PCB Pad finish 방법에 따른 solder의 Board level joint reliability

이 왕 주
(삼성전자(주))

Board level joint reliability of differently finished PWB pad

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Part I
General Knowledge of Board Level Joint Reliability

Introduction

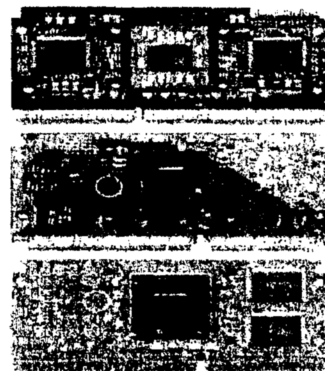
- The reliability of the solder joint of electronic components to the PCB may be required not only extensive physical stress testing but also high reliable joint quality by customers.

- The stress testing is to ;
  Qualify products for specific use categories and/or for specific use environments.

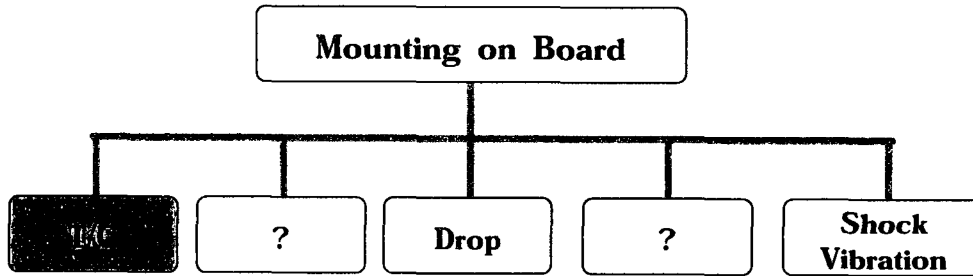
Why BLR ?

- Most packages are using as board mounted environment.

- Customers require component reliability as well as BLR.



BLR Test items & conditions



❑ **BLR Test Items and Conditions**
vary according to user's environment /requirements.

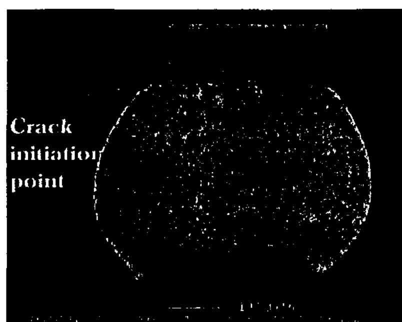
✓ **For Handheld Devices**
Drop Test / Shock and Vibration Test are important

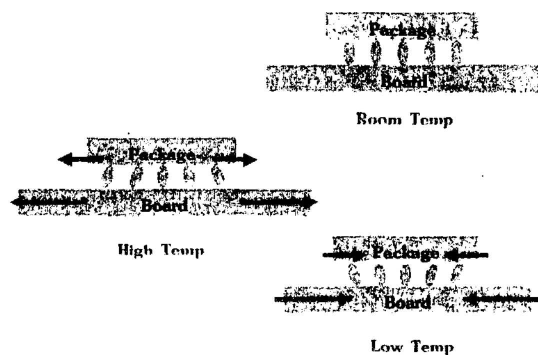
✓ **For In-house Devices**
Lifetime test is more important than mechanical test.

Failures of BL-SJR

❑ **Failure by Thermal Stress**

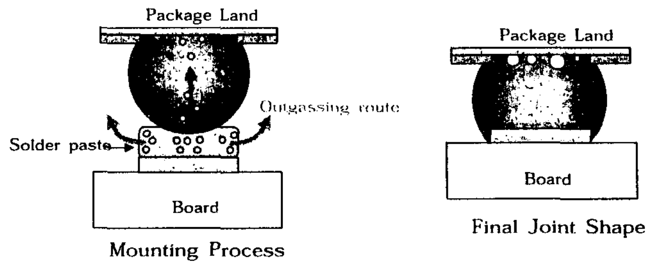
CTE mismatch between package and PCB induces thermal stress during TC and the thermal stress cause Solder Joint Crack.





