RoHS and Green Compliance in IC Packaging

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Abstract
In this report, BGA packages with conventional and green material combination were selected as test vehicles for the investigation of MSL/temperature rating at the packaging level. The IC packaging was also tested at the package level and raw material level to show its RoHS6 compliance. Furthermore, chemical substances testing for halogen and Sb/Sb2O3 show a higher level of green compliance.

Key words: RoHS, Green, MSL, PBGA, Halogen, Sb2O3

Introduction
EU RoHS and China RoHS have been in effect since July 2006 and Mar 2007, respectively. The global environmental pressure to phase out Pb/Cd/Hg/Cr+6 and PBBs/PBDEs usage in electronics application has been becoming inevitable, especially for Asian electronic manufacturers. However, green conversion is not only to simply change a material to a promising alternative, but also a need to consider the impact on current process, equipment compatibility, material cost, even operator training and so on. The conversion involves the entire supply chain in the electronic industry. Thus, the concept of dynamic green procurement has is becoming another important topic in the each part of supply chain of the electronic industry.

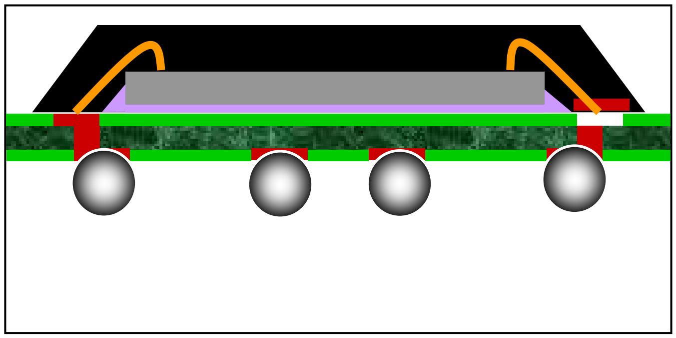
Besides technical concerns like MSL evolution or 260℃ compliance in IC packaging performance, how to identify the whether the product developed complies with regional RoHS or higher levels of green regulation, has been another attractive topic. Various PPM threshold (TLV) recognition depending on customer preference for the substances of concern is making manufacturers confused as to what to follow now. Furthermore, the Pb exemption from EU RoHS is driving so-called RoHS5 compliance in high reliability product such as telcom, automotive, medical and military, which will result in another logistic control headache in the electronic supply chain. The standard testing method for RoHS 6 substances has been studied by IEC based on homogeneous material definition. But with IC packaging evolution to small, fine pitch and SiP devices, it will become very difficult even impossible to disjoint them mechanically into each ingredient before testing them.

EU RoHS identifies Pb/Hg/Cd/Cr+6, PBBs and PBDEs that must be banned since July/2006, but in Japan or number of company from EU and US, there are more environmental conscious substances identified so not only abovementioned will need to phase out gradually based on specific timelines. Whether there is a consensus to integrate the awareness in different areas will be hoped for by many EMS providers and ODM/OEM, especially in Asia region

PBBs and PBDEs are only two type of halogenated flame retardant which have potential risk to generate PBDD (polybrominated dibenzodioxins) and PBDF (polybrominated dibenzofuran) during incomplete incineration. Whether other halogenated flame retardants will also generate similar substances needs more professional study to determine. At this present moment, there have been a number of halogen free solutions applied in molding compounds, substrate, and PCB and so on, but cost, flaming resistance stability to achieve UL94-V0 and reliability performance are existing concerns. Nevertheless, halogen free and RoHS compliance solution is still expected by leading company in Europe, US and Japan. (1-2)
The major concern from the promising lead free solders, such as ternary SnAgCu alloy in laminate package, is the high melting point in comparison with eutectic SnPb alloy (3-8). IC packaging would go through a higher temperature surface mounting soldering process and induce significant thermal stress and vapor pressure inside the packages, which will give easily rise to typical failures inside package like delamination, popcorn and package crack and so on (9-16). In order to reduce the propensity of package failure, one need look for both a reliable material and green compliance. Furthermore, board level reliability is required to check solder joint integrity for portable product due to drop failure concern and high end product due to long service life. More and more challenges for IC packaging development will be coming from the environmental and technical requirements.

Experiment

1.BGA test vehicle selection and BOM in figure 1

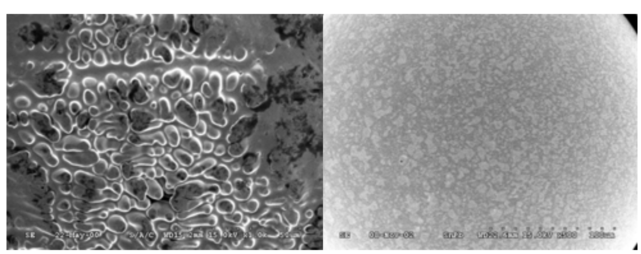


I/O count	492
Die size	300milx300 mil
Min. I/O pitch	1.27mm
Package Size	35mmx35mm
Solder diameter	0.76mm
Substrate	BT (4layer)
Overall thickness	2.33mm

BOM	Normal	Green
Molding compound	Type A	Type B
Die attach	epoxy	hybrid
substrate	Halogen containing	**Halogen free**
Solder ball	SnPb	SnAgCu

Figure 1 BGA test vehicle selection and BOM

2. Package resistance in high temperature soldering
(a)Solder ball selection Sn4Ag0.5Cu solder ball was selected and its appearance was far different from that of eutectic SnPb ball due to dominate β-Sn grain on the surface, as shown in figure2.



(a) Sn4Ag0.5Cu (b) 63Sn37Sb

Figure 2 The appearance comparison of solder ball

(b)Die attach selection
2 types of die attach was selected for comparison. One was single epoxy-based resin; another was a hybrid type containing 2 kinds of resin-base besides epoxy to optimize the balance of the adhesion and moisture uptake. These are shown by the physical properties comparison in table 1.

The hybrid type-based type possess higher Tg, one time lower moisture absorption and higher modulus at high temperature than epoxy- based type.

(c). Molding compound selection
2 molding compounds were selected for comparison: one was a conventional multi-functional type A, another was unique multifunctional green compound B without Br and Sn2O3 containing. These are shown by the properties comparison in table2.

Table 1 The physical properties comparison of die attach

	Epoxy	hybrid	remark
Weight loss @300□ (%)	0.5	0.6	TGA
Tg (□)	27	74	TMA
CTE1 (ppm)	80	74	TMA
CTE2 (ppm)	154	163	TMA
Modulus @25□(MPa)	1400	1000	DMA
Modulus @150□(MPa)	35	305	DMA
Modulus @200□(MPa)	21	297	DMA
Die shear strength (kg)	12	10	2x2 Si die
Moisture absorption (%)	0.5	0.21	85□/85%RH

Type B possess higher filler content, but better spiral flow, lower Tg but lower CTE and higher flexural strength and modulus at high temperature, and lower water absorption than type A.

Table 2 The physical properties comparison of molding compound.

	Type A	Type B
Epoxy resin	Multi-functional	Modify multi-functional
hardener	Multi-functional	Multi-functional
F.R	Br/Sb_2O_3	Organic P
Filler content (%)	84	90
Spiral flow (cm)	130	150
CTEα_1 (ppm)	14	8
CTEα_2 (ppm)	47	28
Tg (℃)	200	180
Flexural strength at 25℃ (MPa)	130	190
Flexural strength at 240℃(MPa)	26	37
Flexural modulus at 25℃(GPa)	14.5	27
Flexural modulus at 240℃(GPa)	1.2	1.8
Water absorption (%) (PCT)	0.44	0.35

(d)Substrate selection
2 type of BT substrate were selected, one was a conventional type with BT832 core plus AUS5 solder mask and the other type was so-called green substrate composed of BT832NB plus AUS308 solder mask without halogenated flame retardant..

(e)Reflow profile comparison in precondition.
The packages assembled with the above 2 material sets waere subject to JEDEC MSL3 (30℃/60%RH, 192hrs soaking) precondition, followed by 3 times reflow with peak temperature 220~225,240~245,250~255,260~265℃, respectively. Sequentially, SAT (Scanning acoustic transmission) and SEM analysis were applied to identify the failure mode.

3. Moisture uptake testing
The certain amount IC packages with above 2 BOMs were subject to moisture absorption at 30℃/60%RH circumstances until 216hrs. The package weight was calculated at each period of 0,3,6,9,24,48,72,96,144,168,192,216hrs. Sequentially, the packages were subject to baking at 125℃ and calculated package weight at each period of 0, 2,4,6,8,10,24,48hrs. The moisture absorption curve and desorption curve can be plotted with the time to compare moisture resistance capability.

4. RoHS and green compliance testing
The major ingredient material like molding compound, substrate and solder ball were subject to destructive digestion pretreatment and sequentially followed by certain analytical method for the identification of Pb/Cd/Hg/Cr^{+6} and halogen and Sb_2O_3 substances.

Result and discussion

1. Package resistance in high temperature soldering

Table3 showed the failure rate with the 2 BOM sets at various temperatures for 3 times reflow soldering operations after MSL3 moisture absorption**.** The normal BOM set can survive at 220~225℃ but begins to fail at 240~245℃ and 250~255℃ while the green BOM set can survive at 250~260℃ but failed in 260~265℃ with a lower failure rate. This finding illustrated the limits in each material set, as well as identifying the vapor pressure impact on package integrity as shown in figure6. The conclusion shows how wide the process window in the SMT process was, as well giving a good indication as to how to pursue higher MSL performance.

Table 3 The failure rate under MSL3 with various reflow profile.

	Normal	Green
Sample size	45 ea/condition	45 ea/condition
Visual inspection	0/135	0/135
SAT1	0/135	0/135
TCT 5 cycle	0/135	0/135
Baking 125□/24hrs	0/135	0/135
30□/60%RH, 192hrs	0/135	0/135
220~225℃, reflow X 3	0/45	na
240~245℃, reflow X 3	10/45	na
250~255℃, reflow X 3	40/45	0/45
255~260℃, reflow X 3	na	0/45
260~265℃, reflow X 3	na	2/45

Table 4 described the 4 typical failure modes for the two BOM set. As above-mentioned the normal BOM set with higher moisture absorption encountered delamination between solder mask and molding compound and die attach because the interfacial adhesion strength was not strong enough. The moisture absorbed will penetrate into weaker interface between them and when the, higher CTE mismatch was combined with vapor pressure generated when going through high temperature reflow delamination occurs.

In the green BOM set, the majority failure mode was in the die attach layer itself and delamination between green compound and die surface at higher reflow temperature, as shown in figure 3.

Table 4 The failure mode description with the 2 BOM set

	Normal	Green
Delamination between SM and compound	V	
Delamination in die attach interface	V	
popcorn in die attach layer		V
Delamination between die and compound	v	v

The adhesion between green compound and halogen free solder mask was strong enough to withstand high temperature soldering, but higher soldering temperature like 260~265℃will cause package damage in weakest point somewhere. The die attach layer encountered popcorn in this case due to lack of cohesive energy as well the delamination happening between the green compound and die surface with Silicone Nitride passivation. The green BOM in the case can survive basically under general lead free reflow 255~260℃, but if one intends to go to higher reflow temperature, an improvement of adhesion of green compound with different die passivation and cohesive energy of die attach layer will be needed.

