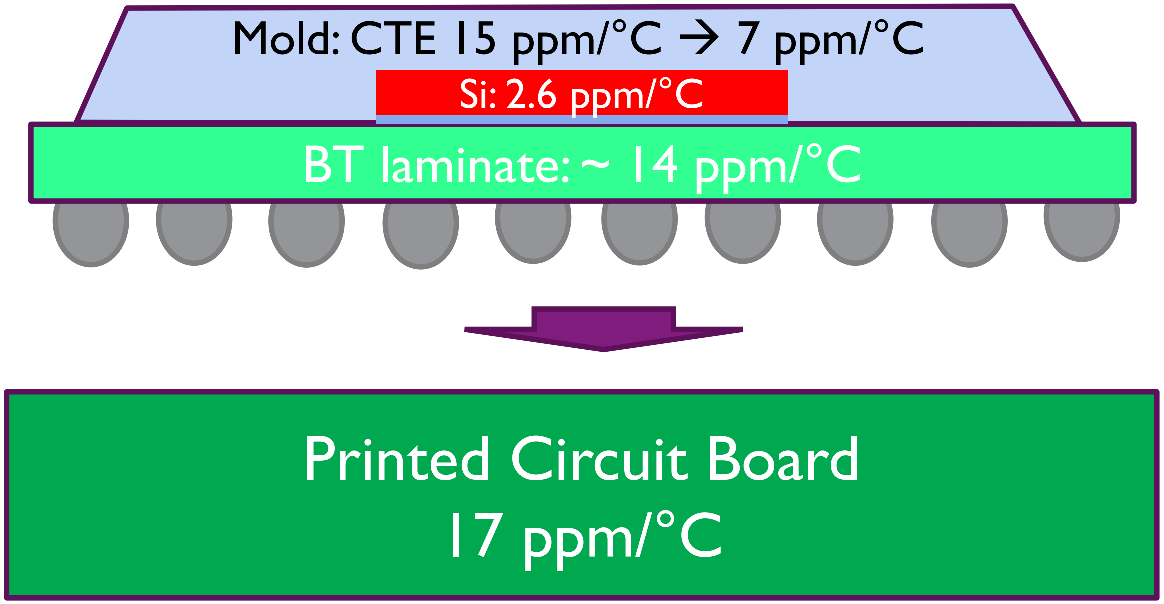


Depending on component and PCB details:
A major increase of thermo-mechanical strain of solder joints and component leads (TSOP).



A major threat to solder joint and interconnect reliability

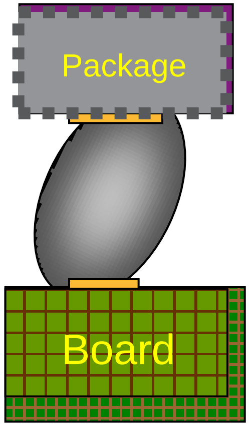
2. IMPACT OF LOW CTE MOLDING COMPOUNDS

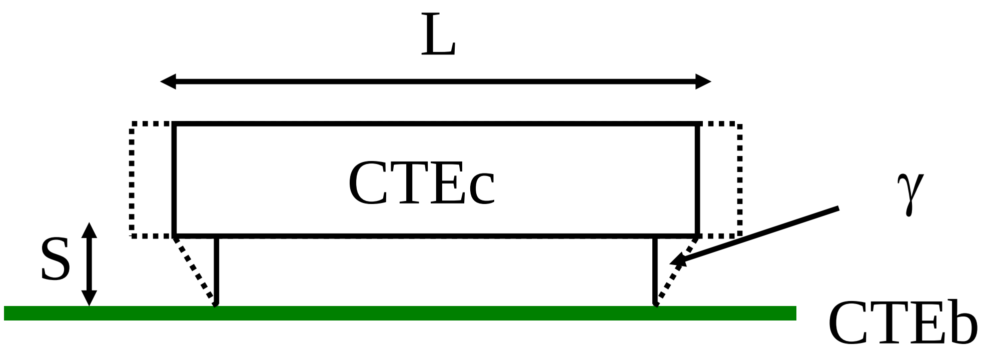


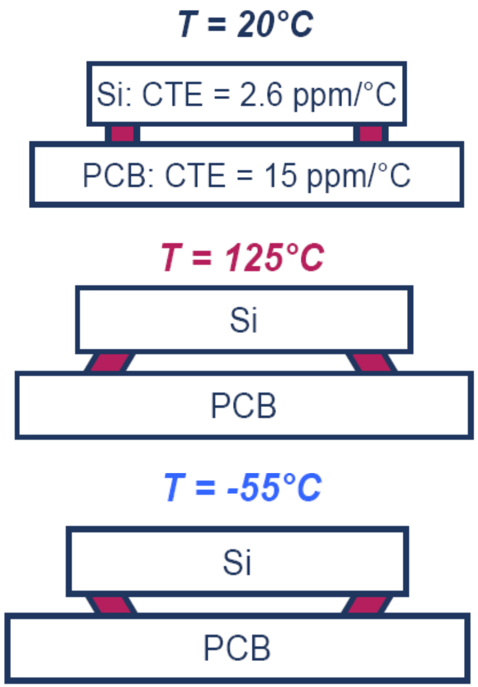
1. Better CTE match with silicon → lower stress in Si die ☺
2. Higher CTE mismatch with BT laminate → more warpage of the package with temperature changes ☹
3. Higher CTE mismatch with PCB → higher loading of the 2nd level solder connections ☹

2.1. SOLDER JOINT FATIGUE

Thermally induced stress-strain







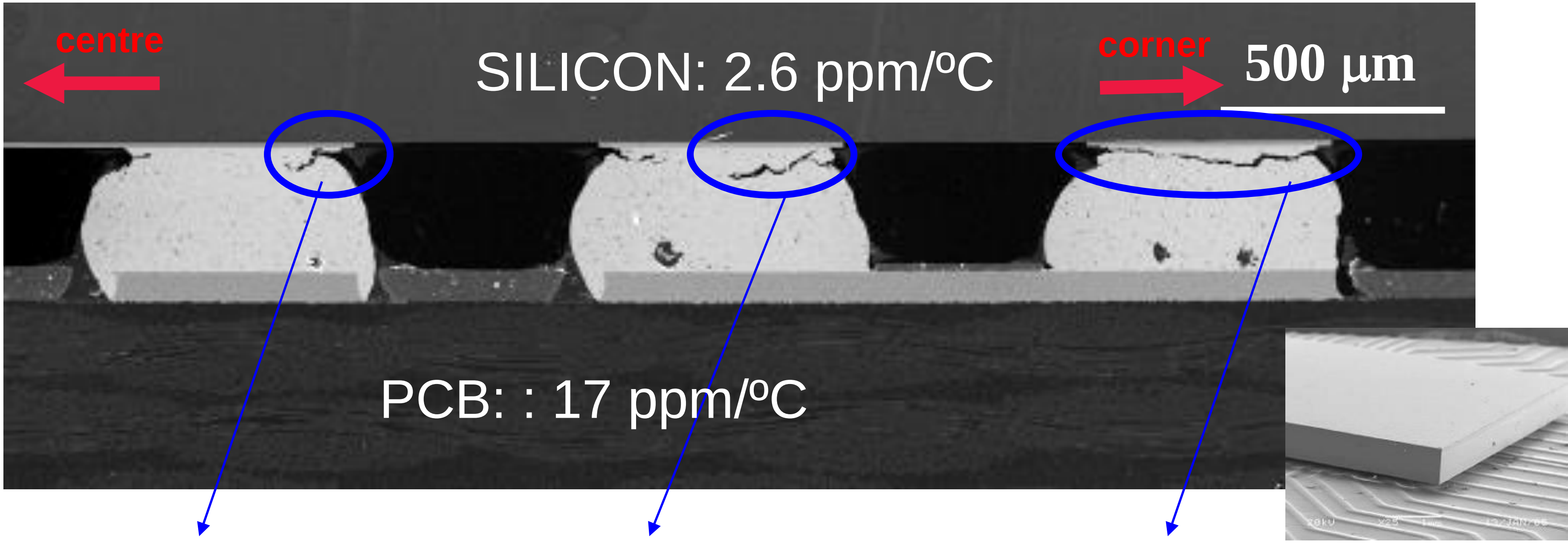
Joint strain $\sim \gamma \sim \Delta L/S \sim L(CTEc - CTEb)\Delta T/2S$

Thermo-mechanical strain increases with:

- increasing thermal mismatch
  (ceramic, bare silicon, **GREEN MOLD COMPOUND**≈ceramic)
- increasing component size (**large BGAs**, large dies)
- decreasing stand-off (**small ball sizes, leadless packages**!)
- increasing thermal cycling (**outdoor, high power dissipation**)

2.1 SOLDER JOINT FATIGUE

Example: 10x10 mm^2 CSP soldered on FR4 PCB after 500 temperature cycles (0 to 100˚C)



Micro-crack initation Crack propagation Fracture

2.1 SOLDER JOINT FATIGUE
GMC VS. CERAMIC

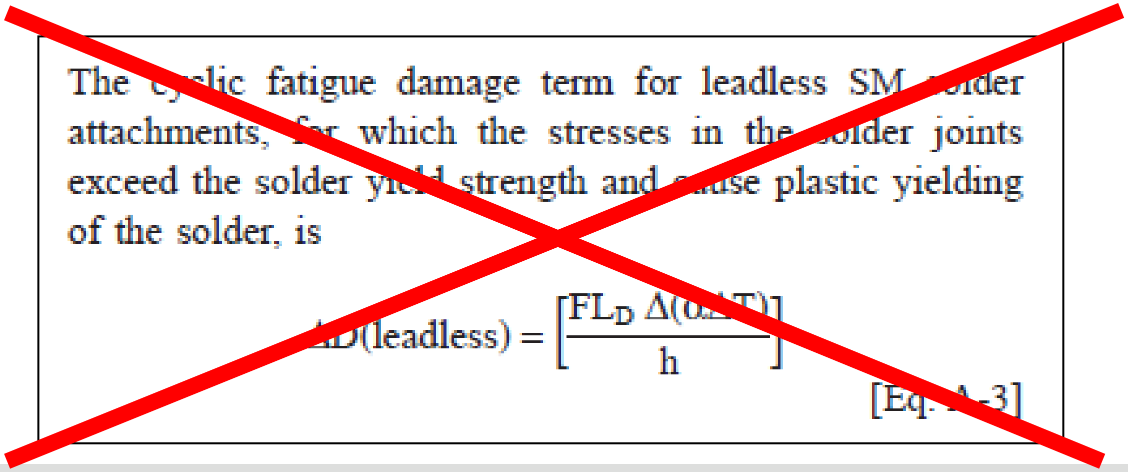
CTE GMC (6-10ppm) comparable to ceramic (Al_2O_3=6.7ppm) CTE

But elasticity of GMC (E-modulus) is an order of magnitude smaller than that of ceramics→ ten times more flexible.

Consequences

Package flexibility becomes a dominating factor in the solder joint reliability.

The simple Engelmaier approach to solder joint reliability of IPC-D-279, cannot be applied to plastic packages.



The cyclic fatigue damage term for leadless SM solder attachments, for which the stresses in the solder joints exceed the solder yield strength and cause plastic yielding of the solder, is

$$\Delta D(\text{leadless}) = \left[\frac{F L_D \Delta(\alpha\Delta T)}{h}\right] \quad \text{[Eq. A-3]}$$

2.2. WHAT IS REQUIRED?

SOME FIGURES FOR REFERENCE (IPC-9701)

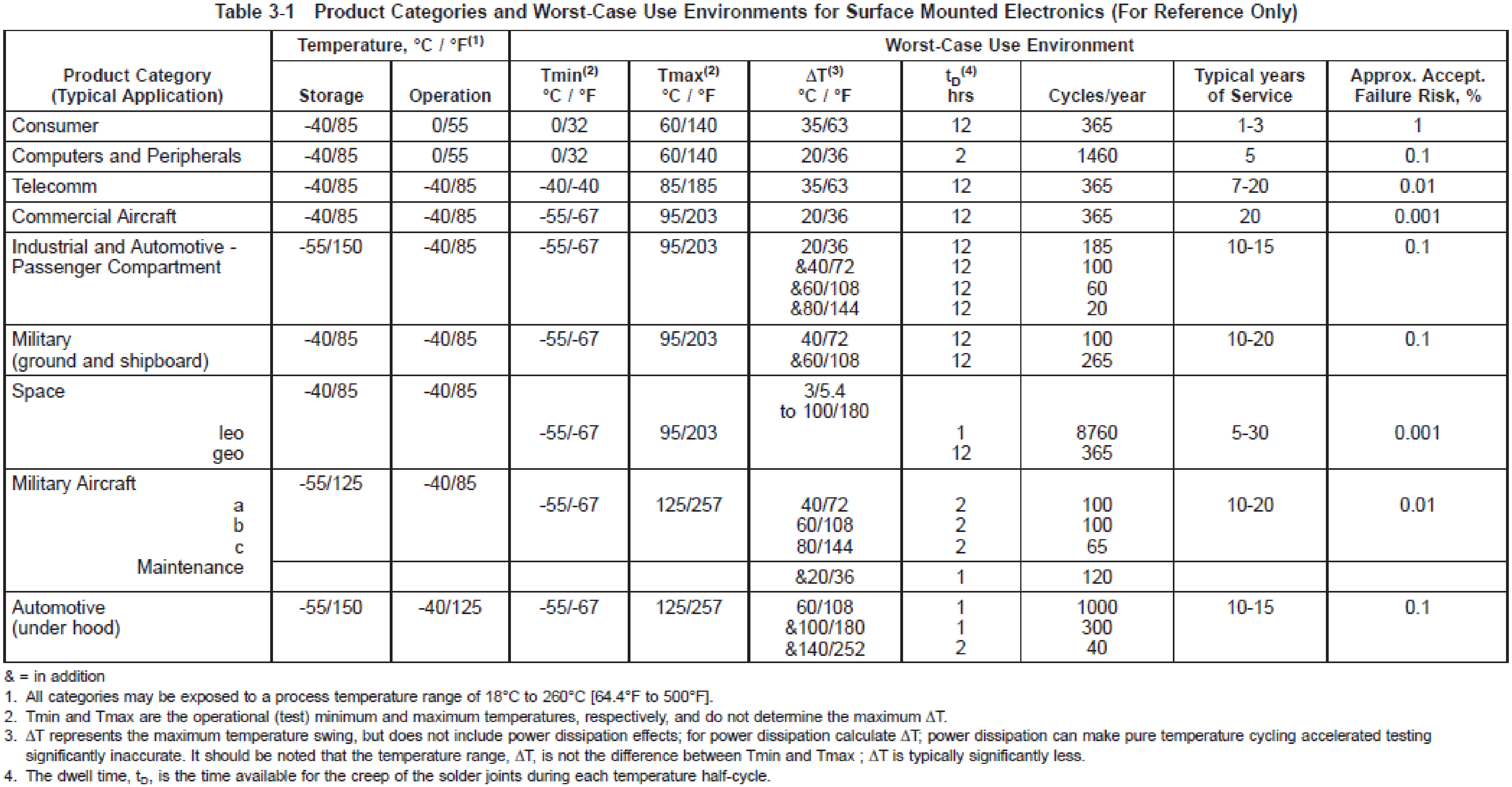


Table 3-1 Product Categories and Worst-Case Use Environments for Surface Mounted Electronics (For Reference Only)

Product Category (Typical Application)	Temperature, °C / °F[1]		Worst-Case Use Environment						
	Storage	Operation	Tmin[2] °C / °F	Tmax[2] °C / °F	ΔT[3] °C / °F	t_D[4] hrs	Cycles/year	Typical years of Service	Approx. Accept. Failure Risk, %
Consumer	-40/85	0/55	0/32	60/140	35/63	12	365	1-3	1
Computers and Peripherals	-40/85	0/55	0/32	60/140	20/36	2	1460	5	0.1
Telecomm	-40/85	-40/85	-40/-40	85/185	35/63	12	365	7-20	0.01
Commercial Aircraft	-40/85	-40/85	-55/-67	95/203	20/36	12	365	20	0.001
Industrial and Automotive - Passenger Compartment	-55/150	-40/85	-55/-67	95/203	20/36 &40/72 &60/108 &80/144	12 12 12 12	185 100 60 20	10-15	0.1
Military (ground and shipboard)	-40/85	-40/85	-55/-67	95/203	40/72 &60/108	12 12	100 265	10-20	0.1
Space leo geo	-40/85	-40/85	-55/-67	95/203	3/5.4 to 100/180	1 12	8760 365	5-30	0.001
Military Aircraft a b c	-55/125	-40/85	-55/-67	125/257	40/72 60/108 80/144	2 2 2	100 100 65	10-20	0.01
Maintenance					&20/36	1	120		
Automotive (under hood)	-55/150	-40/125	-55/-67	125/257	60/108 &100/180 &140/252	1 1 2	1000 300 40	10-15	0.1

& = in addition

1. All categories may be exposed to a process temperature range of 18°C to 260°C [64.4°F to 500°F].
2. Tmin and Tmax are the operational (test) minimum and maximum temperatures, respectively, and do not determine the maximum ΔT.
3. ΔT represents the maximum temperature swing, but does not include power dissipation effects; for power dissipation calculate ΔT; power dissipation can make pure temperature cycling accelerated testing significantly inaccurate. It should be noted that the temperature range, ΔT, is not the difference between Tmin and Tmax ; ΔT is typically significantly less.
4. The dwell time, t_D, is the time available for the creep of the solder joints during each temperature half-cycle.

2.2. WHAT IS REQUIRED?

SOME FIGURES FOR REFERENCE (IPC-9701)

Notes:
- Acc. Factor: SnPb Norris-Landzberg eq.
- Weibull slope=6
- No power cycling
- Tmax= max. operation

Computer and peripherals: ΔT=20K, 4cpd, 5y, 0.1%

- N63%(0-100°C) → 1250 cycles/5y

Telecom: ΔT=35K, 1cpd, 7-20y, 0.01%

- N63%(0-100°C) → >2000 cycles/7y...6000 cycles/20y

Industrial/automotive:

ΔT=20K(50%)/40K(27%)/60K(16%)/80K(6%), 365cpy, 10-15y, 0.1%

- N63%(0-100°C) → >3000 cycles/10y...4500 cycles/15y

Commercial aircraft: ΔT=20K, 1cpd, 20y, 0.001%

- N63%(0-100°C) → 3500 cycles/20y

Military: ΔT=40K(27%)/60K(73%), 365cpy, 10-20y, 0.1%

- N63%(0-100°C) → 5500 cycles/10y...11000 cycles/20y

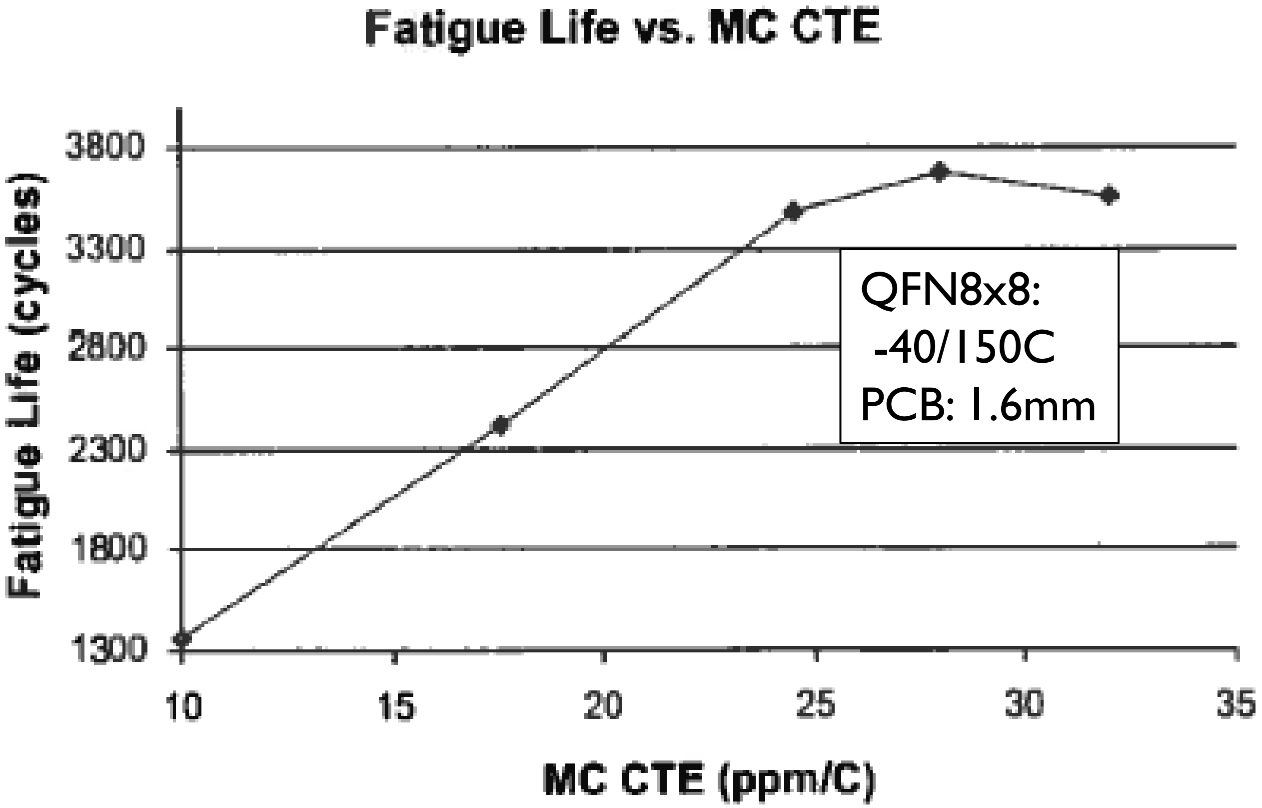
10 year lifetime requires

N63%(0-100°C) **>3000 cycles** (N63%(-40-125°C)>1500 cycles)

2.3. LITERATURE: QFN SIMULATION

- All simulations confirm reduction in lifetime with factor 1 to 4.
- Higher CTE and lower E is recommended: opposite to GMC

T.Y. Tee et al.
2003



QFN8x8:
-40/150C
PCB: 1.6mm

2.3. LITERATURE: QFN SIMULATION

X. Zhang et al., 2002

QFN (BLP)
-55/125C

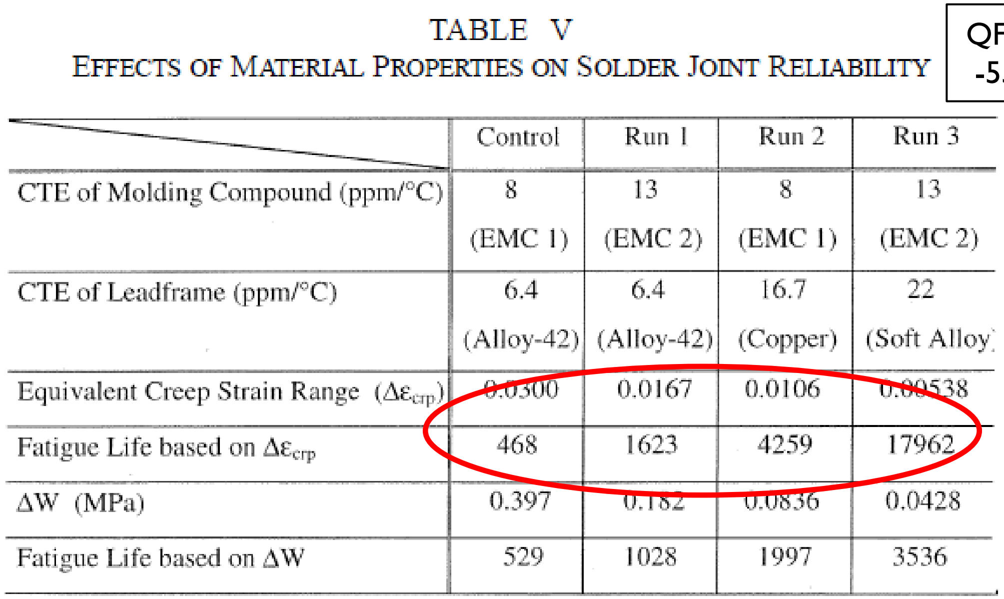


TABLE V
EFFECTS OF MATERIAL PROPERTIES ON SOLDER JOINT RELIABILITY

	Control	Run 1	Run 2	Run 3
CTE of Molding Compound (ppm/°C)	8 (EMC 1)	13 (EMC 2)	8 (EMC 1)	13 (EMC 2)
CTE of Leadframe (ppm/°C)	6.4 (Alloy-42)	6.4 (Alloy-42)	16.7 (Copper)	22 (Soft Alloy
Equivalent Creep Strain Range ($\Delta\varepsilon_{crp}$)	0.0300	0.0167	0.0106	0.00538
Fatigue Life based on $\Delta\varepsilon_{crp}$	468	1623	4259	17962
ΔW (MPa)	0.397	0.182	0.0836	0.0428
Fatigue Life based on ΔW	529	1028	1997	3536

2) The EMC 2 which has a high CTE content (13 ppm/°C) offers at least 1.9 fold improvement in fatigue life over the EMC 1 which has a lower CTE content (8 ppm/°C).