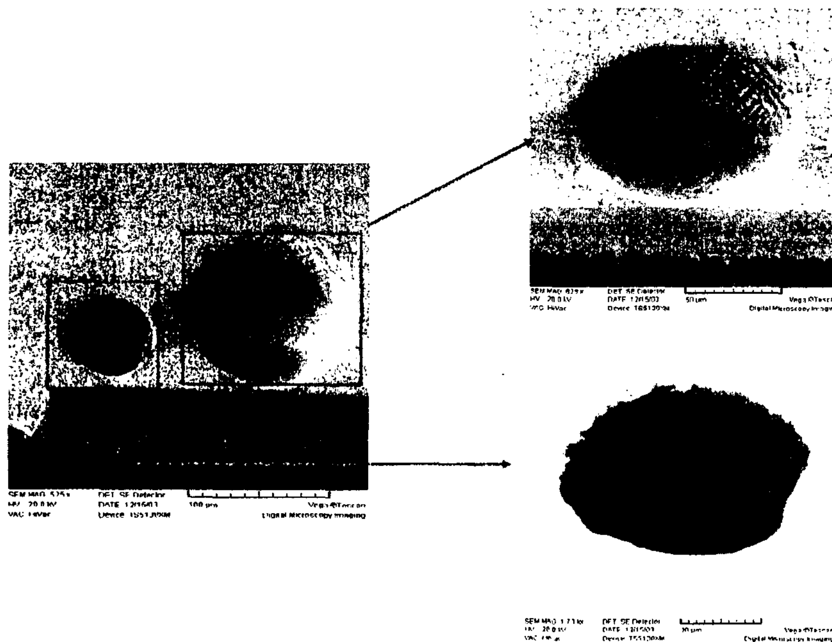
❑ Failure by Voids

Voids are formed during Soldering



Failure by void

❑ Internal structure of void



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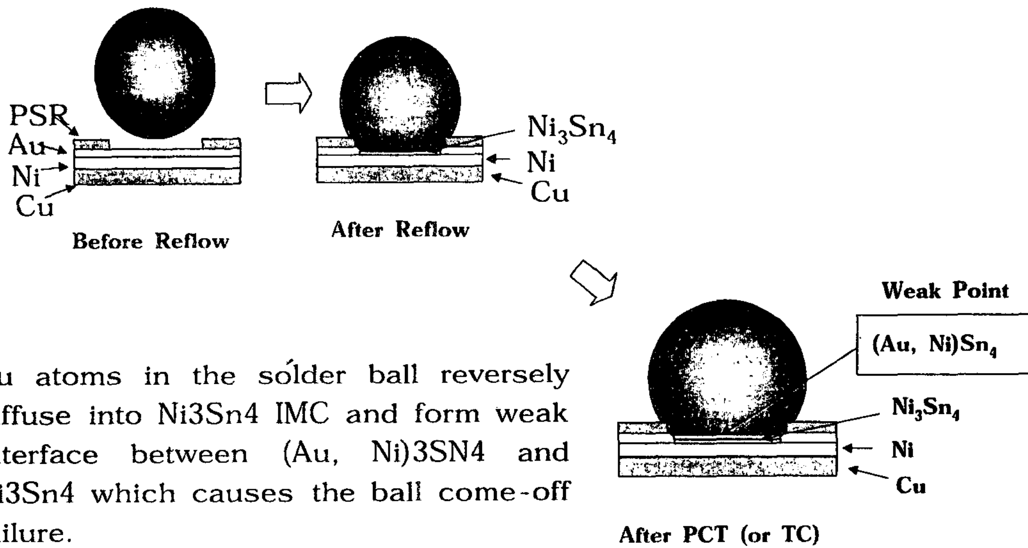
❑ Au Embrittlement



Au atoms in the solder ball reversely diffuse into Ni3Sn4 IMC and form weak interface between (Au, Ni)3SN4 and Ni3Sn4 which causes the ball come-off failure.

❑ Failure by Mechanical Stress

✓ **Crack by drop(Impact) usually occurs at interface between Pad and IMC**

✓ **Crack by bending usually occurs at interface between IMC and bulk solder**

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Crack Driving Factors

- ☐ Global CTE Mismatch between Package and Board
- ☐ Pad Structure (SMD,NSMD), Pad finish (OSP, Ni/Au finished)
- ☐ Mounting Type (Single, Staggered, Dual)
- ☐ Chip, Package Dimension
- ☐ Solder Composition, Thickness of IMC (Cu_6Sn_5, Ni_3Sn_4 ,etc.)
- ☐ Solder material (Elastic, Plastic & Creep Behavior)

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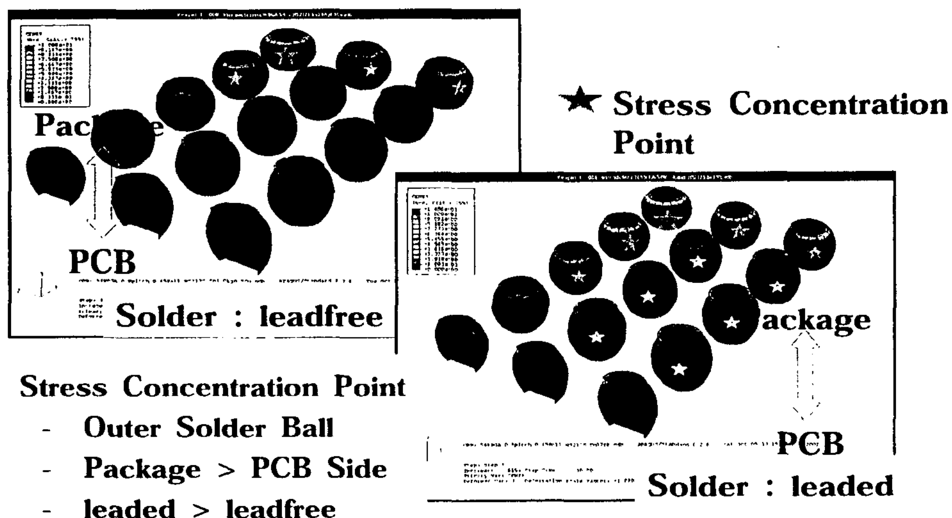
General Solutions for Improving Solder Joint Rel.

☐ Stress Simulation



- Stress Concentration Point
  - Outer Solder Ball
  - Package > PCB Side
  - leaded > leadfree

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❑ CTE Matching

✓ Package CTE ↑
✓ Board CTE ↓

L
C/L

$$\text{Strain} \propto \Delta CTE * \Delta T * \frac{L}{h}$$

■ Increasing CTE of Package

✓ Chip Portion ↓ (Size and/or Thickness)

✓ PCB Substrate Portion ↑ (Thickness)

✓ Use Large CTE EMC

■ Decreasing CTE of Board

❑ Solder Joint Size and Shape

✓ Joint Height ↑
✓ Joint Shape Optimization

■ Joint Height and Shape

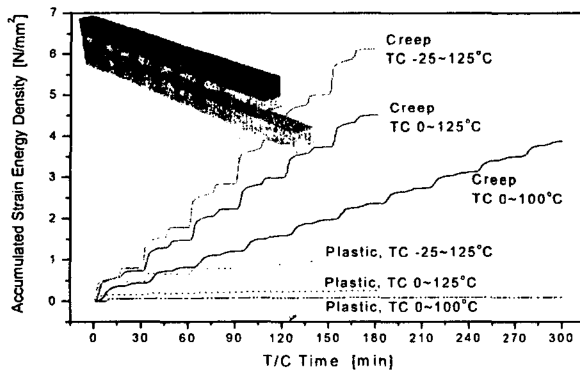
✓ Increase ball height as high as possible

■ Joint Strength

✓ Solder Strength : SnPb < SnAg, SnAgCu...