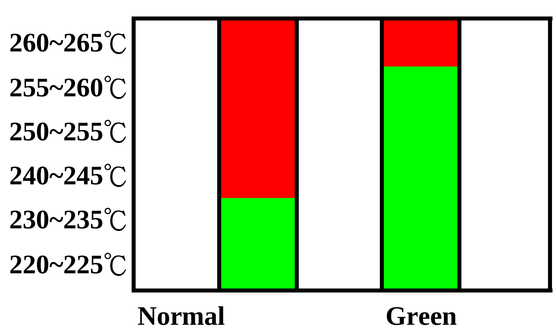


Figure 3 The capability limitation to withstand high temperature reflow between different BOM sets.

Based on the above discussion, the normal BOM set is not recommend for lead free soldering applications above 240℃, in other words, the normal BOM will have a high risk of failure in lead free soldering. The green BOM is recommended for higher temperature lead free soldering due to more robust integrity.

2. Moisture uptake testing

Figure 4 showed the moisture absorption curve under 30℃/60%RH circumstances and desorption curve at baking 125℃ over the time. The weight percentage of moisture absorption was higher in normal material set than that in Green material set, as is shown in the moisture desorption curve under 125℃ baking. The phenomenon is explained because the higher moisture material will produce higher vapor pressure under high temperature reflow soldering like 240 or 260℃, so that the thermal stress induced in the package will lead to the risk of interfacial delamination between individual material, package cracking and popcorning.

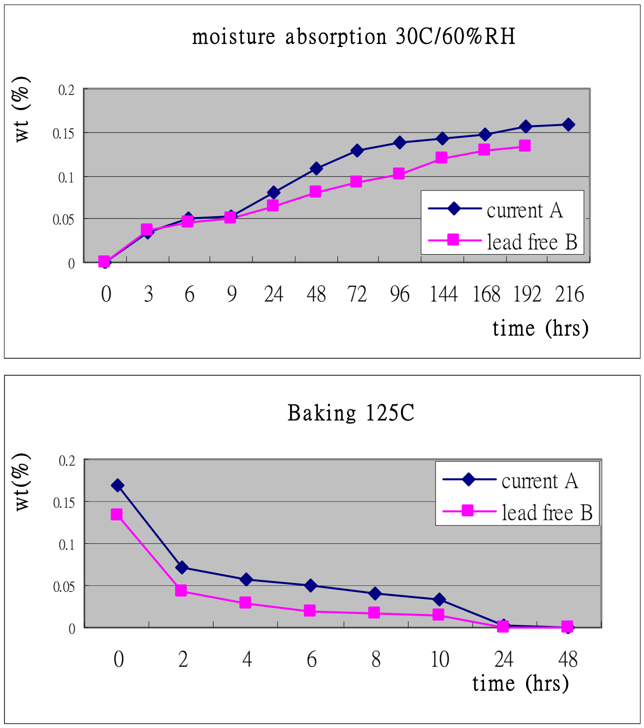


Figure 4 The moisture absorption and desorption curve comparison between two material set.

3. RoHS and green compliance testing

The 6 substances Pb/Hg/Cd/Cr^{+6}, PBBs and PBDEs regulated by EU RoHS directive will not be allowed to exist on the homogeneous material basis. The molding compound, die attach, solder ball and substrate were identified as homogeneously compliant in this case, as shown in figure 5.

Table 5 showed the testing result with the certain wet digestion preconditioning and corresponding analysis. Obviously, the compound, substrate and die attach and SAC ball were RoHS compliance whether they were normal or green types, but there was 40ppm Pb found in the SAC ball illustrating Pb contamination everywhere.

Table 6 shows halogen presence and Sb2O3 testing result for molding compound and substrate. The normal compound contained a high concentration of Br from BFR and ion impurity and the presence Sb2O3 to be flame retardant in order to achieve UL94 V0 performance. In the case, halogenated flame retardant other than known PBBs/PBDEs was usually identified as confidential technology for material supplier, so that only halogen element can be judged instead of chemistry formulation. While in green compound, around 480ppm Cl element was found and no detection of Br and Sb was found, which meant the result was still a halogen free compliance with Br+Cl <1500ppm as described in in IEC 61249-2-21..

Figure 5 The homogeneous compliance of molding compound after grinding.

The normal substrate contained high concentration Cl and Br but was free of Sb_2O_3 as a flame retardant to achieve UL94 V0 performance. Cl usually was contained in the solder mask to function as a dye. In the green substrate, Cl and Br content were reduced to the lowest level possible and replaced by the other flame retardant such as Phosphorus, Nitride or metal hydroxide to achieve UL94 V0 level. The halogen element detected here might not be from flame retardant but from existing ion due to IC testing.

Table 5. The RoHS testing result in raw material

Substances		Pb	Cd	Hg	Cr+6	PBB	PBDE
Analysis method		ICP	ICP	ICP	UV	GC	GC
Compound	N	ND	ND	ND	ND	ND	ND
	G	ND	ND	ND	ND	ND	ND
Substrate	N	ND	ND	ND	ND	ND	ND
	G	ND	ND	ND	ND	ND	ND
Die attach	N	ND	ND	ND	ND	ND	ND
	G	ND	ND	ND	ND	ND	ND
Solder ball	N	**NA**	ND	ND	ND	ND	ND
	G	**40**	ND	ND	ND	ND	ND

Unit: ppm, ND: <2ppm

Table 6 Green testing result in compound and substrate

Substances		Cl	Br	Sb	Sb_2O_3
Analysis method		IC	IC	ICP-AES	ICP-AES
Compound	N	ND	6690	47600	57000
	G	480	ND	ND	ND
Substrate	N	560	30600	ND	ND
	G	88	40	ND	ND

Unit: ppm, ND: <2ppm

Conclusion

Electronics for environmental preservation is an inevitable trend in the world. Not only RoHS compliance must be satisfied due to legislative driving, but one must also consider green compliance for customized requirements such as halogen free and Sb_2O_3 free or other substances defined from various customers. Besides necessary RoHS and green compliance, the BOM set must also be able to survive under higher soldering temperature due to high melting point SnAgCu solders. Low moisture uptake, high adhesion capability with related material and mechanical behavior re-design in organic packaging material will be required for further improvement.

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RoHS and Green Compliance in IC Packaging

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RoHS/Green Compliance Activity in IC Packaging

Alloy Selection	Ball; Plating; Paste
Reliability	Package level; Board level
Material & Process Characterization	Die attach; Solder plating; Underfilling; Molding; Solder printing; Substrate; Ball mounting; Flux cleaning
Green Compliance Control	Toxic substances recognition; CAS*; Testing method identification; Compliance declaration
Regulation	Japan/Korea; US; Europe; China

*CAS: Compliance Assurance System : QC080000, IPC LF Process Certificate; SONY GP

Content

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- **Motivation from environmental and reliability perspective**
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- **Experiment (PBGA 35x35 as test vehicle)**
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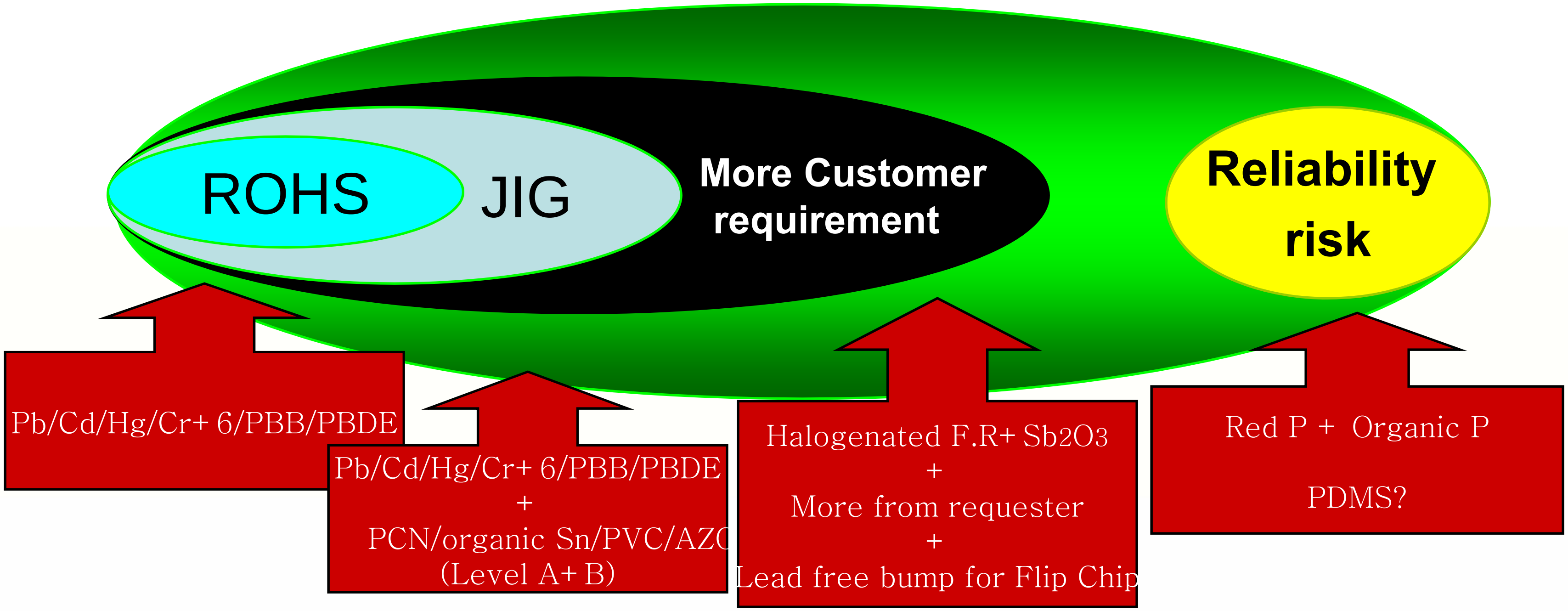
  - **RoHS and Green testing (Halogen + Sb2O3)**