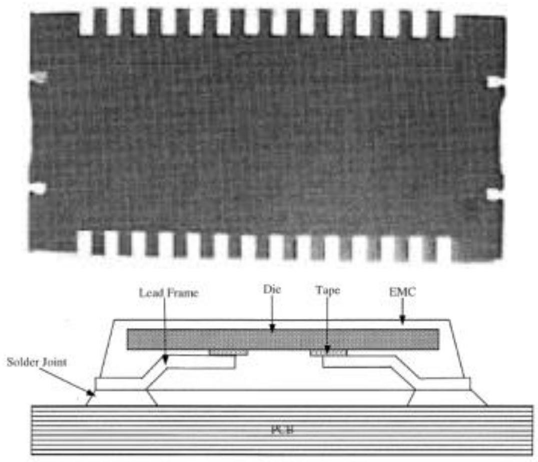


Fig. 2. Schematic diagram of the cross section of a 28-pin BLP package.

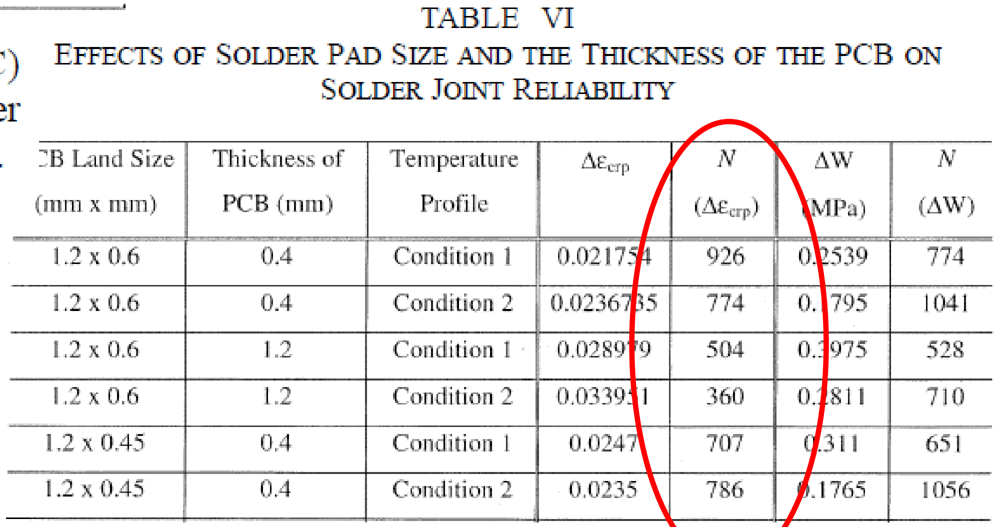


TABLE VI
EFFECTS OF SOLDER PAD SIZE AND THE THICKNESS OF THE PCB ON SOLDER JOINT RELIABILITY

CB Land Size (mm x mm)	Thickness of PCB (mm)	Temperature Profile	$\Delta\varepsilon_{crp}$	N ($\Delta\varepsilon_{crp}$)	ΔW (MPa)	N (ΔW)
1.2 x 0.6	0.4	Condition 1	0.021754	926	0.2539	774
1.2 x 0.6	0.4	Condition 2	0.0236735	774	0.1795	1041
1.2 x 0.6	1.2	Condition 1	0.028979	504	0.3975	528
1.2 x 0.6	1.2	Condition 2	0.033951	360	0.2811	710
1.2 x 0.45	0.4	Condition 1	0.0247	707	0.311	651
1.2 x 0.45	0.4	Condition 2	0.0235	786	0.1765	1056

2.3. LITERATURE: BGA SIMULATION

T.Y. Tee et al.
2006

BGA:
-40/125C

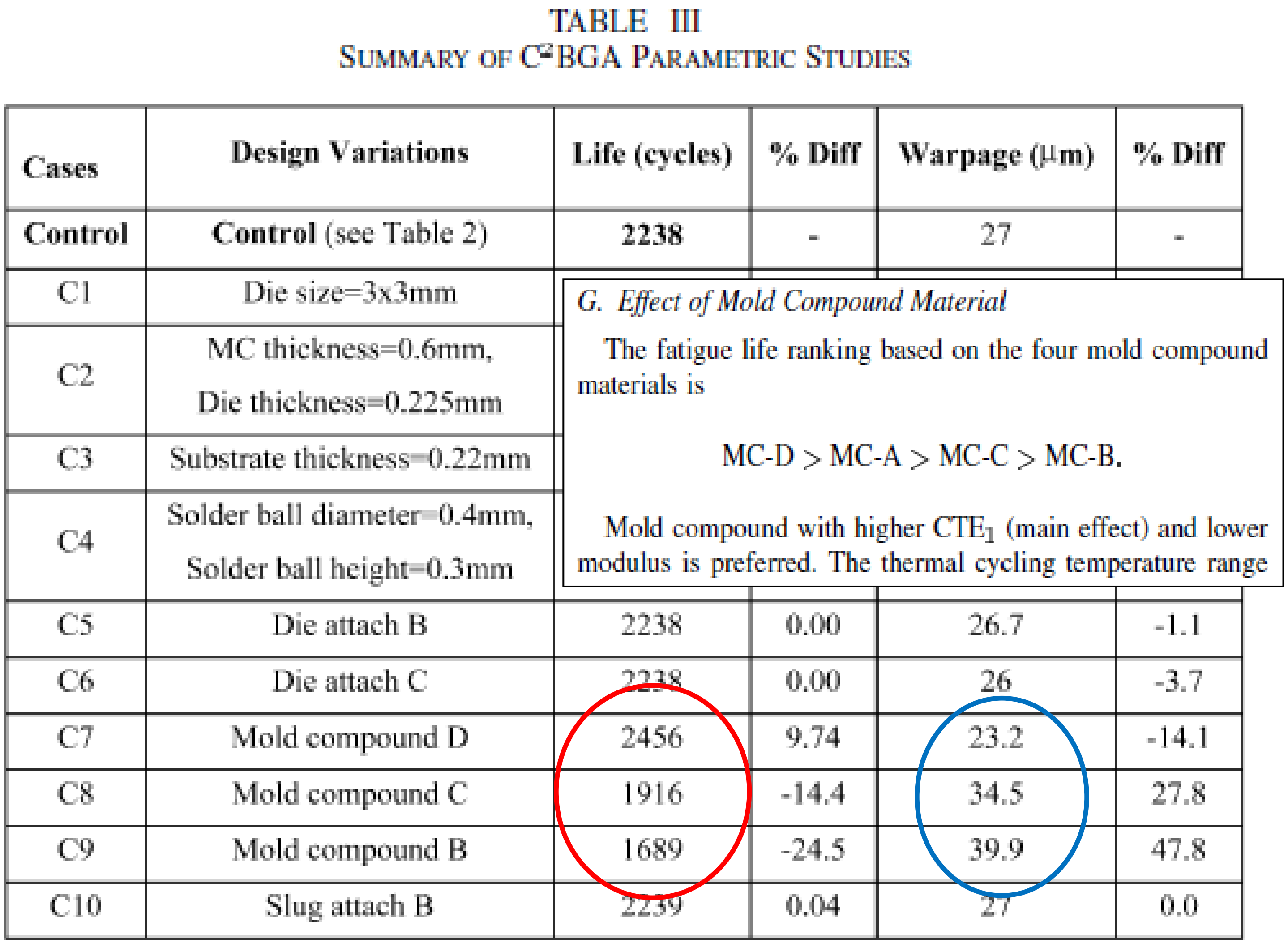


TABLE III
SUMMARY OF C²BGA PARAMETRIC STUDIES

Cases	Design Variations	Life (cycles)	% Diff	Warpage (μm)	% Diff
Control	**Control** (see Table 2)	**2238**	-	27	-
C1	Die size=3x3mm				
C2	MC thickness=0.6mm, Die thickness=0.225mm				
C3	Substrate thickness=0.22mm				
C4	Solder ball diameter=0.4mm, Solder ball height=0.3mm				
C5	Die attach B	2238	0.00	26.7	-1.1
C6	Die attach C	2238	0.00	26	-3.7
C7	Mold compound D	2456	9.74	23.2	-14.1
C8	Mold compound C	1916	-14.4	34.5	27.8
C9	Mold compound B	1689	-24.5	39.9	47.8
C10	Slug attach B	2239	0.04	27	0.0

G. Effect of Mold Compound Material

The fatigue life ranking based on the four mold compound materials is

MC-D > MC-A > MC-C > MC-B.

Mold compound with higher CTE$_1$ (main effect) and lower modulus is preferred. The thermal cycling temperature range

Lifetime

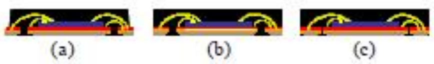
Warpage

2.3. LITERATURE: EXPERIMENTAL QFN

BOARD LEVEL ASSEMBLY AND RELIABILITY CONSIDERATIONS
FOR QFN TYPE PACKAGES

QFN7x7:
-55/125C
PCB: 1.6mm

Ahmer Syed and WonJoon Kang
Amkor Technology, Inc.
1900 S. Price Road
Chandler, Arizona


(a) (b) (c)

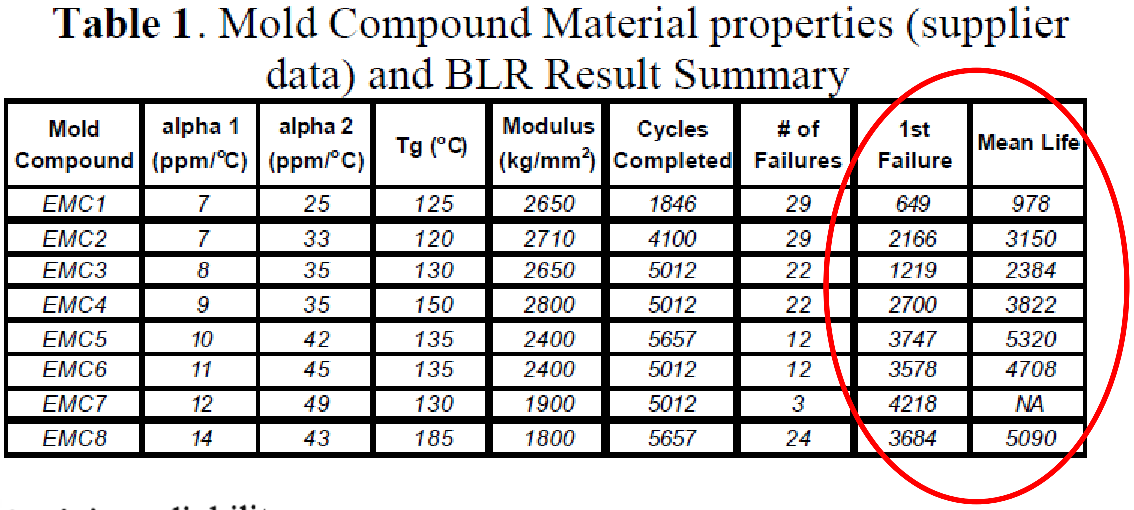
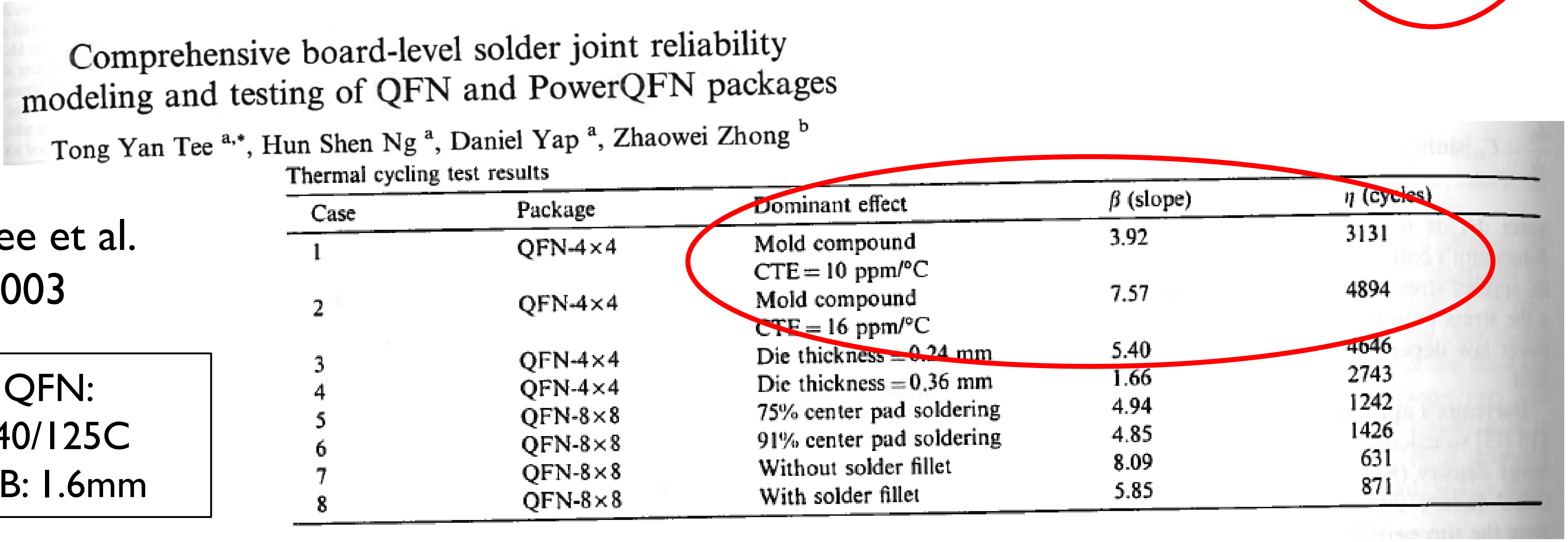


Table 1. Mold Compound Material properties (supplier data) and BLR Result Summary

Mold Compound	alpha 1 (ppm/°C)	alpha 2 (ppm/°C)	Tg (°C)	Modulus (kg/mm^2)	Cycles Completed	# of Failures	1st Failure	Mean Life
EMC1	*7*	*25*	*125*	*2650*	*1846*	*29*	*649*	*978*
EMC2	*7*	*33*	*120*	*2710*	*4100*	*29*	*2166*	*3150*
EMC3	*8*	*35*	*130*	*2650*	*5012*	*22*	*1219*	*2384*
EMC4	*9*	*35*	*150*	*2800*	*5012*	*22*	*2700*	*3822*
EMC5	*10*	*42*	*135*	*2400*	*5657*	*12*	*3747*	*5320*
EMC6	*11*	*45*	*135*	*2400*	*5012*	*12*	*3578*	*4708*
EMC7	*12*	*49*	*130*	*1900*	*5012*	*3*	*4218*	*NA*
EMC8	*14*	*43*	*185*	*1800*	*5657*	*24*	*3684*	*5090*



Comprehensive board-level solder joint reliability modeling and testing of QFN and PowerQFN packages

Tong Yan Tee [a,*], Hun Shen Ng [a], Daniel Yap [a], Zhaowei Zhong [b]

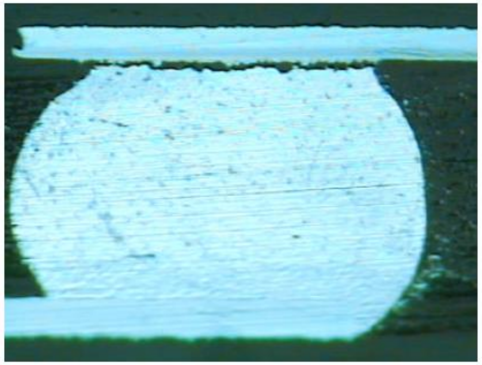
Thermal cycling test results

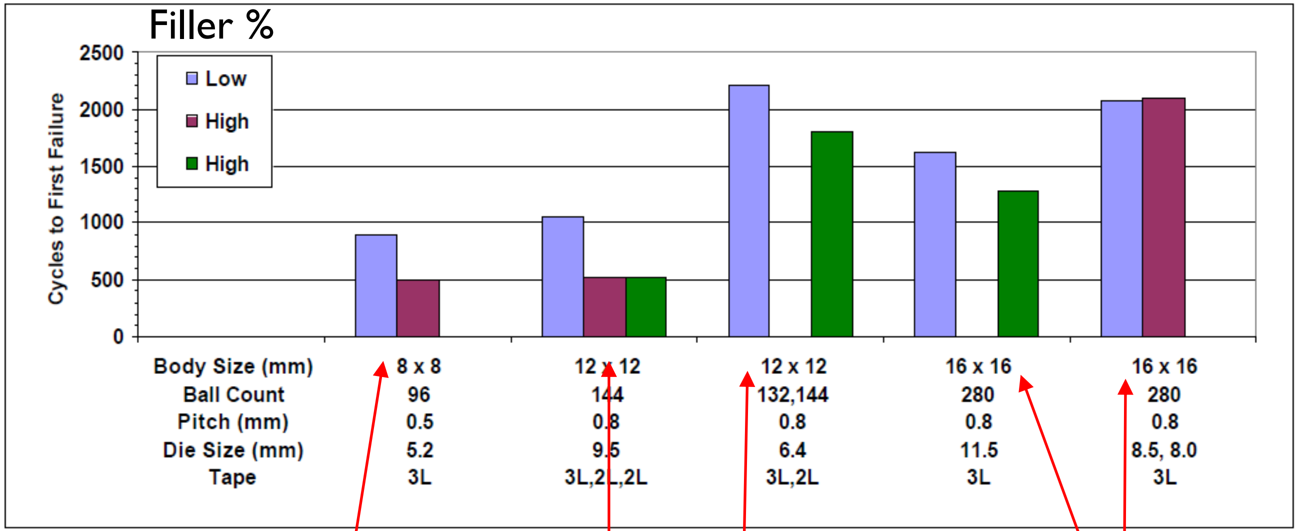
Case	Package	Dominant effect	β (slope)	η (cycles)
1	QFN-4×4	Mold compound CTE = 10 ppm/°C	3.92	3131
2	QFN-4×4	Mold compound CTE = 16 ppm/°C	7.57	4894
3	QFN-4×4	Die thickness = 0.24 mm	5.40	4646
4	QFN-4×4	Die thickness = 0.36 mm	1.66	2743
5	QFN-8×8	75% center pad soldering	4.94	1242
6	QFN-8×8	91% center pad soldering	4.85	1426
7	QFN-8×8	Without solder fillet	8.09	631
8	QFN-8×8	With solder fillet	5.85	871

T.Y. Tee et al.
2003

QFN:
-40/125C
PCB: 1.6mm

2.3. LITERATURE: EXPERIMENTAL BGA





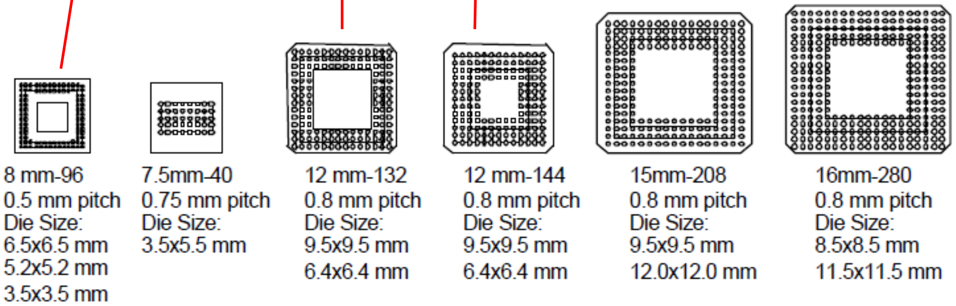
Body Size (mm)	8 x 8	12 x 12	12 x 12	16 x 16	16 x 16
Ball Count	96	144	132,144	280	280
Pitch (mm)	0.5	0.8	0.8	0.8	0.8
Die Size (mm)	5.2	9.5	6.4	11.5	8.5, 8.0
Tape	3L	3L,2L,2L	3L,2L	3L	3L

Figure 9. Fatigue life decreases higher filler content mold compound (0.85mm thick test board, –40C ⇔ 125C, 1 cycle/hr).

SOLDER JOINT FATIGUE LIFE OF FINE PITCH BGAs - IMPACT OF DESIGN AND MATERIAL CHOICES

Robert Darveaux[1], Jim Heckman[1], Ahmer Syed[1], and Andrew Mawer[2]

(1999)



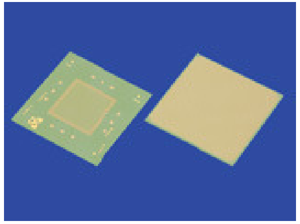
Effect of Mold Compound Filler Content

Shown in Figure 9 are several data sets comparing low and high filler content mold compounds. It is seen that the higher filler content mold compound can cut the fatigue life in half. The effect was less severe for packages with smaller relative die size or a larger ball count.

2.3. A VIEW FROM THE CERAMIC PACKAGING WORLD

KYOCERA THE NEW VALUE FRONTIER

Ceramic Packages for Large Scale Integration (LSI) Devices



Flip Chip HITCE LTCC BGA Package

Kyocera provides both ceramic and organic packages for Large Scale Integration (LSI) devices. In addition to alumina (Al2O3) ceramics, we produce aluminum nitride (AlN) with high thermal conductivity (150W/mK), as well as Low Temperature Co-Fired Ceramic (LTCC) packages with high (12.3ppm/K) and low (3.4ppm/K) coefficients of thermal expansion.