✓ Ball Land Design : Land Size, SMD vs. NSMD

❑ Temperature Range(ΔT)



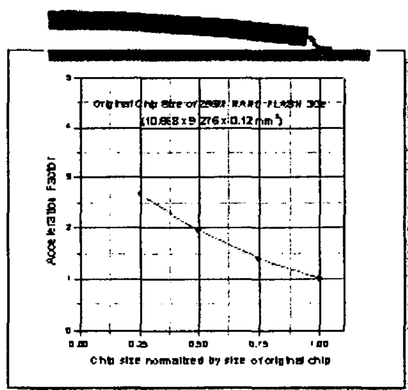
Δ T increase → TC life decrease

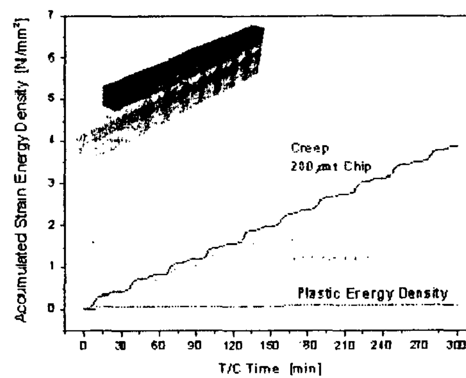
For equal Δ T , The higher T_{max}(or T_{min}), The less TC life.

ex) 0~125°C < -25~100°C < -50 ~ 75°C → Better SJR

❑ Chip size and Chip thickness

✓ Chip Size **✓ Chip thickness**





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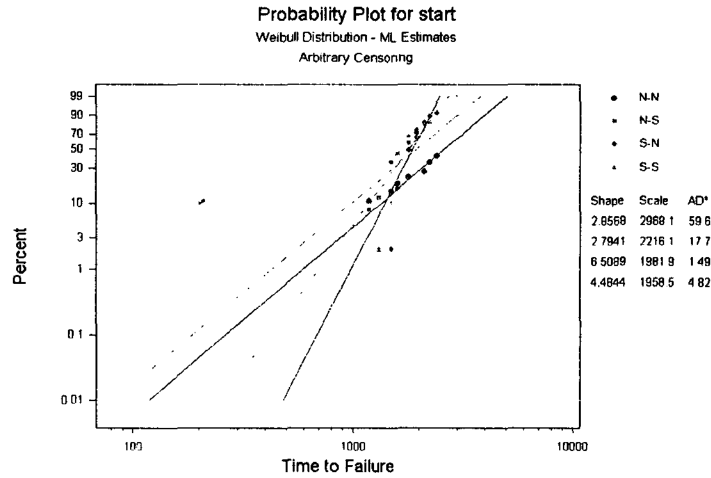
❑ NSMD vs. SMD for TC

✓ **Generally, the ranks for T/C test is as follows,**

PKG-Board : N-N > N-S > S-N > S-S



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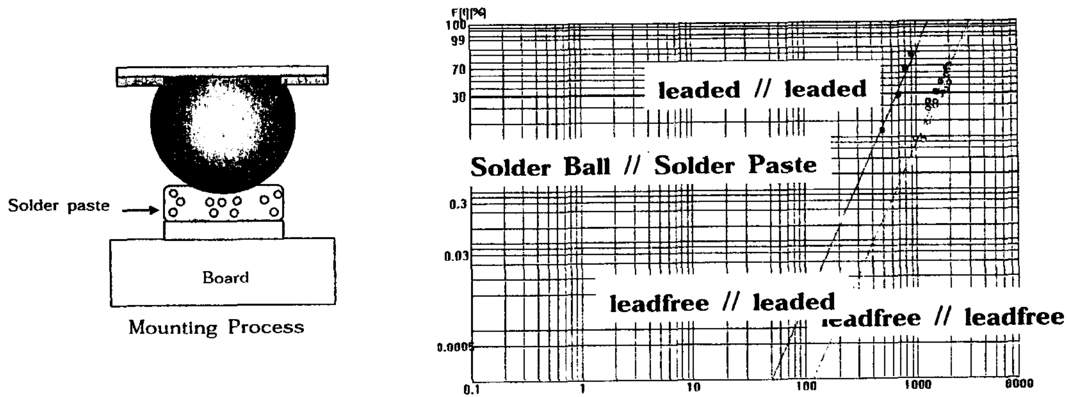
❑ Solder composition

Comparison of Weibull distribution

- ✓ **Leaded/Leaded paste(× 1.0)**
- ✓ **Leadfree/Leadfree paste (× 2.5)**
- ✓ **Leadfree/leaded paste(× 2.3)**



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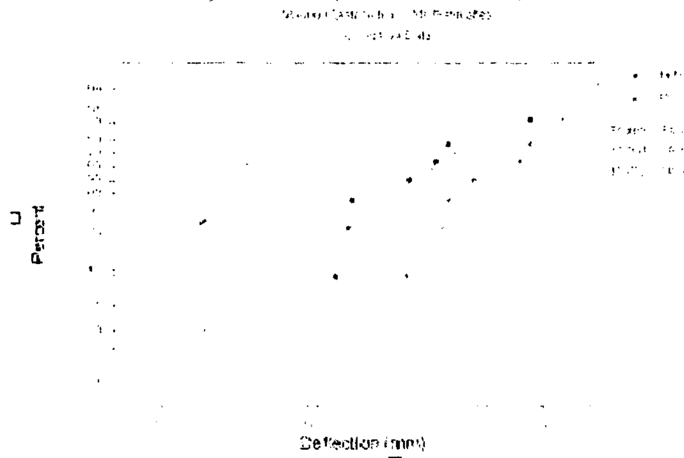
❑ NSMD vs. SMD for Bending