- **Result and Discussion**

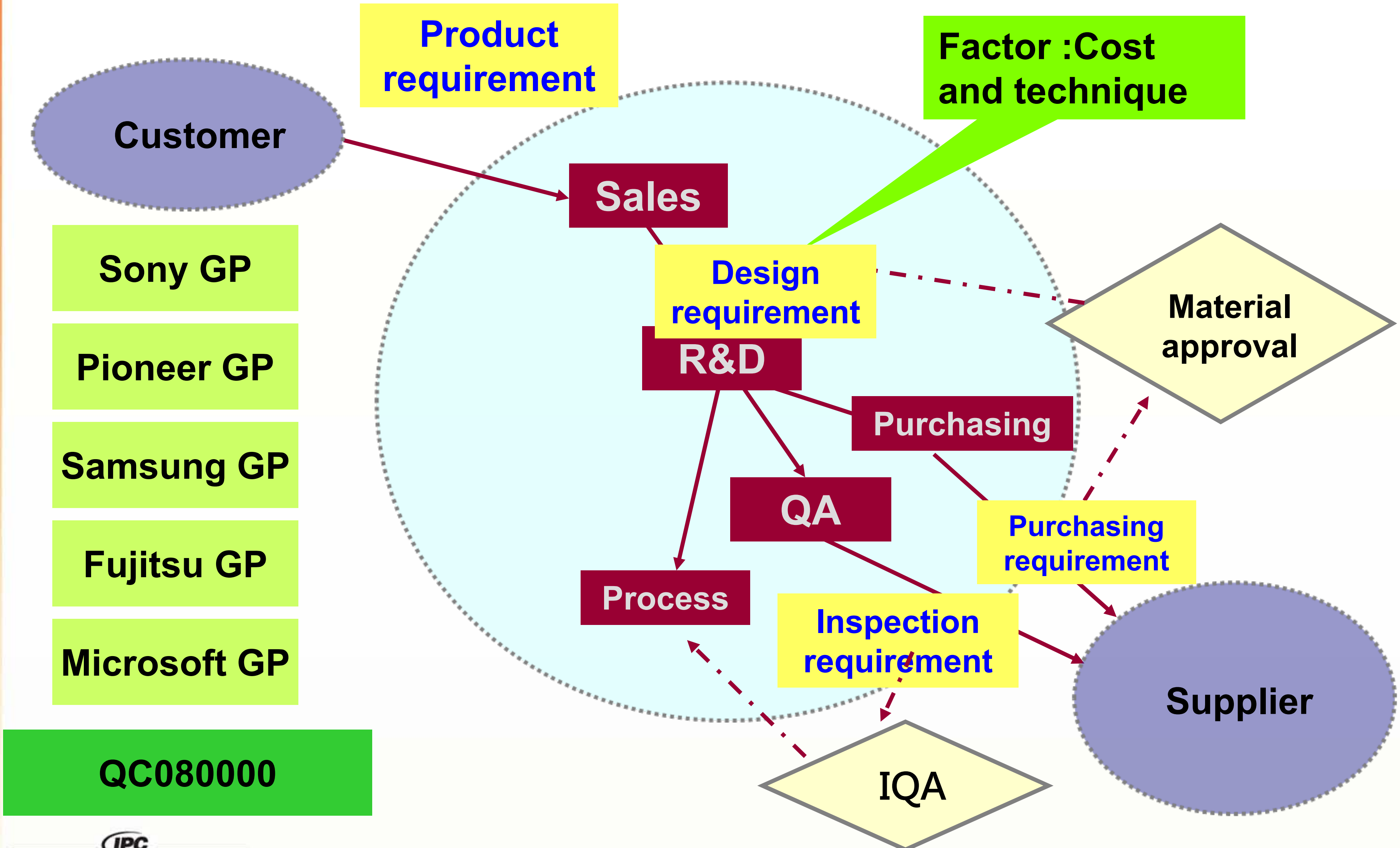
- **Conclusion**

Introduction-
Identification of RoHS v.s Green



- **Halogen free defined by** IEC 61249-2-21:
  1500 ppm maximum total halogens
  Cl <900ppm, Br<900ppm
- **Green : Environmental (RoHS + JIG A/B + REACH +More for customization) + Reliability concern**
- **RoHS : Environmental concern from 6 regulated substances**

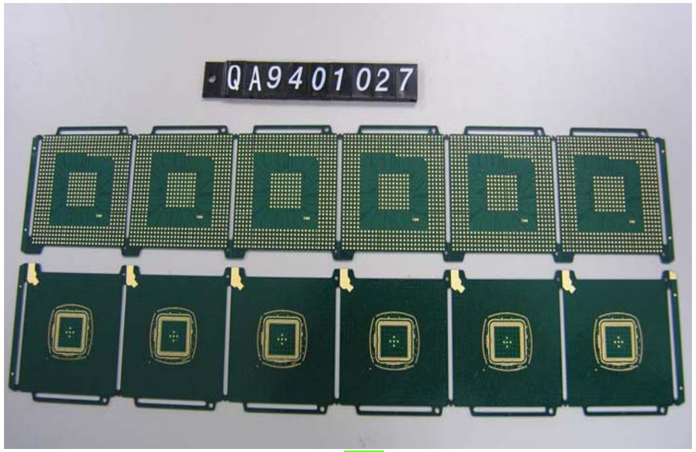
CAS : Compliance Assurance System

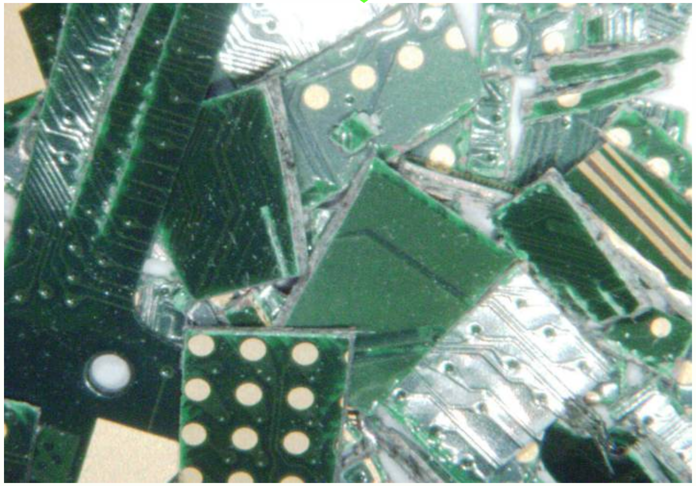


Example in homogeneous material grinding

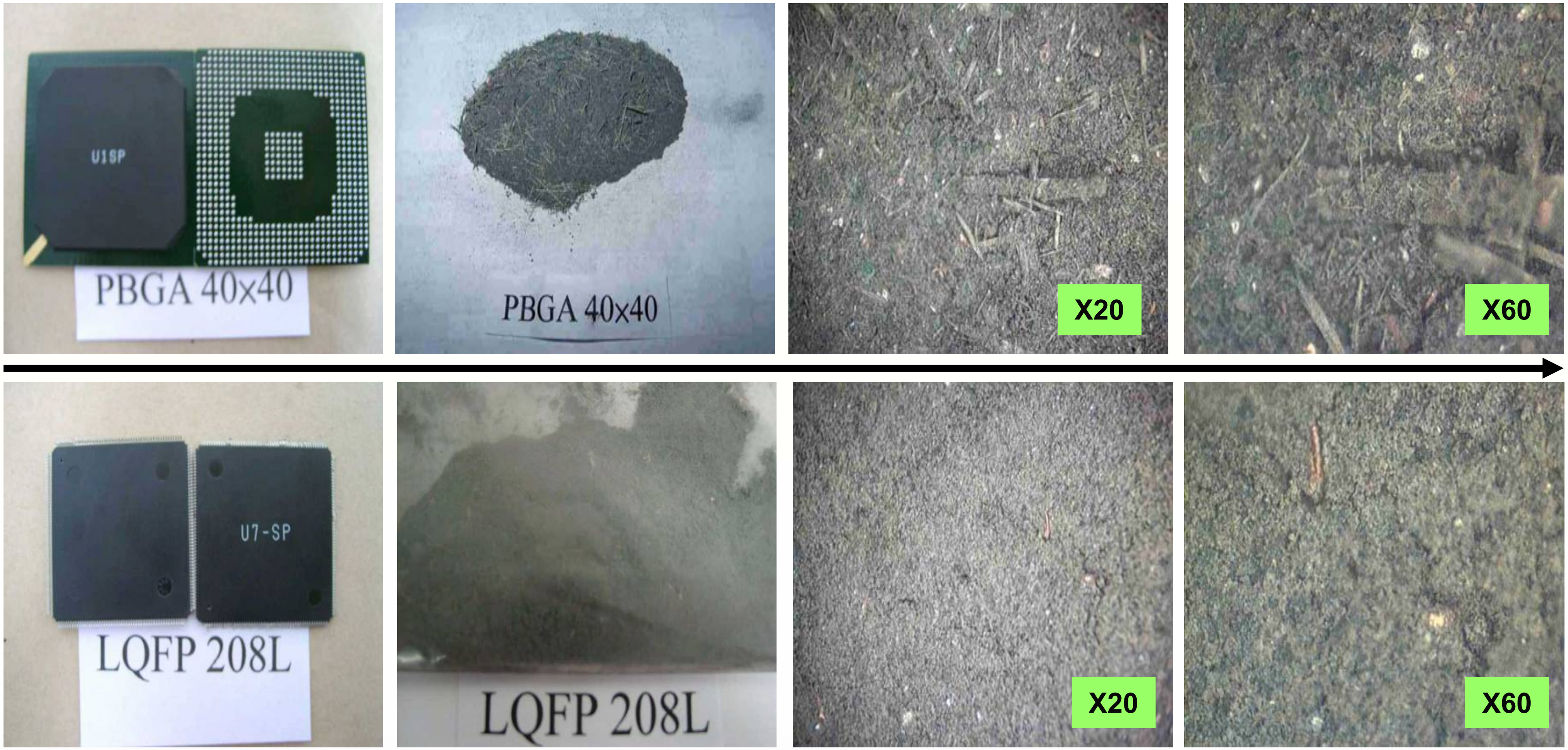
Molding compound

Substrate





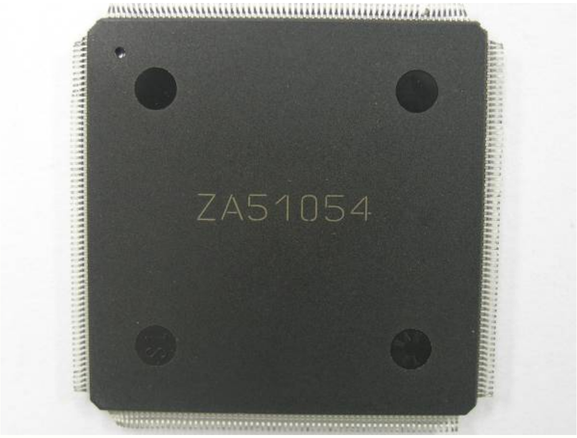
Example in grinding the entire package

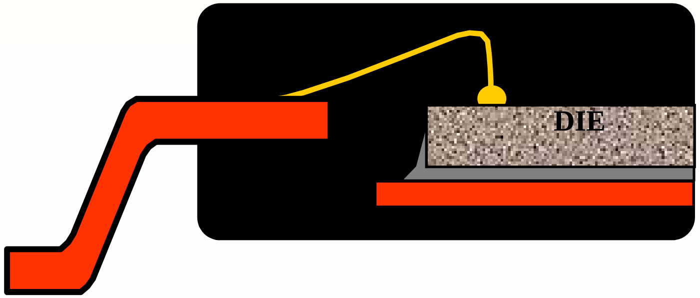


Package disassembly before testing will be recommended for more accuracy

Package or Material ?