→ Material Properties

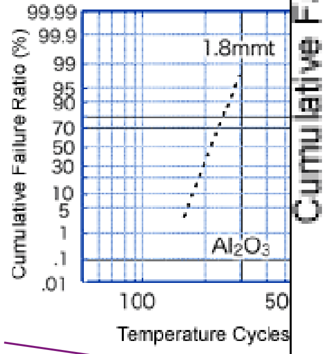
⇨ Organic Packages (KYOCERA SLC Technologies)

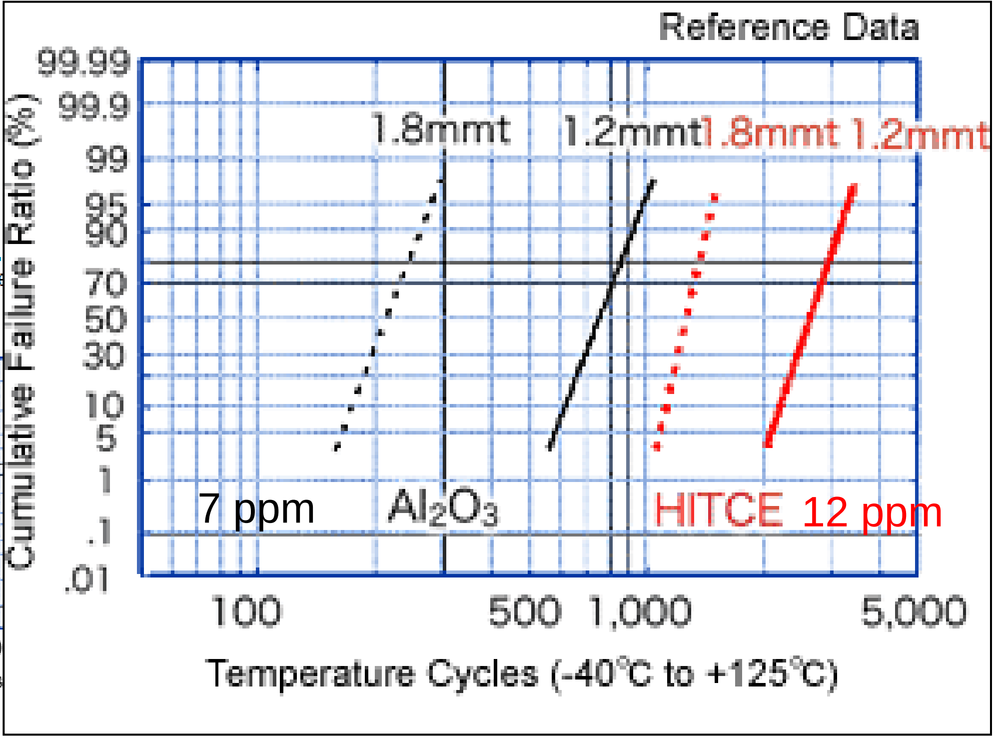
■ High Second Level Reliability

Kyocera's HITCE LTCC material offers a coefficient of thermal expansion (CTE) close boards, providing high reliability in board assembly.

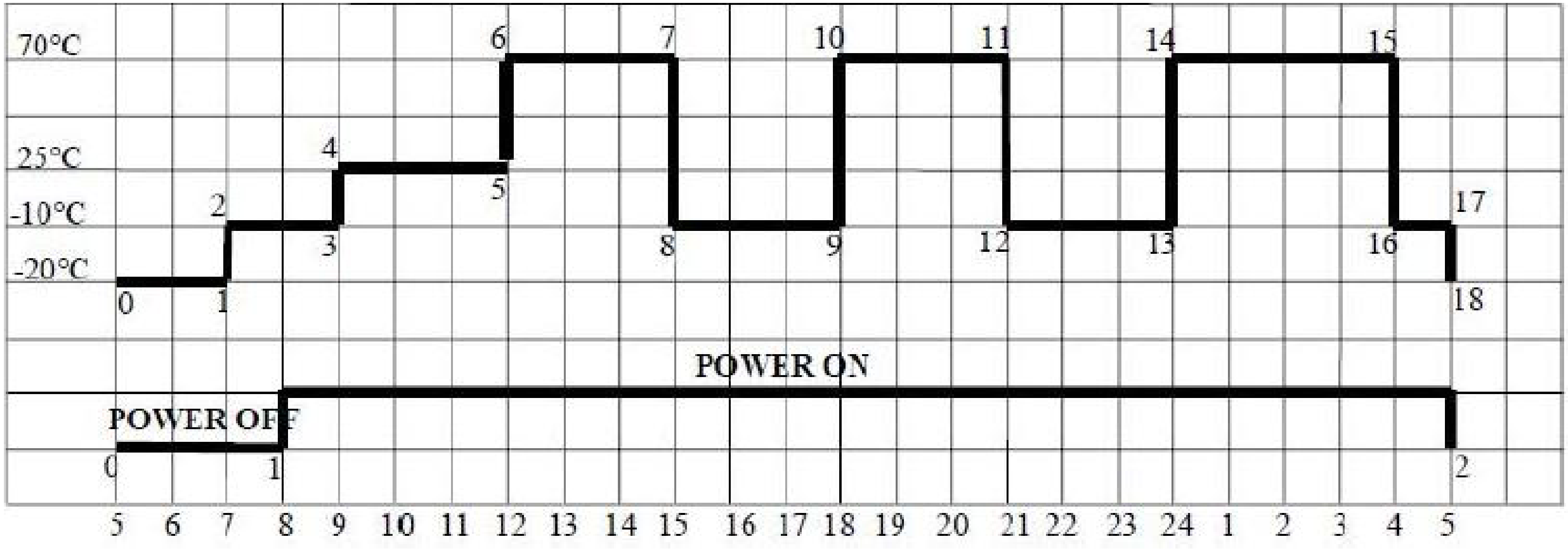
- ·CTE: 12.3ppm/K (R.T. to 400°C)
- ·Young's Modulus of Elasticity: 74GPa

Second Level Reliability Test Samples
Ceramic Package
  Configuration: BGA (1.27mm pitch)
  Materials: Alumina (Al2O3), HITCE LTCC
  Outer Dimension: 33mmSQ
  Thickness: 1.2mm and 1.8mm
Motherboard
  Material: FR-4 (CTE:15ppm/K)
  Outer Dimension: 65mmSQ
  Thickness: 1.6mm





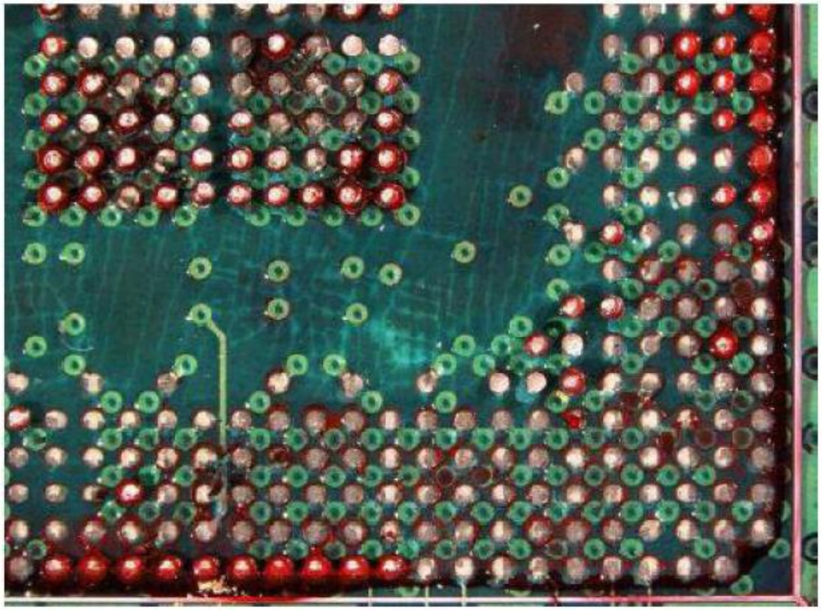
2.4. FAILURE RESULTS (I)

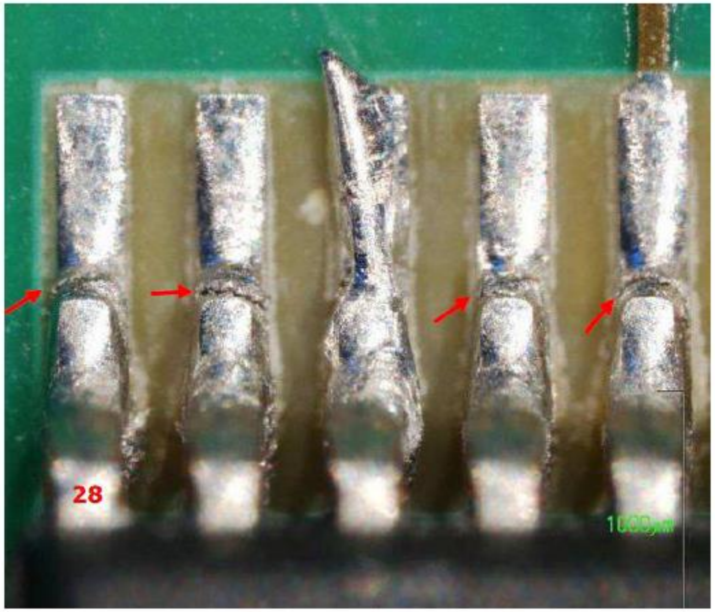


Two reoccurring issues have been identified.

Time to FAILURE (hours)			
Product	**A**	**B**	**C**
BGA solder crack	2789 (=349c)	3587 (=448c)	5523 (=690c)
TSOP solder crack	4364 (=546c)	No issues yet, however starting cracks are visible!	No issues yet, however starting cracks are visible!

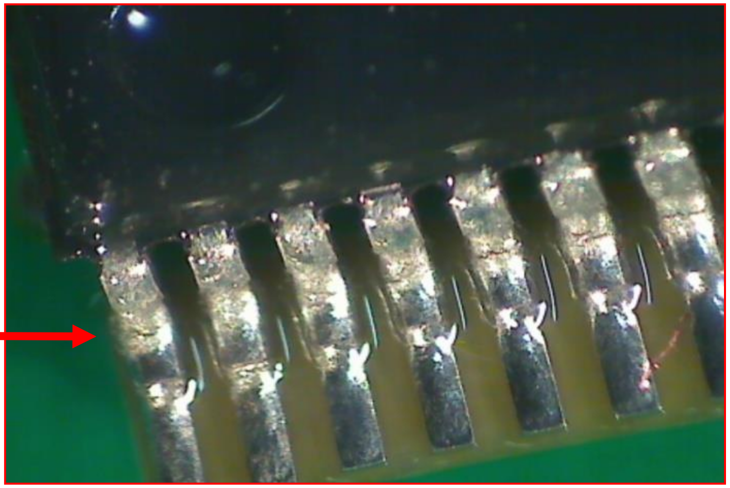
2.4. FAILURE RESULTS (2)





Solder joint failure:
BGA and TSOP II

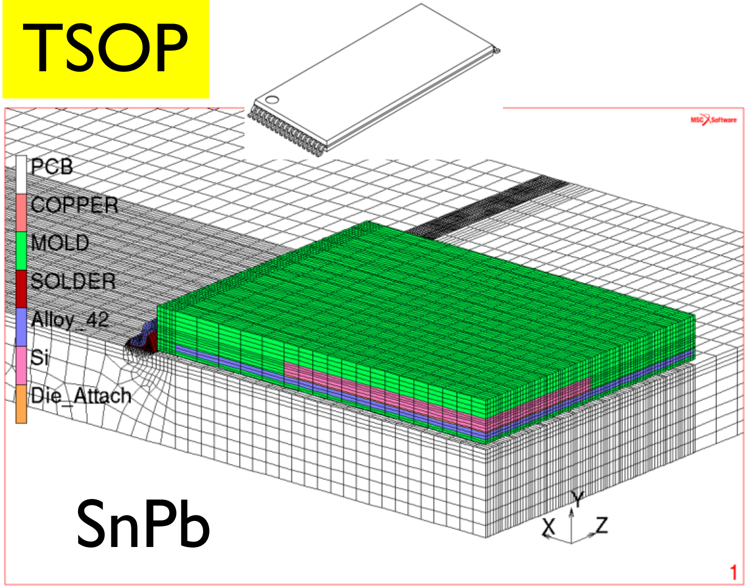
Lead failure!
TSOP I – Cu leadframe



3. FE STUDIES

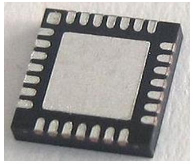
B. Vandevelde, M. Lofrano,
G. Willems:
Green Mold Compounds:
Impact on Second Level
Interconnect Reliability
EPTC, Singapore, 12/2011