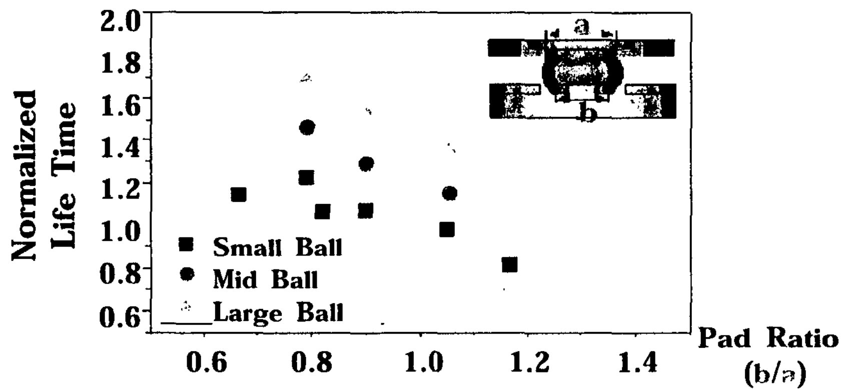
✓ **Generally, the ranks for Bending test is as follows,**

PKG-Board : S-S > S−N > N−N or N−S



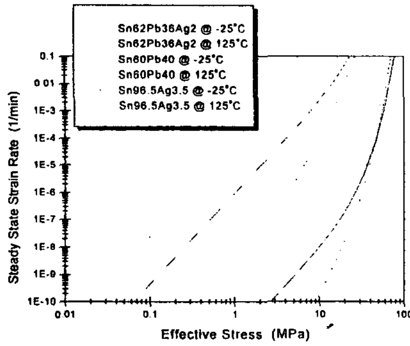
❑ Pad size of Package and Board

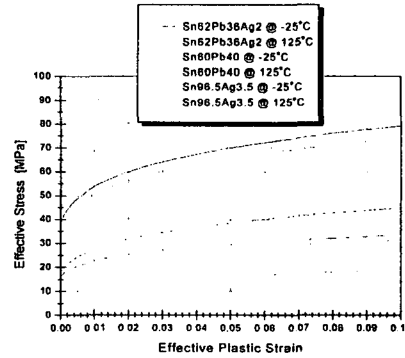
✓ **Pad Ratio Simulation**



- **Pad Ratio ↓ Package vs. PCB stress balance → Life Time ↑**
  - **Package Pad Size(a) > PCB Side(b) → Life Time ↑**

❑ Solder properties





$$\frac{d\varepsilon_{cr}}{dt} = A[\sinh(B\sigma)]^n \exp\left(-\frac{Q}{RT}\right)$$

$$\varepsilon_{pl} = C\left(\frac{\sigma}{G}\right)^m$$

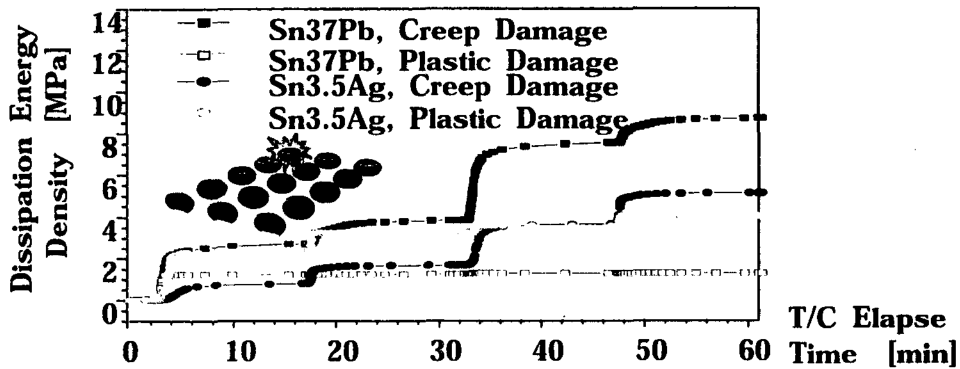
Time dependent creep behavior

Sn96.5Ag3.5 > Sn62Pb36Ag2 > Sn-Pb

Time-Independent Plastic Flow

Lead-free << Leaded

❑ Creep & Plastic Behavior



- ✓ **Creep Damage > Plastic Damage**
- ✓ **Solder Ball Damage for TC : Leaded > Lead free(x 1.5~2)**

  *** Plastic behavior has little relation to T/C**

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❑ Linear properties of Lead-free Solder

Elastic Modulus

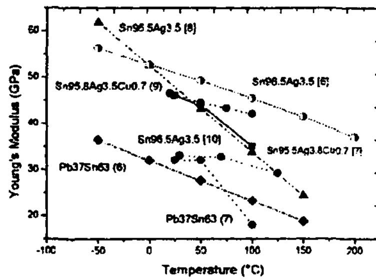
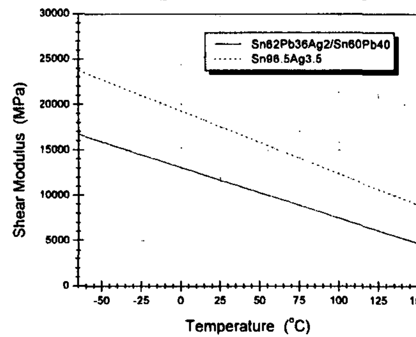


Fig. 2: Temperature dependent Young's moduli of some solders [6-10]