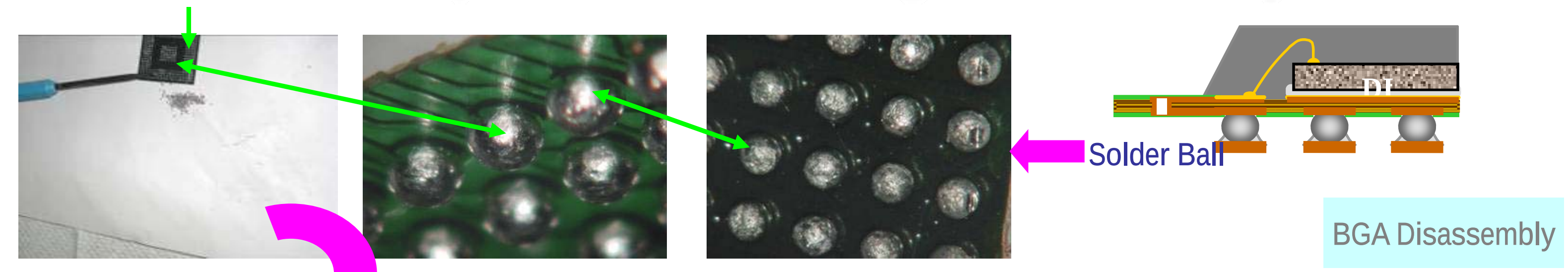
- **Example – QFP IC Package**
  - **Sn/Pb coating with 10~15% Pb is plated on lead-frame surface**
  - **Pb is 0.09% (900ppm) by weight based on package**
  - **This part would be compliant if the package is considered to be homogenous.**

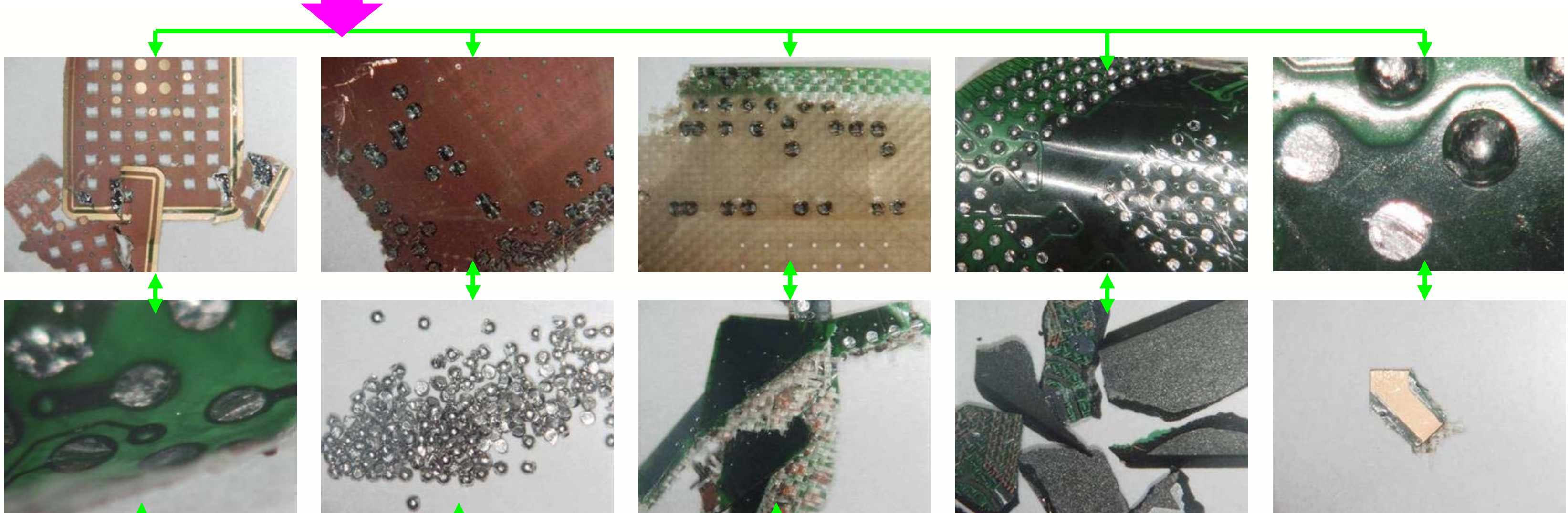


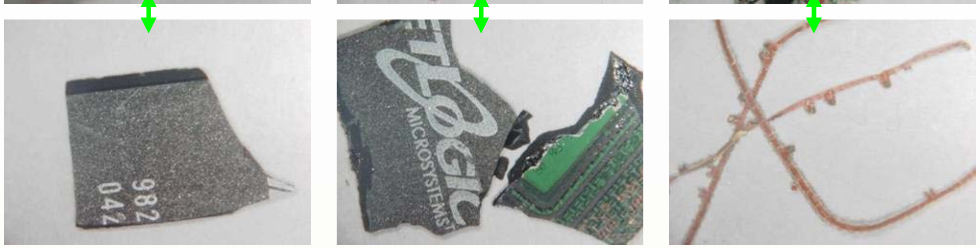


- **Actually, package is not on the homogeneous material basis in RoHS regulation.**

Example in BGA Package Disassembly







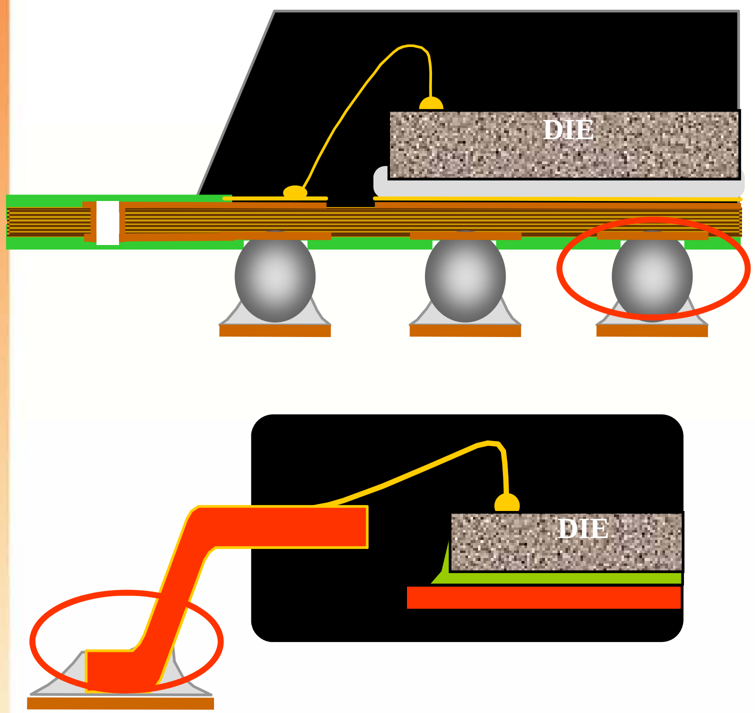
China RoHS

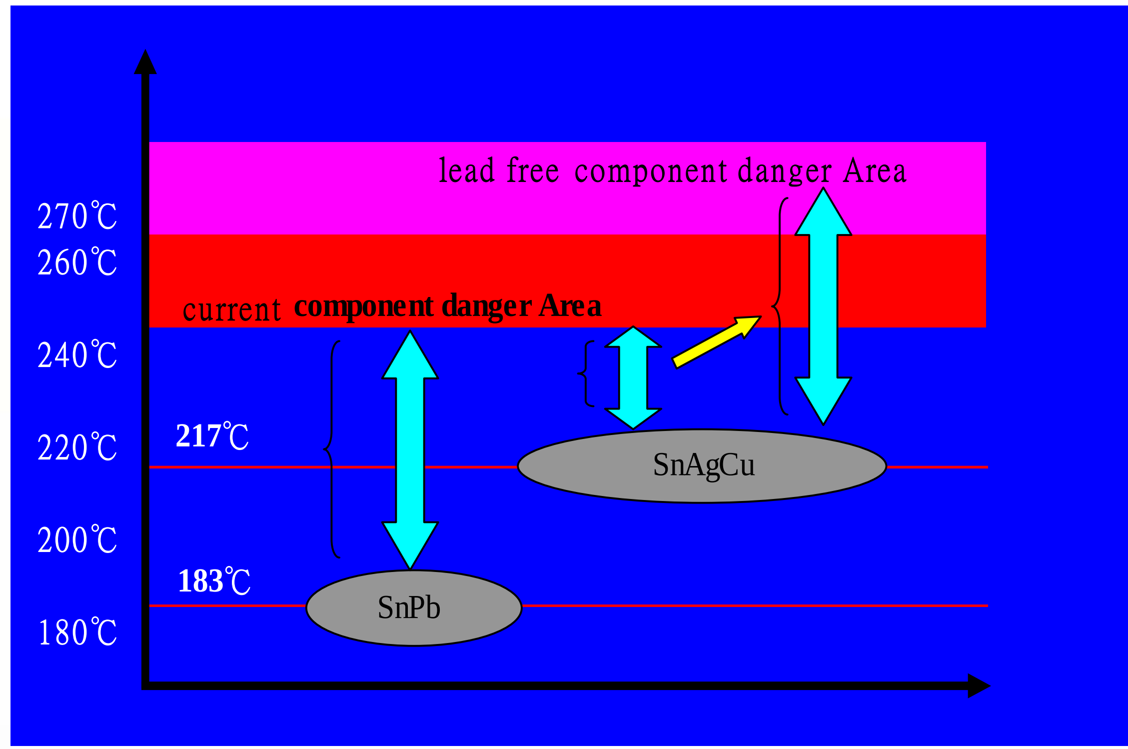
- **>4mm^3 : need dis-aasembly**
- **<4mm^3 : no need**

Refer from Jennifer Sun report

Motivation from reliability perspective

Sn-Pb interconnect → SAC Pb-free interconnect

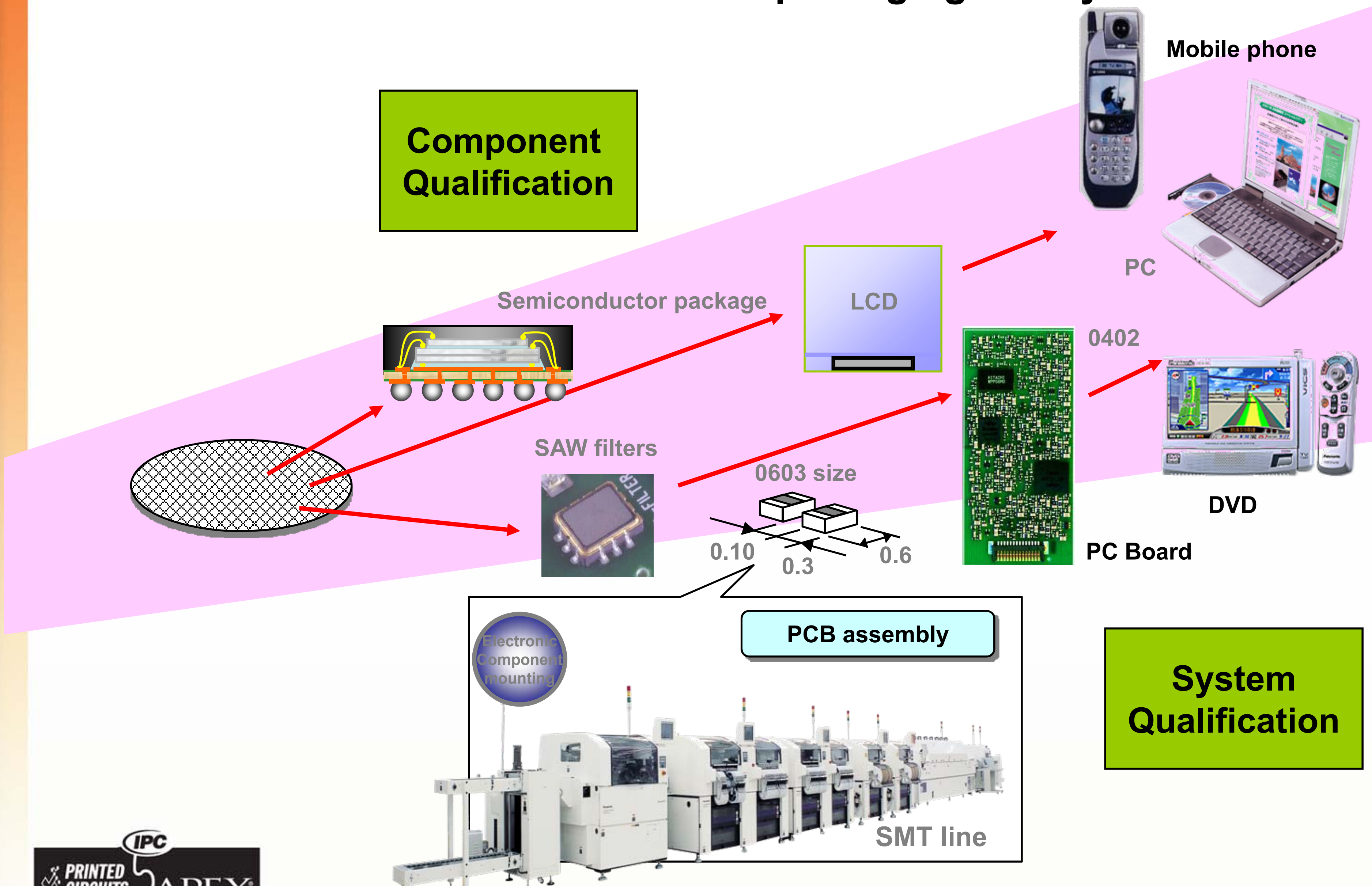




Stress generated = $\alpha . a^2/h^2 . P$
P: vapor pressure
a: package width
h : package height