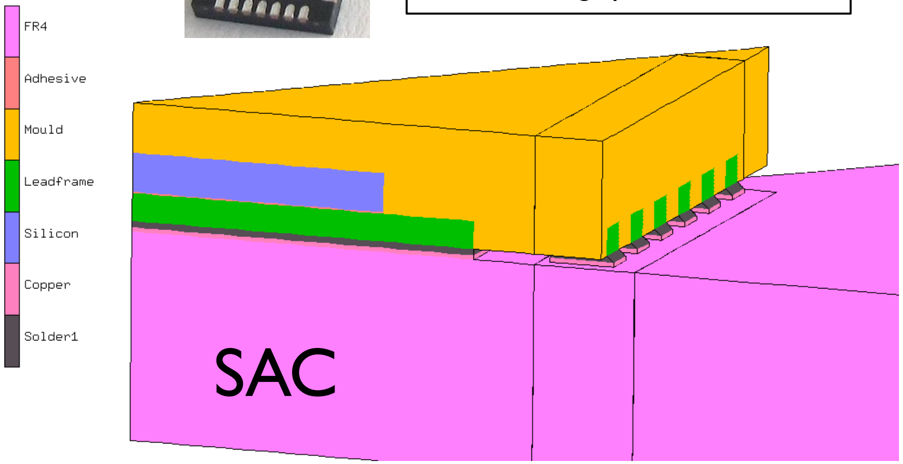
TSOP



SnPb

QFN

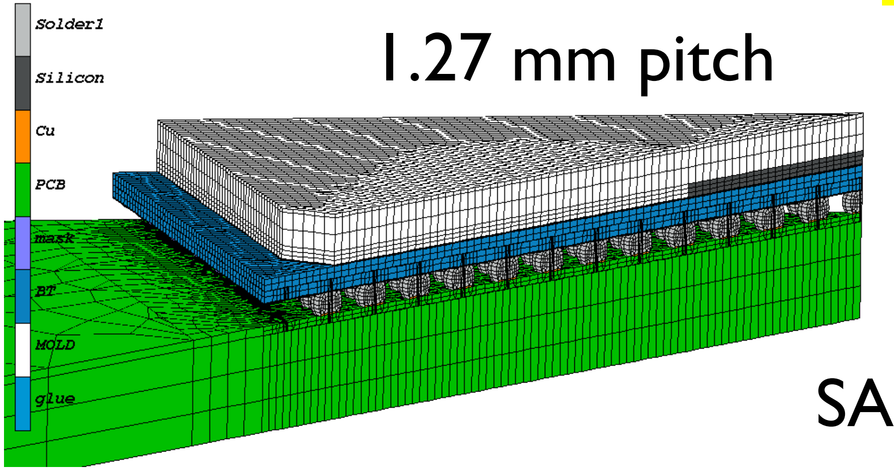




SAC

PBGA

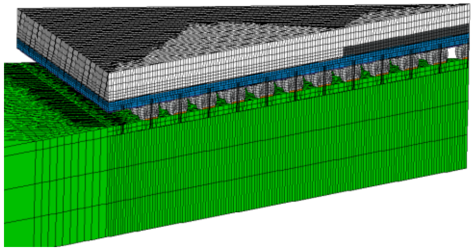
1.27 mm pitch



SAC

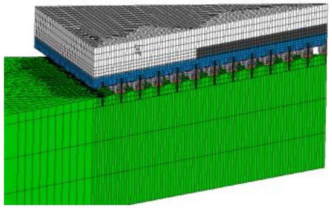
FBGA

0.8 mm pitch

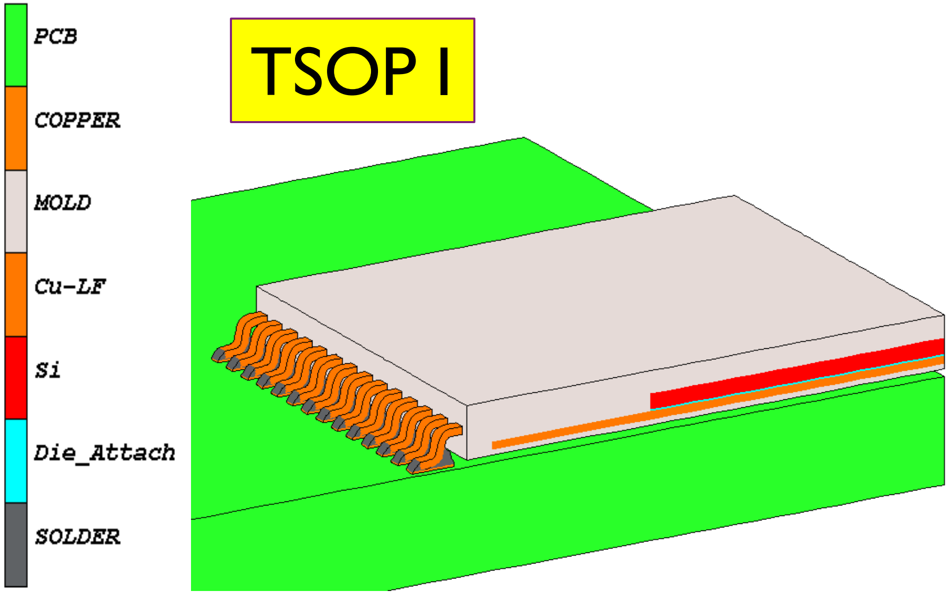


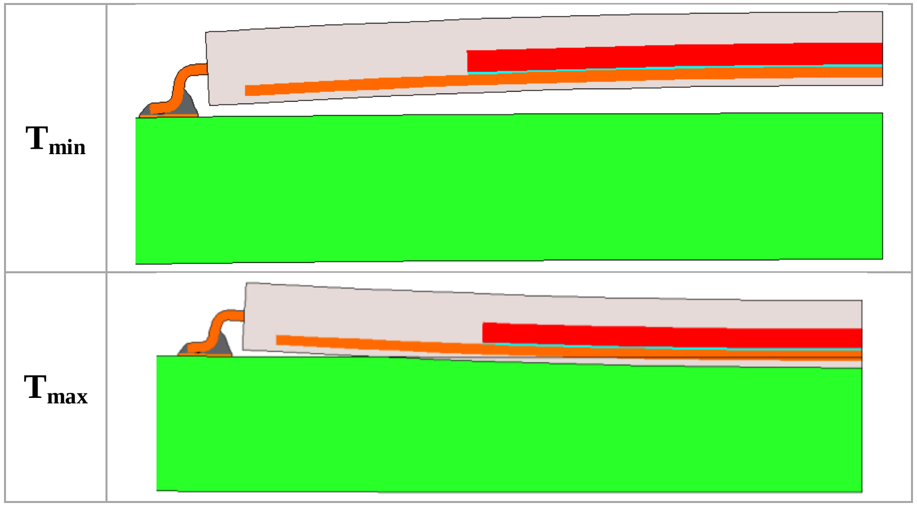
C2BGA

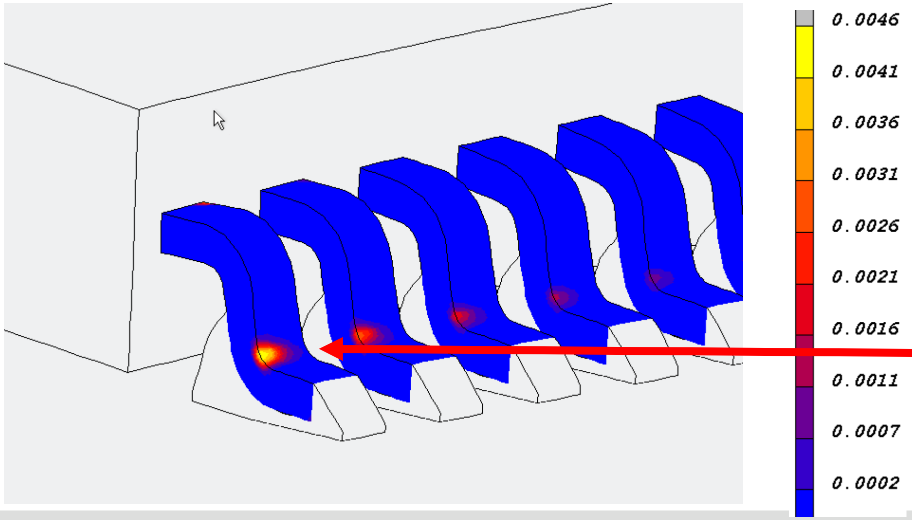
0.5 mm pitch



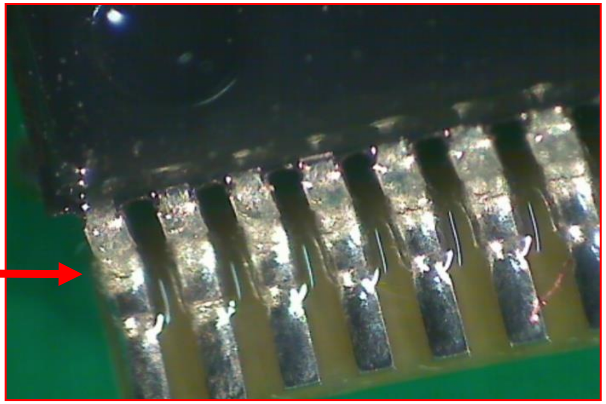
3. TSOPI WITH GMC





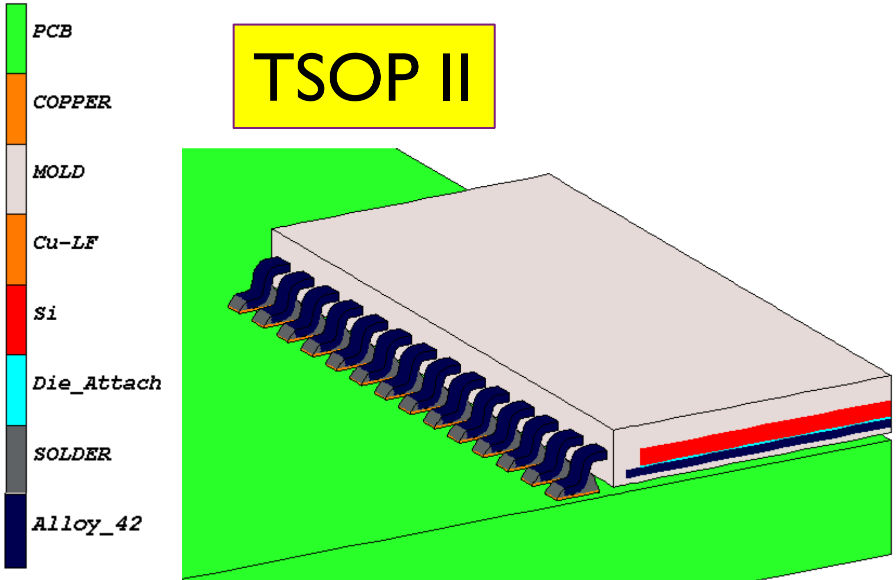


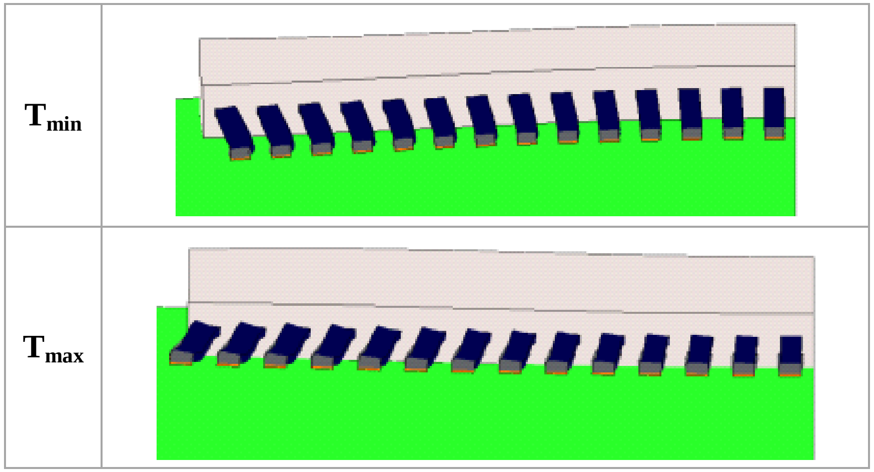
Plastic deformation in Cu leads

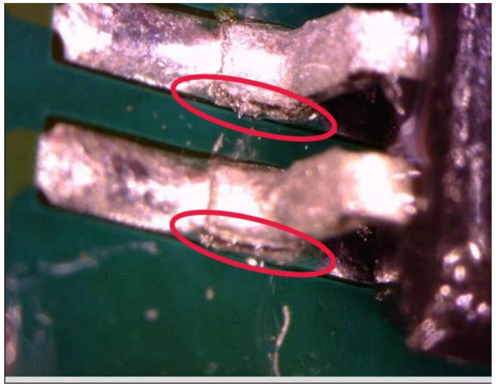


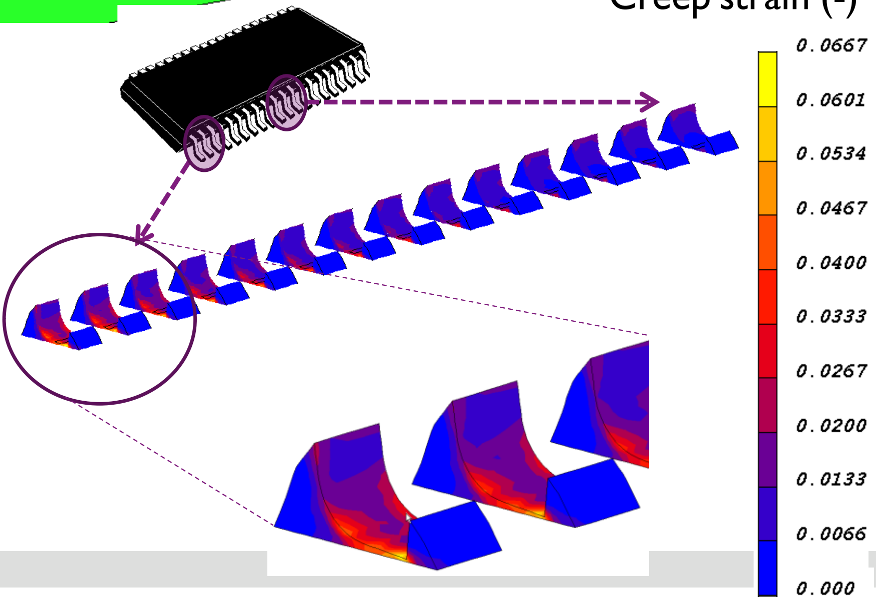
3. TSOPII WITH GMC

TSOP II

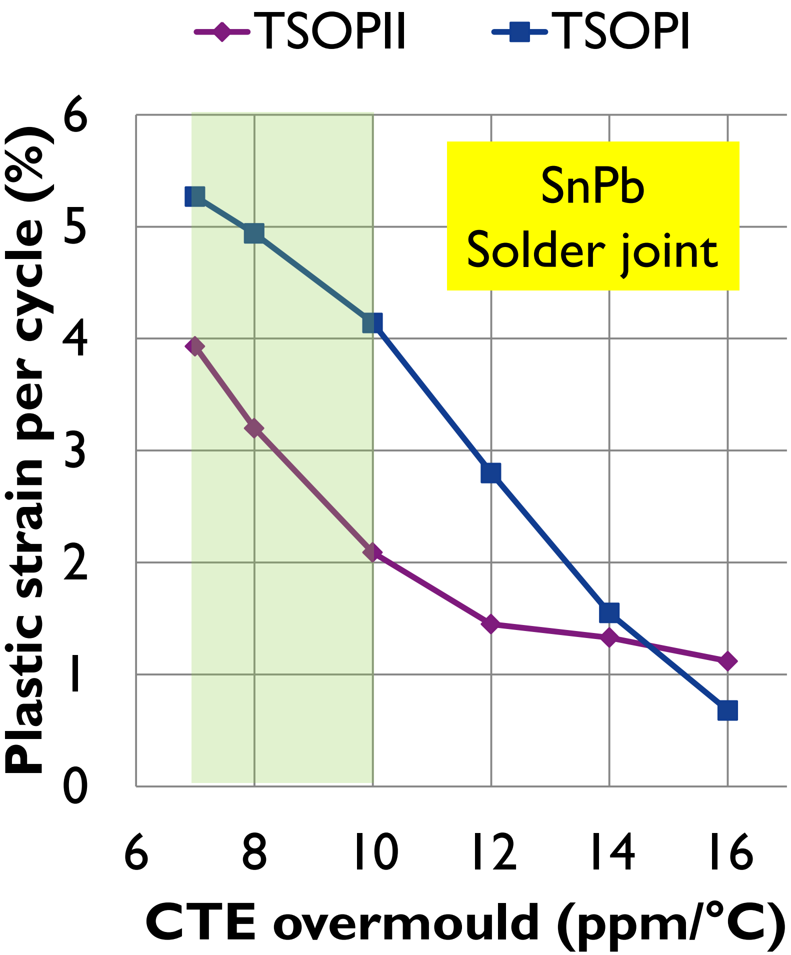


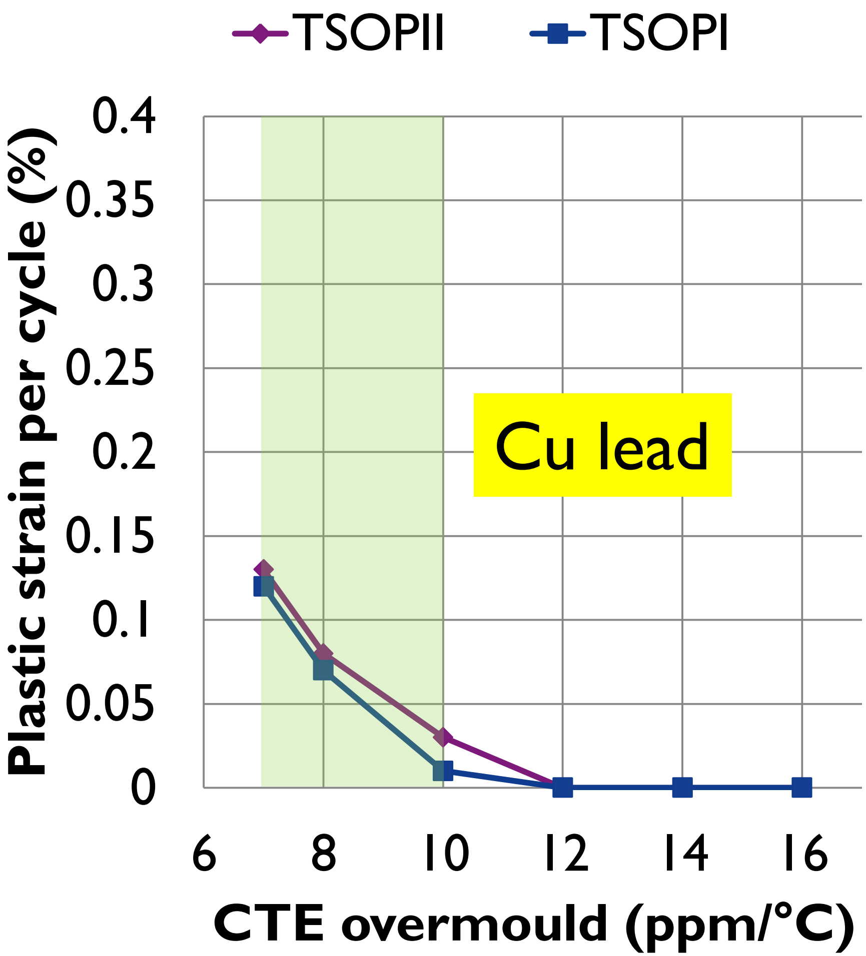




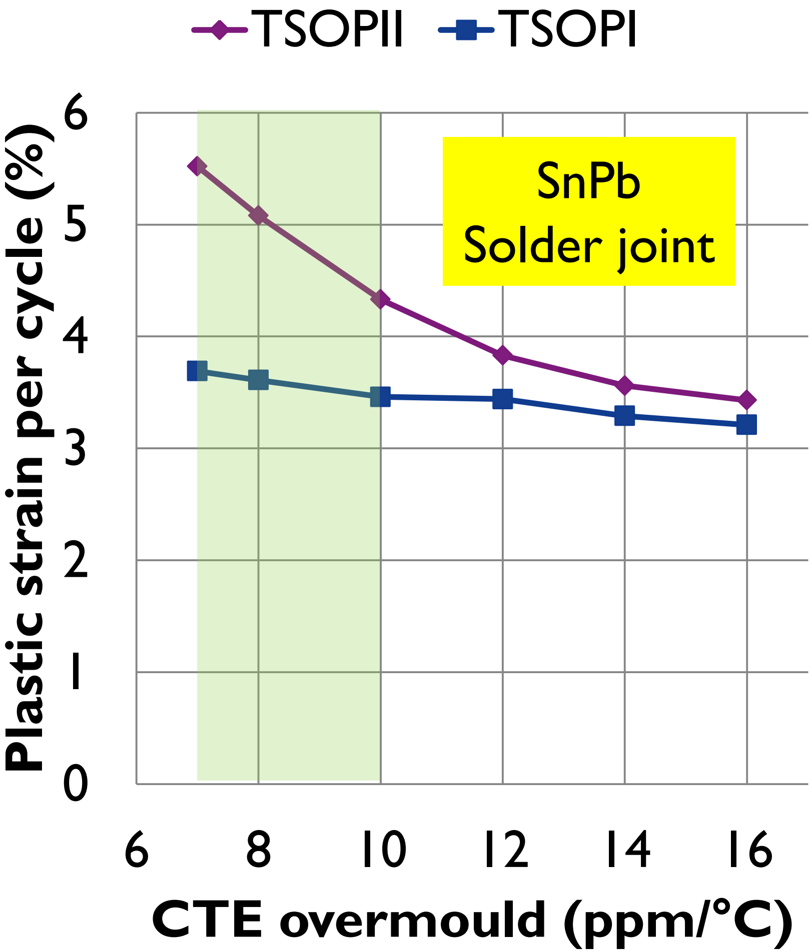


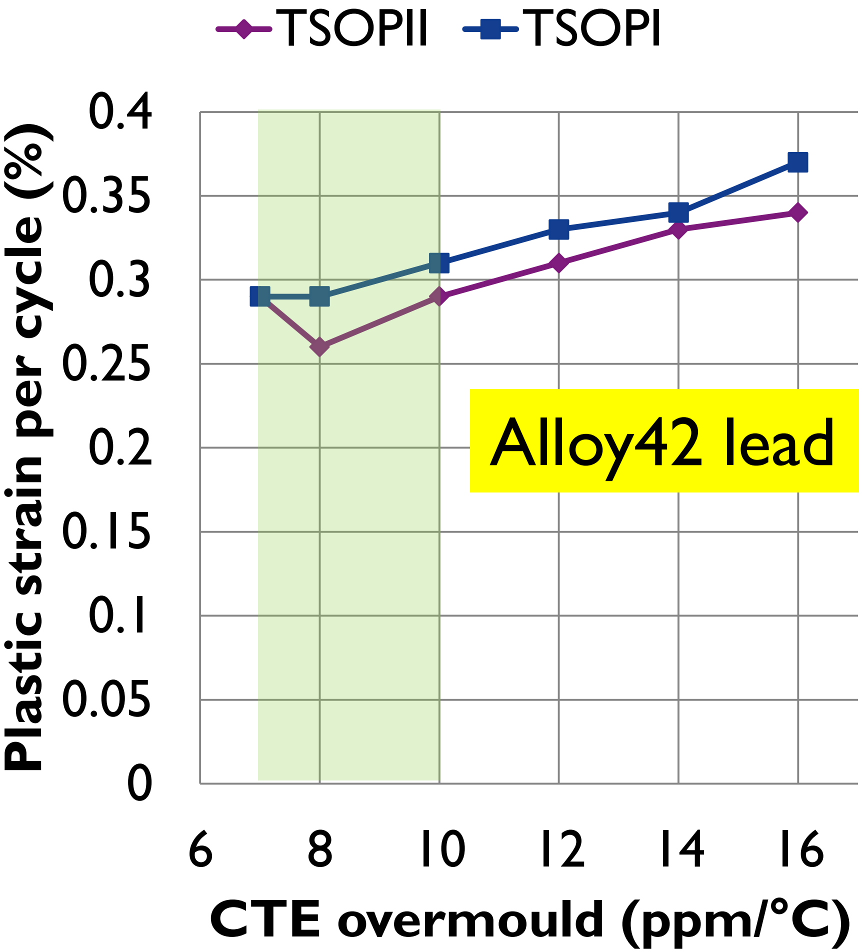
3. TSOP PACKAGES – COPPER LEADFRAME


SnPb
Solder joint

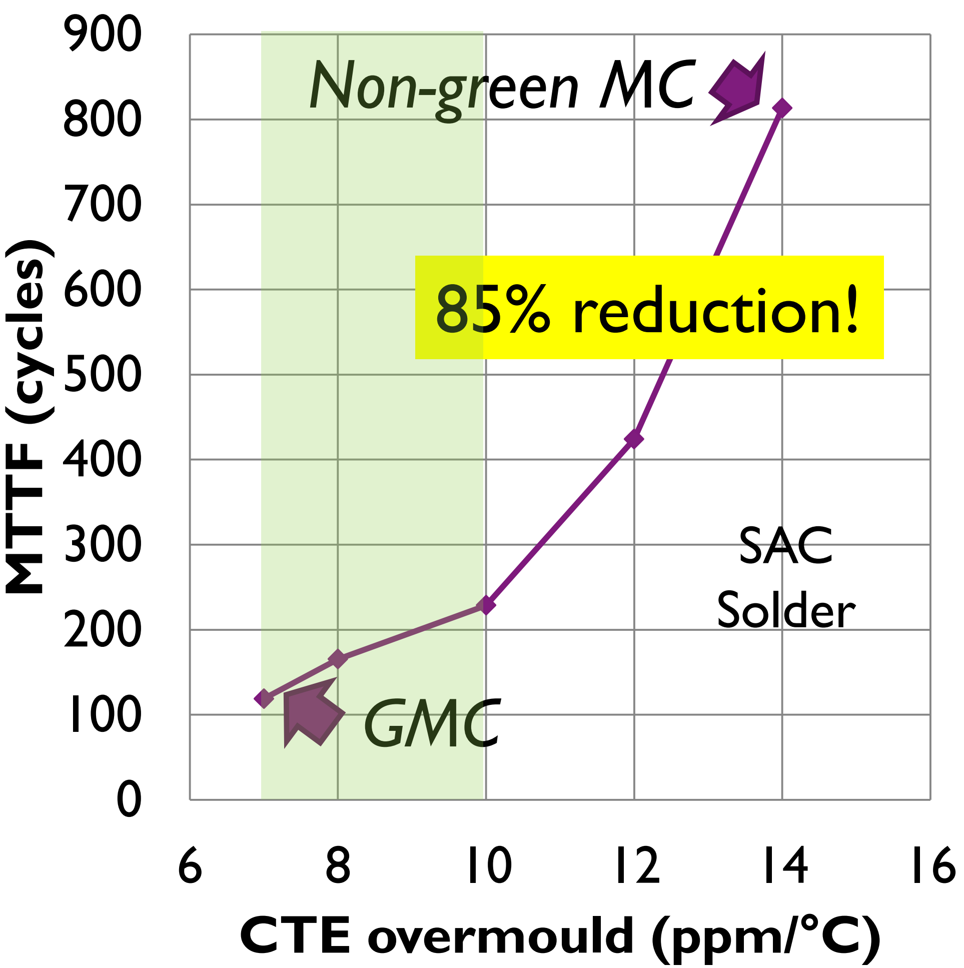

Cu lead

3. TSOP PACKAGES – ALLOY42 LEADFRAME





3. QFN 7MM X 7MM



Literature data shows 81% reduction

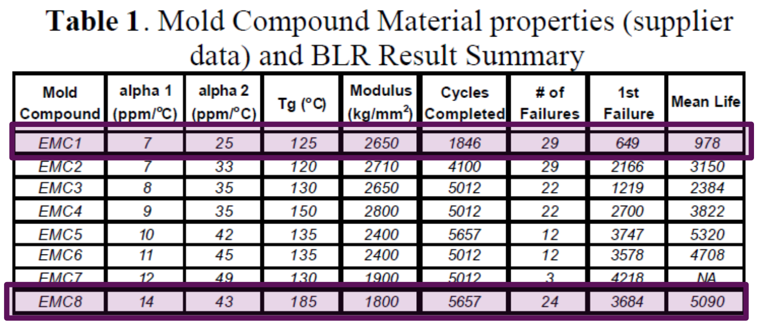


Table 1. Mold Compound Material properties (supplier data) and BLR Result Summary

Mold Compound	alpha 1 (ppm/°C)	alpha 2 (ppm/°C)	Tg (°C)	Modulus (kg/mm^2)	Cycles Completed	# of Failures	1st Failure	Mean Life
EMC1	7	25	125	2650	1846	29	649	978
EMC2	7	33	120	2710	4100	29	2166	3150
EMC3	8	35	130	2650	5012	22	1219	2384
EMC4	9	35	150	2800	5012	22	2700	3822
EMC5	10	42	135	2400	5657	12	3747	5320
EMC6	11	45	135	2400	5012	12	3578	4708
EMC7	12	49	130	1900	5012	3	4218	NA
EMC8	14	43	185	1800	5657	24	3684	5090

BOARD LEVEL ASSEMBLY AND RELIABILITY CONSIDERATIONS FOR QFN TYPE PACKAGES

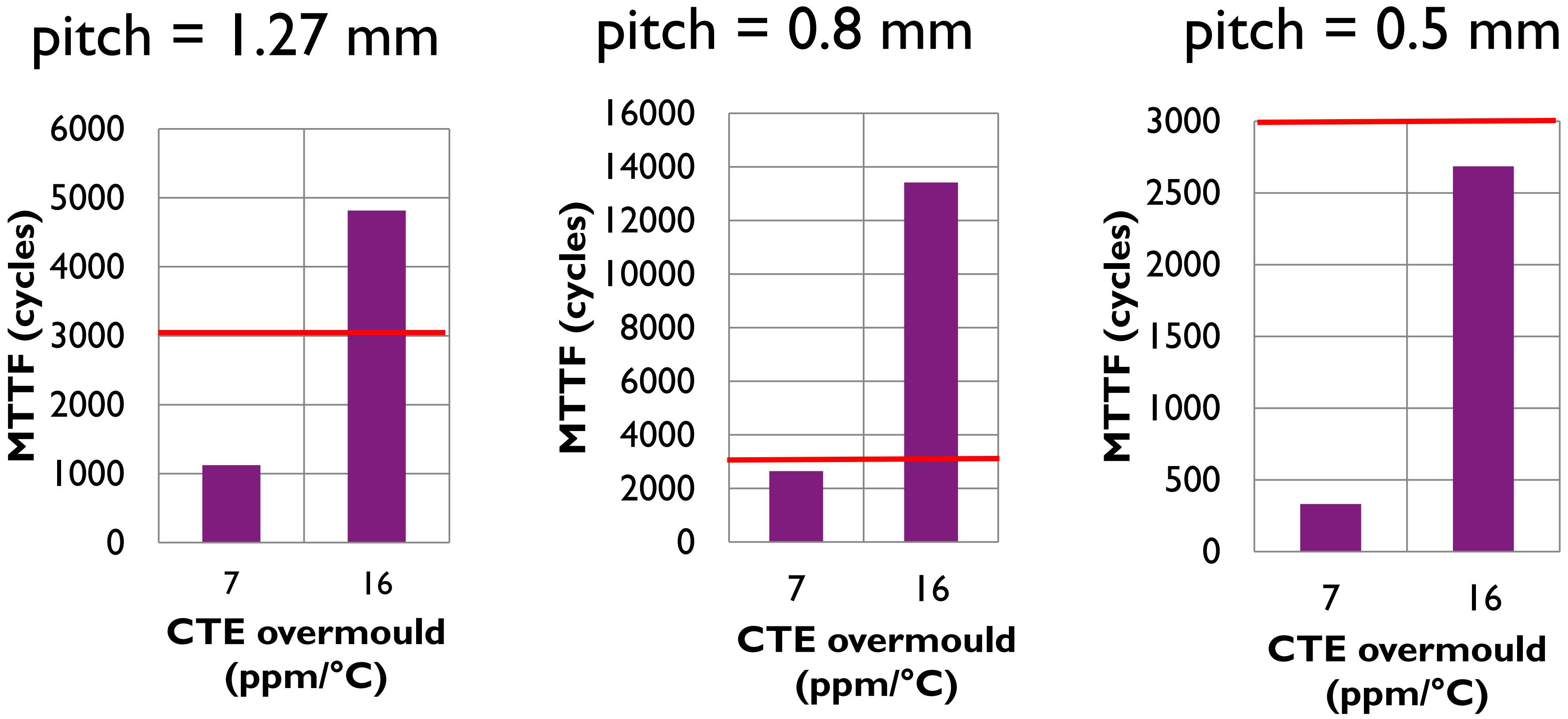
QFN7x7:
-55/125C
PCB: 1.6mm

Ahmer Syed and WonJoon Kang
Amkor Technology, Inc.
1900 S. Price Road
Chandler, Arizona

Temperature cycles: -40 to 125˚C; 2.4 mm PCB

3. PBGA (~ 27X27 FULL AREA ARRAY)

SAC
Solder



75% reduction!

