The Whisker Growth Investigation of IC Packaging on the PC Board Assembly

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ABSTRACT
The whisker concern has been greatly affecting lead free RoHS conversion confidence in the lead frame packages, particularly for high end product conversion. Although plenty of related study in E4 and iNEMI have directed standard whisker testing conditions and measurement methods, the practical whisker performance data in service life is still very small due to numerous extra factors involved from surface mounting and waving soldering.

Most of the literature on Tin (Sn) whiskers study are test results based at the component level in storage or reflow preconditioning to simulate backward and forward conversion in service life. However, for practical Sn-whisker issues, it is necessary to consider the entire structure, i.e., the component characteristics, solder joint, PCB and process effect.

In this study, matt Sn plated packages with Cu and Alloy 42 based in PLCC, PDIP, LQFP and TSOP were subject to lead free surface mounting and wave soldering on PCBs with OSP surface finish, followed by TCT (-55 to 85℃) 1000 cycle, THT (60℃/90%RH) 3000hrs and ambient condition 3000hrs to investigate whisker growth propensity. Whisker growth on the PCB after reflow simulation and separate from the component level was examined to understand whether the whisker risk will be reduced or raised because of factors such as the matt Sn structure, lead frame base, reflow profile and solder paste wetting behavior. Furthermore, SnPb and SnBi plated 4 types of the same package types as above were used as controls for whisker growth comparison. Additionally, corrosion phenomenon due to higher temperature THT testing to correlate to whisker growth after the surface mounting condition will be explored with FIB analysis as well.

Keywords: Whisker, matt Sn, SnBi, SnPb, PCB, surface mounting, TCT, THT, corrosion, FIB

INTRODUCTION
EU RoHS specifies Pb/Hg/Cd/Cr^{+6}, PBBs and PBDEs as banned substances since July/2006. It is thus inevitable that the whole electronic supply chain comply. Pb elimination, while only one of the 6 banned substances, was most complicated in terms of finding potential alternatives due to the materials, process and equipment involved. Lead free package development, optimum lead free solder ball composition for laminate package, lead free solder plating for lead frame package and lead free solder bump composition for flip chip package, have not been fully aligned in the industry, especially in Japan and the EU region. SAC305 and SAC405 solder ball composition for laminate package were highly expected to be the only direction for IC package subcontractors to take, with the lead frame package using SnBi, SnCu and matt Tin (Sn) plating.
Matt Sn plating as alternative for lead frame package has achieved consensus in Europe and U.S based on cost and compatibility in backward and forward conversion although some whisker concerns still exist for the products with high reliability requirements. The current whisker acceptance criteria and its test condition defined by JEDEC has not been fully standardized in the industry yet. Various design concepts to approach so-called whisker free requirement from chemical supplier were proposed for user selection, but all results showed certain whisker growth after whisker testing. A number of whisker guidelines were proposed for practice, such as post baking, Ni or Ag under plate, thicker Sn deposit and so on. No matter what kind of best practice, the practical field application in service life could not be predicted confidently due to more extra factor involved from surface mounting.

The lead frame package after mounting on the PCB, the characteristic of solder deposit will vary with the reflow or wave soldering or even hand soldering condition. The internal stress during solder deposit might be re-distributed to lead to different whisker potential from that observed in individual package level. Currently, most studies on Sn whisker were test results from the package level. Actually in service life, the whisker observation should include entire solder joint and non-wetting area across the lead frame in order to control how risky is the whisker in practical field application. This is shown in figure 1.

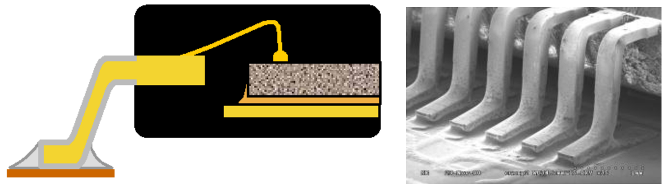


Figure 1 - The outline of solder joint of lead frame package on board for whisker observation

EXPERIMENT

1.4 package vehicles (LQFP/PLCC/TSOP/PDIP) with matt Sn plating and 150ºC /1hr post baking pretreatment were selected as shown in table 1. These were subjected to optimized lead free SAC305 surface mounting at 245ºC with a hat type profile and wave soldering at 260ºC peak temperature. Likewise, SnPb surface mounting was done at 220ºC with an angle type profile and wave soldering at 220ºC peak temperature. The packages on the board samples, as shown in figure 2, were subjected to whisker testing under TCT (-55ºC /85ºC) 1000cycle, THT (60ºC /95%RH) 3000hrs and ambient condition (30ºC/60%RH) 3000hrs, respectively. Longest whisker length was recorded following JESD22A-121 with SEM observation across solder joint and non-wetting area at sample size X2 to show whisker intensity. Furthermore, SnPb and SnBi plated package were examined as controls as well.

Table 1 - the package profile for on board whisker DOE

Packages	LQFP	PLCC	TSOP	PDIP
Leadframe	Olin 7025	Olin 151	A42	Olin 194
Base metal	Cu/Ni/Si/Mg	Cu/Zr	Fe/Ni	Cu/Fe/P/Zn
Thickness	8~12um	8~12um	8~12um	8~12um
C content	<300ppm	<300ppm	<300ppm	<300ppm
Lead shape	Gull wing	J-bend	Gull-wing	Dual in line

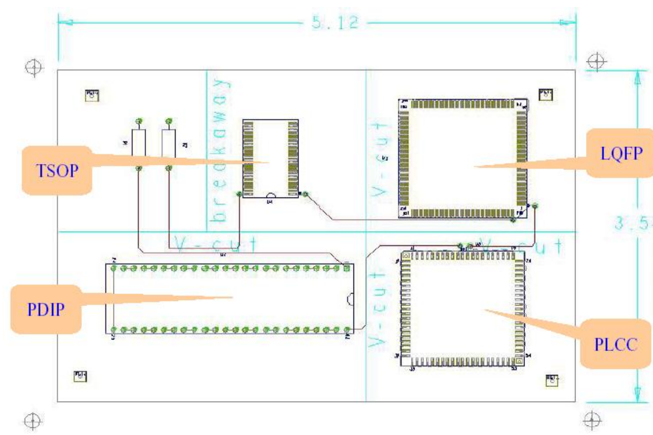


Figure 2 - The outline of PCB with 4 package vehicles

1. All observations were checked with optical microscope (OM) and followed by SEM. FIB can be used for whisker verification too.

2. A one time reflow precondition to simulate SAC surface mounting at 260ºC and SnPb at 220ºC was conducted for Sn plated LQFP to verify corrosion resistance with reflow effect after THT 3000hrs by surface appearance observation and FIB X-section analysis. The vehicle w/o reflow can be as control.

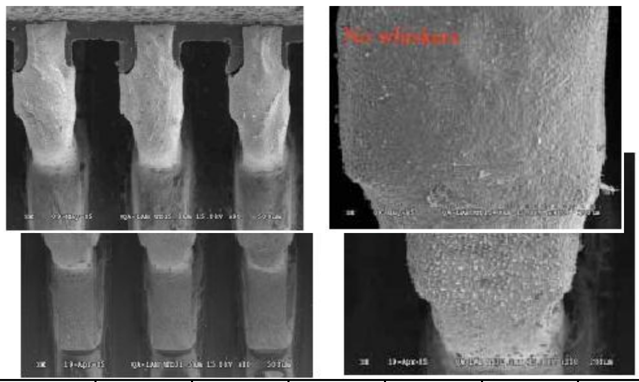
RESULT and DISCUSSION

1. On board condition effect on the whisker at TCT

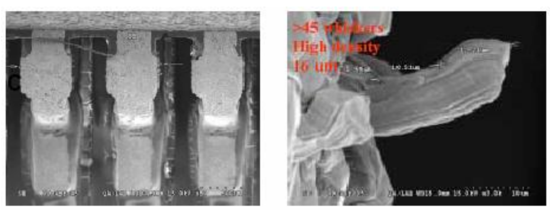
Table2 shows the whisker results for Sn plated package with SnPb paste (backward conversion) and SAC paste (lead free conversion) at various testing condition. In term of TCT 1000cycle, there was no great whisker difference in SnPb mounting with various packages, but whiskers did happen in non-wetting area, as shown in figure3, as well as in SAC mounting with higher reflow temperature where there were still whiskers found in non-wetting area. The whisker length was reduced greatly in TSOP from 18um to 6um when compared SnPb mounting with SAC mounting.

Table2 - On board whisker result in Sn plated package (unit: um)

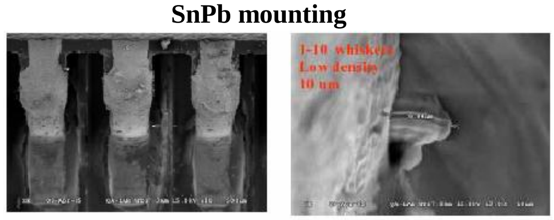
	SnPb mounting			SAC mounting		
	TCT	THT	Amb.	TCT	THT	Amb.
	1000C	3000H	3000H	1000C	3000H	3000H
LQFP	16	42	0	10	0	0
PLCC	21	78	0	20	34	0
TSOP	18	0	0	6	0	0
PDIP	20	57	0	30	97	0



***Red : Corrosion finding**

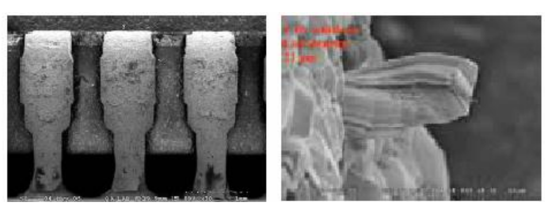


SnPb mounting

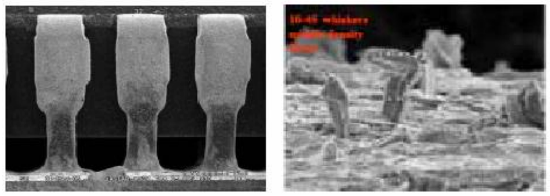


SAC mounting

Figure3 - 1.LQFP on board whisker at TCT 1000C 1000cycle

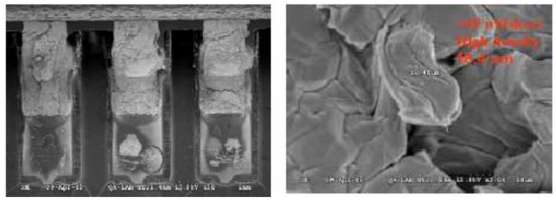


SnPb mounting

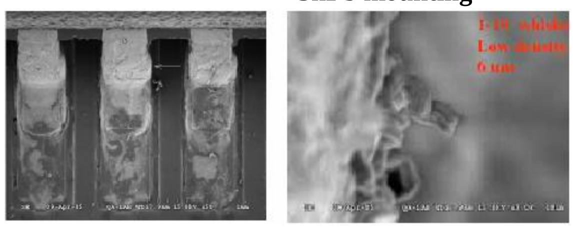


SAC mounting

Figure3-2.PLCC on board whisker at TCT1000C



SnPb mounting



SAC mounting

Figure3-3.TSOP on board whisker at TCT 1000C

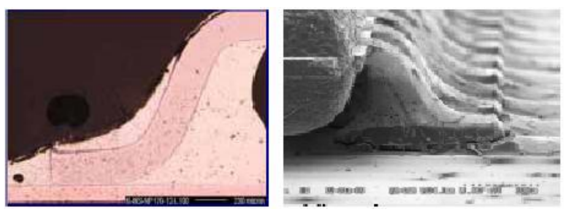
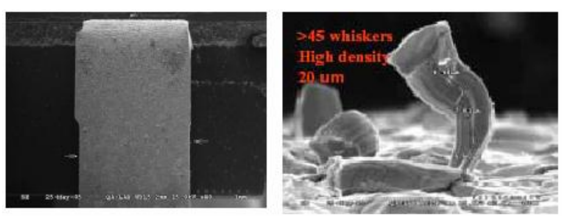
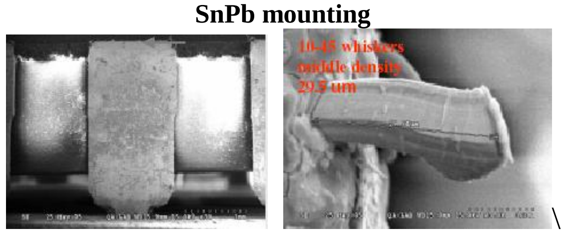


Figure4 - The X-section view in TSOP with SAC mounting



SnPb mounting



SAC mounting

Figure3-4 - PDIP on board whisker at TCT 1000C

At the package level, the CTE mismatch between the Fe/Ni alloy based lead frame and solder will be greater than that between Cu lead frame and solder. This means there will be a larger thermal stress generated inside the Sn deposit in TSOP so as to produce a number of whiskers during the TCT test. During surface mounting, a number of whiskers will be covered by SAC solder paste to mitigate whisker growth propensity dramatically, as shown the solder joint X-section in figure4.