- Interfacial adhesion degradation between materials
- Thermal stability endurance limit in organic material

Current lead free conversion issue in packaging and system level



More board level reliability data will be required to verify lead free package integrity

- JEDEC
- JEITA
- Customer spec

Component Qualification → **PCBA** → **System Qualification**

- IPC
- Moto
- HP
- Cisco
- NOKIA
- Apple

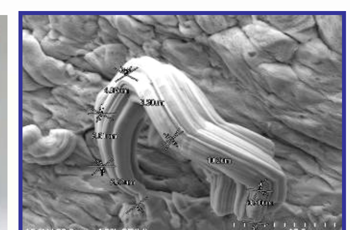
Bridge

2nd level qualification to approach real service application as possible

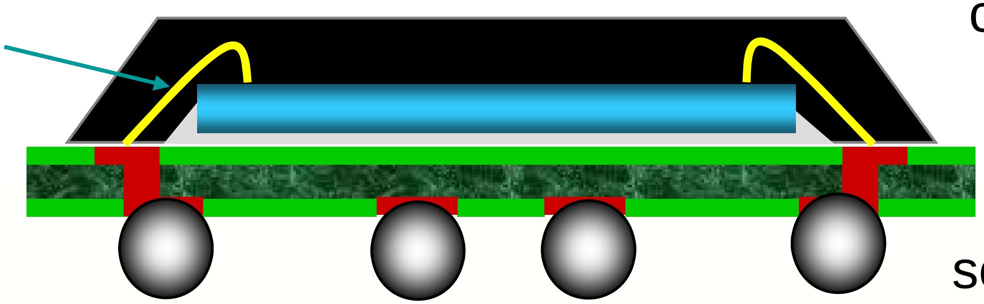
- Vibration
- Mechanical shock
- Bending test
- Thermal cycle
- Tin whisker on board
- Strain gage measurement

Simulate PCBA process

Major reliability concern
- Fine pitch
- High I/O
- High current carrier
- Low K (90/65/45nm)
- Unknown field application



Experiment
-test vehicle (PBGA 35x35)

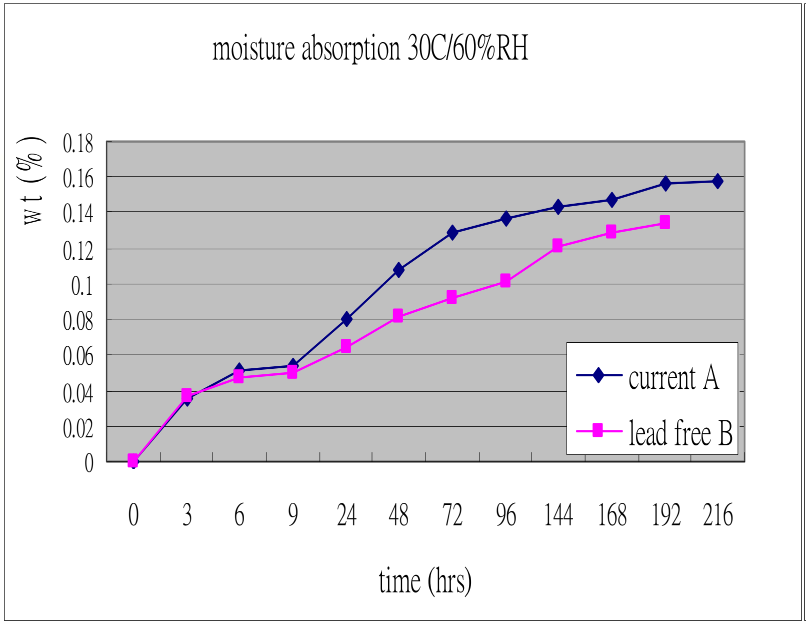


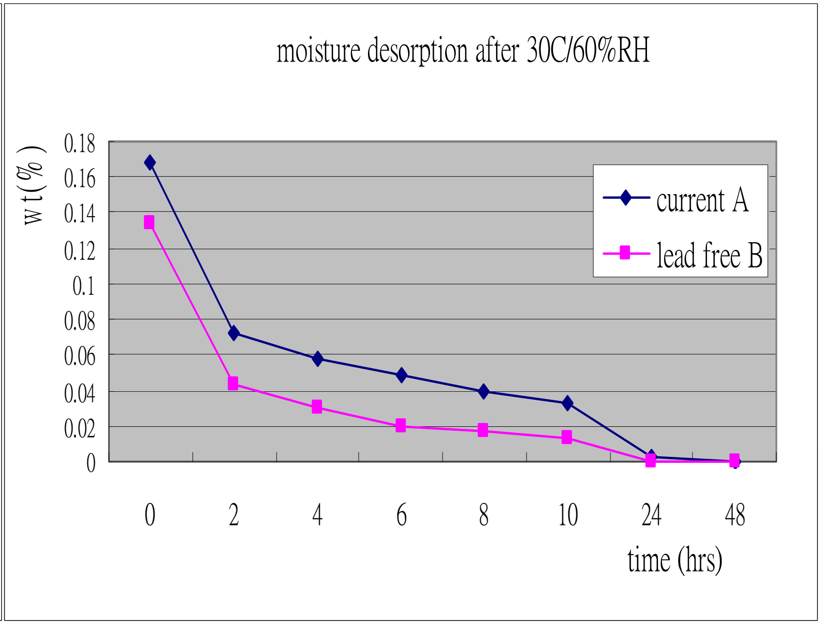
I/O count	**492**
Die size	**300x300 mil**
Min. I/O pitch	**1.27 mm**
Package Size	**35x35 mm**
Solder diameter	**0.75 mm**
Substrate	**4 (BT)**
Overall thickness	**2.33mm**

BOM	Normal	Green*
Molding compound	Normal	Green
Die attach	epoxy	hybrid
substrate	Normal	Green
Solder ball	E-SnPb	SAC405

***Green : RoHS+HF+SbF**

Package level reliability
Moisture absorption and desorption curve comparison at 30℃/60%RH for PBGA 35x35

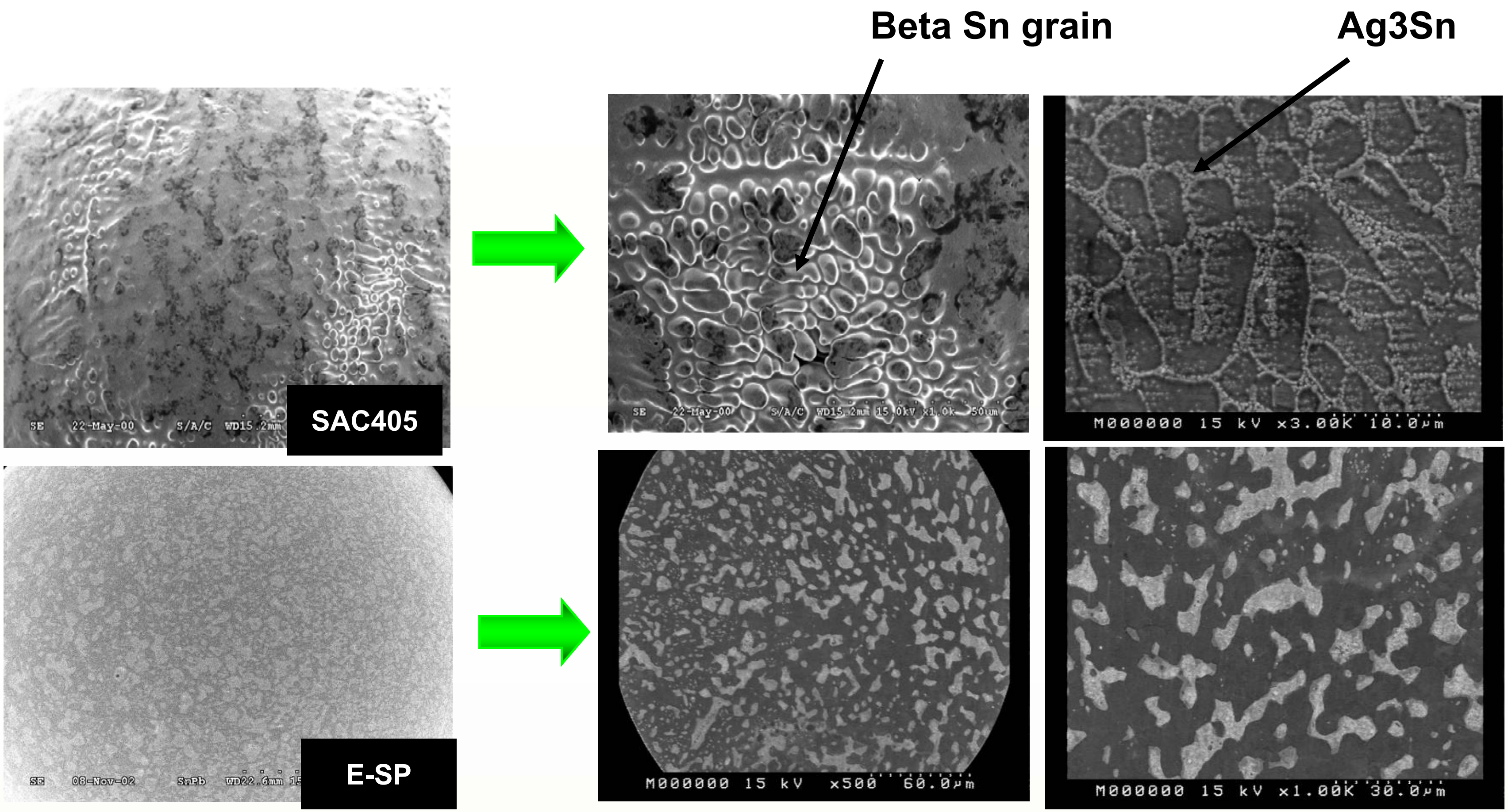




- **Moisture absorption rate in 30℃/60%RH**
  Normal BOM > Green BOM

- **Assumption :Vapor pressure inside package when 240 or 260℃reflow**
  Normal BOM > Green BOM