6. Lau, J. H., Pao, Yi-Hsin, "Solder Joint Reliability of BGA, CSP, Flip Chip, and Fine Pitch SMT Assemblies", McGraw-Hill, New York, 1997, p. 120.
7. Biglari, M. H., Oddy, M., Oud, M. A., Davis, P., " Pb-Free Solders Based on SnAgCu, SnAgBi, SnCu and SnCu for Wave Soldering of Electronic Assemblies", Proc. Electronics Goes Green 2000+, Berlin, Germany, Sept. 11-13, pp. 73-82.
8. Darveaux, R., Banerji, K., Mawer, A., Dody, G., "Reliability of Plastic Ball Grid Array Assembly" in Ball Grid Array Technology (ed. J. L. Lau), McGraw-Hill, New York, 1995, pp. 379-442.
9. Private Communication (TU Wien).
10. Lau, J. H., Chang, Ch., "TMA, DMA, DSC, and TGA of Lead Free Solders", Proc. ECTC, 1998, pp. 1339-1344

Shear Modulus

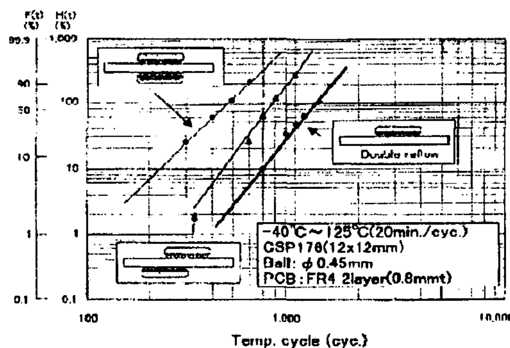


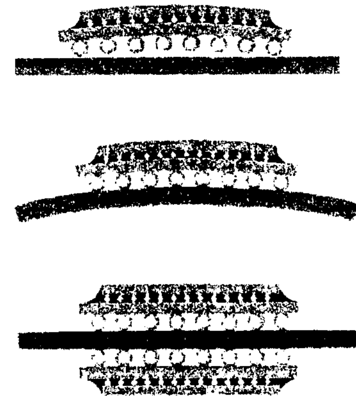
✓ E leadfree > E leaded

✓ $\Delta\sigma = E \cdot \varepsilon$

for Vibration Leaded > Lead free

❑ Mounting Type





✓ **Life Time :**

Single > Staggered Mounting > Double Mounting

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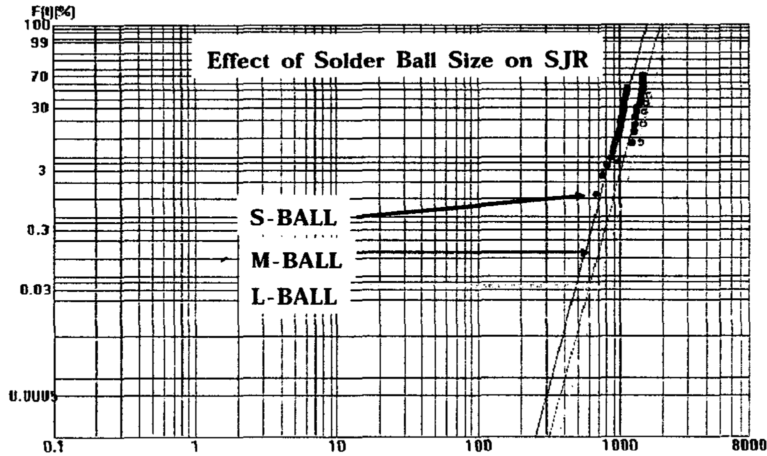
❑ Solder Ball Size

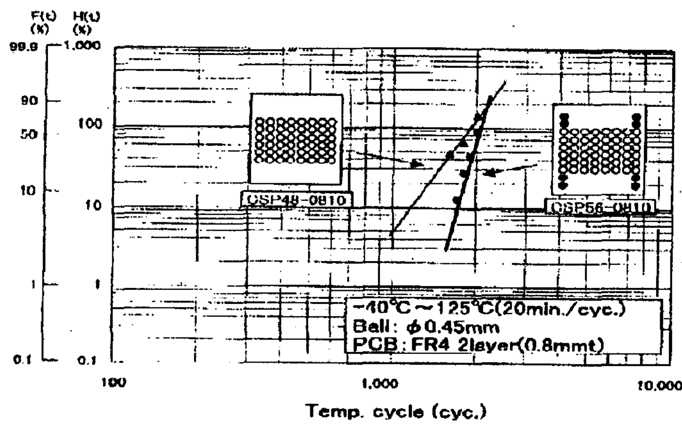
✓ TC life is proportional to ball diameter.



❑ Dummy Balls

✓ Dummy Ball → SJR increase

Dummy balls located on near weak balls are more effective



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Design Concept for SJR

- Consider ball geometry including support ball for test socket issue, die cracking by handling damage, etc.
- Minimize the crack driving force.
- Maximize the crack resistance force.
- Reduce the variance of joint lifetime using by robust design and quality control.

Part II
Board Level Joint Reliability Evaluation for pad finishes

Evaluation Scope

❑ Evaluation combinations

✓ Package and Board pad finish
- Au/Ni(Component) – OSP/ENIG (Board)

✓ Solder alloys
- SAC lead free solder

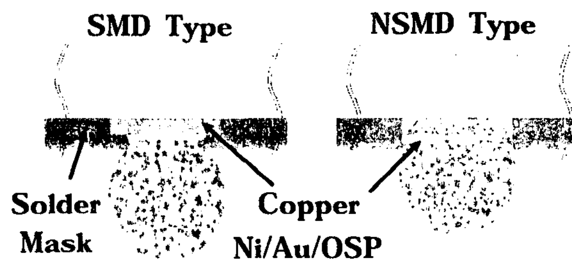
❑ Testing Methods

✓ Impact Test (Simulate Drop Test)