Nevertheless, whiskers still appeared in this area.

In Cu lead frame category, there were different lead frame material composition among LQFP, PLCC and PDIP, but this seemed not to be major factor for growing whiskers in an on-board condition. The wetting behavior between solder paste and lead shape under certain soldering profiles will dominate whisker performance. Longer gull-wing lead in LQFP are hard to be wet completely across the lead frame with SAC paste, and J-bends in PLCCs and dual in line in PDIPs will be impossible to be wet completely with SAC paste or even eutectic SnPb paste as shown in figure 1. These non-wetting areas will have a high potential to grow whiskers. Whether higher reflow temperature to melt the Sn deposit can overcome the concern will be discussed later. But too high reflow temperature will be detrimental to package and PCB integrity.

SnBi plating has gotten more attention in Japanese market and has been in volume production in the industry. In this study, SnBi plated package was taken as control. PLCCs and PDIPs grew whiskers in non-wetting areas and had equivalent whisker length to Sn plated package as shown in table 3. Interesting our finding was there was shorter whisker lengths in LQFPs, with no whiskers found at SAC mounting, as shown in figure 5. The melting point in SnBi was a little lower than that of the matt Sn deposit. It is very possible that the SnBi deposit in SnPb mounting will not be melted completely, so that a number of short whiskers were formed on the lead top of the non-wetting lead. No whiskers were found in the wetting area and solder joints. In SAC mounting, it was apparent that the SnBi grain from the view on the top of lead frame in the non-wetting area became finer after SAC soldering, which meant grain boundaries disappeared due to SnBi deposit melting. The stress redistribution from solder joint of SnBi plus SAC during TCT was assumed to contribute some stress releasing effect between lead frame and deposit, but it should not be a major effect and need to be investigated further. If confirmed this result will be attractive for fine pitch device applications with SnBi plating.

Table3.The on board whisker comparison at TCT1000cycle among 3 deposits (unit: um)

	SnPb mounting (220ºC)			SAC mounting (245ºC)		
deposit	**Sn**	**SnBi**	**SnPb**	**Sn**	**SnBi**	**SnPb**
LQFP	**16**	**<5**	**7**	**10**	**0**	**na*2**
PLCC	**21**	**27**	**7**	**20**	**13**	**na*2**
TSOP	**18**	**na*1**	**7**	**6**	**na**	**na*2**
PDIP	**20**	**17**	**11**	**30**	**23**	**na*2**

***1 SnBi can not be plated on the A42 due to process limits, therefore there is no data in TSOP.**
***2 No forward conversion study in the case**

SnPb plating has been popular in the industry and always gives reliable whisker performance with long terms service life. But apparently, SnPb can show whisker growth under TCT condition although lengths are very short, as shown in figure6. If the thermal stress induced by CTE mismatch is present it is inevitable, whatever any kind of Sn or Sn based alloy, that there is a potential to grow whiskers. From the observation, the whisker length in SnPb deposit was far shorter than that of matt Sn and SnBi in each package even FeNi-TSOP. It is possible this is due to the SnPb deposit grain structure and more ductile behavior which relieves thermal stress. The large Pb atom could play a role to mitigate Sn atom migration along the grain boundary. Additionally, the temperature distribution during reflow may not be even over the whole lead frame due to process control. Thus the whisker growth is pushed out on the non-wetting area.

From above discussion, one can see the difficulty to be whisker free in real world.

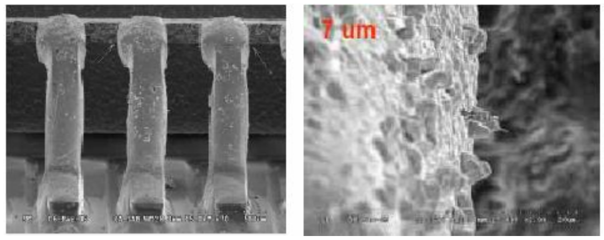


Figure6-1.SnPb-LQFP on board (SnPb mounting) whisker in TCT 1000cycle

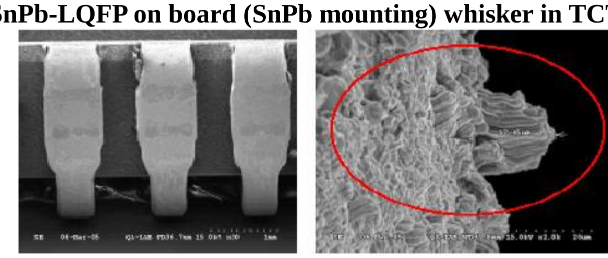


Figure6-2.SnPb-PLCC on board (SnPb mounting) whisker in TCT 1000cycle

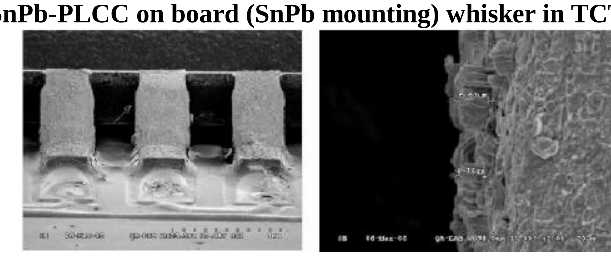


Figure6-3.SnPb-TSOP on board (SnPb mounting) whisker in TCT 1000cycle

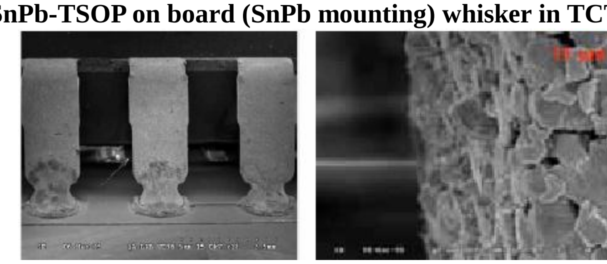
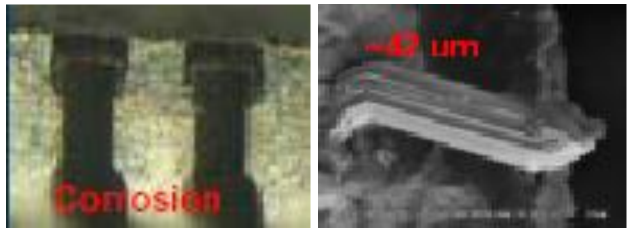


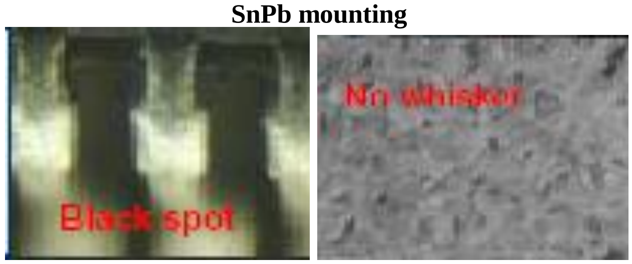
Figure6-4.SnPb-PDIP on board (SnPb mounting) whisker in TCT 1000cycle

2. On board condition effect on the whisker at THT

In terms of THT condition, Sn oxide (SnO_2 and SnO) will be expected to be generated and pinned into the Sn deposit to drive whisker growth due to the stress redistribution induced. As Table2 illustrates Sn plated packages, except for TSOPs, show significant whisker growth in THT3000hrs in SnPb mounting condition The surface of the deposit on top and side non-wetting areas presented localized corrosion and black spots near the compound due to possible solder cracking from lead bending. Very little corrosion was observed on the middle of lead frame due to good Sn coating or flux coverage. It was observed that whiskers were usually shorter in this location. The SnO_2 is more thermodynamically favored than SnO, so that the increased number of O atoms can occupy more lattice sites creating more vacancies for nearby for Sn atom migration. Therefore there is more whisker growth especially around the corrosion locations as the system compensates for the stress induced.



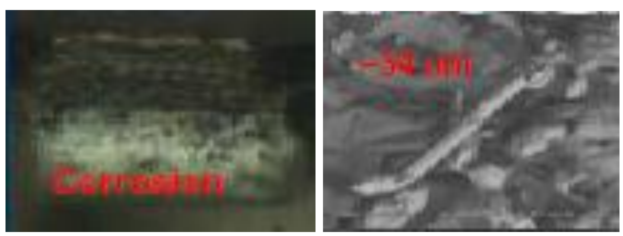
SnPb mounting



SAC mounting

Fgure7-1.LQFP on board whisker at THT 3000hrs

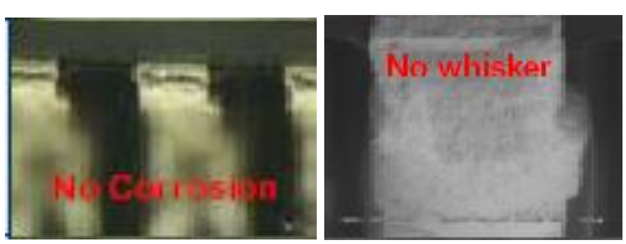
SnPb mounting



SAC mounting

Figure7-2.PLCC on board whisker at THT 3000hrs

Apparently in figure7, the corrosion that occurred likely pushed significant numbers of whiskers out in the vehicle during lower temperature SnPb mounting on the Cu lead frame based package. The Sn solder deposit with meting point 232 ℃ did not melt fully due during 220 ℃ soldering. The possible solder crack or perhaps the thinner Sn layer caused by extension in the bending position is assumed to not have provided good coverage on the Cu lead frame. In this situation the galvanic potential difference between Cu lead frame and Sn will cause corrosion to occur. Thus the location of significant whisker growth is close to the corrosion location. It was interesting that there was no corrosion happening in Alloy 42 based TSOP and no whiskers were found after THT 3000hrs. It was supposed that the potential difference between Fe/Ni alloy and Sn was not enough to induce galvanic interaction. The whisker growth mechanism caused from corrosion in THT is different from previous theoretical approaching such as irregular Cu_6Sn_5 IMC growth causing compression of the Sn layer. In fact, it could be judged as noise for whisker measurement. Figure7 showed clear picture with OM of the corrosion phenomenon. More detailed explanations can be found in the "whisker workshop" of ECTC 2005.

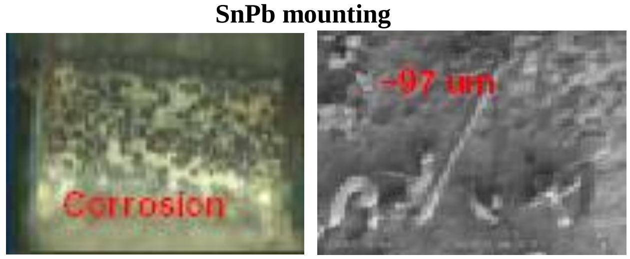


SnPb mounting

SAC mounting

Figure7-3.TSOP on board whisker at THT 3000hrs

SnPb mounting



SAC mounting

Figure7-4. PDIP on board whisker at THT 3000hrs

In terms of the observation of vehicles with higher temperature SAC mounting, corrosion was still observed on the non-wetting areas near the molding compound in all Cu based lead frame. The 245ºC hat type profile and subsequent wave soldering at 260ºC peak temperature seemed not to be capable of delivering enough thermal input to solder the deposit to make it melt. This is due to the high melting point of the Sn deposit. It was noticed that no whiskers were found in LQFP vehicles although there were some black spots there. It was likely the corrosion severity in these is not enough to induce whiskers. This will be tested at a later date to confirm.