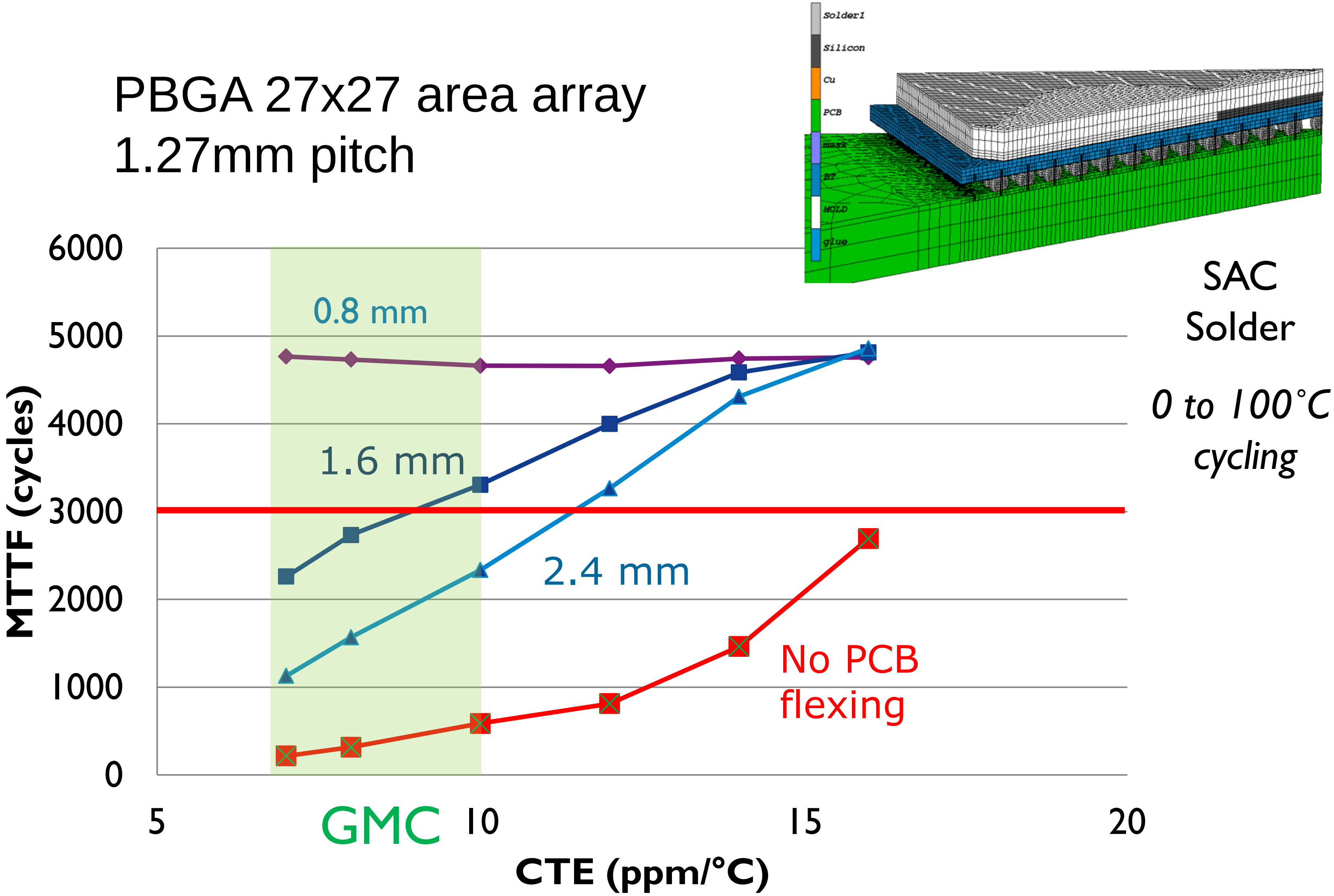
80% reduction!

85% reduction!

0 to 100˚C cycling; 2.4 mm PCB thickness

3. PBGA: IMPACT OF BOARD THICKNESS

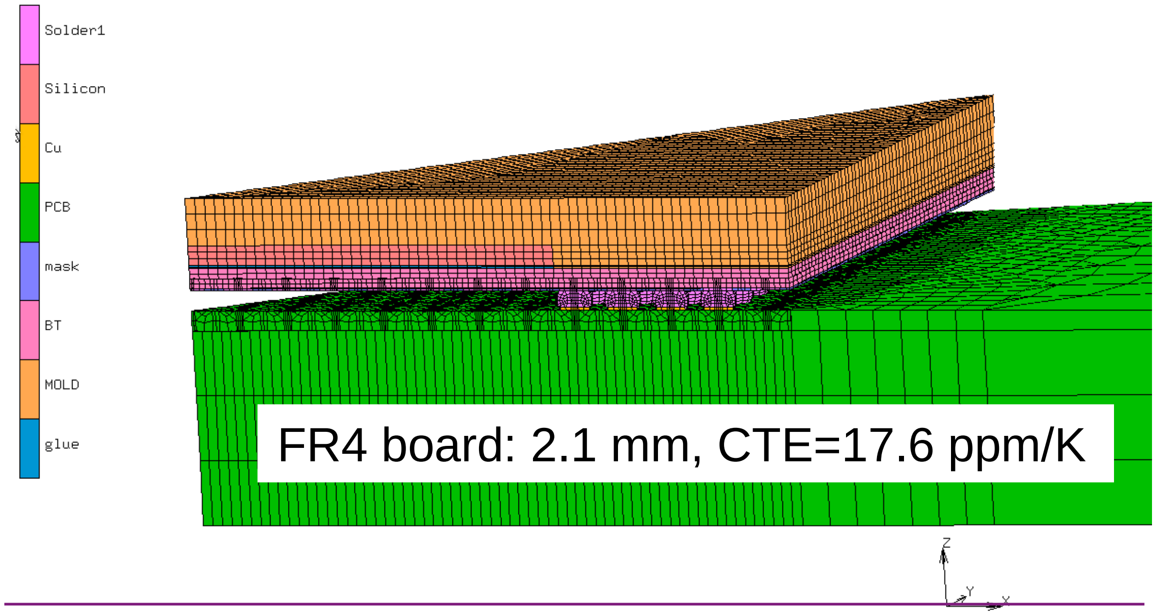
PBGA 27x27 area array
1.27mm pitch



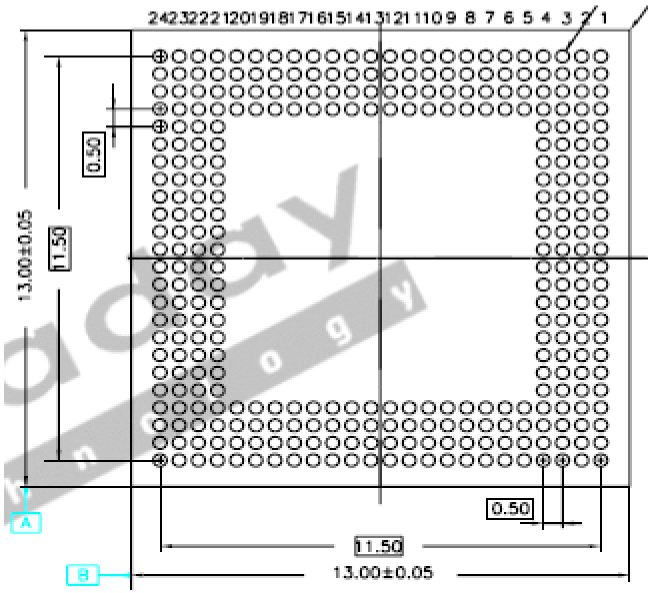
SAC
Solder

0 to 100°C cycling

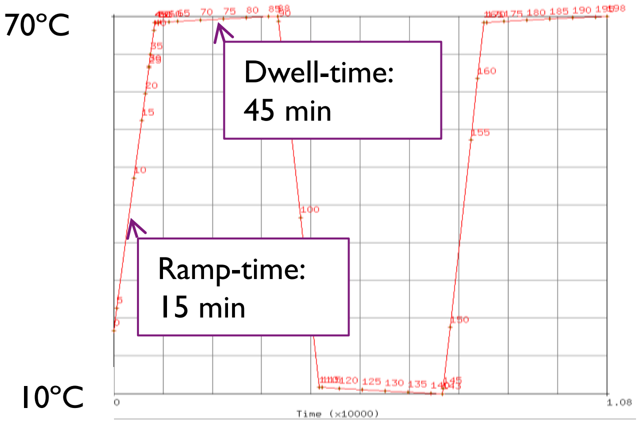
3. 0.5MM PARTIALLY POPULATED PBGA



FR4 board: 2.1 mm, CTE=17.6 ppm/K



Ball size	0.3 mm
Ball pitch	0.5 mm
Size	13x13 mm^2
Array size	24x24 (4 rows – 320 balls)
Overmould CTE	8 ppm/°C

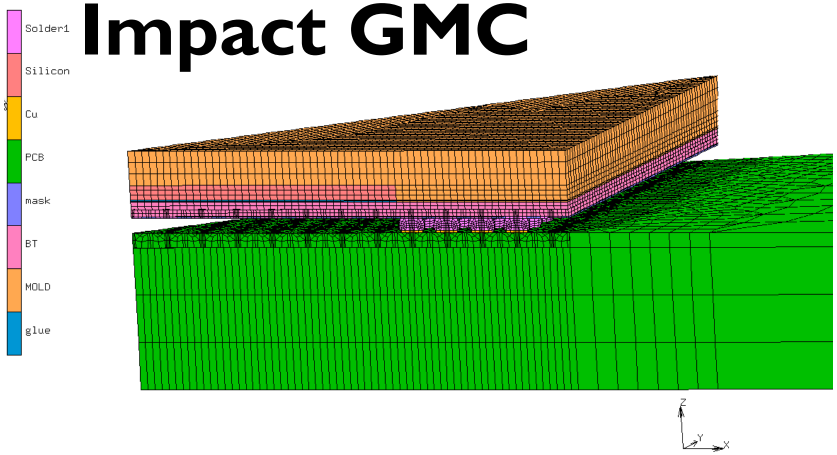


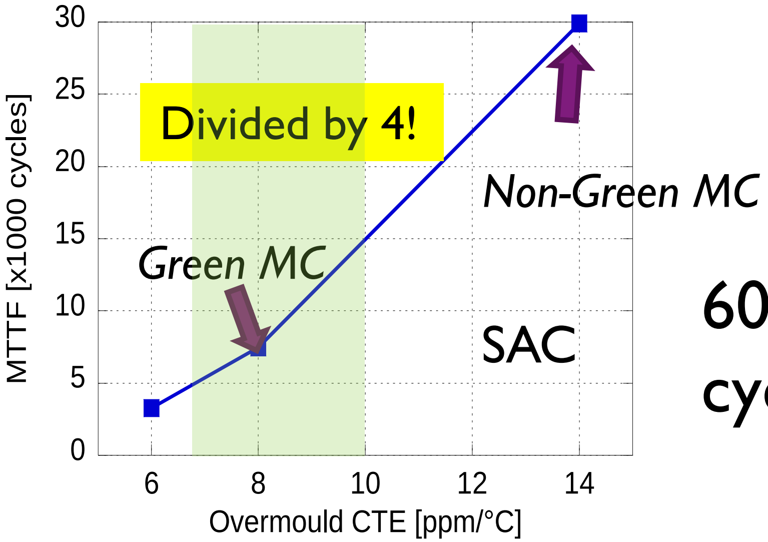
Dwell-time: 45 min

Ramp-time: 15 min

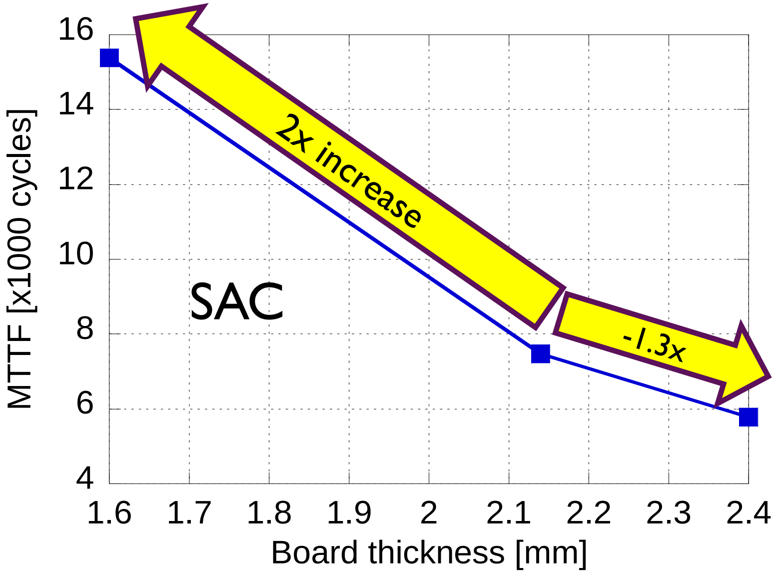
3. 0.5MM PARTIALLY POPULATED PBGA

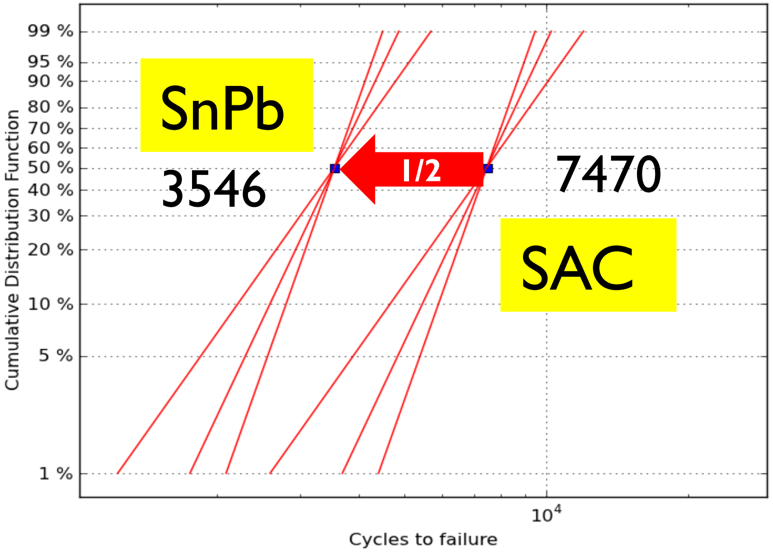
Impact GMC





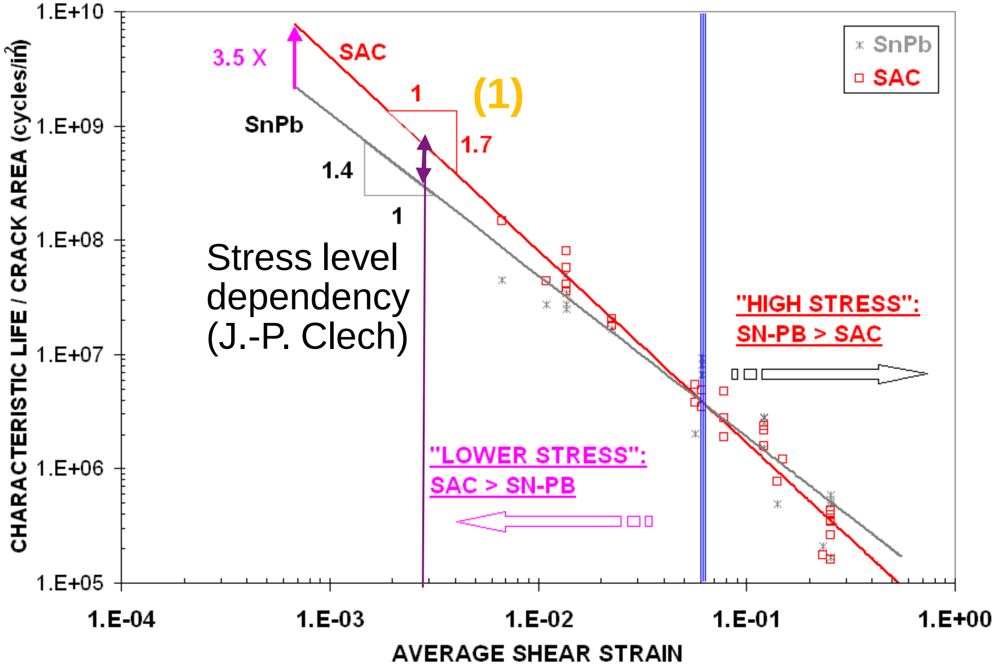
60°C cycle





3. SNPB VERSUS SAC SOLDER

Why is SnPb version worse than SAC?

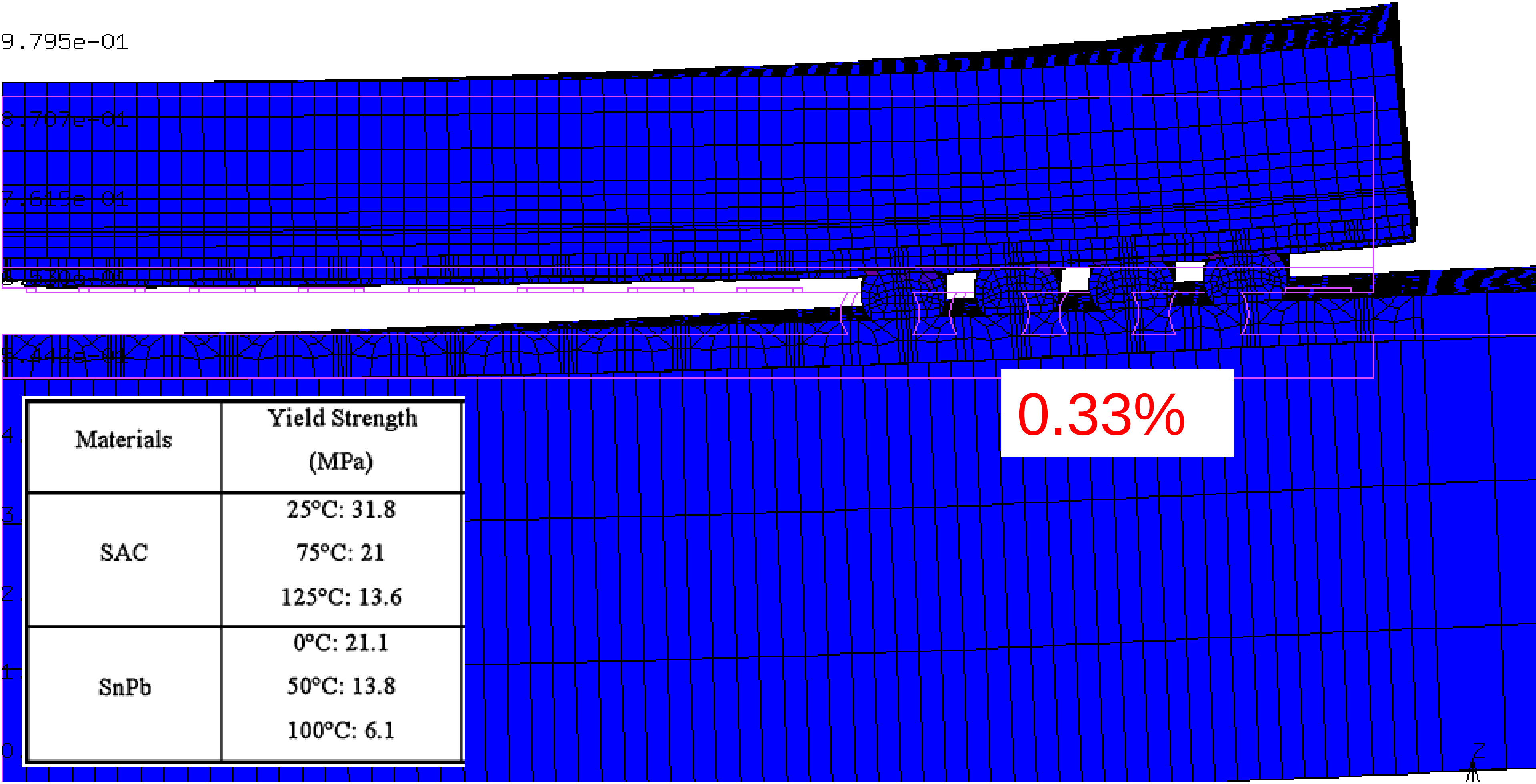


1. Under low stress conditions lifetime of SAC is higher than that of SnPb.

2. Strain itself depends on the solder alloy.

SAC is stronger than SnPb. Therefore SAC solder joints of flexible components on flexible PCBs will deform less than SnPb solder joints under the same conditions of thermal cycling.