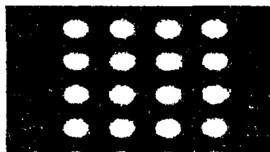
✓ Bending Fatigue Test

Pad designs and finishes

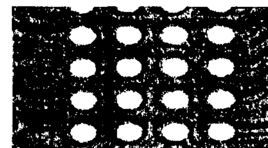
❑ Pad Designs



❑ Pad Finishes

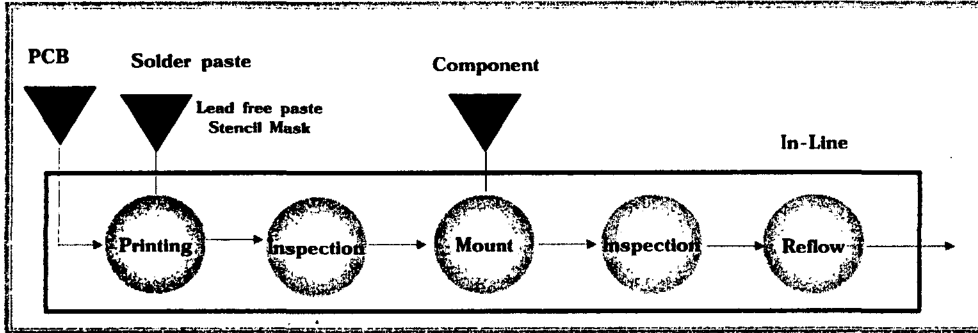


Au/Ni finish



OSP fifnish

Overview of SMT Process



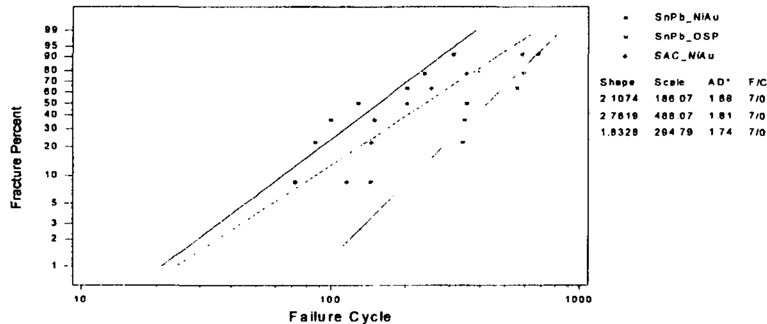
Brief process flow of SMT

- ❑ Use normal reflow profile for lead free solder alloy
- ❑ Heating and cooling rates are moderately selected according to published data and convection type equipment was used.

Result of Impact Test

Split #	Component	Solder	Board	Drop Test
A	Ni/Au	SAC	OSP	F
B			ENIG	G
C	Ni/Au	Sn-Pb	OSP	E
D			ENIG	G

Probability Plot for SnPb_NiAu-SAC_NiAu
Weibull Distribution - ML Estimates
Complete Data



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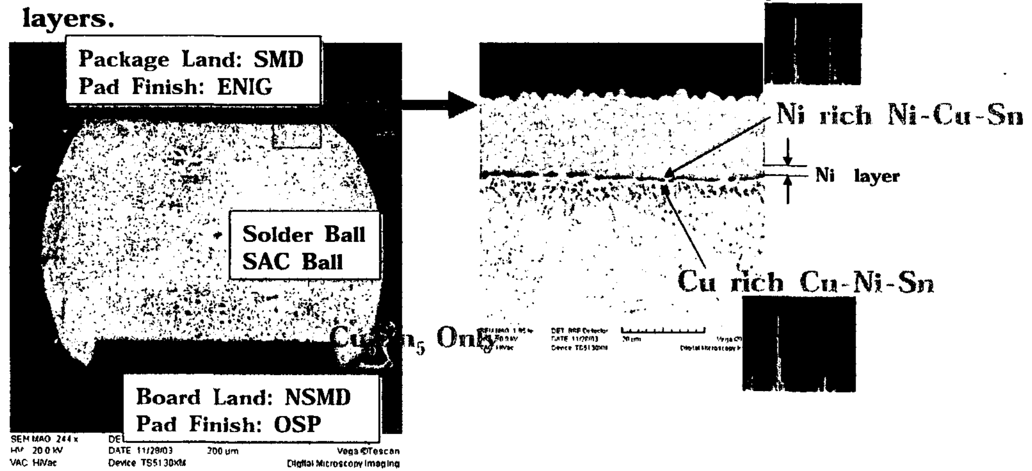
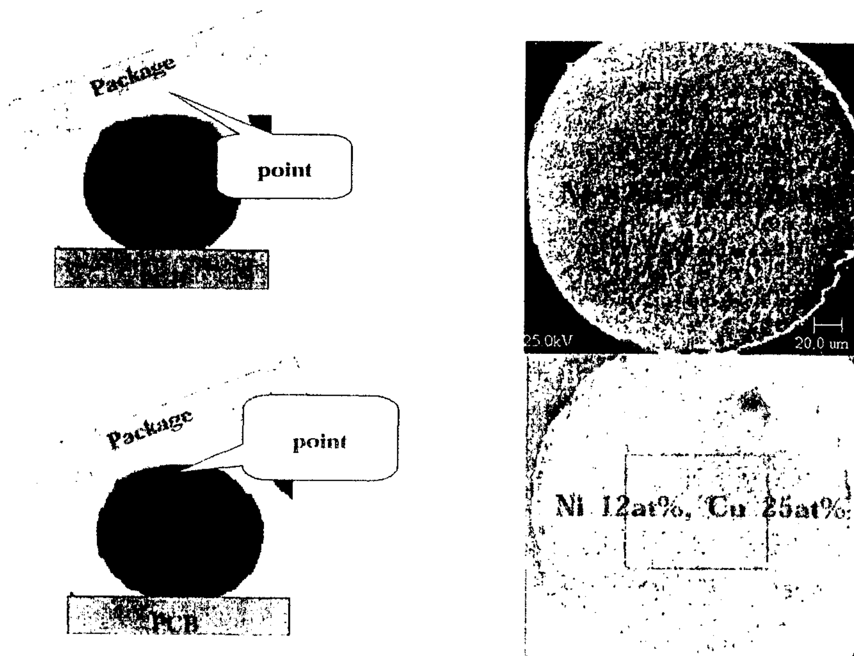
Failure Analysis(Ni/Au-OSP)

- ✓ The brittle fracture occurred at very low Impact cycle in lead free solder-OSP combination
- ✓ Ni rich Ni-Cu-Sn IMC layer is so thin as 0.1~0.2㎛ thick and Cu rich Cu-Ni-Sn IMC layers is as thick as about 2~8㎛.
- ✓ The brittle fracture occurred between the two different IMC layers.