The significant whisker growth with corrosion is not suggested as the ideal failure criterion idicating deposit capability in mitigating whisker growth. More careful chamber control and new temperature and humidity testing conditions correlated to real service life should be developed to demonstrate that there is no whisker growth over product life. The whisker mechanism caused by corrosion has been studied by iNEMI and E4 group since 2005, but there has not been data available in the absence of corrosion if the test vehicles were subject to long time and high temperature THT condition testing.

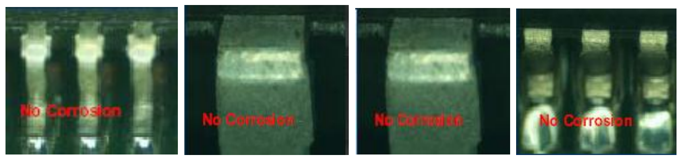
Table 4 compares results from SnPb and SnBi plated packages at 3000hrs THT condition. It was interesting that there were no whiskers found in all SnPb plated packages And there was no corrosion found in non-wetting areas as shown in figure 8. It can be assumed that the equiaxial grain structure with many horizontal grain boundaries in SnPb deposit, as opposed to the columnar grain in matt Sn deposits, is not prone to grow whiskers unless there is enough CTE mismatch induced in the TCT test. Furthermore, the grain size became bigger and grain boundaries became indistinct after reflow above Sn Pb melting point, as shown in figure 9. This contributes greatly to whisker mitigation. In addition the smaller vacancies between Sn grains inhibit Sn atom migration.

Table4.The on board whisker comparison at THT3000hrs among 3 deposits (unit: um)

	SnPb mounting (220ºC)			SAC mounting (245ºC)		
deposit	Sn	SnBi	SnPb	Sn	SnBi	SnPb
LQFP	42	8	0	0	8	na*1
PLCC	78	21	0	34	42	na*1
TSOP	0	na	0	0	na	na*1
PDIP	57	52	0	97	80	na*1

***red: Corrosion**

***1 No forward conversion study in the case**

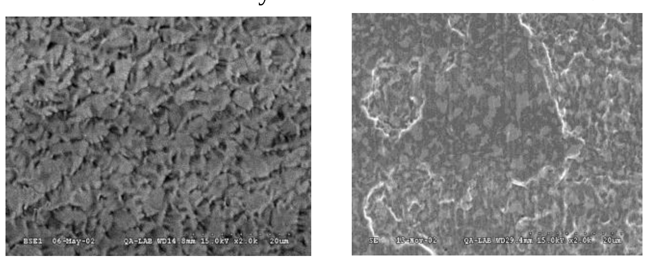


LQFP PLCC PDIP TSOP

Fgure8. SnPb-package on board whisker (SnPb mounting) at THT 3000hrs

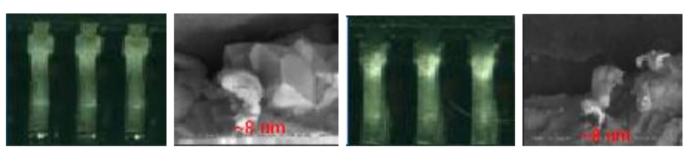
Figure 10 shows the results of whisker observation for SnBi plated packages after SnPb and SAC mounting. The corrosion was not still avoided in THT 3000hrs, so great whisker growth occured. The reflow with SAC soldering did not melt the SnBi deposit and prevent corrosion. The SnBi melting point in the deposit was around 228 ºC, thus the reflow soldering at SnPb or SAC mounting was not able to melt the deposit completely.

The corrosion mechanism inducing whisker growth is not fully understood in Sn-alloy plated packages But more attention should be paid to it for metrology establishment to identify whisker resistance conditions.

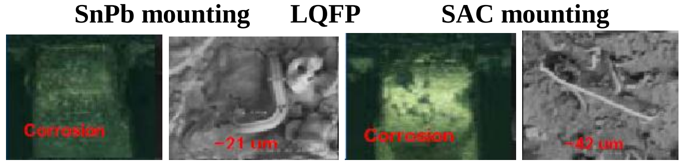


before 220 ºC reflow after 220 ºC reflow

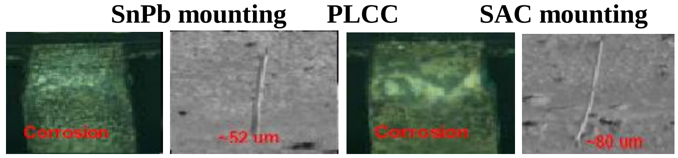
Fgure9. Surface morphology observation in SnPb-deposit



SnPb mounting LQFP SAC mounting



SnPb mounting PLCC SAC mounting



SnPb mounting PDIP SAC mounting

Fgure10. SnBi-package on board whisker at THT 3000hrs

3. On board condition effect on the whisker at ambient condition

As expected in table 2, there was no whisker growth or even corrosion found at ambient conditions after 3000hrs for Sn deposits. The time to grow a whisker on board is expected to be longer than that at package level due to to the SMT process mitigating whisker growth. This is good news for practical applications.

4. FIB for whisker analysis

FIB was a useful tool to identify detailed metallurgy structure. With more and more unknown mechanism regarding whisker growth, FIB contributed efficient knowledge about this concern.

Figure 11 shows whisker observations for Sn plated LQFPs w/o reflow preconditioning at TCT 1000cycle. After FIB cross-sectioning, the Cu_6Sn_5 interfacial IMC induced by 150ºC /1hr post baking plus thermo cycling can be identified , as well as the Sn grain size and boundary. From the picture, the interfacial IMC did not grow significantly showing that the cause of whisker growth might be due to CTE mismatch between Sn deposit and Cu lead frame. The Sn grain was compressed to form whisker for stress releasing. Apparently, there was no grain boundary in whisker structure.

Figure12 shows whisker observations for Sn plated LQFPs w/o reflow precondition after THT 3000hrs.It was obvious that the corrosion happened everywhere inside Sn deposit and the intensive SnO_2 compresses the Sn grains to drive whisker growth. There was also corrosion found on the whisker surface. The phenomenon was assumed due to the fact that the whisker grew before corrosion initiation.Evidentally the Sn whisker also will oxidize after staying a long time in the high humidity environment.

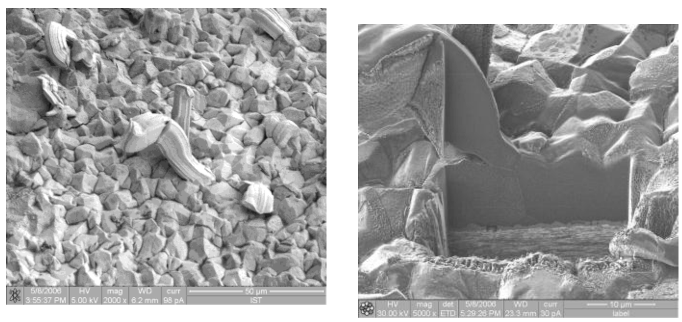


Figure11. Whisker observation for Sn plated LQFP at TCT 1000cycle

Figure12 Corrosion effect after THT 3000hrs with FIB analysis.

Figure13 shows corrosion observation with and without reflow precondition for Sn plated LQFPs at THT 3000hrs with OM. Significant corrosion occurred without any reflow preconditioning, while the lead corners had little corrosion after 220 ºC reflow precondition. Apparently, no corrosion occurred after 260 ºC reflow precondition due to Sn grain melting to coalesce the grain boundary. When this occurs moisture can not penetrate into the Sn deposit.

Figure14 shows more evidence of this phenomenon with the FIB cross section analysis. Sn oxide penetrated everywhere inside the Sn deposit if there was no reflow preconditioning, while less or no corrosion was found in 220 and 260 ºC preconditioning respectively. Figure 15 shows EDX analysis for the corrosion area illustrating Sn oxide formation. The interesting finding shows definitely that corrosion can be prevented after surface mounting if high enough reflow temperature is used to melt Sn grains. If this finding is applied in practical PCBA with various Sn based plating alloy, such as matt Sn, SnCu and SnBi, the process window becomes very narrow due to diverse melting points among the finishes.

The interfacial Cu_6Sn_5 IMC between Sn and Cu was also found to grow irregularly due to 260 ºC reflow better than that reflow in 220ºC. However very short whiskers were found after THT 3000hrs in the LQFP case. Further results will be published in another study.

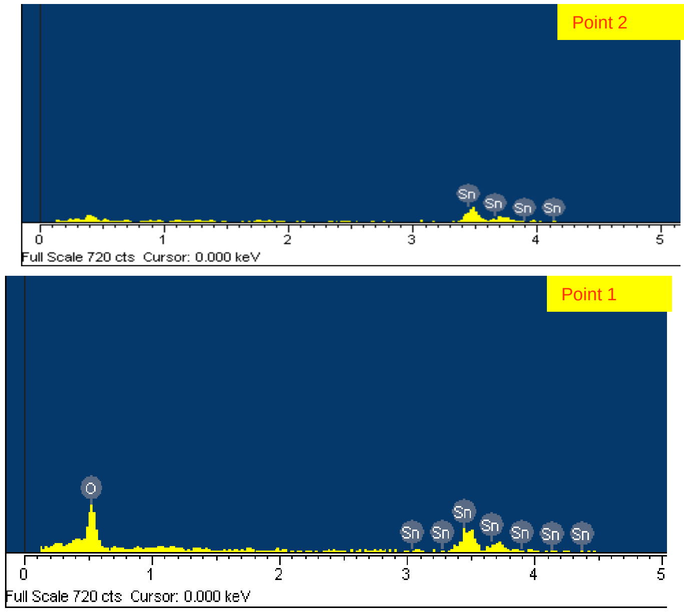


Figure15. EDX analysis to verify Sn oxide in corrosion area (Up: no corrosion , Bottom : corrosion)

CONCLUSION

Matt Sn plating in lead frame IC packages has become main stream in lead free conversion due to backward and forward compatibility. Whiskers are a major concern limiting its application, especially in high end and automotive products. In this study, 4 typical packages vehicle were tested for whisker growth potential in terms of on-board conditions modeling practical service life. It can be concluded that zero whisker level growth is impossible to achieve in lead free Sn based alloy plating. But whisker growth should be able to be suppressed to certain lengths that meet current JEDEC requirements. This suppression is done by way of SMT process condition.

However, the most important point will be how to ensure the SMT process can cover all components on the PCB to enable good soldering for solder joint integrity and deposit melting on the non-wetting areas of the lead frame. This will be very difficult to control during PCB assembly for the large PCB size, such as PC desktop, NB, server and so on. Higher reflow temperatures or longer wetting time to deliver enough energy to the various thermal mass components will be able to satisfy the situation, but on the contrary, the over heating will influence adversely the component's and the PCB's reliability. Further development from the material and process perspective in component, PCB and SMT is suggested for high end product application.

Additionally, a corrosion phenomenon happens easily during long THT periods if there is not good control of the sample and the chamber. This corrosion phenomenon generates noise that interferes with correct evaluation of whisker growth. A high enough reflow temperature to melt Sn deposit is effective in preventing this corrosion from happening. Optimization of testing conditions and correct definition of acceleration metrology for specific product applications is still needed to be developed further.

ACKNOWLEDGEMENT

The author thanked I-Ping Wang in R&D of IST for his support of dual beam FIB analysis in whisker and corrosion.