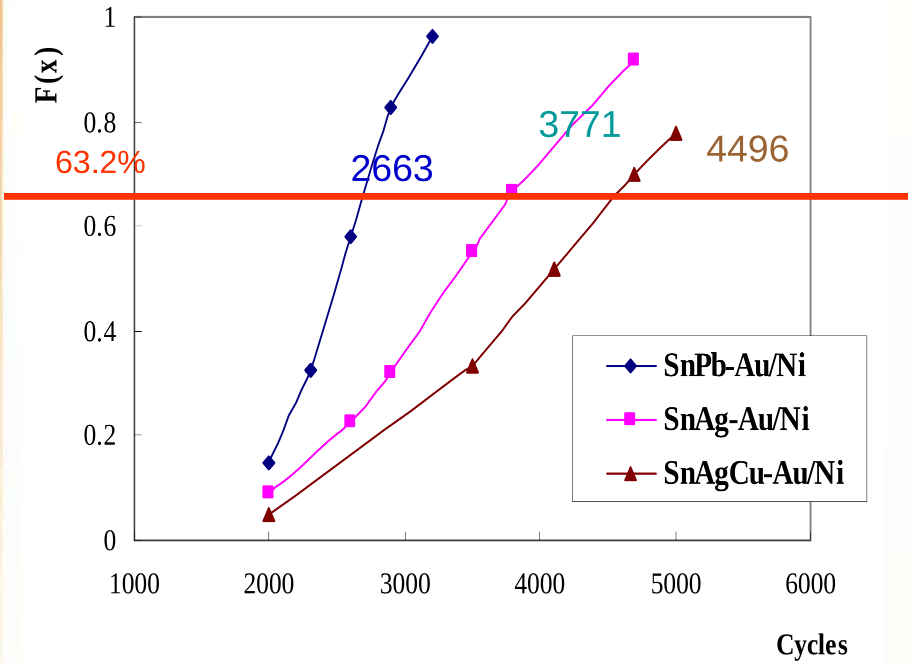
Material selection - solder ball

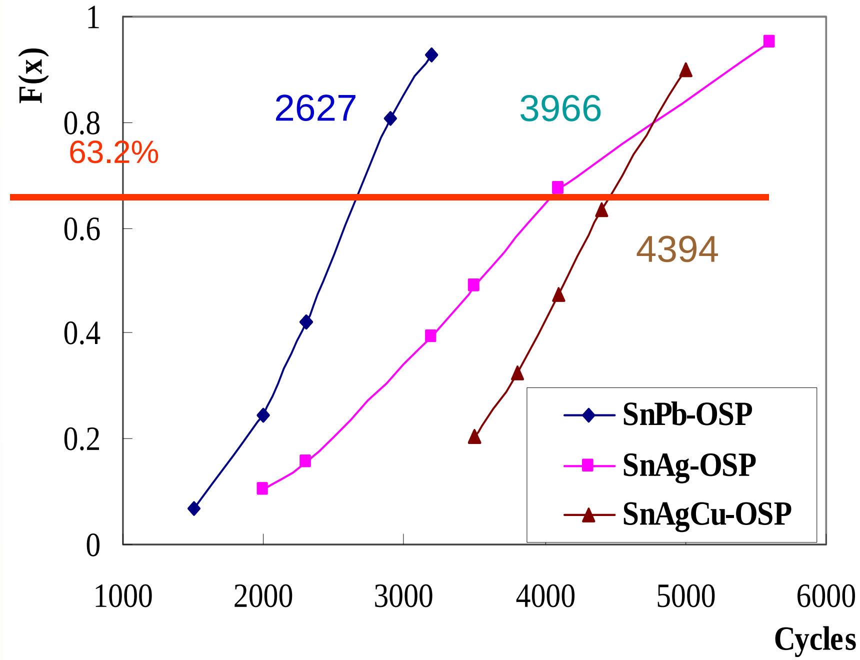


Board level experiment

Board level TCT (-40C/125C) to verify solder joint life

sample size	solder ball	solder paste	test board finish
12	Sn63/Pb37	Sn63/Pb37	Ni/Au
12	Sn63/Pb37	Sn63/Pb37	OSP
12	Sn/3.5Ag	Sn/3.5Ag	Ni/Au
12	Sn/3.5Ag	Sn/3.5Ag	OSP
12	Sn/4.0Ag/0.5Cu	Sn/4.0Ag/0.5Cu	Ni/Au
12	Sn/4.0Ag/0.5Cu	Sn/4.0Ag/0.5Cu	OSP





- SAC>SA>SP in characteristic life (63.2%)

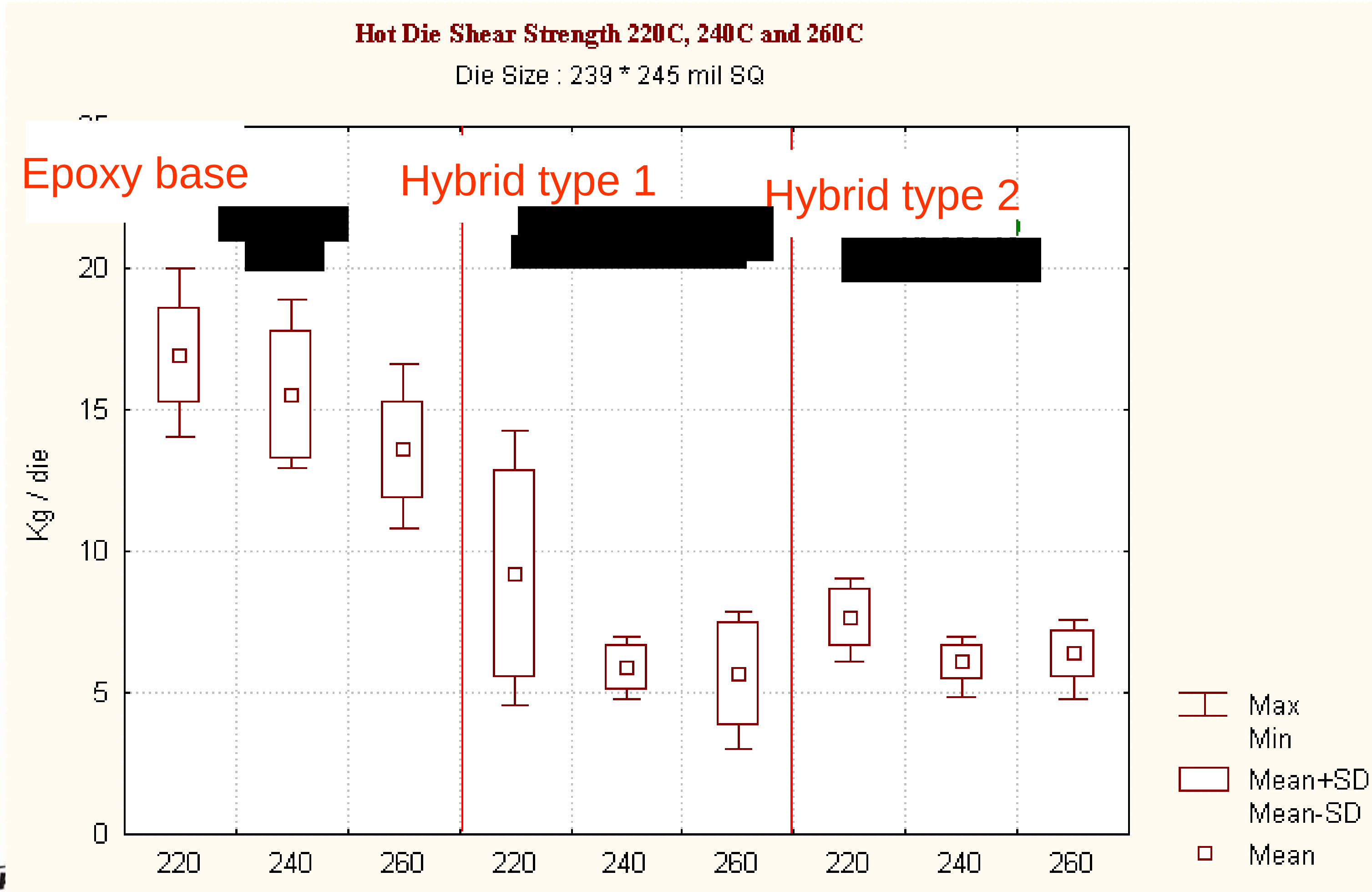
Material selection - Die attach

Resin type	epoxy base	hybrid type	NOTE
Weight loss@300'C	0.50%	0.60%	TGA
Glass transition temperature(Tg)	27℃	74℃	TMA
CTE1, below Tg	80ppm/'C	74ppm/'C	TMA
CTE2,above Tg	154ppm/'C	163ppm/'C	TMA
Modulus 25'C	1400Mpa	1000Mpa	DMA
Modulus 150'C	35Mpa	305Mpa	DMA
Modulus 200'C	21Mpa	297Mpa	DMA
Die shear stress	12kg	10kg	2x2 silicon die
Moisture absorption	0.50%	0.21%	85'C/85%RH
Cure Profile	Oven Cure	Fast Cure	

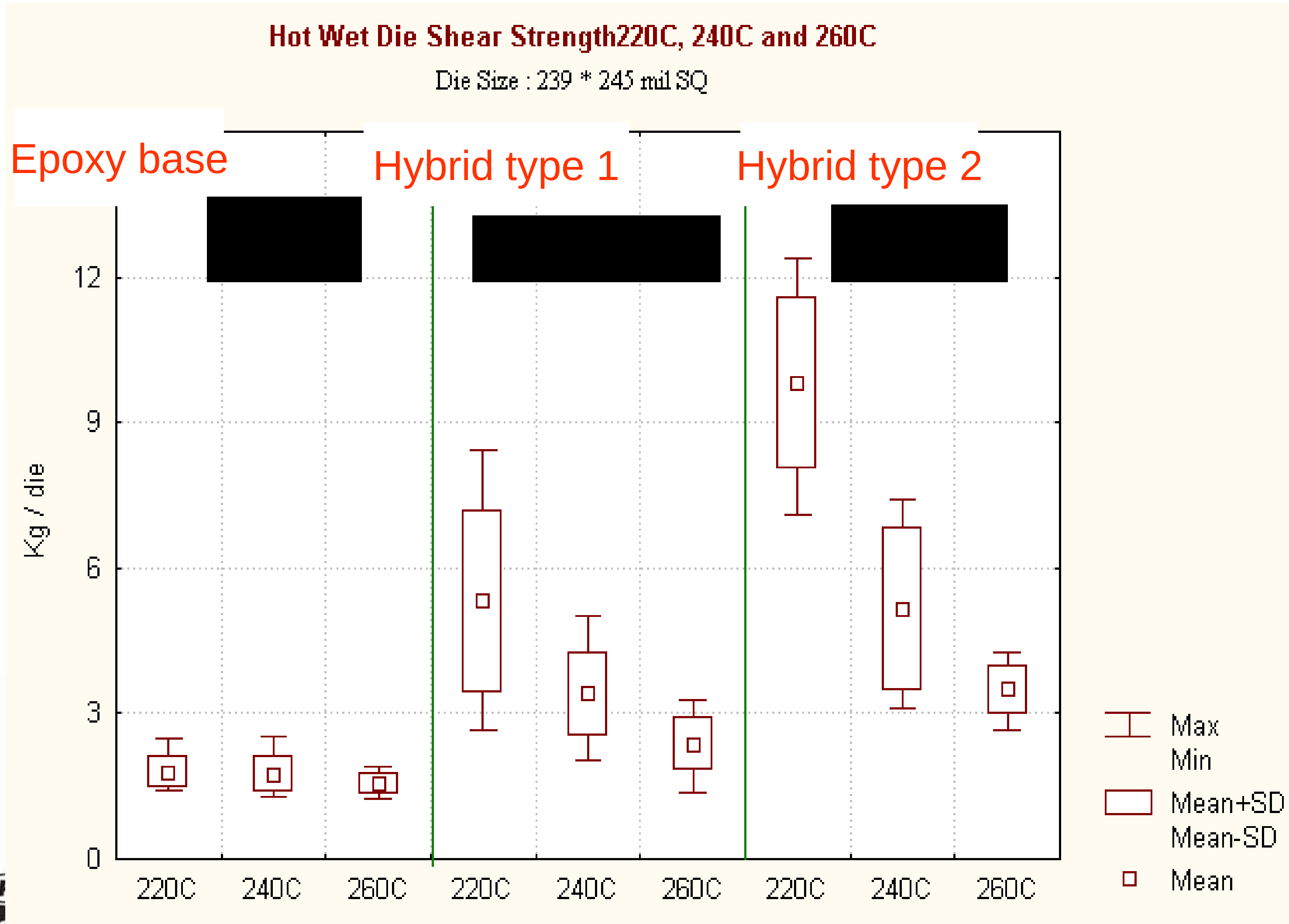
■**Moisture absorption and modulus at high temperature will be dominant consideration !**