Fractured Surface Analysis

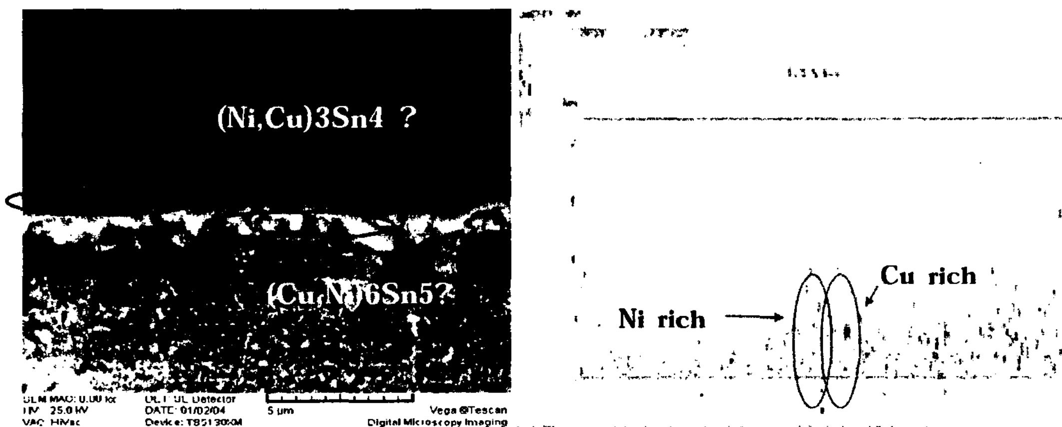


Questions !

- ❑ **Does the brittle fracture really occurred between the two IMC layers ? Or between pad and IMC ?**
- ❑ **What's the main source of Cu6Sn5 IMC formation on Ni3Sn4 IMC layer ? Does it Cu in solder alloy ? Cu in OSP pad ?**

IMC analysis for EOL

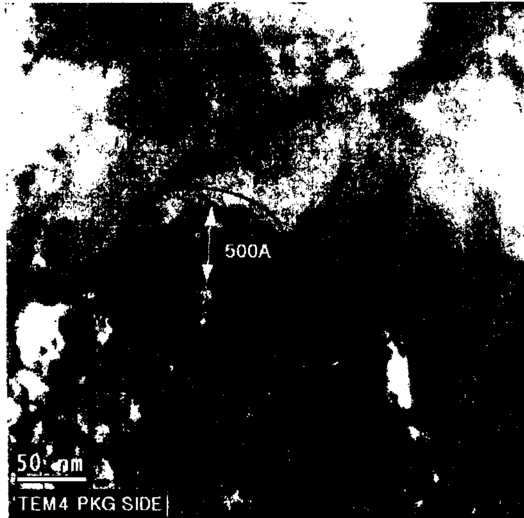
❑ Au/Ni-SAC interfacial reaction

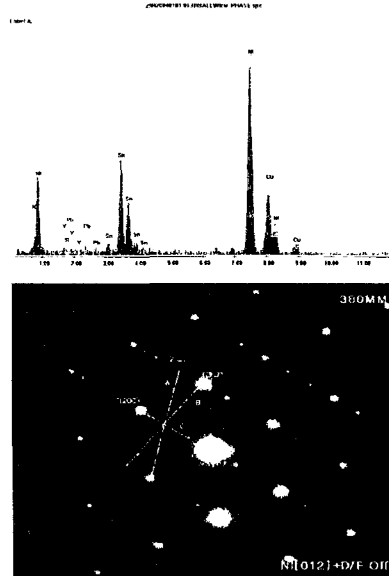


- ✓ **IMC Thickness is about 2~5㎛**
- ✓ **(Ni,Cu)3Sn4 and (Cu,Ni)6Sn5 IMCs are detected by EDX. But they were not distinguished by SEM image.**

IMC Analysis for as reflowed

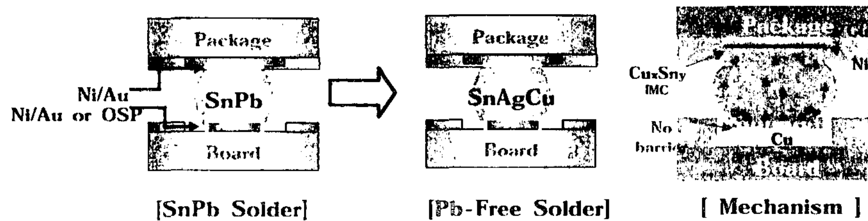
The red circled layer is strongly assumed as Ni3Sn4 or (Ni,Cu)3Sn4 by the EDX spectrum. But no certain evidence is found by DP Peak





Effect of solder alloy/Board finish for Impact test

Split #	Component	Solder	Board	Drop Test
1	Ni/Au	SAC	OSP	Fail
2			Ni/Au	Good
3	Ni/Au	Sn-Pb	OSP	Good
4			Ni/Au	Good



[SnPb Solder] [Pb-Free Solder] [Mechanism]

➲ Dominant Factor : Cu Composition in Solder Alloy ?