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The Whisker Growth Investigation of IC Packaging on the PC Board Assembly

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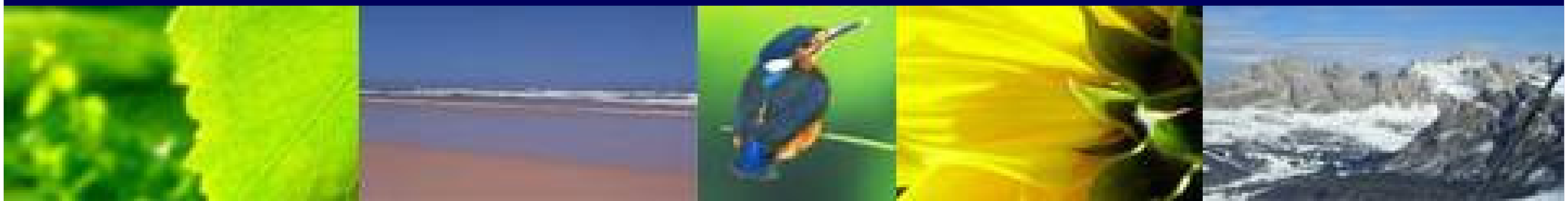
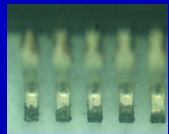


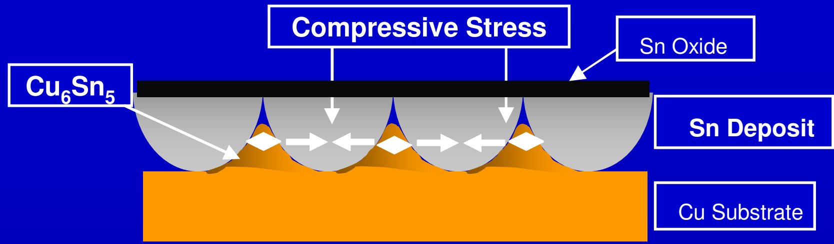
Content

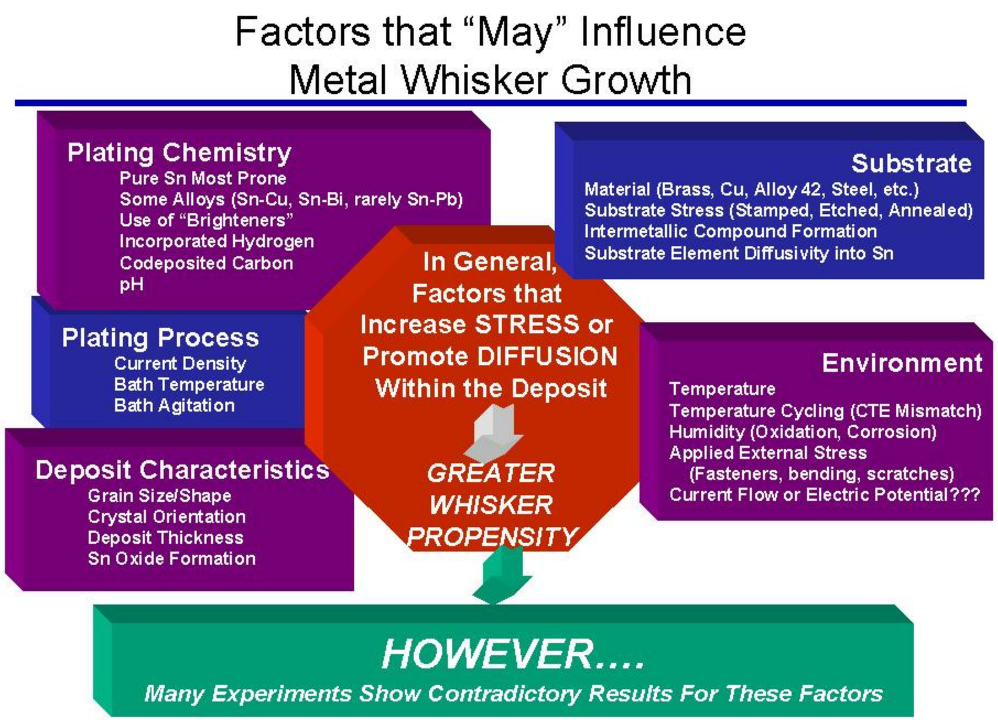
- **Introduction**
  - Primary whisker cause
  - Best mitigation practice
- **Motivation for the study**
- **Experiment**
  - Package test vehicle matrix : matt Sn /SnBi /SnPb plating
  - Related PCBA condition
  - Condition for whisker testing and check
- **Result and Discussion**
  - On board whisker at TCT 1000cycle
  - On board whisker at THT 3000hrs including corrosion effect
  - Ni underlayer + Sn efficiency for whisker mitigation
- **Conclusion**

Primary whisker cause

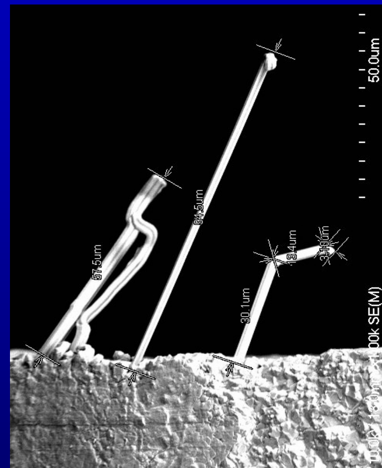
- Cu6Sn5 IMC diffusion
- Impurities in plating bath
- Oxide formation and humidity on the surface of deposit
- Condensation and corrosion

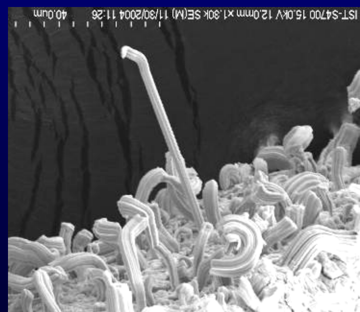


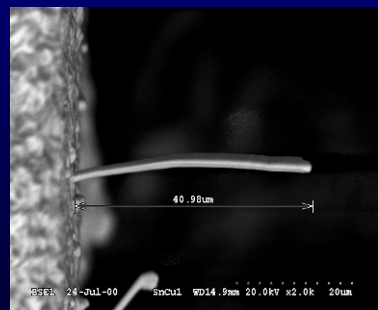




(Refer to NASA web-site)

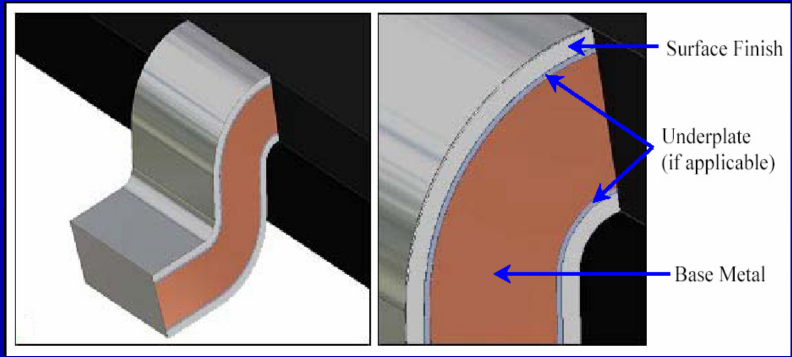






Sn whisker mitigation guideline
Please refer to JP002 :
(Current Sn whisker theory and mitigation practice guideline)

- Non- Sn plating such as PPF (Ni/Pd/Au or Ni/Pd)



- Sn plating alloys
  - Pb addition
  - Bi addition
  - Ag addition
  - Cu addition
- Underlayer as barrier for Cu_6Sn_5 diffusion : Ni or Ag
- Heat treatment
  - Fusing Sn plating
  - Annealing matt Sn like 150 ℃ /1hr post baking after Sn plating
- Hot dip Sn
- Thick Sn deposit (>7.5um or even >10um)
- Chemical etching Cu alloys
- Conformal coating
- Others to be updated

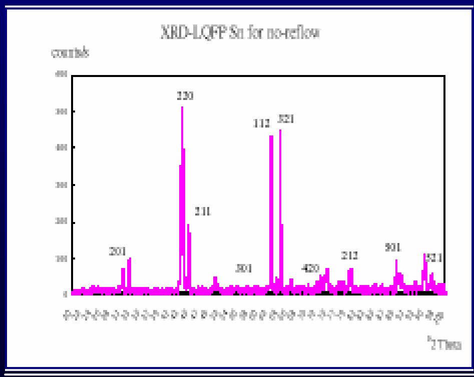
Motivation

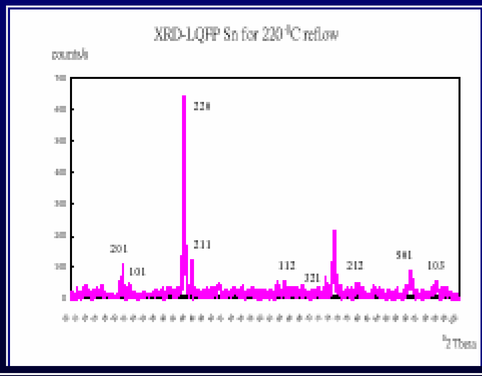
- Major whisker concern will be in the high reliability product such as telecom, automotive, large computer markets and military, very few questions in 3C market.

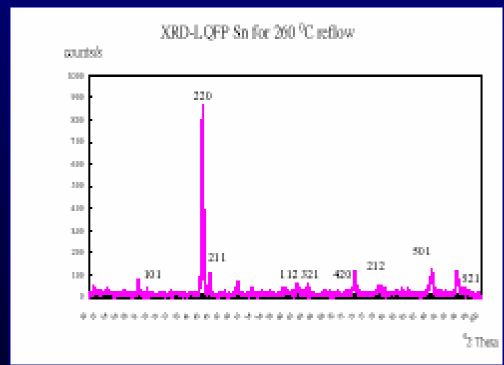
- Currently, most study on Sn whisker is based on package level to simulate storage issue.

- Actually, characteristic of solder deposit will vary with the reflow, wave soldering and hand soldering condition.

Reflow temperature(℃)	Preferred orientation
no reflow	(220)(321)(112)
220	(220)(211)(201)
260	(220)(501)(211)



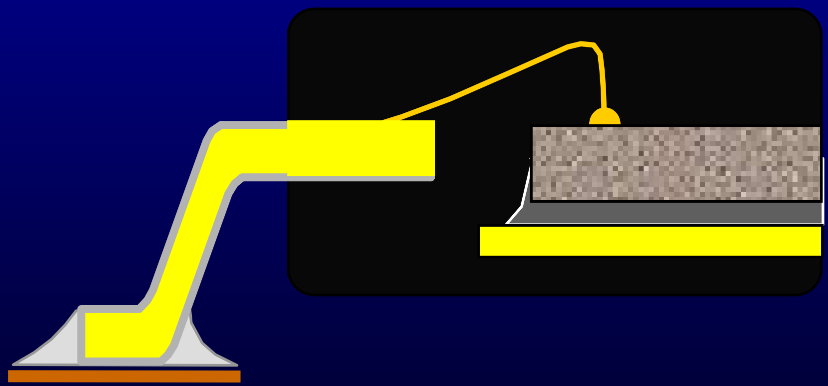


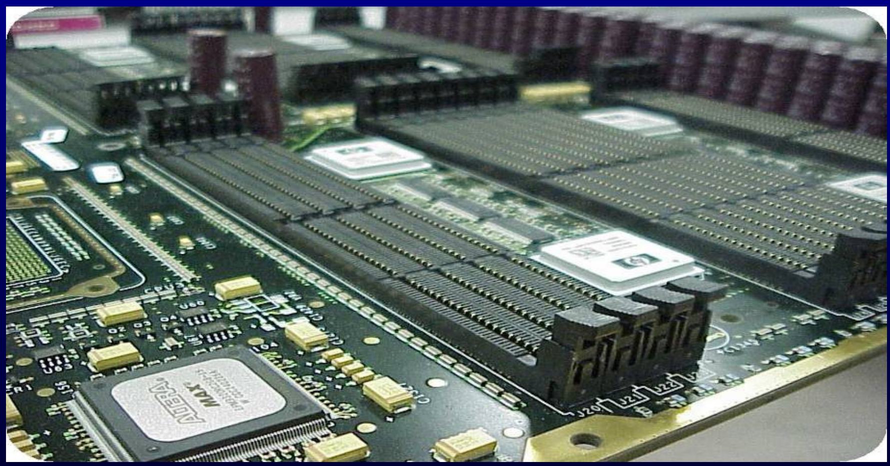


Motivation

Assumption

- After PCBA, the re-distribution of the internal stress from the change in deposit thickness, grain boundary, grain size, IMC growth and so on, will lead to different whisker potential.
- External factors from flux, solder joint, SMT process, PCB characteristics, compatibility between solder paste and plating deposit, and so on.
- In practical PCBA, the lead frame component could include Sn, SnBi, SnCu even SnPb deposit in the same PCB.