The die attach comparison between hybrid and epoxy base

Hot dry die shear test



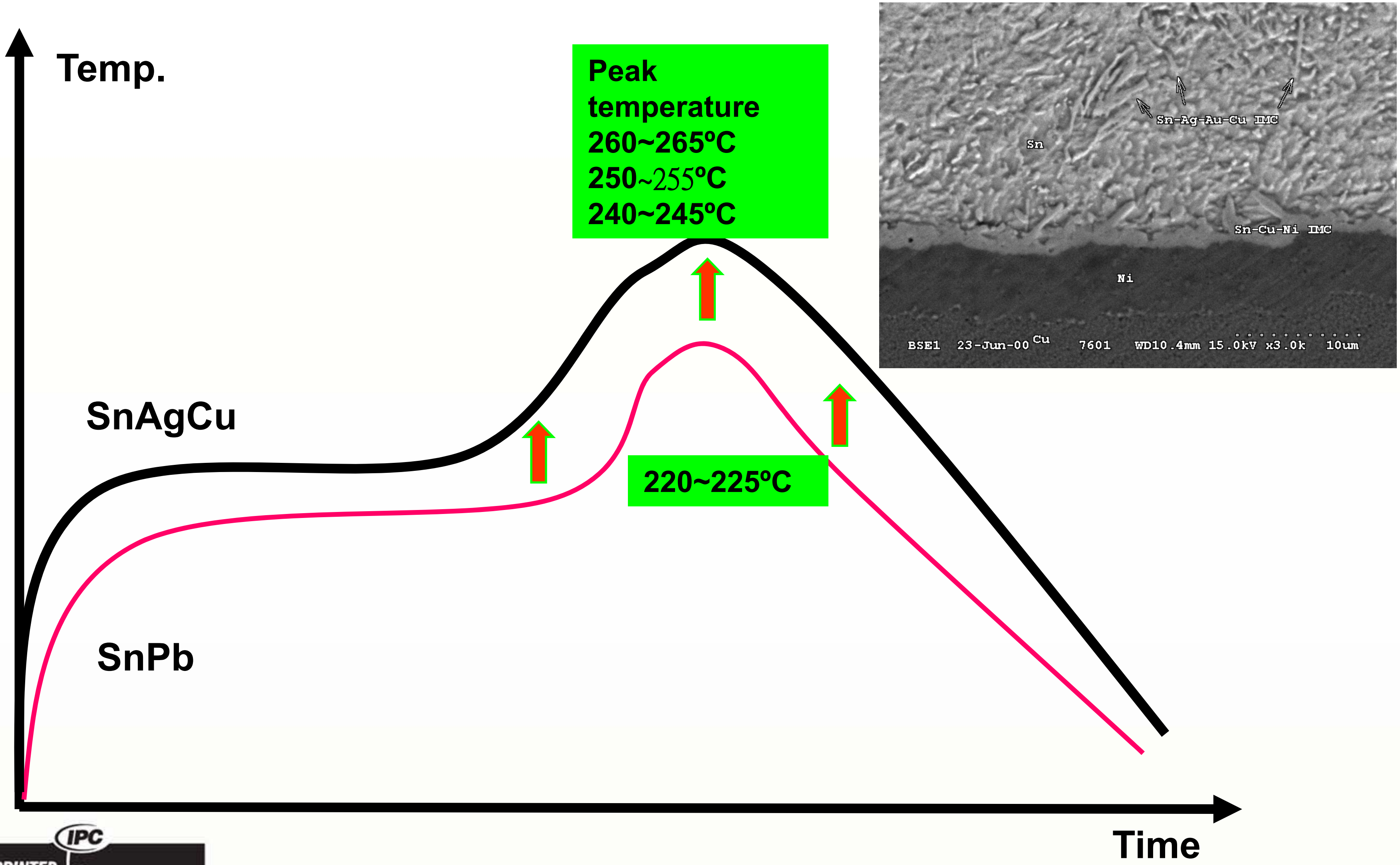
Hot wet die shear test after 85ºC/85%RH, 168hrs



Material selection - Molding compound

Compound		Normal	Green
Epoxy Resin		Multifunctional	Modified Multi.
Hardener		Multifunctional	Multifunctional
Flame Retardant		Br/Sb_2O_3	Br/Sb_2O_3 free
Filler Content	.wt%	84	90
Spiral Flow	cm	130	150
CTE - alpha1	X 10 -5/℃	1.4	0.8
- alpha2	X 10 -5/℃	4.7	2.8
Tg	℃	200	180
Flexural Strength 25degC	MPa	130	190
Flexural Strength 240degC	MPa	26	37
Flexural Modulus 25degC	GPa	14.5	27
Flexural Modulus 240degC	GPa	1.2	1.8
Water Absorption (PCT)	%	0.44	0.35

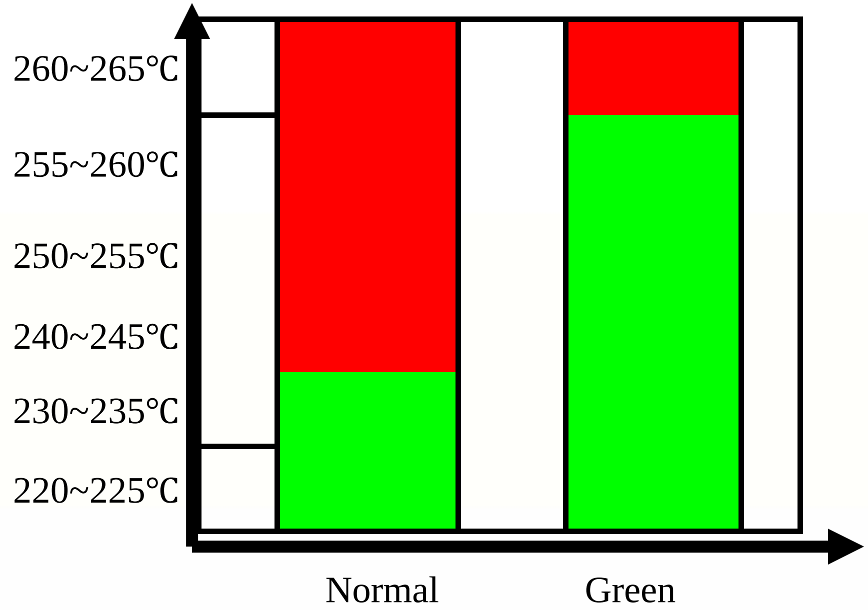
The reflow profile applied in the study



Result and Discussion
The failure rate under MSL3 with various reflow profile

BOM		Normal	Green
Molding Compound		Type A	Type B
Epoxy		epoxy	hybrid
Substrate Version		BT832+AUS5	BT832NB+AUS308
solder		E-SnPb	SAC405
Sample Size		45/each condition	45/each condition
Pre-condition	Visual Inspection	0/135	0/135
	SAT 1	0/135	0/135
	TCT 5 cycles	0/135	0/135
	Baking 125℃ , 24 hrs	0/135	0/135
	30℃/60%RH , 192hrs	0/135	0/135
	Reflow 220-225℃ x 3 cycle	0/45	na
	Reflow 240-245℃ x 3 cycle	10/45	na
	Reflow 250-255℃ x 3 cycle	40/45	0/45
	Reflow 255-260℃x 3 cycle	na	0/45
	Reflow 260-265℃x 3 cycle	na	2/45

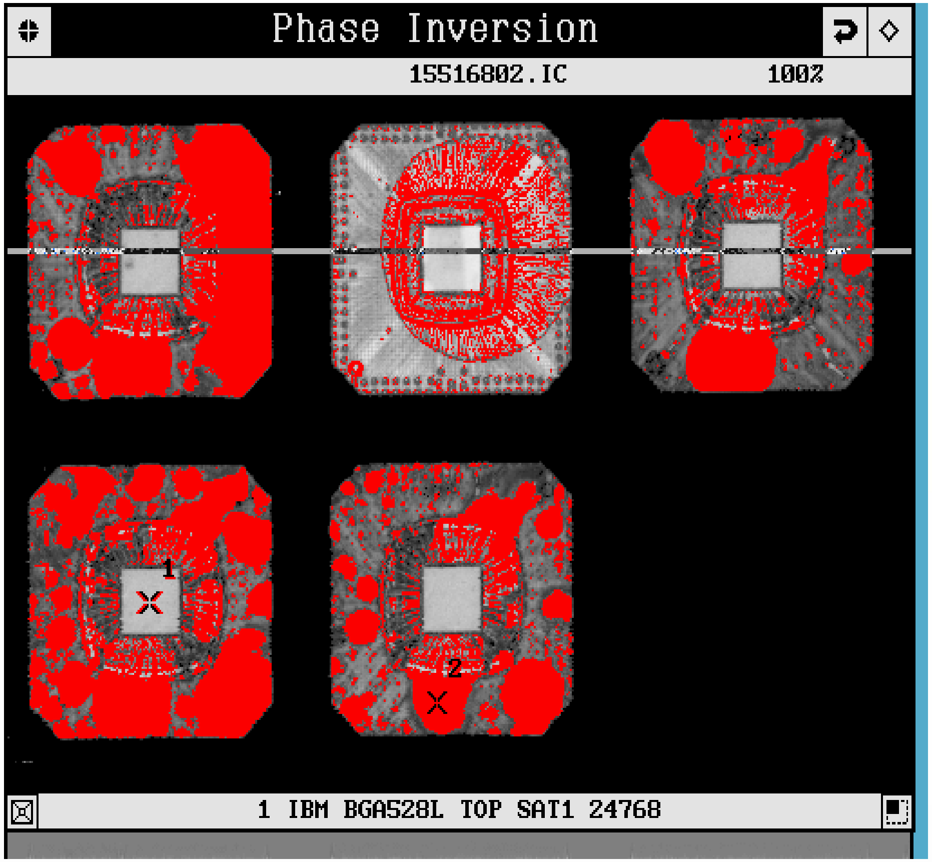
Failure Mode Mapping

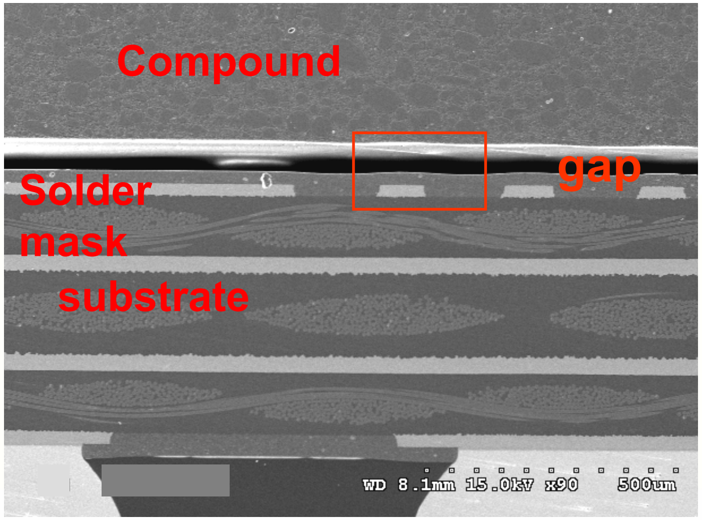


	Normal	Green
Delamination between SM and compound	V	
Delamination in die attach interface	V	
popcorn in die attach layer		V
Delamination between die and compound	V	V