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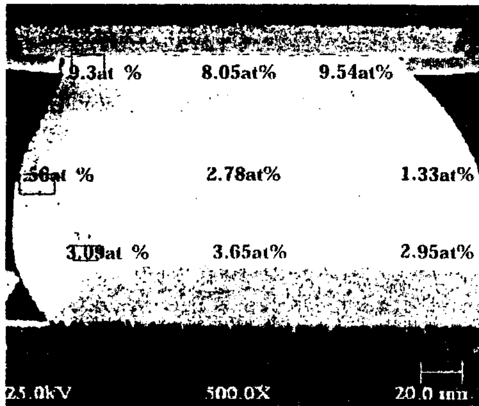
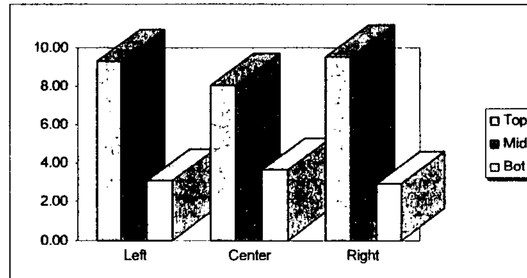
Diffusion of Cu atoms

❑ Cu contents variation in bulk solder(Sn-Ag)



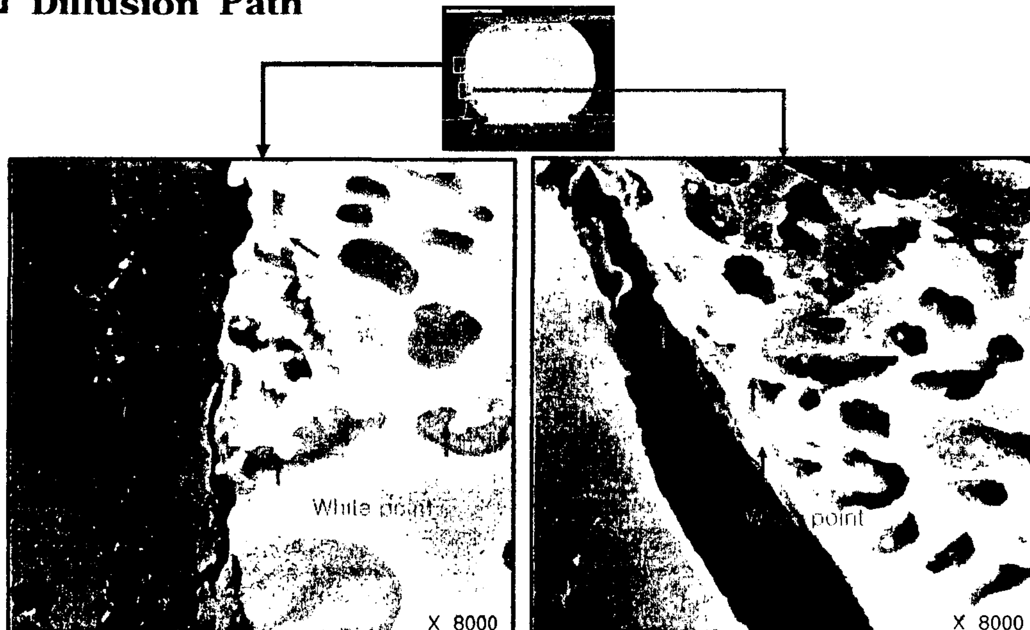
	Left	Center	Right
Top	9.30	8.05	9.53
Mid	1.56	2.78	1.33
Bot	3.09	3.65	2.95



✓ Surface diffusion is dominant and much faster than inter-diffusion during soldering.

✓ The highest Cu % detected at top side of the ball and it can be considered as evidence that Cu in IMC is from OSP pad.

❑ Diffusion Path



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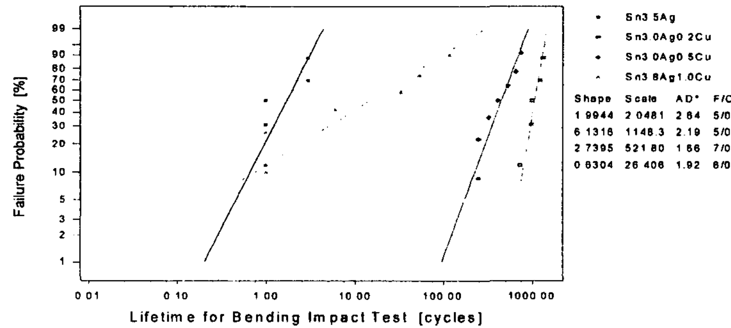
Bending Impact Test (deflection 3.5mm)



Experimental Composition				Lifetime for Bending Impact Test (deflection = 3.5mm)	
Solder Ball	Solder Paste	Package Pad(SMD)	Board Pad (NSMD)	Scale Parameter	Shape Parameter
Sn3.5Ag	Sn3.5Ag		OSP	2.0481	1.9944
Sn3.0Ag0.2Cu	Sn3.5Ag	Ni/Au	OSP	1148.3	6.1316
Sn3.0Ag0.5Cu	Sn3.0Ag0.5Cu	finished	OSP	521.80	2.7395
Sn3.0Ag1.0Cu	Sn3.0Ag0.5Cu		OSP	26.406	0.6304

Summary

- In the case of Ni/Au finished pad on the package side, the solder joint of SnAgCu system can bring brittle fracture under impact load such as drop test. Therefore, it's difficult to prevent the brittle fracture of lead-free solder, by controlling Cu content.
- The failure locus existing on the interface between $(Ni,Cu)_3Sn_4$ and $(Cu,Ni)_6Sn_5$ IMC layers must be changed to other site in order to avoid brittle fracture due to impact load.
- It was not found any clear evidence that there were two IMC layers exist. But it was strongly assumed there were two layers which have different Cu-Ni composition.
- From the above analysis it was assumed that Cu atom in the solder alloy or substrate seemed to affect IMC composition and cause to IMC brittle fracture.