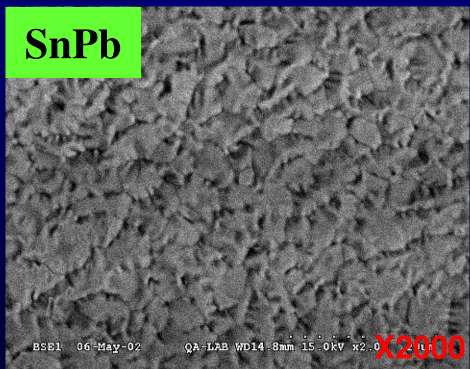


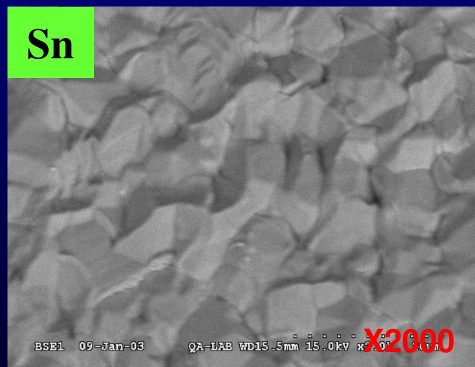


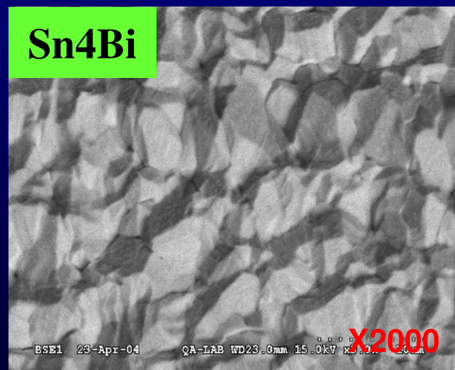
Experiment

IC Package Profile

Packages	LQFP	PLCC	TSOP	PDIP
Lead frame	Olin 7025	Olin 151	Alloy 42	Olin 194
Base metal	Cu/Ni/Si/Mg	Cu/Zr	Fe/Ni	Cu/Fe/P/Zn
Deposit Thickness (matt Sn, SnBi, SnPb)	8~12um	8~12um	8~12um	8~12um
C content	<300ppm	<300ppm	<300ppm	<300ppm
Lead shape	Gull wing	J-bend	Gull-wing	Dual in line
Package Outline				







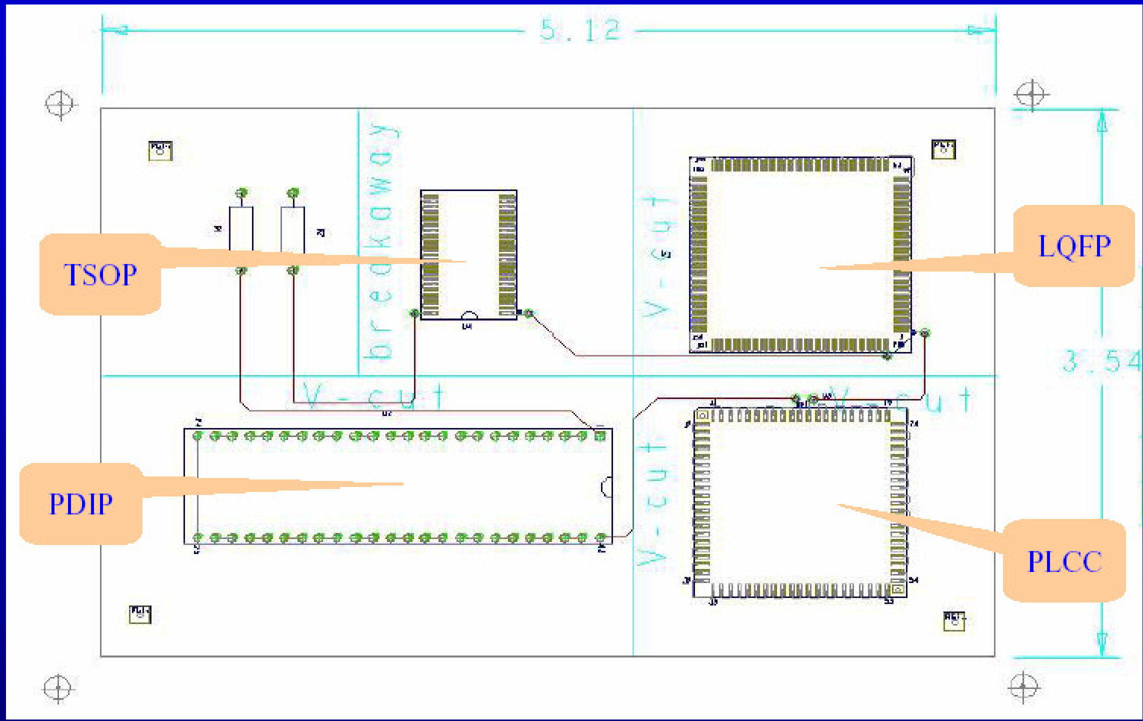
Comparison among plating deposit

lead finish	Sn/15Pb	Sn/2Cu	matt Sn	Sn/4Bi	Sn/3.5Ag
melting point (℃)	183~199	>227	232	228	221
elongation (%)	28~30	>30	>30	20 (brittle)	73
resistivity (μohm-cm	14.99	11.67	11.5	34.48	12.31
process control	easy	middle	easy	middle	hard
solderability	excellent	good	good	good	good
metal cost	low	low	low	high	high
whisker concern	no	serious	serious	middle	middle
compatibility	good	good	good	middle	middle

- Matt Sn is best replacement to SnPb as long as whisker concern is figured out.
- SnCu and SnBi seem more welcomed than matt Sn in Japan .
- SnAg are not cost effective solution.
- PPF will be zero whisker solution instead of Ni under layer + matt Sn

Surface mounting condition

PCB Layout



Solder paste	Procedure	Flux	Surface Finish	PCB Thickness
Sn37Pb	Reflow + Wave	NC Type	OSP	1.6mm
Sn3Ag0.5Cu	Reflow + Wave	NC Type	OSP	1.6mm

DOE
(Experiment Flow)

Reliability test for whisker test condition

After SMT

Whisker check by OM

Whisker testing

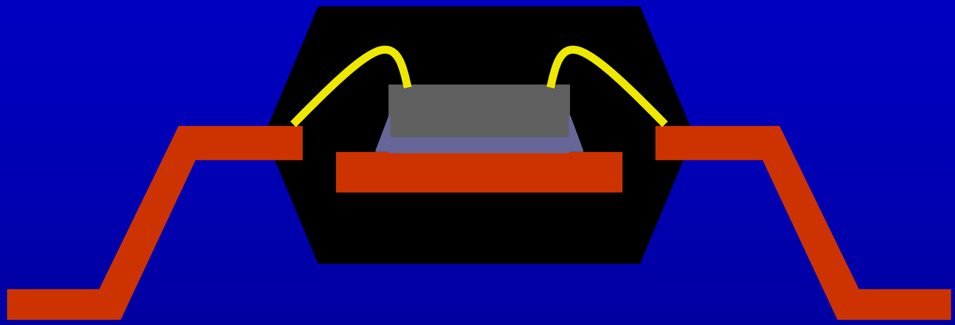
- TCT :–55~85℃ 1000 cycle
- THT: 60℃/90% 3000 hrs
- Ambient 30℃/60% 3000 hrs

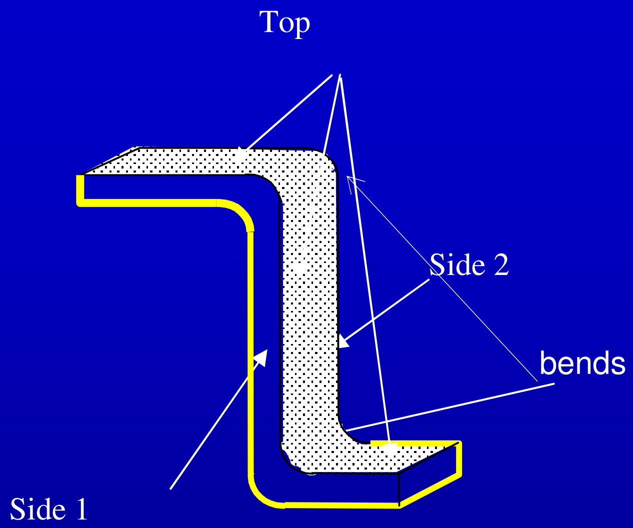
Whisker check by OM

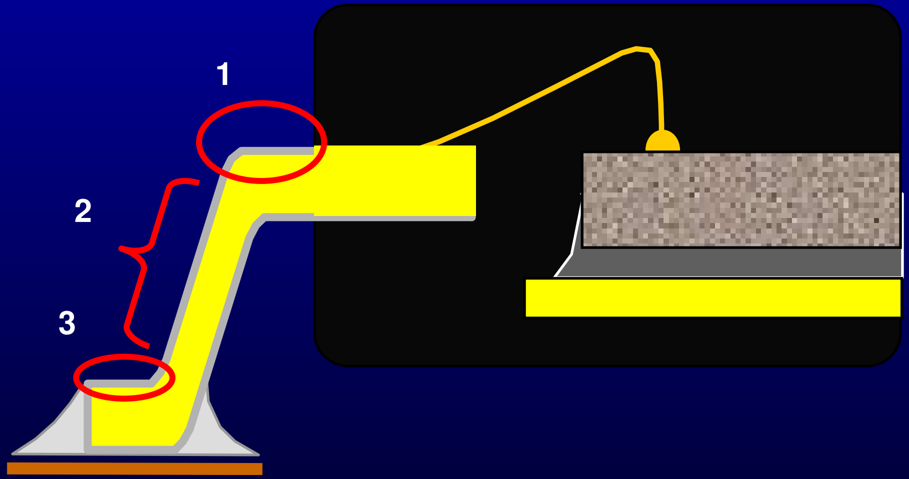
Whisker check by SEM : 2 units with all leads were recorded with max whisker length.