3. 0.5MM PBGA: SAC SOLDER BALLS

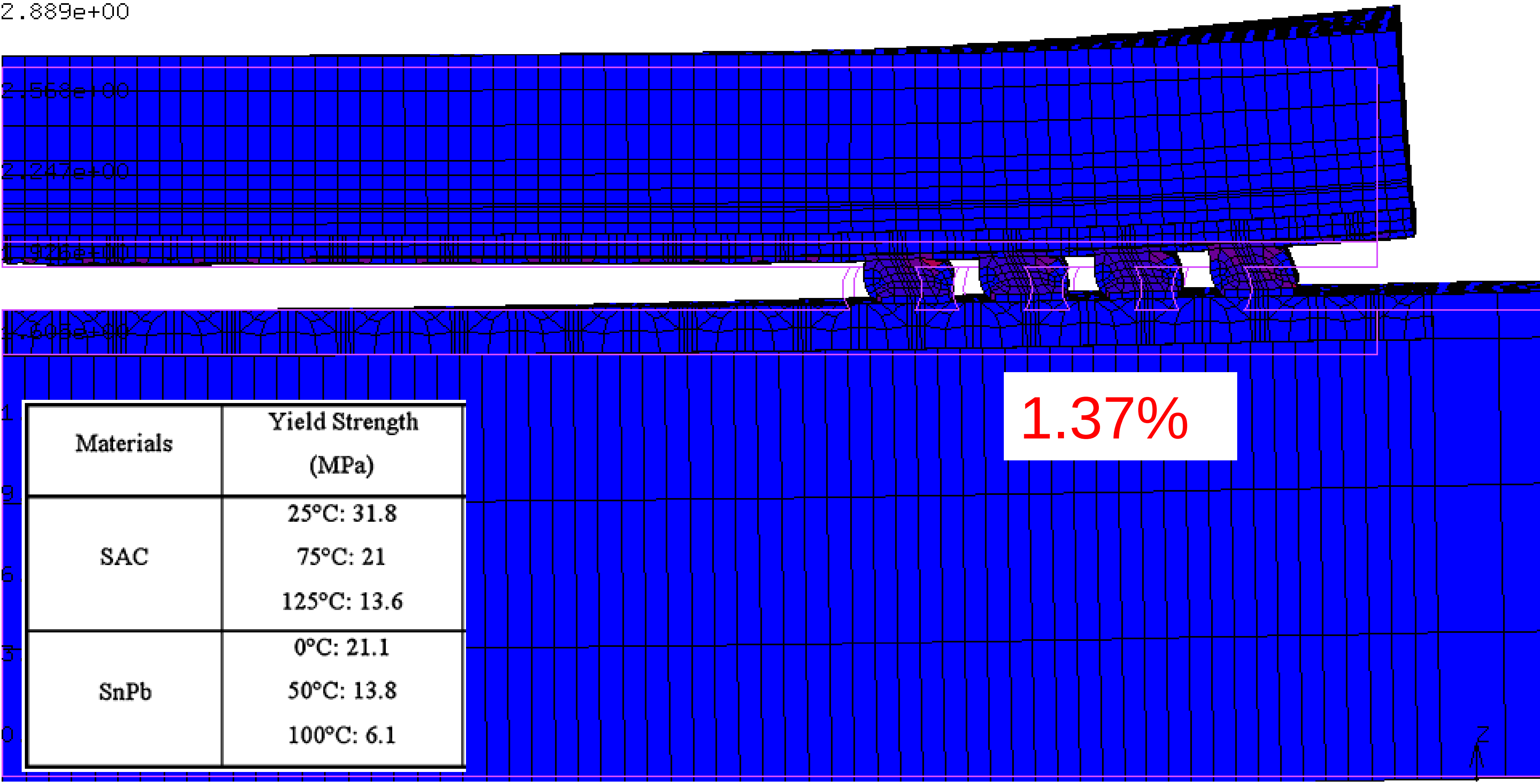


Materials	Yield Strength (MPa)
SAC	25°C: 31.8 75°C: 21 125°C: 13.6
SnPb	0°C: 21.1 50°C: 13.8 100°C: 6.1

0.33%

Stronger connections: more bending of both board and package.
Less strain/deformation of solder balls

3. 0.5MM PBGA: SNPB SOLDER BALLS



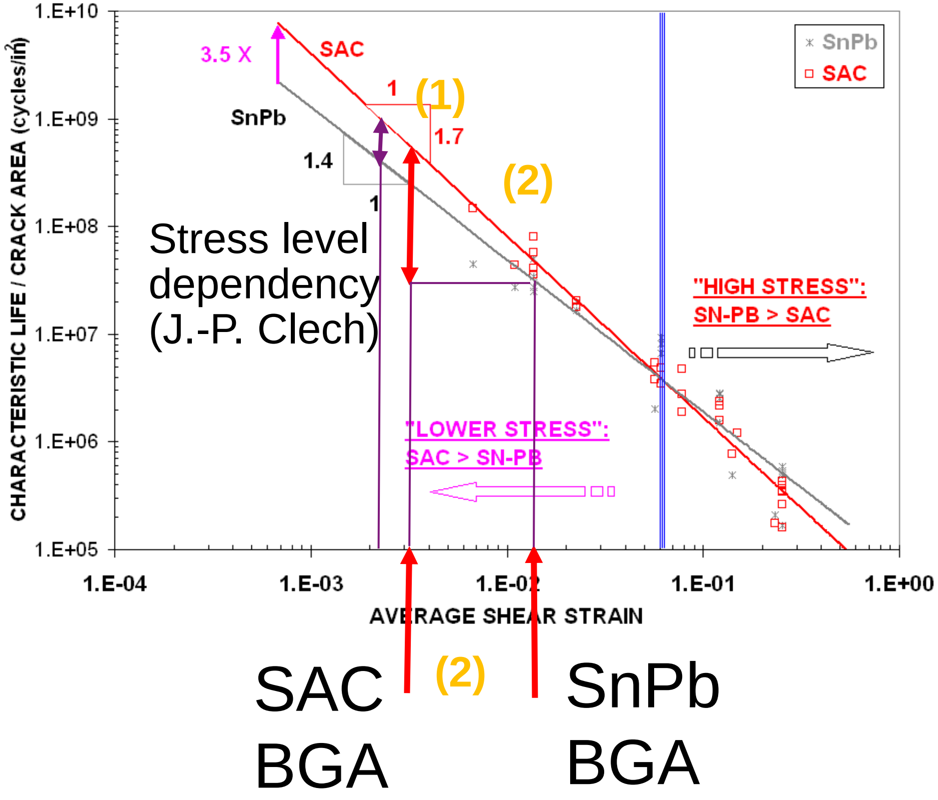
Materials	Yield Strength (MPa)
SAC	25°C: 31.8 75°C: 21 125°C: 13.6
SnPb	0°C: 21.1 50°C: 13.8 100°C: 6.1

1.37%

Weaker connections: limited board bending because solder balls plastically deform (more solder joint deformation)

3. SNPB VERSUS SAC SOLDER

Why is SnPb version worse than SAC?



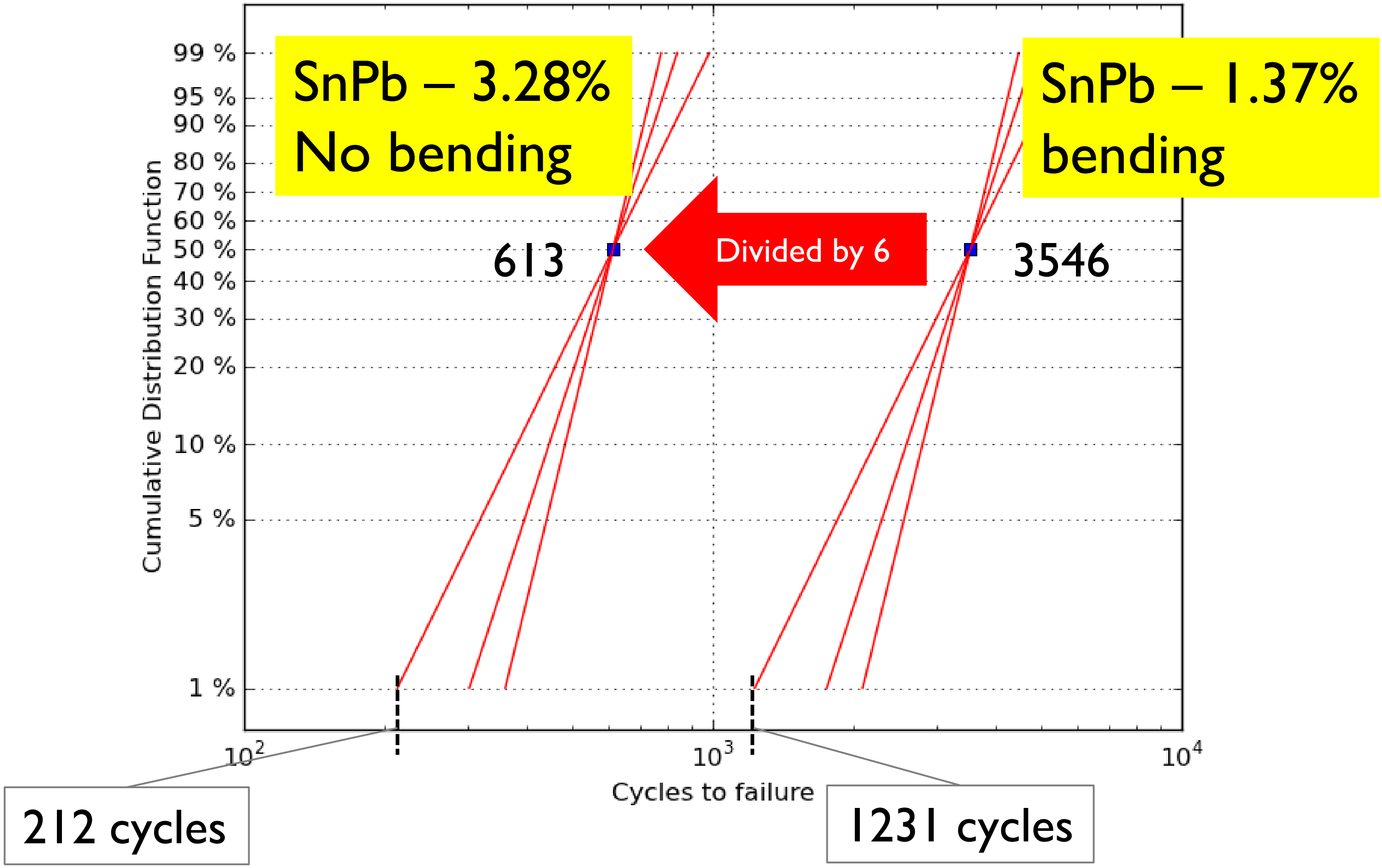
Stress level dependency (J.-P. Clech)

1. Under low stress conditions lifetime of SAC is higher than that of SnPb.
2. Strain itself depends on the solder alloy.

SAC is stronger than SnPb. Therefore SAC solder joints of flexible components on flexible PCBs will deform less than SnPb solder joints under the same conditions of thermal cycling.

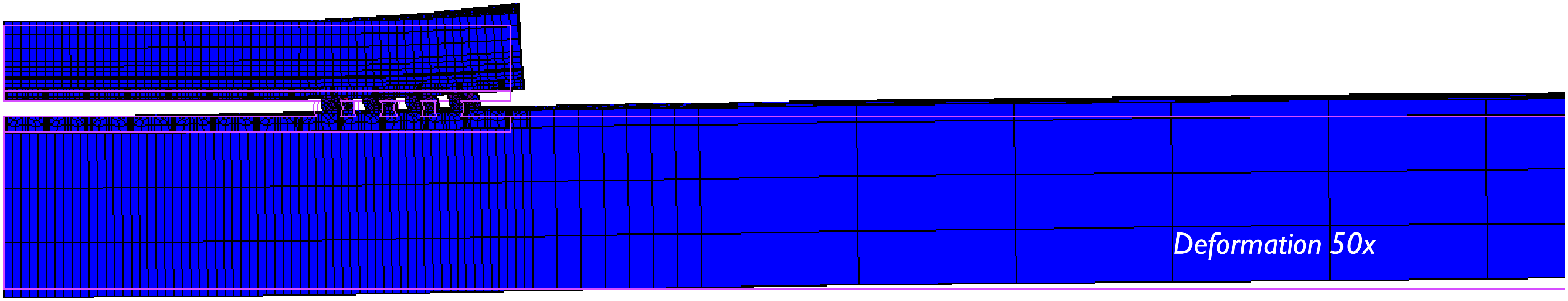
3. 0.5MM PBGA: NO PCB BENDING

No PCB bending yields even more strain



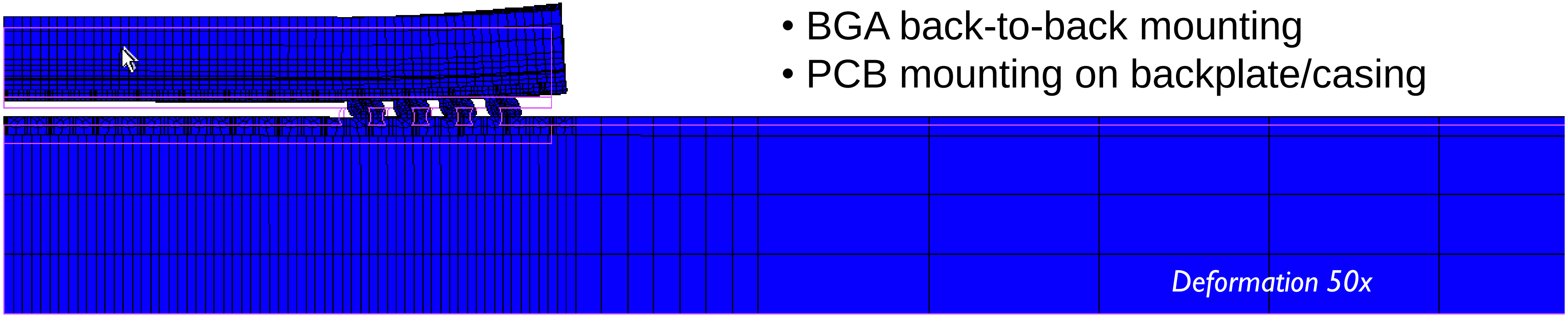
3. 0.5MM PBGA: NO PCB BENDING

Board bending allowed



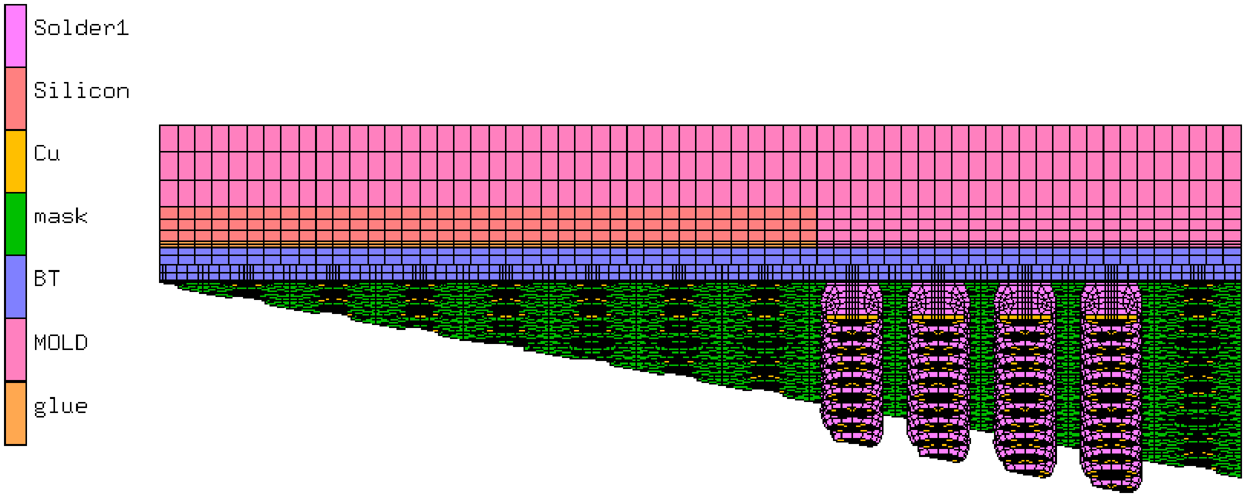
- No board bending allowed

- PCB stiffners on backside
- Components on backside
- BGA back-to-back mounting
- PCB mounting on backplate/casing

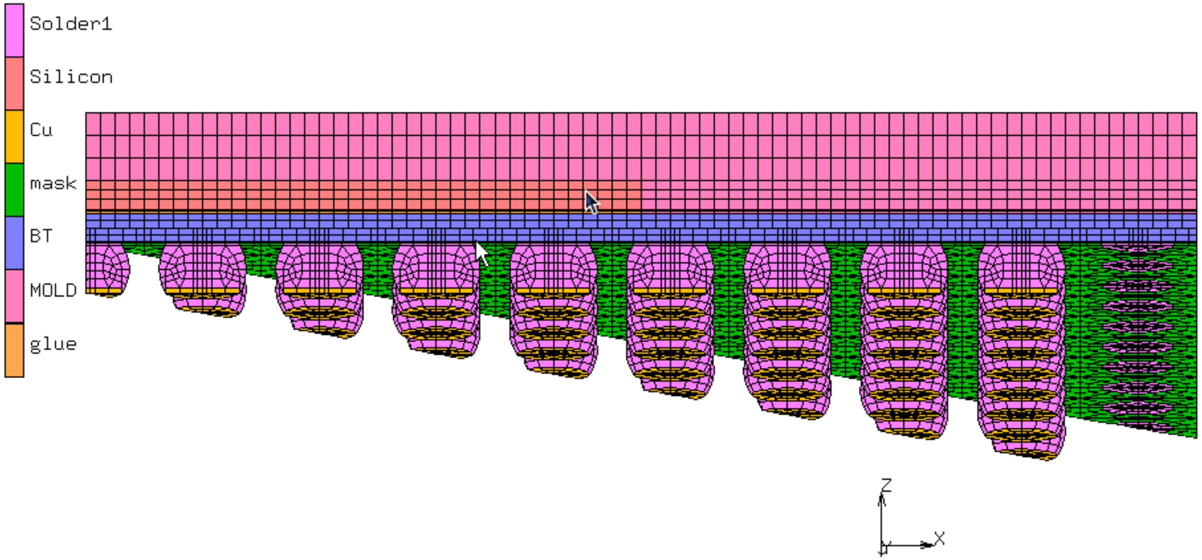


3. 0.5MM VS. 0.8MM PITCH PBGA

Partly populated area array
0.5mm pitch
Ball size 0.3mm

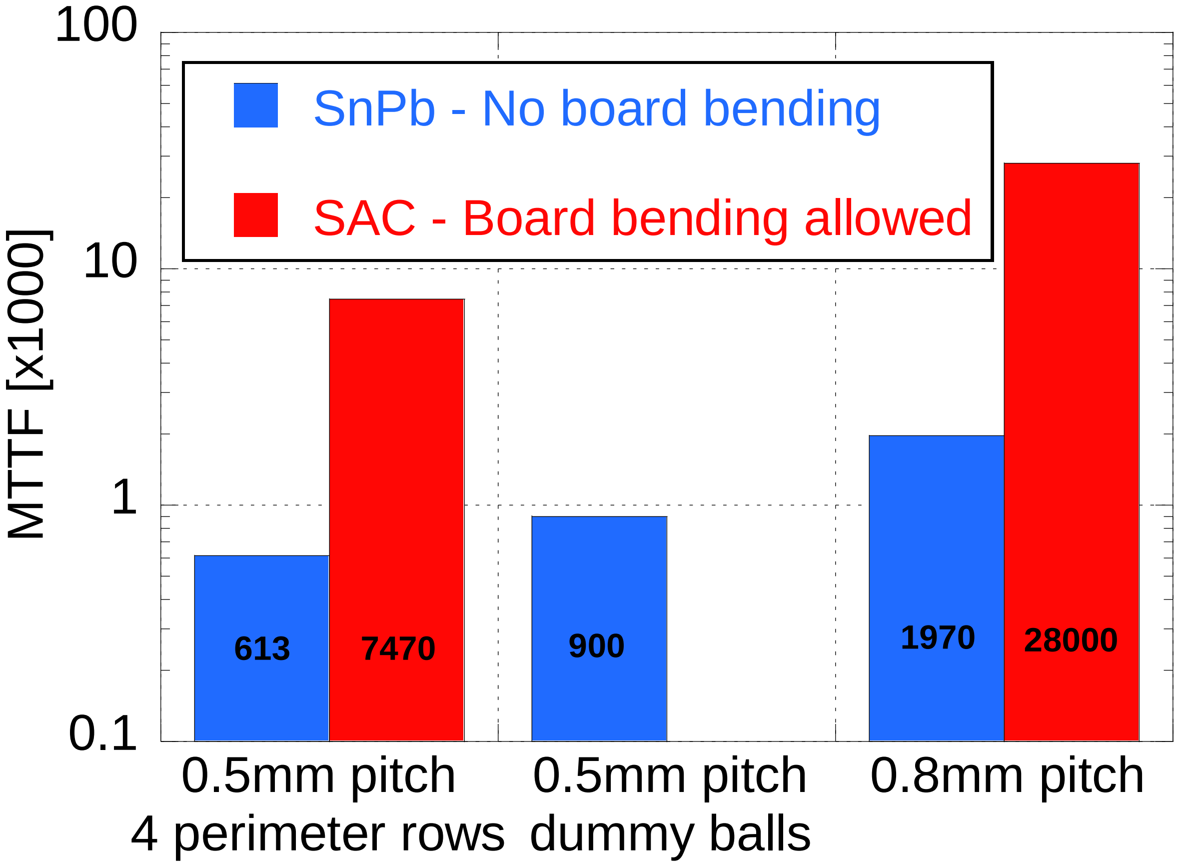


Fully populated area array
0.8mm pitch
Ball size 0.5mm



3. 0.5MM VS. 0.8MM PITCH PBGA

Changing package type can improve lifetime up to 4x

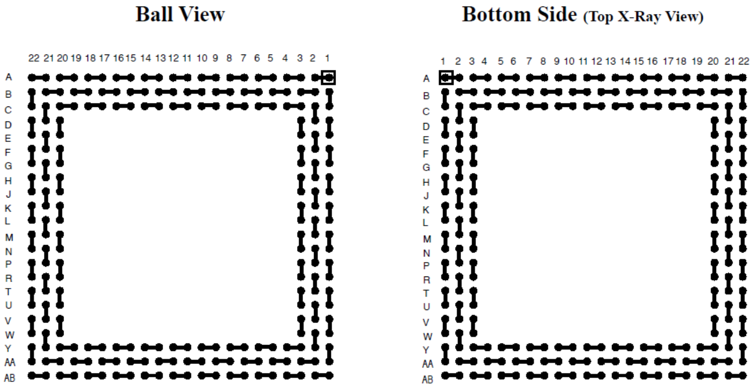


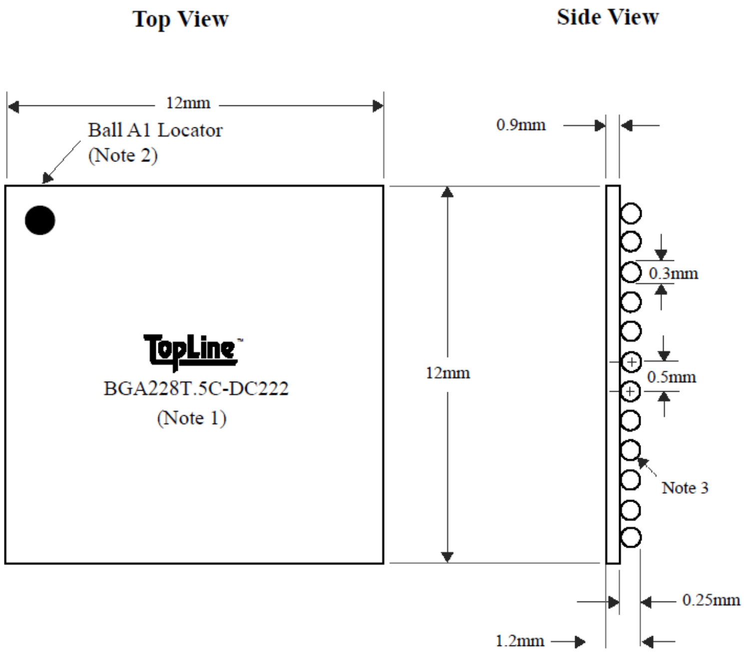
4. RECENT EXPERIMENTAL RESULTS
GREEN MOLD COMPOUND TEST VEHICLE BGA228

Small pitch BGA :

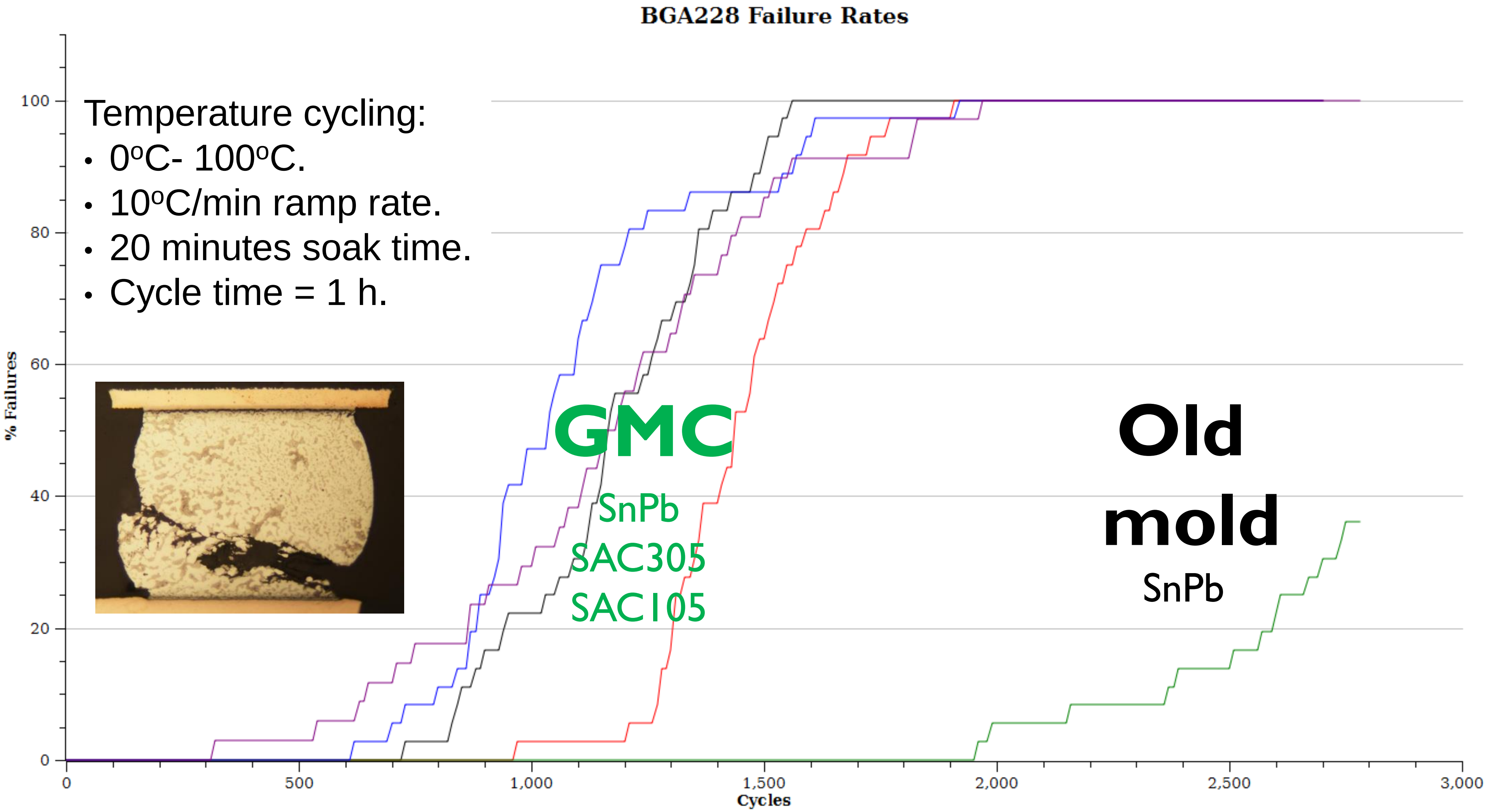
- 0.5 mm pitch, 12 mm x 12 mm, 228 pins.
- 4 types :
  - Pb en Pb-free versions (SAC305, SAC105).
  - Old (non-green) components: SnPb .
- 36 components on each board, all placed on the same side.