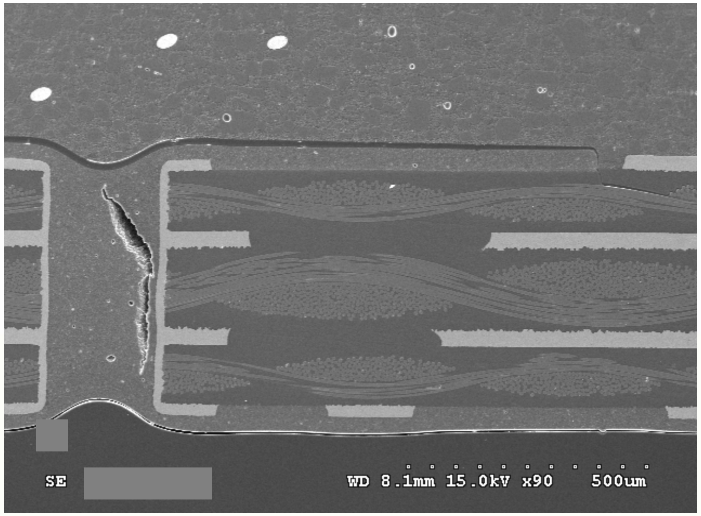
Failure mode-

Delamination between molding compound and SM

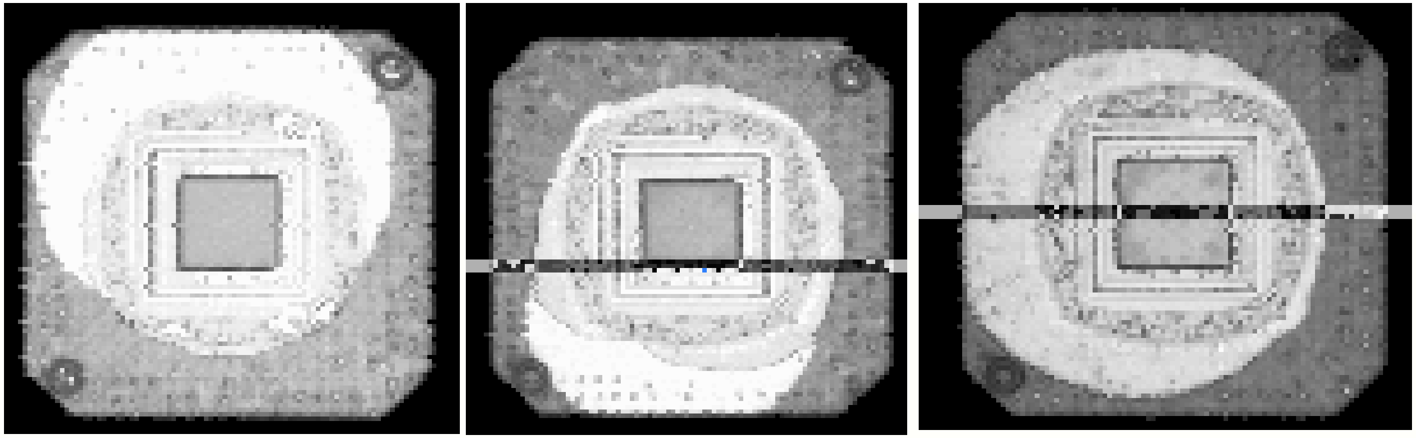


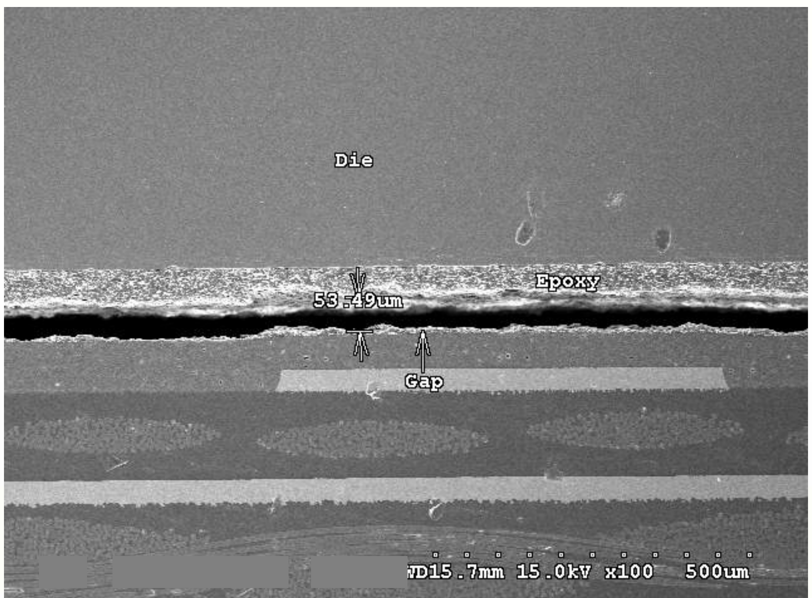


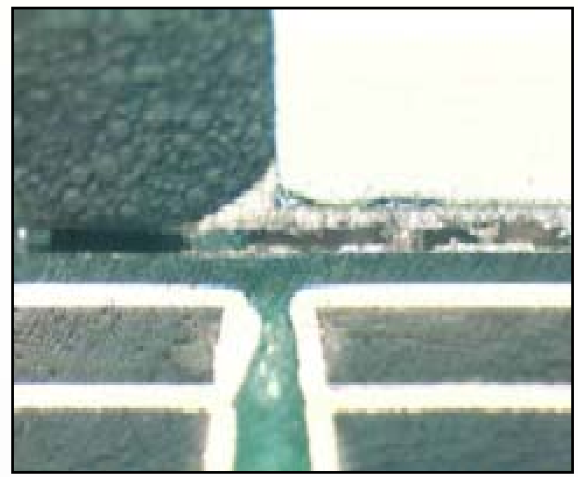
Weak adhesion between compound and SM at higher temperature



Failure mode-
Delamination in die attach interface to SM

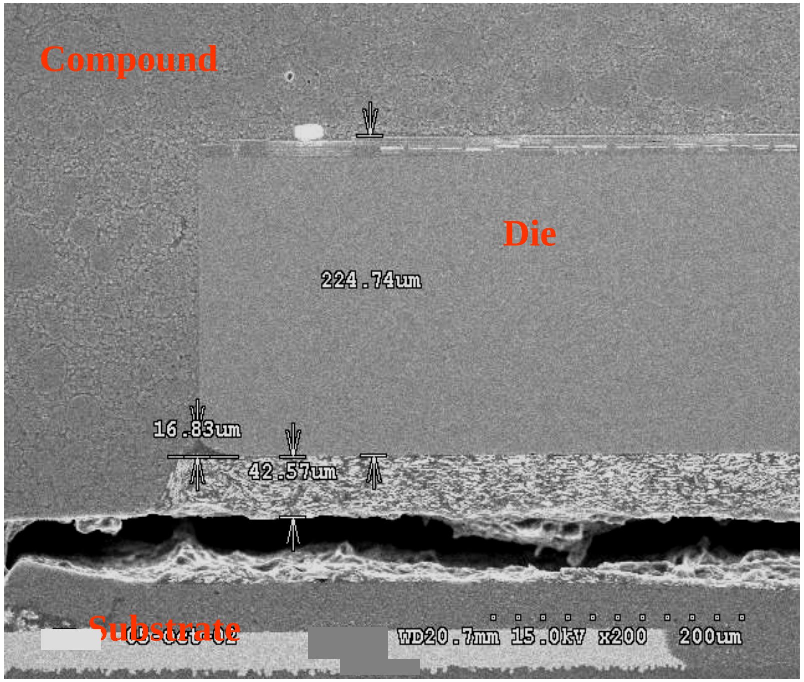


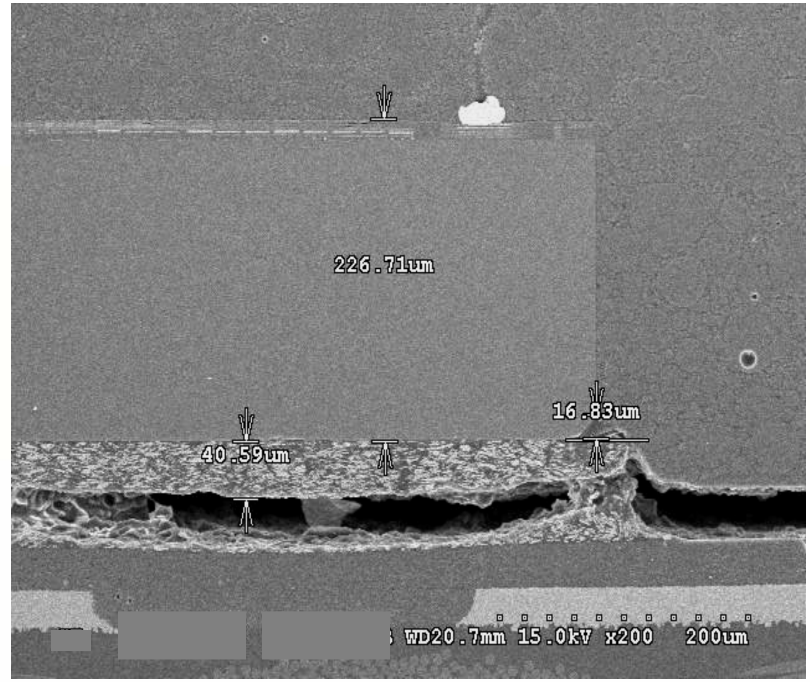




Weak adhesion between die attach and solder mask

Failure mode-
Popcorn in die attach layer





Not enough cohesive energy in die attach layer even if better adhesion to SM interface.

RoHS testing result in raw material

Substances		Pb	Cd	Hg	Cr+6	PBB	PBDE
Analysis method		ICP	ICP	ICP	UV	GC	GC
Compound	Normal	ND	ND	ND	ND	ND	ND
	Green	ND	ND	ND	ND	ND	ND
Substrate	Normal	ND	ND	ND	ND	ND	ND
	Green	ND	ND	ND	ND	ND	ND
Die attach	Normal	ND	ND	ND	ND	ND	ND
	Green	ND	ND	ND	ND	ND	ND
Solder ball	Normal	NA	ND	ND	ND	ND	ND
	Green	40	ND	ND	ND	ND	ND

Unit: ppm

Green testing result in compound and substrate

Substances		Cl	Br	Sb	Sb2O3
Analysis method		IC	IC	ICP-AES	ICP-AES
Compound	Normal	ND	6690	47600	57000
	Green	480	ND	ND	ND
Substrate	Normal	560	30600	ND	ND
	Green	88	40	ND	ND

Unit: ppm

- **Green material still contain certain % halogen, but below 900ppm.**

Summary and Conclusion

■In terms of material selection, green materials with lower moisture uptake and higher interfacial adhesion with related materials outperform normal materials to achieve higher reflow temperature resistance, which illustrate that material suppliers have considered the balance of environmental material development from the environmental and technical perspectives.

■Board level reliability test will be necessary to validate emerging IC package integrity due to the evolution trend in high I/O, fine pitch and large or thin die/package size and lead free requirement.

■Green compliance rather than RoHS compliance will be mainly for marketing driving. The compliance testing and acceptance criteria is still under debate in the industry. Work together among industry to identify methodology and criteria for consensus will be expected.

Thanks for your attention !