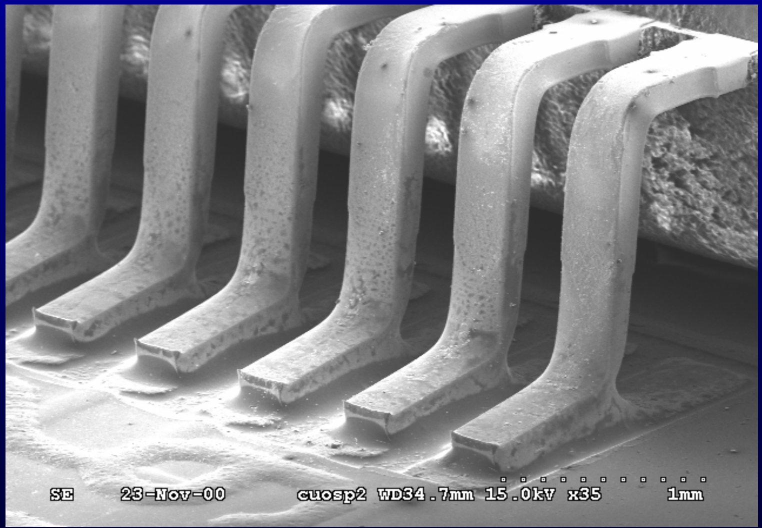
(Chamber capability was humidity ±2.5%RH, temperature ± 0.3 ℃)

The position for whisker check

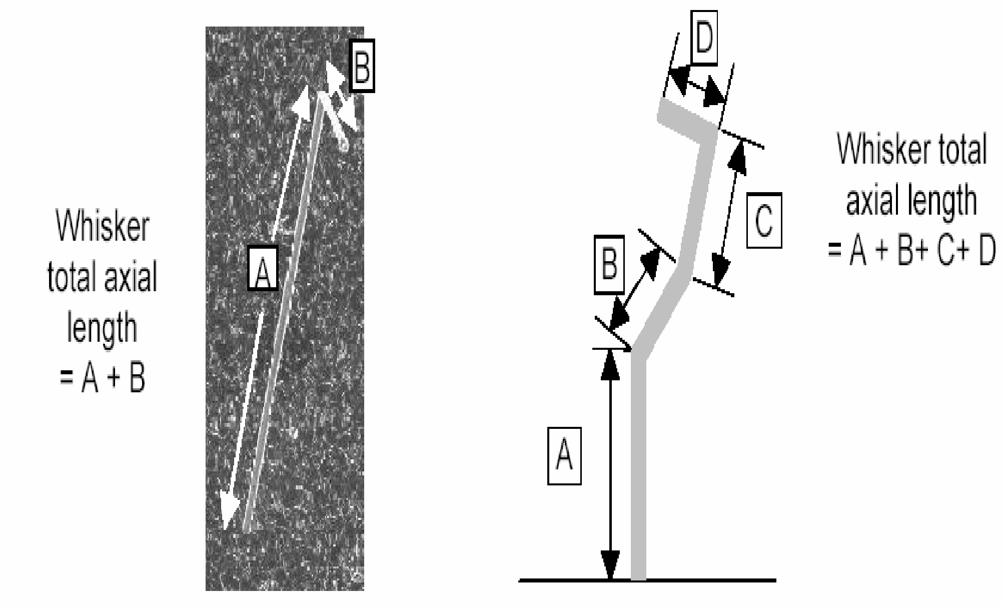


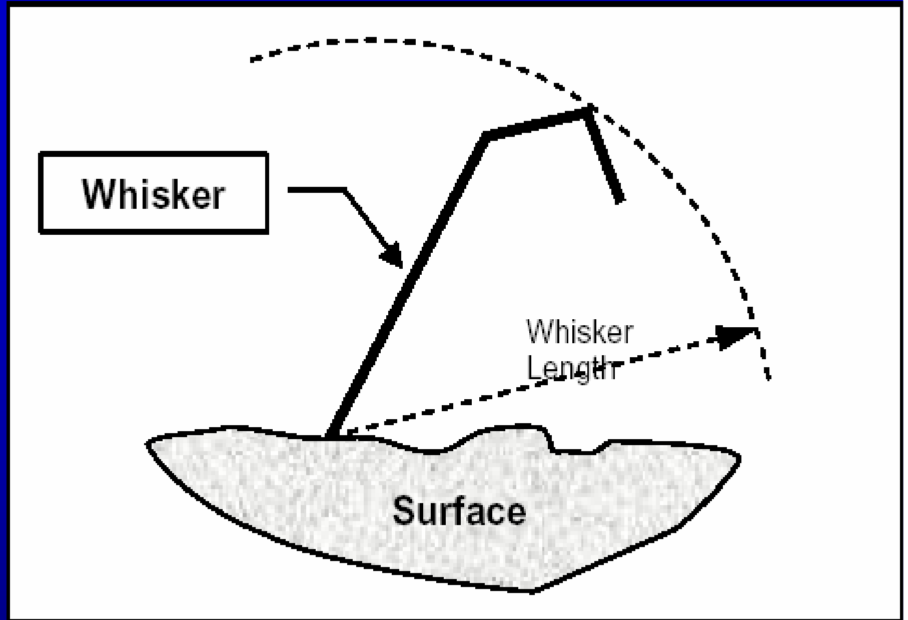






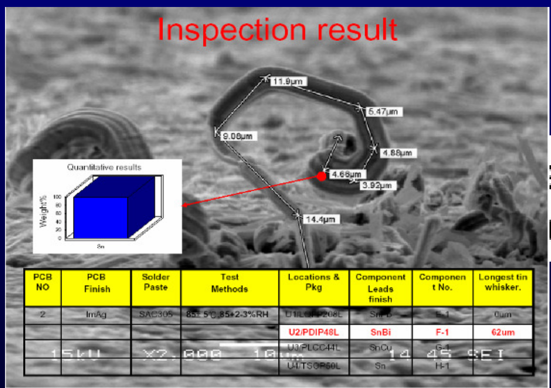
Whisker Length Measurement

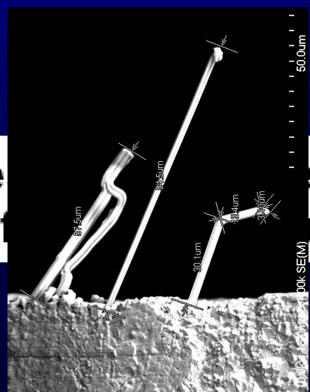


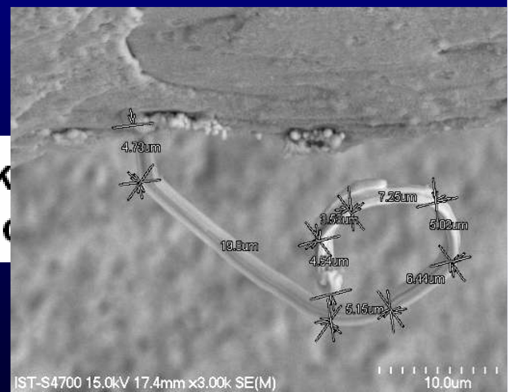


Refer to JESD 22A121

Refer to JESD 201







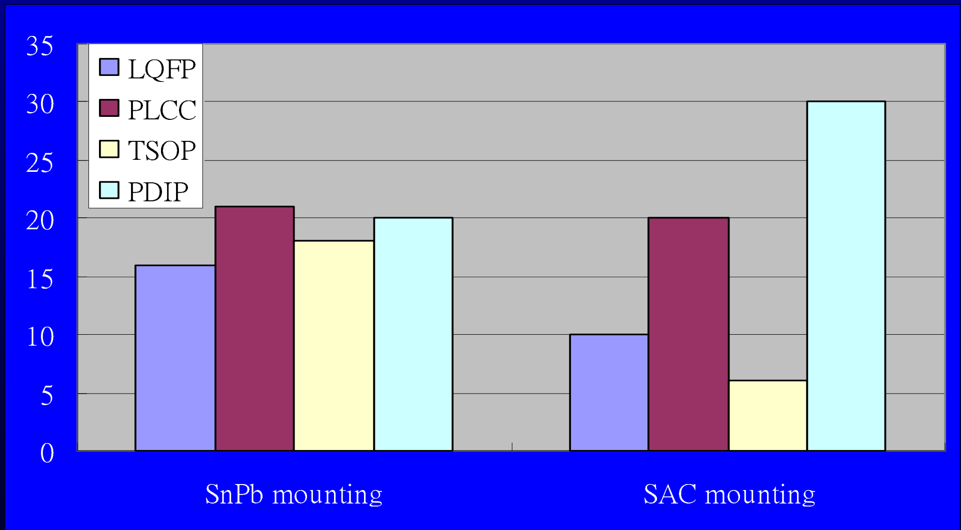
Result and Discussion

Sn plated package on board whisker at TCT 1000cycles

Matt Sn Deposit	SnPb mounting			SAC mounting		
	TCT	THT	Amb.	TCT	THT	Amb.
	1000C	3000H	3000H	1000C	3000H	3000H
LQFP	16	42	0	10	0	0
PLCC	21	78	0	20	34	0
TSOP	18	0	0	6	0	0
PDIP	20	57	0	30	97	0

(unit: um)

*Red : Corrosion finding



The on board whisker comparison at TCT1000cycle among 3 deposits

	SnPb mounting (220ºC)			SAC mounting (245ºC)		
deposit	Sn	SnBi	SnPb	Sn	SnBi	SnPb
LQFP	16	<5	7	10	0	na*2
PLCC	21	27	7	20	13	na*2
TSOP	18	na*1	7	6	na	na*2
PDIP	20	17	11	30	23	na*2

(unit: um)

- *1 SnBi can not be plated on the A42 due to process limit, therefore there is no data in TSOP.
- *2 No forward conversion study in the case

Summary in TCT test

- Zero whisker is not easy to achieve due to the major driving force from CTE mismatch in nature for whisker growth in Sn based alloy plating.
- SMT with SnPb and SAC paste at practical reflow and wave soldering can not cover entire lead frame surface, especially in PLCC and PDIP.
- Higher temperature is not able necessarily to mitigate whisker growth if the deposit can not be melted completely. And too higher process temperature in order to melt the deposit will damage possibly component and PCB. Therefore, delta T across large size PCB will be concerned.
- The whisker acceptance on board level whisker check should be compensated although max whisker length meet the requirement in whisker acceptance criteria in JESD22A121 and JES201.

Result and Discussion
Sn plated packages on board whisker at THT 3000hrs

Matt Sn Deposit	SnPb mounting			SAC mounting		
	TCT	THT	Amb.	TCT	THT	Amb.
	1000C	3000H	3000H	1000C	3000H	3000H
LQFP	16	42	0	10	0	0
PLCC	21	78	0	20	34	0
TSOP	18	0	0	6	0	0
PDIP	20	57	0	30	97	0

*Red : Corrosion finding

(unit: um)

- Corrosion happen in the Cu based package
- No corrosion in the A42 based package

The on board whisker comparison at THT3000hrs among 3 deposits

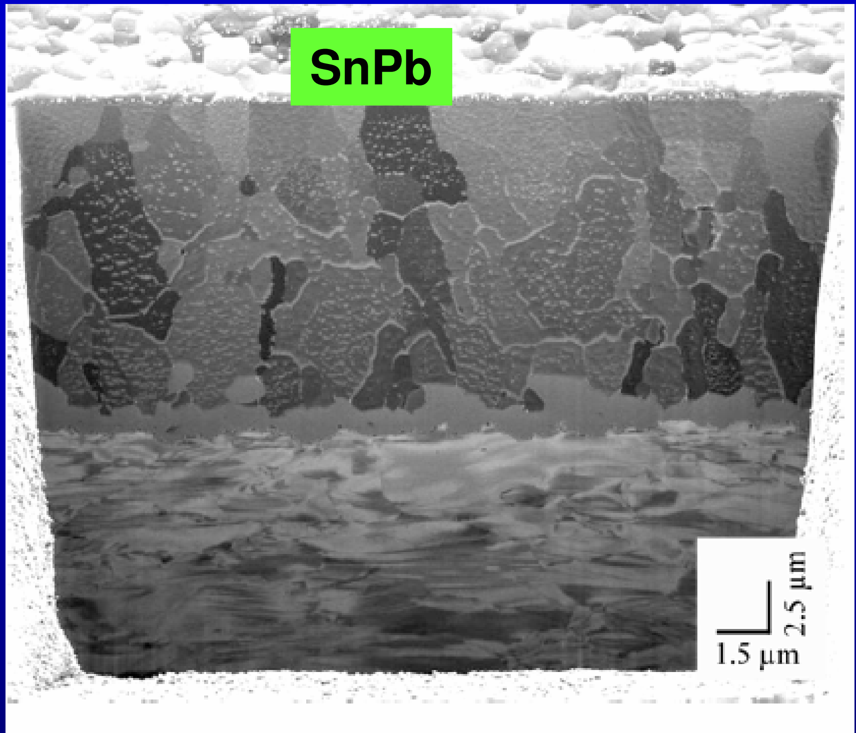
	SnPb mounting (220ºC)			SAC mounting (245ºC)		
deposit	Sn	SnBi	SnPb	Sn	SnBi	SnPb
LQFP	42	8	0	0	8	na*1
PLCC	78	21	0	34	42	na*1
TSOP	0	na	0	0	na	na*1
PDIP	57	52	0	97	80	na*1