PCB: 2.4mm – 8-layer Cu





4. RECENT EXPERIMENTAL RESULTS
GREEN MOLD COMPOUND TEST VEHICLE BGA228



BGA228 Failure Rates

Temperature cycling:
- 0ºC- 100ºC.
- 10ºC/min ramp rate.
- 20 minutes soak time.
- Cycle time = 1 h.

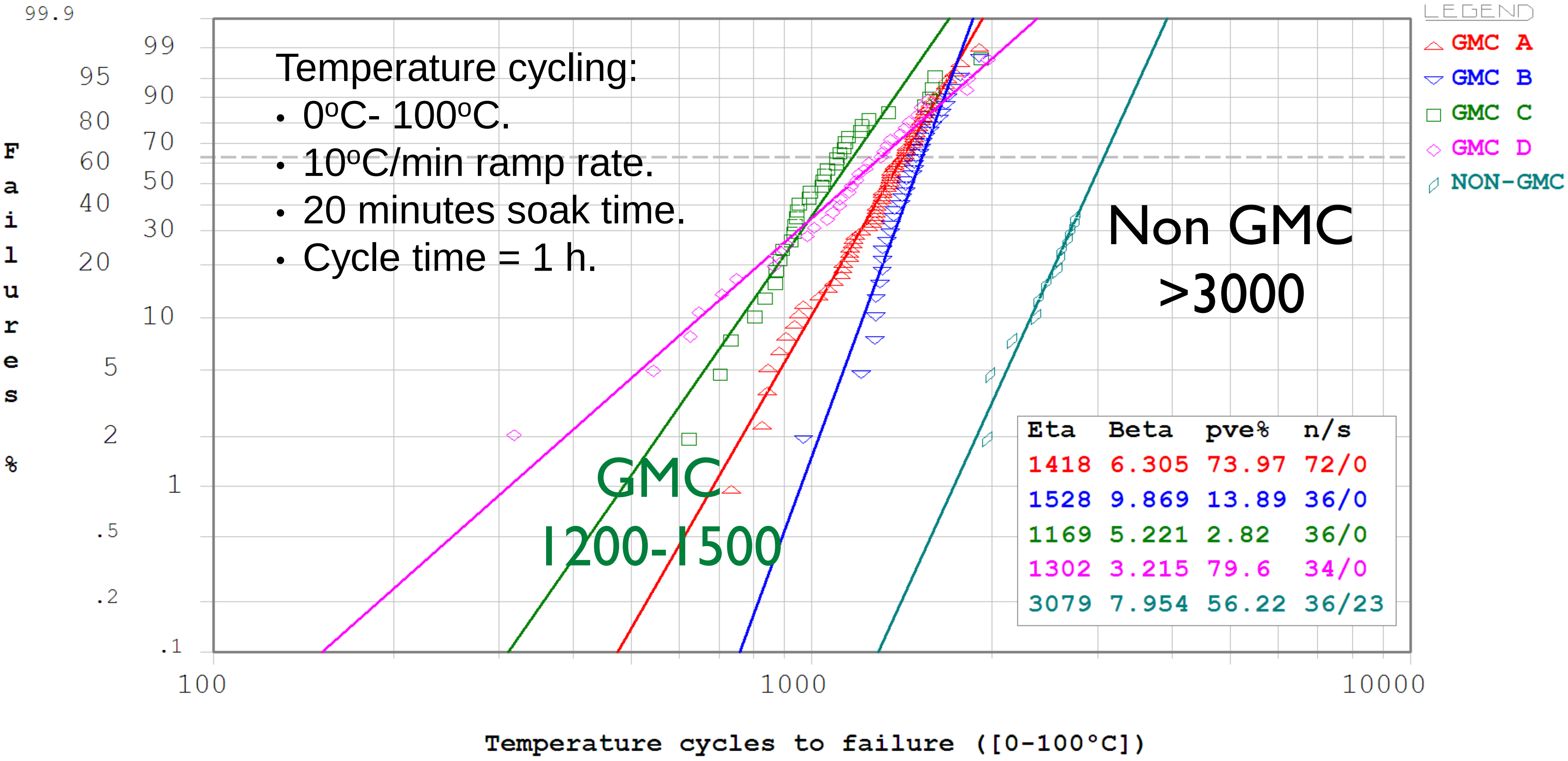
GMC

SnPb
SAC305
SAC105

Old mold

SnPb

4. RECENT EXPERIMENTAL RESULTS
GREEN MOLD COMPOUND TEST VEHICLE BGA228



Temperature cycling:

- 0ºC- 100ºC.
- 10ºC/min ramp rate.
- 20 minutes soak time.
- Cycle time = 1 h.

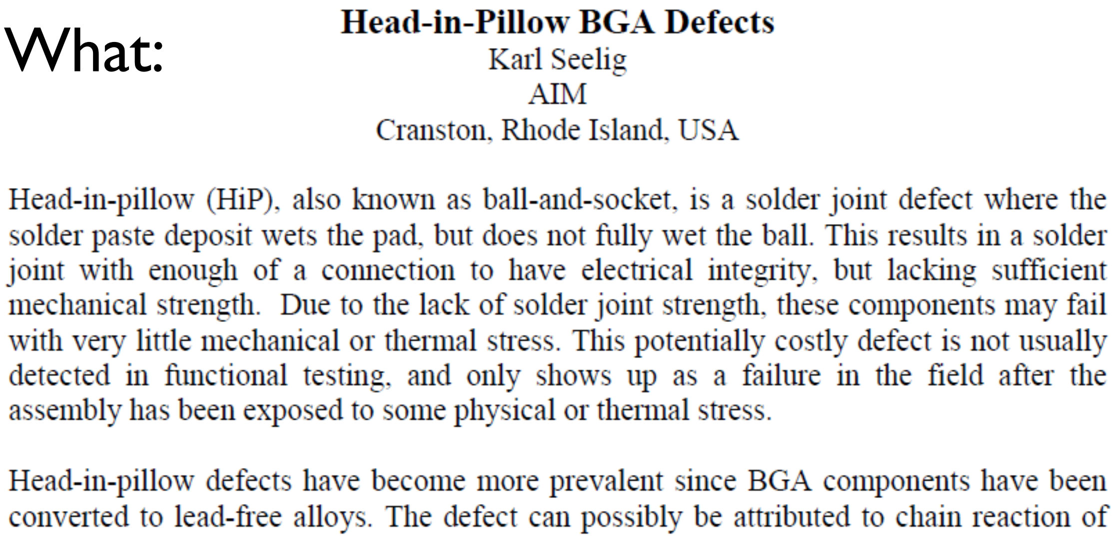
GMC
1200-1500

Non GMC
>3000

Eta	Beta	pve%	n/s
1418	6.305	73.97	72/0
1528	9.869	13.89	36/0
1169	5.221	2.82	36/0
1302	3.215	79.6	34/0
3079	7.954	56.22	36/23

5. IMPACT ON ASSEMBLY: HEAD-IN-PILLOW

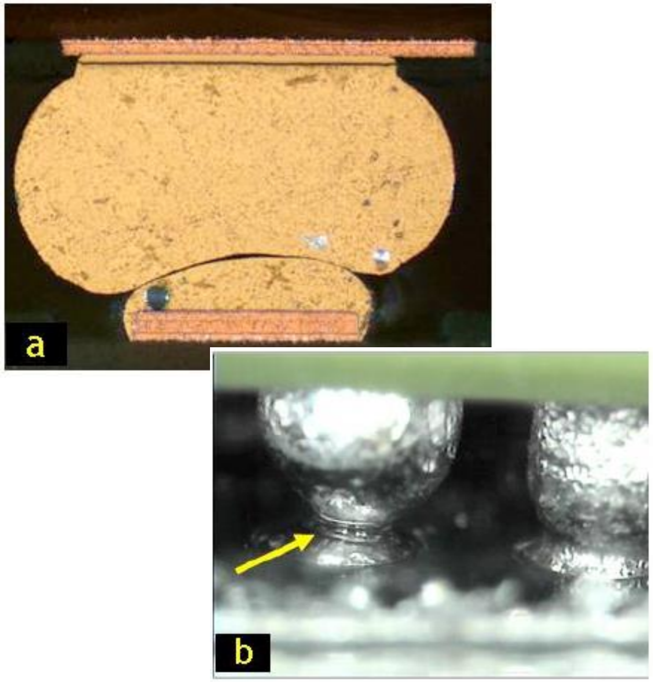
What:



Head-in-Pillow BGA Defects
Karl Seelig
AIM
Cranston, Rhode Island, USA

Head-in-pillow (HiP), also known as ball-and-socket, is a solder joint defect where the solder paste deposit wets the pad, but does not fully wet the ball. This results in a solder joint with enough of a connection to have electrical integrity, but lacking sufficient mechanical strength. Due to the lack of solder joint strength, these components may fail with very little mechanical or thermal stress. This potentially costly defect is not usually detected in functional testing, and only shows up as a failure in the field after the assembly has been exposed to some physical or thermal stress.

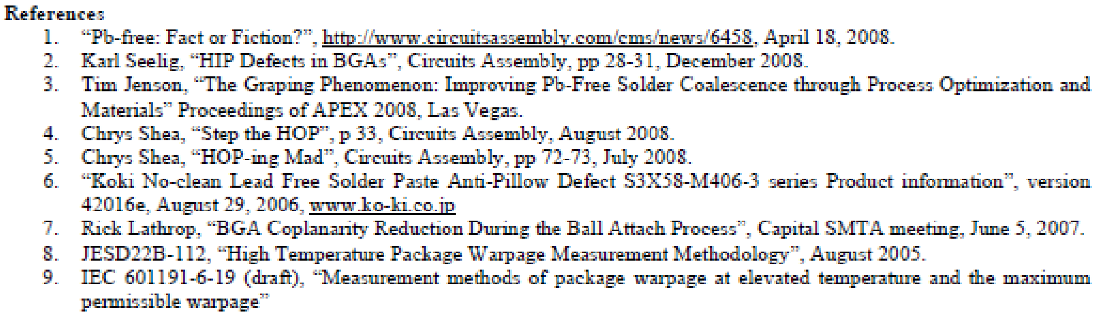
Head-in-pillow defects have become more prevalent since BGA components have been converted to lead-free alloys. The defect can possibly be attributed to chain reaction of



Associated to lead-free soldering?

But:

- Seems to become more and more prevalent 1-2 years after 1/7/2006
- Occurs also with SnPb soldering.
- HiP unheard of in SnPb soldering prior to 2008?!



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2. Karl Seelig, "HIP Defects in BGAs", Circuits Assembly, pp 28-31, December 2008.
3. Tim Jenson, "The Graping Phenomenon: Improving Pb-Free Solder Coalescence through Process Optimization and Materials" Proceedings of APEX 2008, Las Vegas.
4. Chrys Shea, "Step the HOP", p 33, Circuits Assembly, August 2008.
5. Chrys Shea, "HOP-ing Mad", Circuits Assembly, pp 72-73, July 2008.
6. "Koki No-clean Lead Free Solder Paste Anti-Pillow Defect S3X58-M406-3 series Product information", version 42016e, August 29, 2006, www.ko-ki.co.jp
7. Rick Lathrop, "BGA Coplanarity Reduction During the Ball Attach Process", Capital SMTA meeting, June 5, 2007.
8. JESD22B-112, "High Temperature Package Warpage Measurement Methodology", August 2005.
9. IEC 601191-6-19 (draft), "Measurement methods of package warpage at elevated temperature and the maximum permissible warpage"

5. IMPACT ON ASSEMBLY: HEAD-IN-PILLOW

Major root cause of Head-in-Pillow is component warpage.

More warpage when temperature is higher → lead-free

But:

- Is also reported for SnPb soldering of BGA
- Became an issue after the introduction of lead-free soldering.

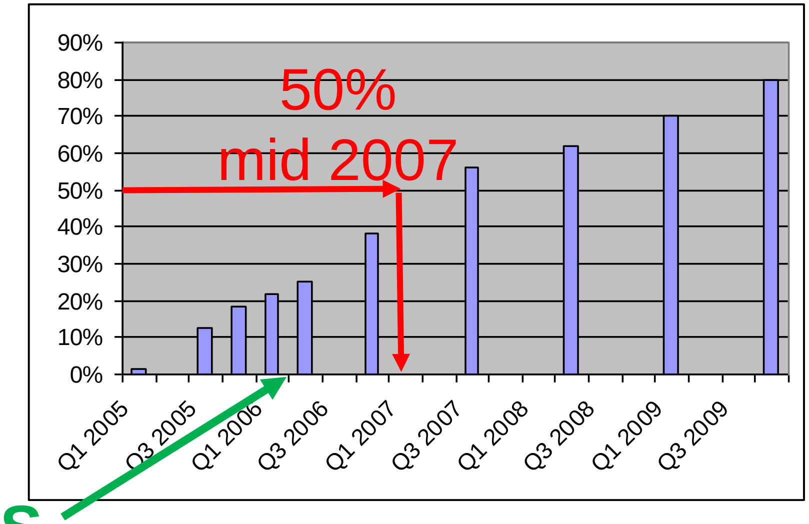
Lower mold compound CTE will increase/alter the warpage behaviour of PBGA.

Look at the GMC introduction→

Conclusion seems to be:

GMC most likely root cause

of "HiP-epidemic".



6. CONCLUSIONS

Green molding compounds with CTE in the range 6-10ppm increase the thermal mismatch between "plastic" packages and the PCB upto tenfold (1→10ppm).

This creates major issues:

- Reduction in lifetime (1/1...1/4...) below acceptable level due to solder joint failure of "plastic" packages especially TSOP, BGA, QFN

- Reduction in lifetime below acceptable level due to Cu lead failure of TSOP type I components.
- Assembly: Yield reduction due to Head-in-Pillow of BGA solder joints.
- Increased risk of "Early Failure" due to electrically undetected HiP BGA solder joints.
- Very limited (and costly) workarounds: underfill (?)

6. CONCLUSIONS

GMC are a far greater threath to reliability than the transition to lead-free solder ever was:

- Reduction of lifetime: factor 1 to 10 instead of tens of %.
- High reliability SnPb soldered products are most affected!
- Introduction “below the radar”.

To make reliable electronics on PCB we need plastic packages with mold compounds having a CTE>12ppm.

END of PART I
Thank you

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PART 2:
EARLY FATIGUE FAILURES IN COPPER WIRE BONDS INSIDE PACKAGES WITH LOW CTE

BART VANDEVELDE, GEERT WILLEMS

IMEC – CENTER FOR ELECTRONICS DESIGN & MANUFACTURING

EDM
Electronics Design & Manufacturing

imec

TWO MAJOR TRENDS IN IC PACKAGING

Conventional
high-CTE mold
compounds

Green **low-CTE**
mold compounds

Trend 1

2005

2010

Trend 2

Gold wire
bonds

Copper wire
bonds

TREND 2:
SWITCH FROM AU TO CU WIRE BOND MATERIAL

Drivers:

- Cost
- Increased electrical performance (lower electric resistivity): higher currents are possible
- Higher thermal conductivity: higher capability to pull heat away from the die, leading to better performance at elevated temperatures and greater reliability
- Copper wire can be bonded on die pads plated with thick copper and nickel palladium finish:
  stable metal joint at high temperatures

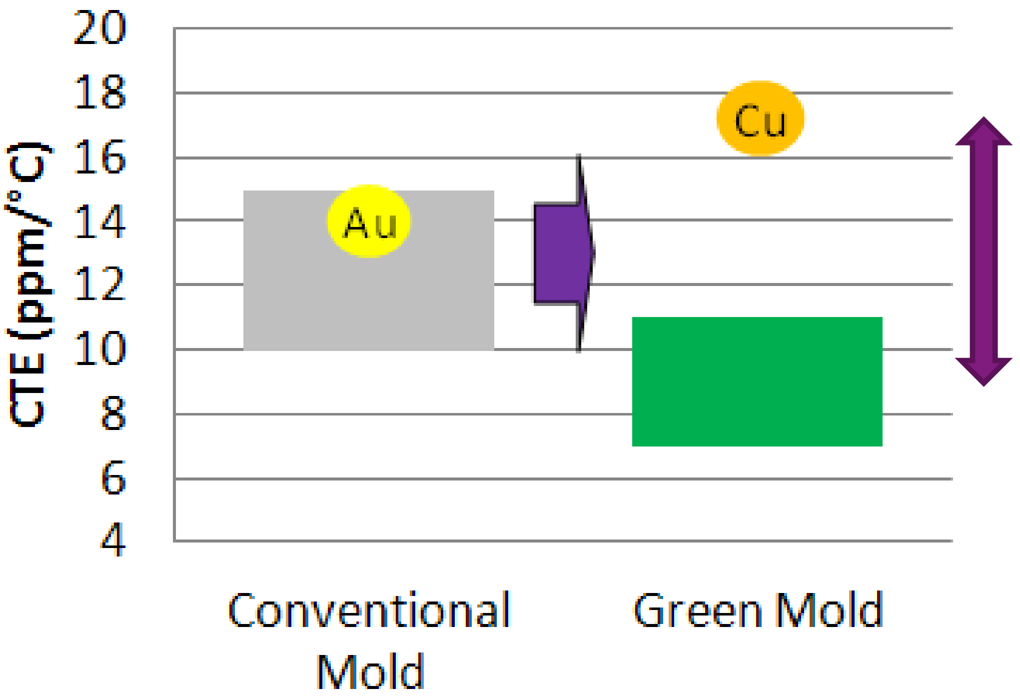
TREND 2:
SWITCH FROM AU TO CU WIRE BOND MATERIAL

Concerns:

- higher stiffness of copper leads to higher bond forces on the bond pads requiring a stronger design of the bond pad protecting the underlying circuitry
- NEW:
  potential wire bond fatigue in combination with low-CTE overmold compounds

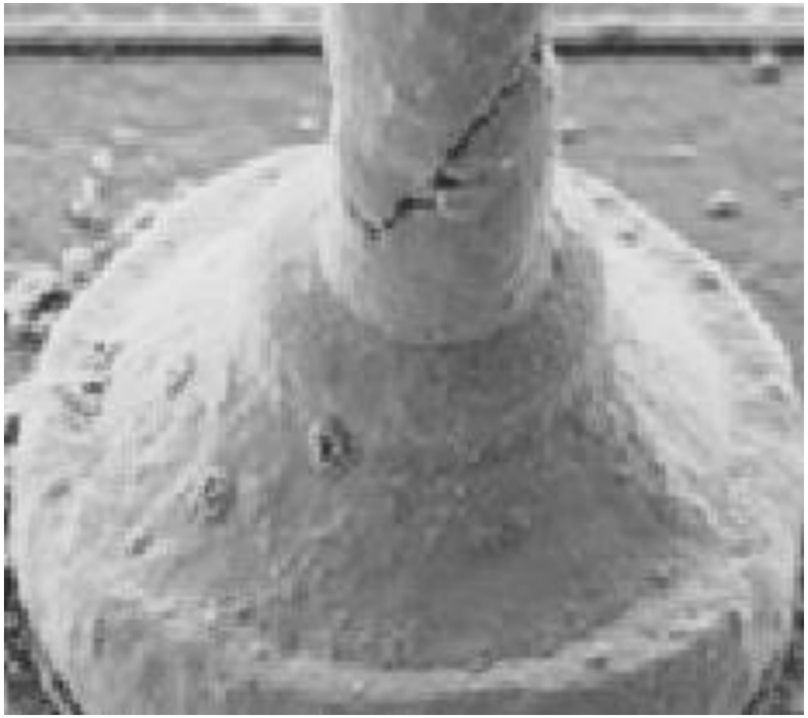
TWO TRENDS COMBINED

Moving the CTE mismatch from 0 to 10 ppm/°C difference



CTE mismatch of about 10 ppm/°C

EXPERIMENTAL FINDINGS: FAILURE ANALYSIS AFTER QUALIFICATION TESTS



- Wire bond failures have been seen after temperature cycling tests
- Failures are under 45°, indicating copper wire got vertical stretching and compression
  (highest shear stress along 45° plane)
- Low number of cycles to failure (< 10000) indicates that repeated plastic deformation occurred in the wire.