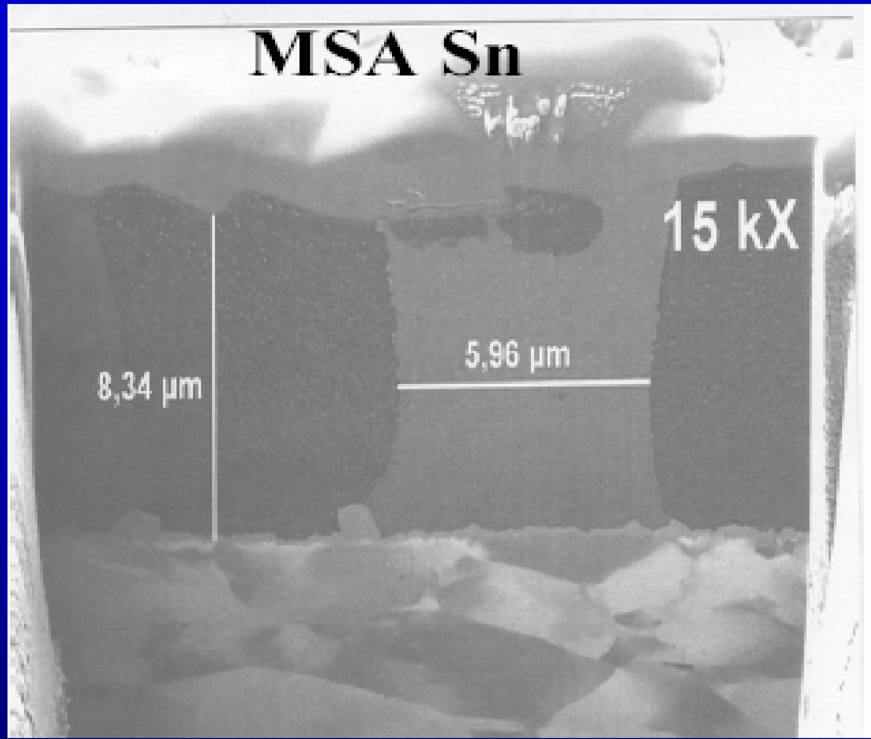
*red: Corrosion

(unit: um)

*1 No forward conversion study in the case

Grain structure comparison between Sn and SnPb deposit





- Non columnar structure
- Horizontal grain boundary
- Less whisker propensity based on known whisker mechanism

- Vertical grain boundary
- Columnar structure
- High potential for Sn atom migration

(Refer to NIST in whisker workshop ECTC2005)

Corrosion Intensity Over Reflow after THT3000hrs by FIB (Focus Ion Beam) Analysis

FIB 800xP System

Figure 1-2 FIB 800xP System

Table top with EMO, console, joystick, monitor, MUI, keyboard, mouse, real-time monitor, and videoprinter; computer on the floor

Vacuum stand with ion column, GIS injectors, and loadlock for sample exchange

Strata FIB 200xP System

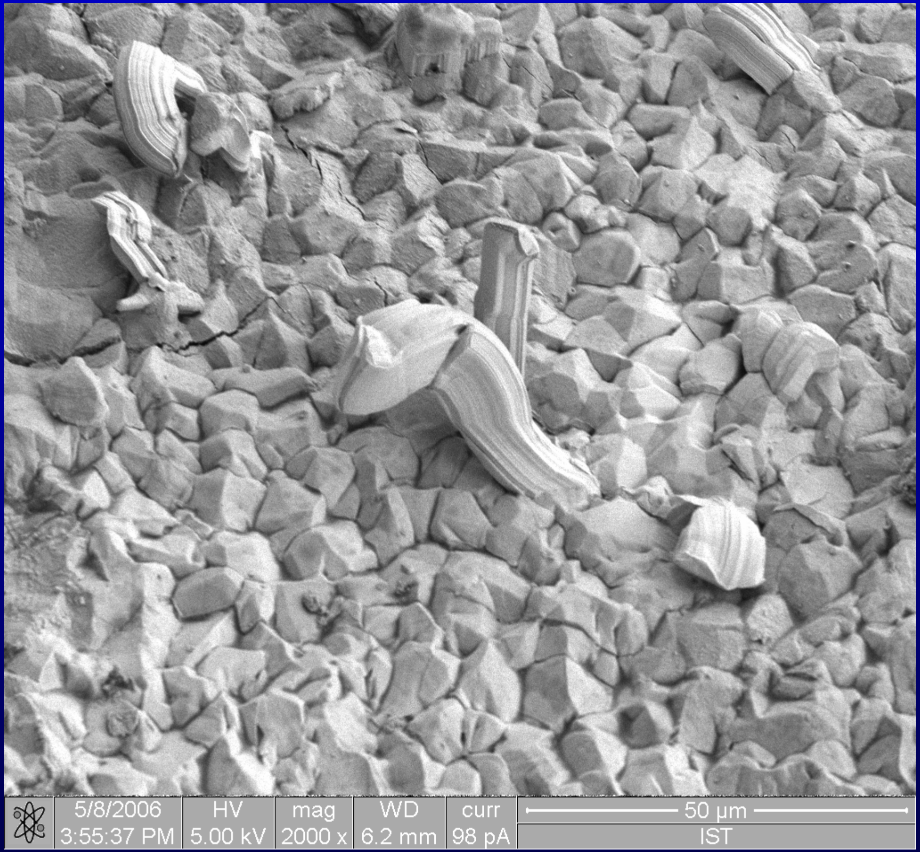
Figure 1-1 Strata FIB 200xP System

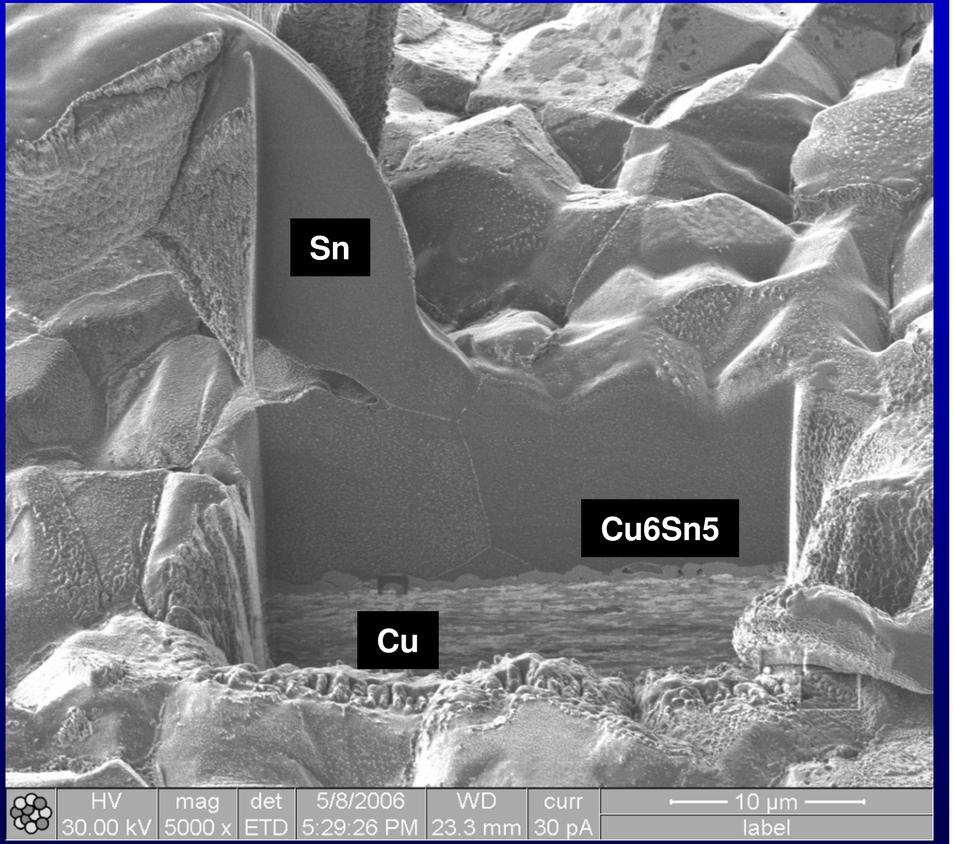
Table top with EMO, console, joystick, monitor, MUI, keyboard, and mouse; computer on the floor

Ion column, GIS injectors, and specimen chamber on the vacuum stand

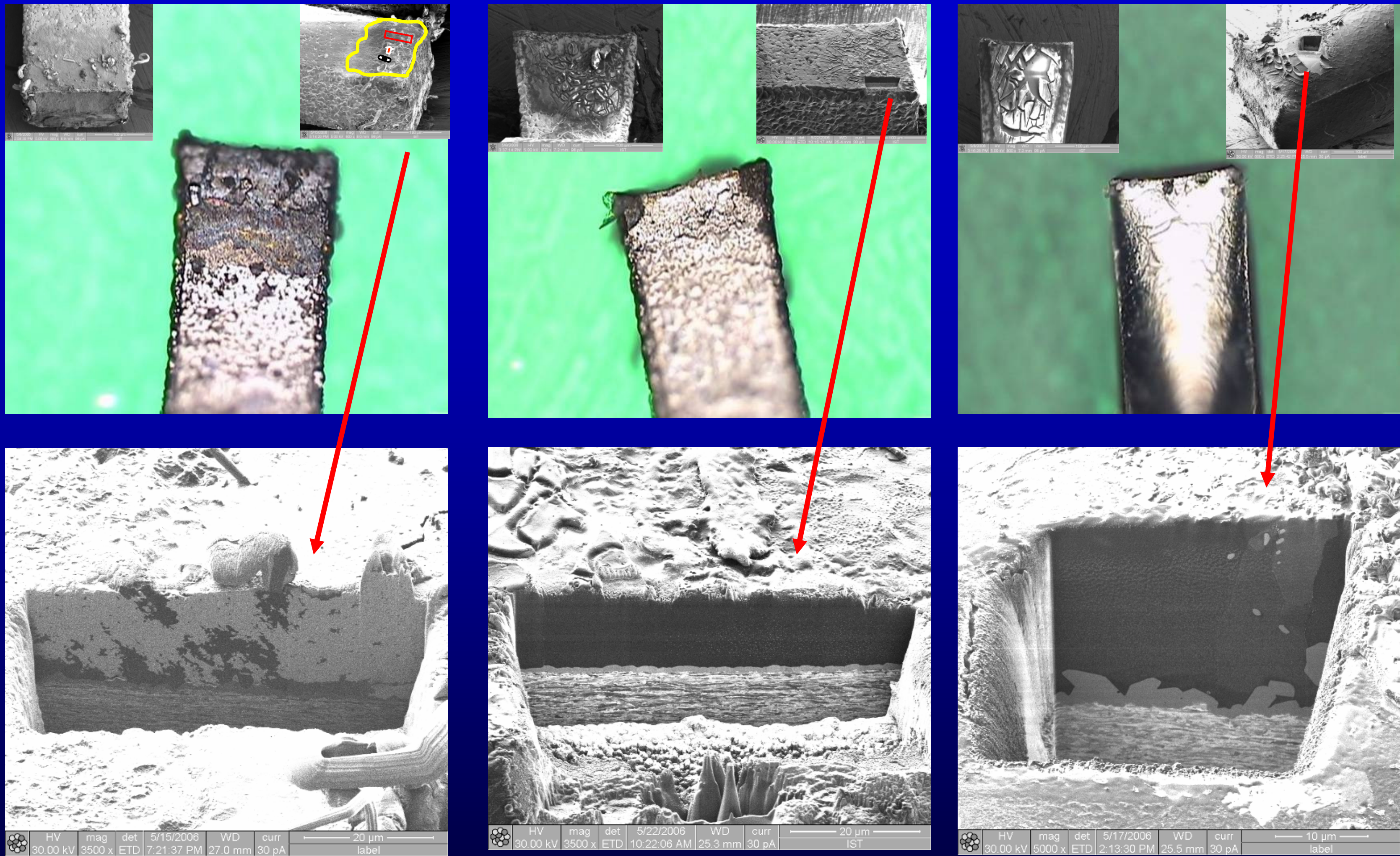
Electronics rack

FIB for whisker analysis example



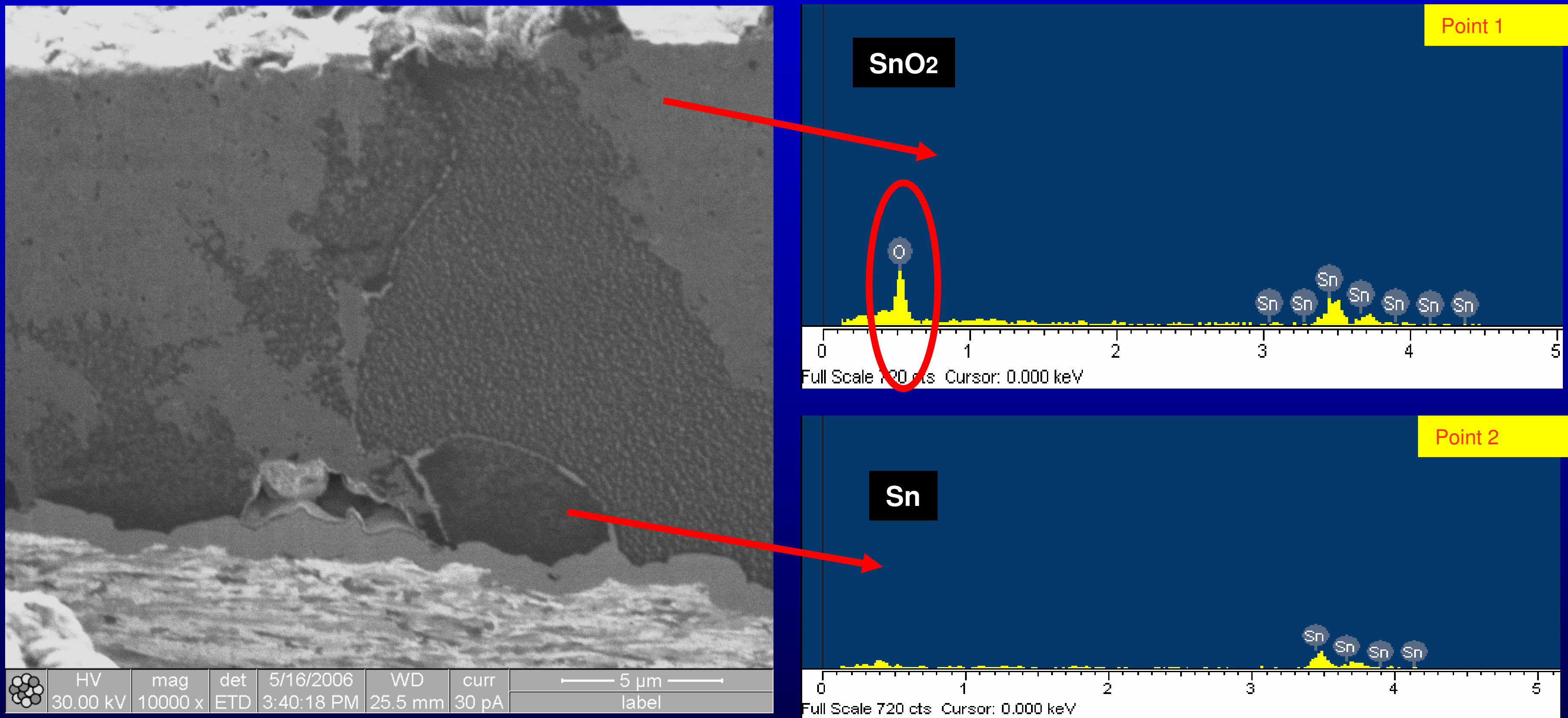


Corrosion Intensity Over Reflow at LQFP after THT3000hrs

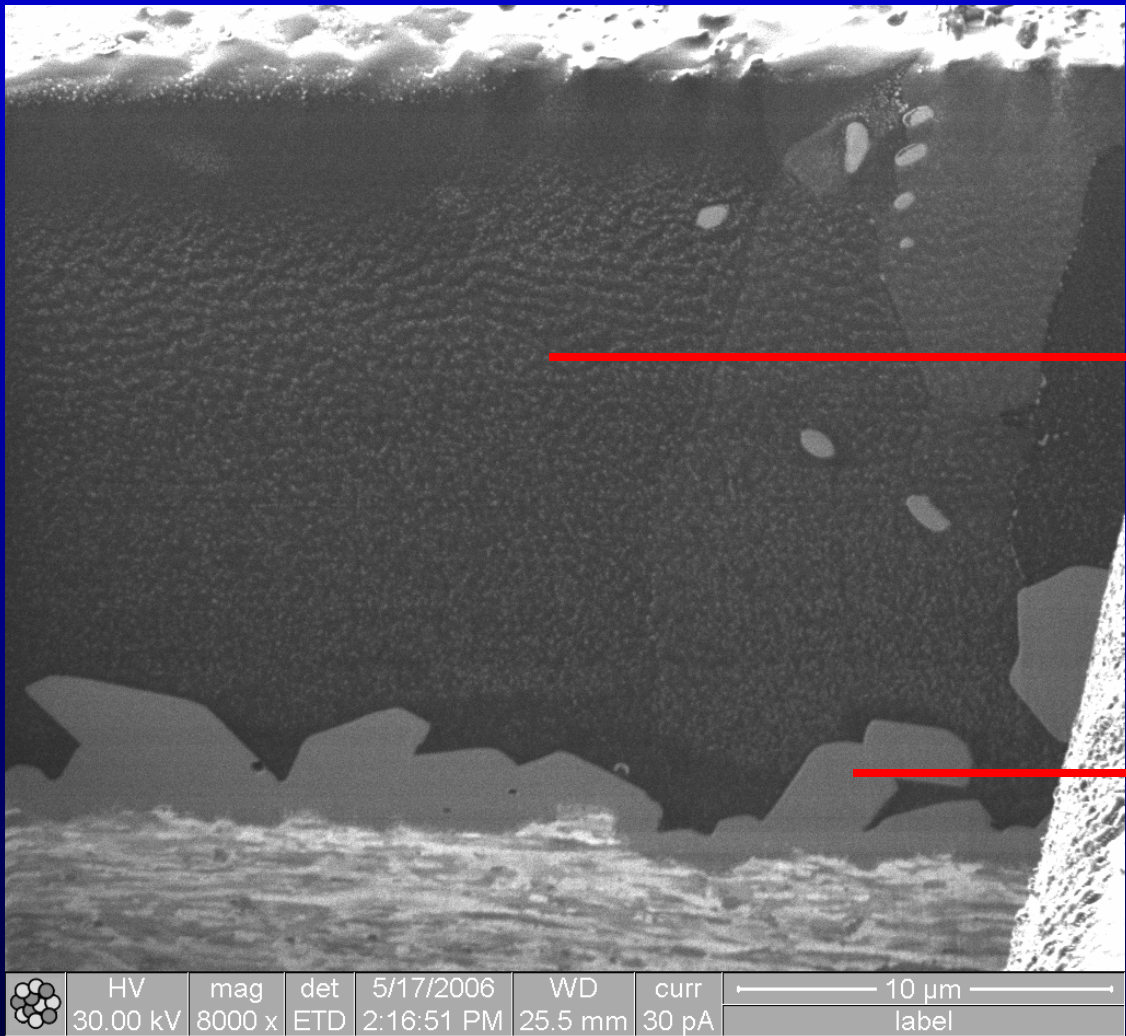


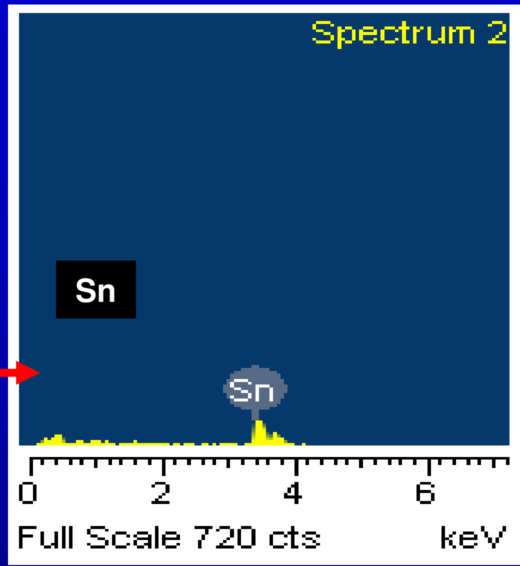
No reflow **220C reflowX1** **260C reflowX1**

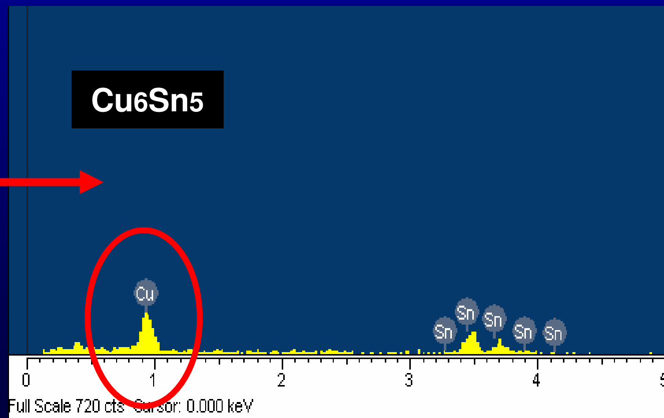
EDX Analysis for No Reflow



EDX Analysis for Reflow at 260℃







Summary in THT test

- Whisker can be induced significantly when corrosion happening in long term humidity acceleration test.
- Corrosion is another mechanism for whisker growth beyond known mechanism from Cu_6Sn_5 IMC growth.
- Flux residue did not play good role for corrosion prevention.
- There is no corrosion found in Alloy42 based TSOP, suppose less galvanic potential difference between Fe and Sn than Cu and Sn.
- Whether high enough process temperature is able to reduce corrosion happening if the high m.p Sn or SnBi deposit can be melted completely. But beware that too high process temperature could damage component and PCB.

Conclusion

- In practical PCBA, the surface deposit in the lead frame IC package could not be controlled due to preference difference in Japan, EU and U.S. The process profile to accommodate each component will be difficult for whisker mitigation completely.
- The higher process SMT temperature for SAC solder joint seems not working well for whisker mitigation. And beware that too higher process temperature will adversely influence component and PCB material reliability if intending to melt all Sn based deposits.
- Zero whisker is not easy to achieve in all tests for Sn based alloy.
- The corrosion happening due to long THT acceleration test should not be original Sn deposit characteristics regarding whisker potential. The correlation between acceleration test and service life should be defined again for high end product.
- Ni underlayer is not good whisker mitigation skill at TCT condition unless low Sn thickness can be controlled well in plating process.

INTEGRATED SERVICE TECHNOLOGY

Question :
Is it possible to achieve whisker free by way of surface mounting design?

Remind—timetable is getting very short

Now EU RoHS has been in effect and China RoHS is coming!

Thanks for your kind attention !