This problem was never seen with Au wires nor with Cu wires in combination with conventional mold compounds

PROPERTIES FOR OVERMOLD MATERIALS

Property	Conventional Mold	Green Mold	Green over Conventional
Young’s modulus	17000 MPa	28000 MPa	**65% higher**
CTE	13 ppm/°C	7 ppm/°C	**45% lower**
Glass Transition Point	150°C	130°C	**15 % lower**

Data extracted from datasheets of two particular materials

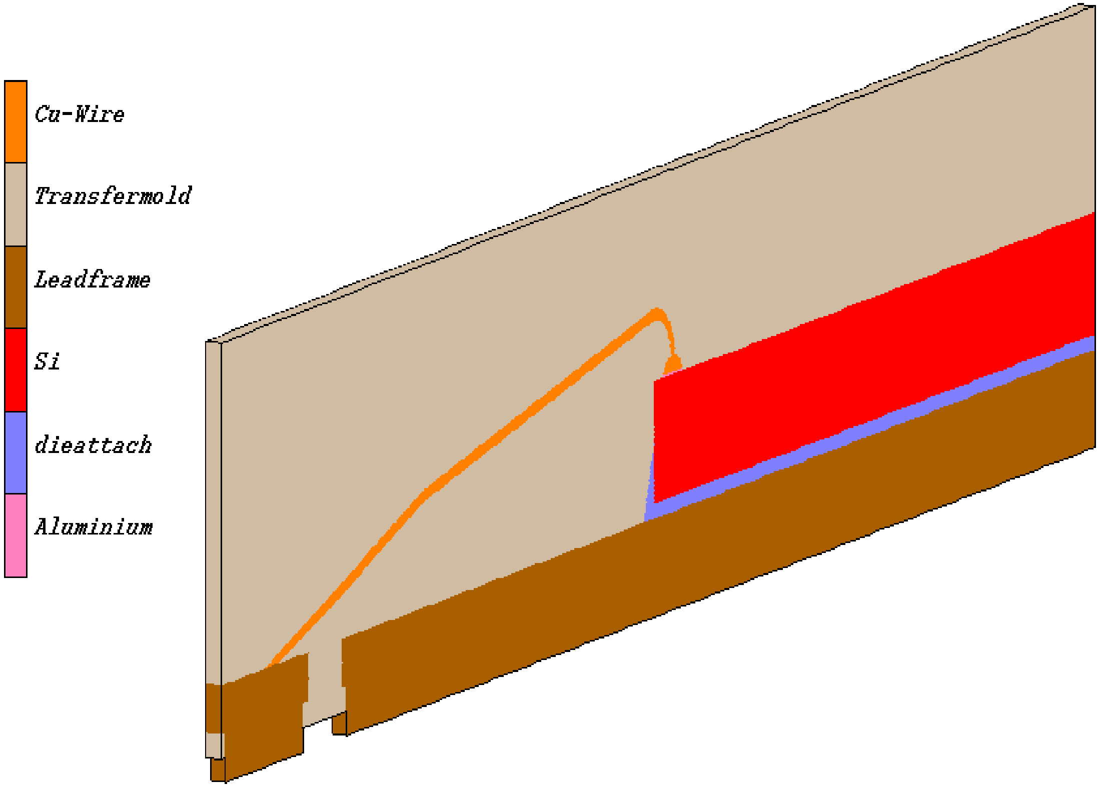
PROPERTIES FOR WIRE BOND MATERIALS

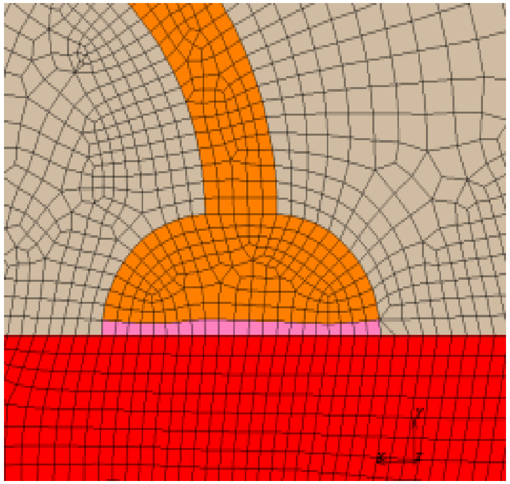
Property	Gold wire	Copper wire	Cu over Au
Young's modulus	79000 MPa	123000 MPa	55% higher
CTE	14.2 ppm/°C	16.5 ppm/°C	16% higher
Yield stress	~ 200 MPa	~ 160 MPa	20 % lower
Electrical Resistivity	2.2 10-8 Ω m	1.7 10-8 Ω m	23% lower

Reference: Heraeus website

SIMULATING THE MATERIAL CHANGE IMPACT USING A FINITE ELEMENT MODEL

3D slice model



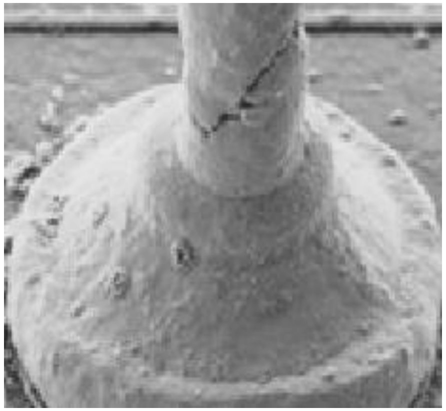


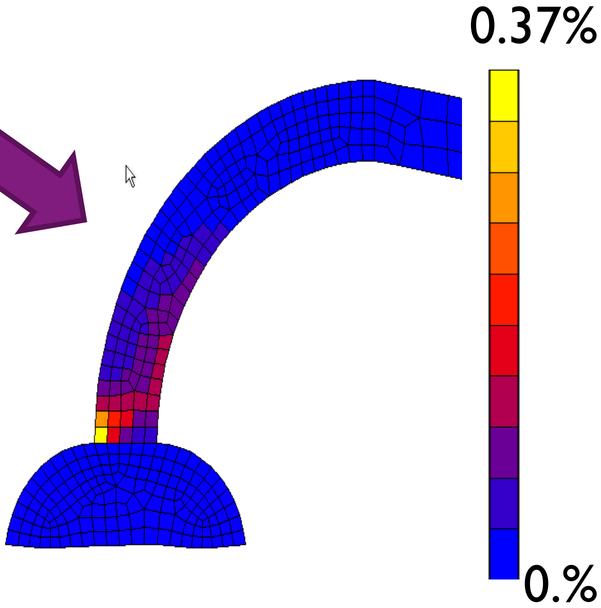
Applied load: cycling between -40°C and +150°C

RESULTS

	Conventional (high CTE) overmold *13 ppm/°C*	**Green (low CTE) overmold** *7 ppm/°C*
Au wire *(14.2 ppm/°C)*	No plastic deformation	No plastic deformation
Cu wire *(16.5 ppm/°C)*	No plastic deformation	$\Delta\varepsilon_{pl} = 0.37\%$

- Only plastic deformation seen for the combination GMC & Cu wire
- Good agreement between maximum strain point in FEM and the failure mode seen in SEM





PREDICTION OF LIFE TIME?

	Conventional (high CTE) overmold *13 ppm/°C*	**Green (low CTE) overmold** *7 ppm/°C*
Au wire *(14.2 ppm/°C)*	No plastic deformation	No plastic deformation
Cu wire *(16.5 ppm/°C)*	No plastic deformation	**$\Delta\varepsilon_{pl}$ = 0.37%**

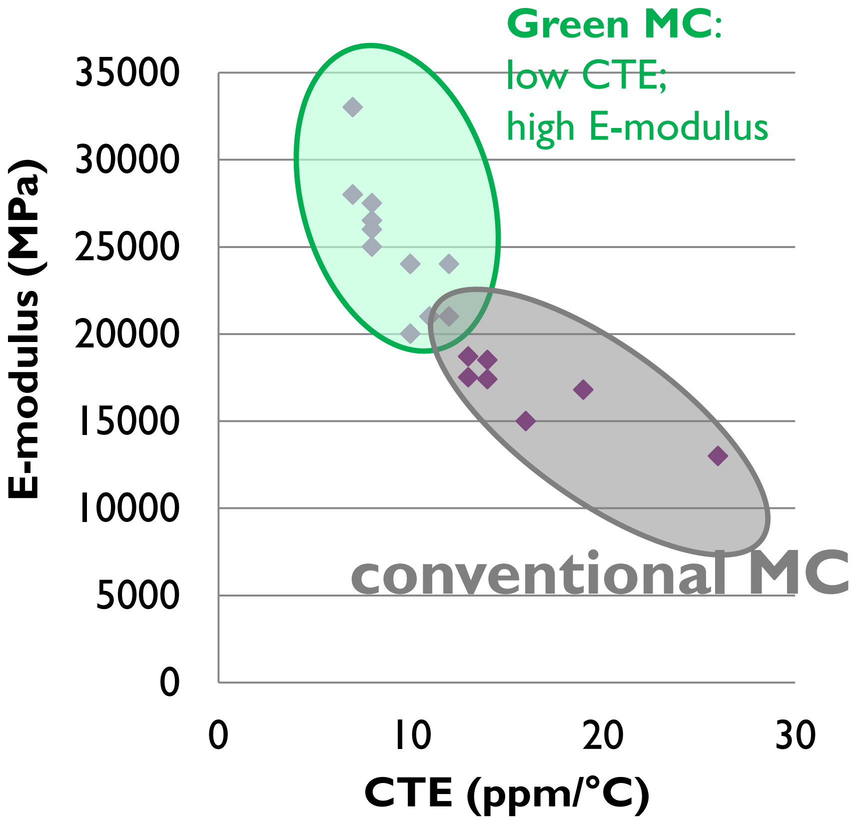
High cycle fatigue (> 10000 cycles)

Prediction based on fatigue model for PTH: 0.37% → ~ 1500 cycles to failure

Same order of magnitude as seen in experiments

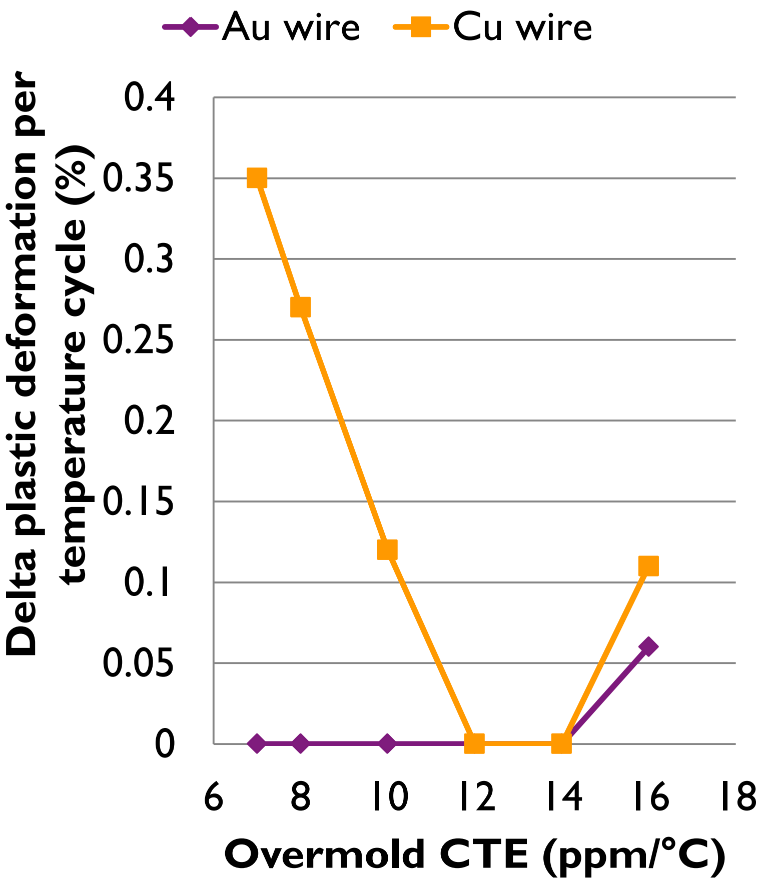
FEM BASED PARAMETER STUDY: WHAT IS THE MINIMUM OVERMOLD CTE REQUIRED TO AVOID WIRE BOND FAILURE?

Parameter study: overmold CTE from 7 to 16 ppm/°C



	CTE	E-modulus	
OM1	7 ppm/°C	30000 MPa	Green MC
OM2	8 ppm/°C	26500 MPa	
OM3	10 ppm/°C	24000 MPa	
OM4	12 ppm/°C	21000 MPa	
OM5	14 ppm/°C	18500 MPa	
OM6	16 ppm/°C	15000 MPa	Conventional MC

RESULTS OF FEM BASED PARAMETER STUDY

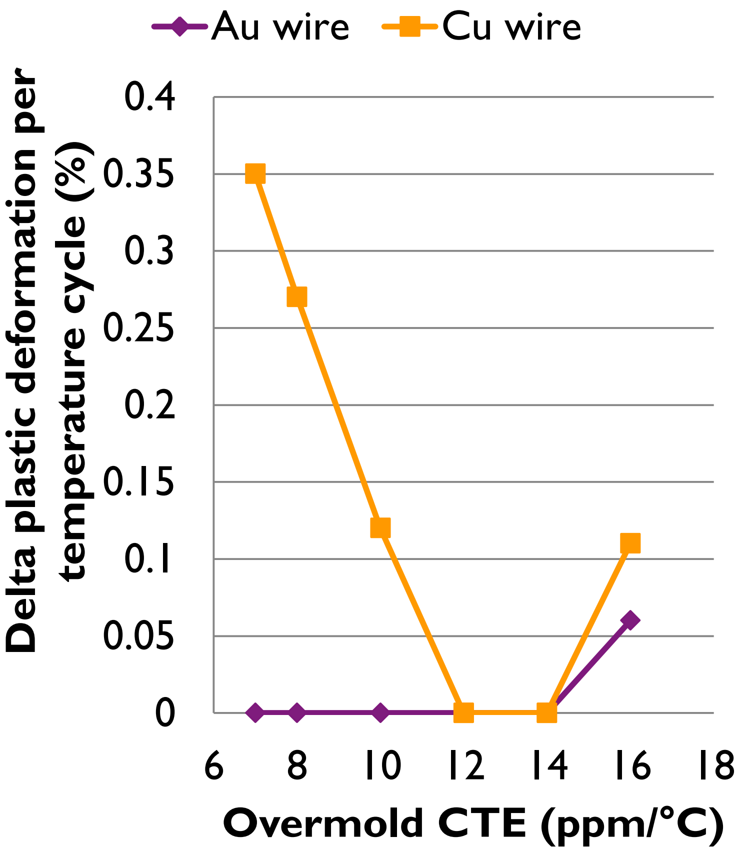


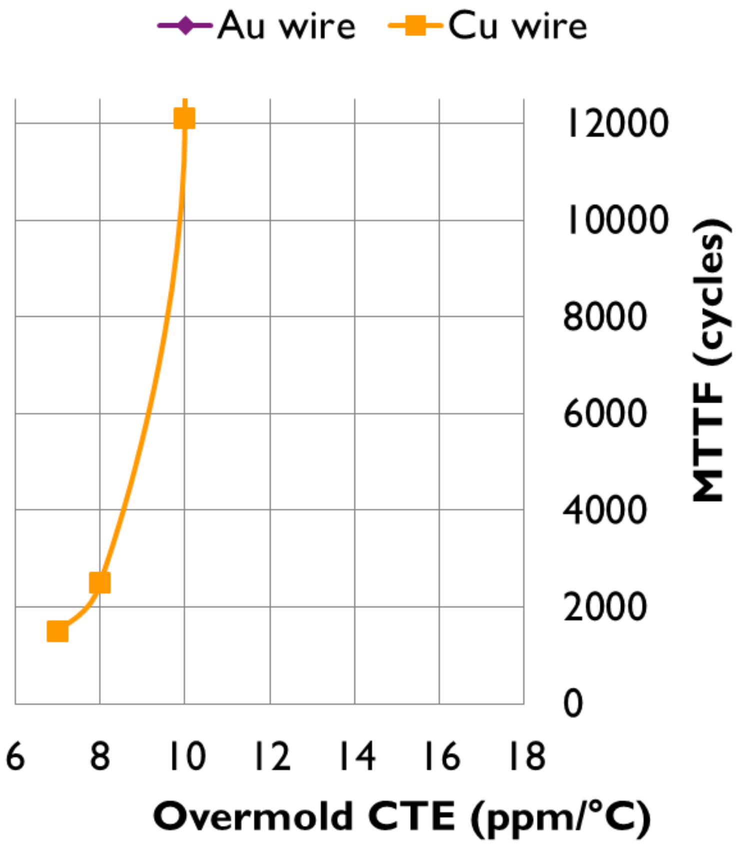
- Below 12 ppm/°C, plastic deformation is seen in copper wire, not in Au wire

- The plastic deformation is linear to the CTE difference with Cu, indicating that CTE-difference is the driving force.

- For 16 ppm/°C overmold, the CTE mismatch above glass transition point causes higher stress

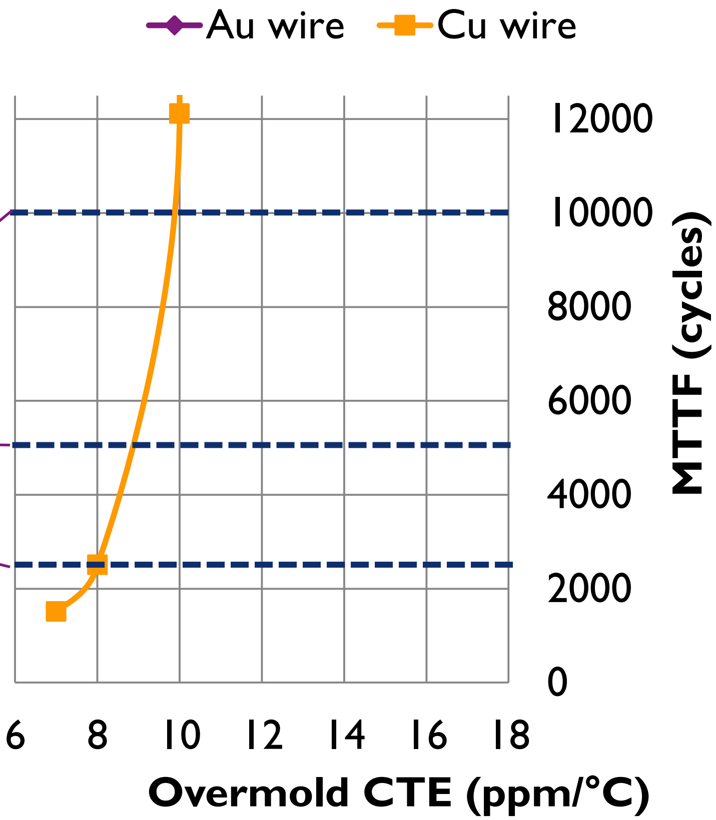
TRANSLATING THE PLASTIC STRAIN INTO LIFE TIME PREDICTION





MINIMUM CTE OF OVERMOLD

Minimum life time	**Minimum CTE**
N > 10000 cycles	CTE > **10** ppm/°C
N > 5000 cycles	CTE > **9** ppm/°C
N > 2500 cycles	CTE > **8** ppm/°C



Important remark:
These results also depend on wire bond shape, wire coating and package construction

CONCLUSIONS

Large CTE mismatch between Cu wire and low-CTE overmold leads to mechanical fatigue in Cu wire

Could the combination of low-CTE overmolds be a showstopper for copper wire bonds?

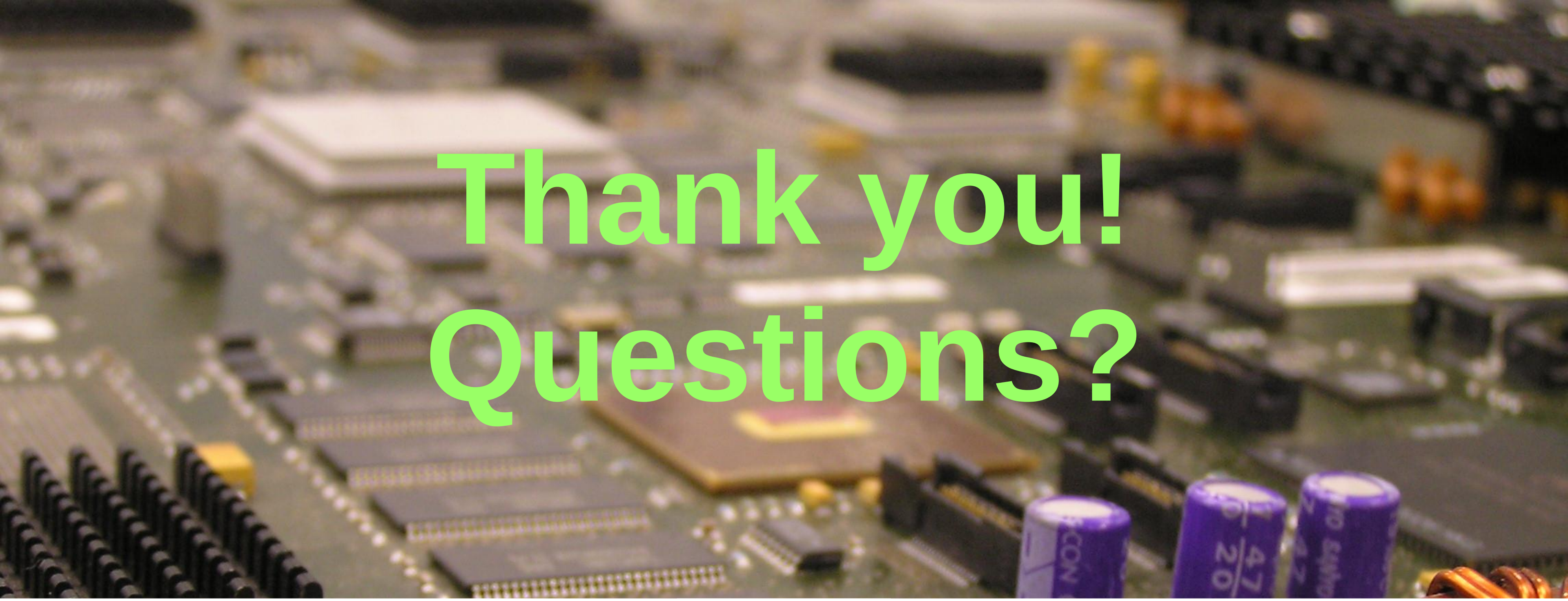
- Yes for extreme conditions and long life time requirements

Guidelines to avoid this failure:

- Select a molding compound with a bit higher CTE than 7 ppm/°C which reduces the CTE mismatch avoiding plastic deformation in the wire (minimum CTE depends on TC conditions, life time, package design)
- Improved shape of the wire can also help to minimise the stress impact

IMEC'S INTEREST

- Experimental work confirming the solder joint and copper wire bond reliability predictions.
- Experimentally determined life time numbers with sufficient details on geometry and used materials to support predictability of FEM and ongoing analytical modeling work.
- Reliable electronics needs mold compounds with a CTE>12ppm. A requirement that must come from telecom, automotive, avionics, industrial equipment and other high reliability product OEM.
  Imec can and is willing to provide scientific support.



Thank you!
Questions?

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SUMMARY

Is this an opportunity for collaboration?

iNEMI initiative survey in Q4 confirmed industry interest in the area of GMC and copper wire bonding

Imec has interest in pursuing experimental work to confirm solderjoint and/or copper wire bonding reliability.

iNEMI already has ongoing project on copper wire bonding relability:

http://www.inemi.org/project-page/copper-wire-bonding-reliability

THE INEMI PROJECT PROCESS - 5 STEPS

1 SELECTION ✓

2 DEFINITION ✓

Open for Industry input

3 PLANNING

------------------- iNEMI Technical Committee (TC) Approval Required for Execution

4 EXECUTION / REVIEW

5 CLOSURE

Limited to Committed Members

Goal is to submit Statement of Work (SOW)
To Technical Committee (TC) in June

SUMMARY

Next steps

iNEMI to contact webinar attendees and others to confirm interest (Feb)

Form initiative teams in March – iNEMI membership not necessary for initative phase

Develop Statement Of Work (SOW) by June 30

Call for participation in Project (July & August)

Project start in September

For more information contact: gomalley@inemi.org

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