Quantification of the influence of all important physical and chemical Tin plating bath parameters on the propensity for whisker formation

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Abstract
With the EU legislation imposing lead-free production in 2006 for most of the electrical and electronic equipment, also the IC/leadframe as well as the connector industry are eagerly looking for solderable alternatives to the commonly used SnPb alloys. In outer lead plating a tendency towards the Ultrathin Ni/Pd/Au finish is observed at present, because of the danger of whisker formation with pure matt tin layers. Other Sn alloys like SnBi, SnCu or SnAg are either equally susceptible to whisker formation and/or technically difficult to handle and/or unacceptable due to the large process costs involved. The following figure shows that transition for leadframe plating finish 2005 vs. 2010.

Matte tin (Sn) is the most obvious choice due to the simple transition from SnPb plating and the expected low cost of Sn coatings.Therefore basic and applied research on the most economical alternative for outer lead plating, pure tin, continues in order to be able to provide the industry with a widely acceptable solution for the future.

The paper presented is a complete documentation and comparison of the whisker propensity of matt and bright MSA based tin electrolytes as a function of the three iNEMI/Jedec storage conditions and all important physical and chemical plating parameters.

The variables investigated were Sn concentration, current density, agitation, bath temperature, MSA concentration, additive (carrier) and grain refiner (brightener) concentration. On top of that the influence of a post bake (1h, 150°C) and different Ni interlayer's (Sulfamate and Watt's) of variable thickness was explored. After storage the samples were characterised with respect to their maximum whisker length (MWL) and the occurrence rate (OR) of the whiskers found. This leads to the quantification of a variable's influence and propensity as a function of storage condition. According to this the individual plating parameters were classified as critical, influential or non-influential. The conclusions drawn from this extensive data base will lead the manufacturer to a comprehensive process and control guideline for the deposition of pure tin deposits on outer leads.

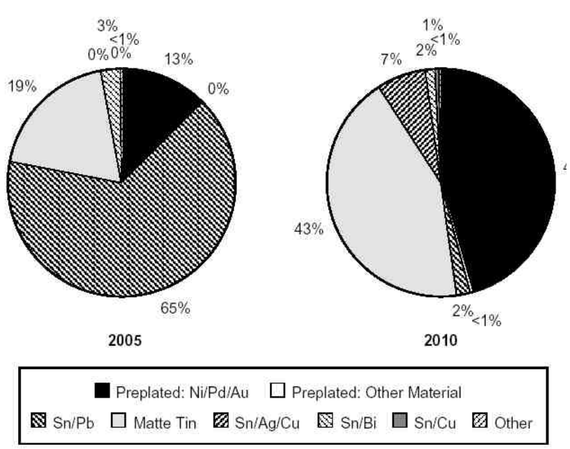

Figure 1: Leadframe Plating Finish, 2005 vs. 2010, IC Packaging Material, 2006 [1]

Industrial Practice and Remaining Issues with Plating Pure Tin

The formation of whiskers when switching from SnPb to pure Sn finishes affects two main segments of the electronic industries: IC/leadframe and connector. These two applications take different approaches to mitigate the formation of whiskers. While in the connector case the majority of products are being plated with a nickel interlayer, in the IC assembly companies a post bake of 150°C is applied for one hour after Sn plating. Both options are very effective means to prevent the phenomenon from occurring. The remaining issues within these industries are the formation of whiskers due to pressure exerted by the molding compound (connectors) and due to the corrosion of the Sn layer during storage [2]. The latter instance is favored by heat/humidity and contamination of the plated parts. Connectors and ICs are affected. Figure 2 shows various images taken from of a "post molded" connector with whisker formed due to the pressure of the molding compound. Figure 3 gives an images of the Cu-Sn interface (exposed by trim and form) of an outer lead after heat/humidity storage and of corrosion whiskers therein.

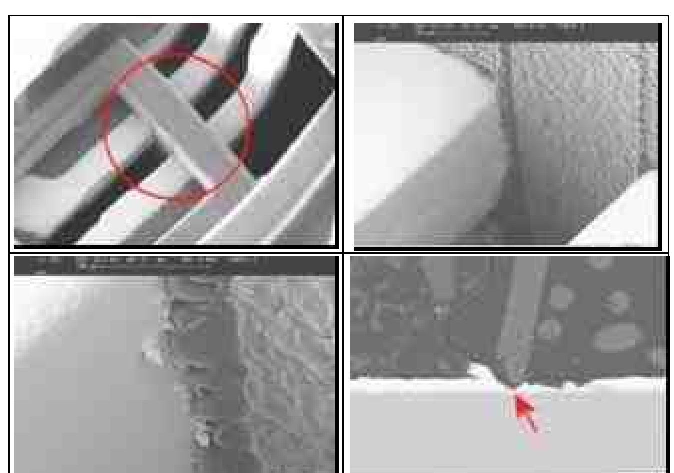

Figure 2: Images taken from of a "post molded" connector; whiskers formed at the interface due to the pressure of the molding compound on the Sn layer

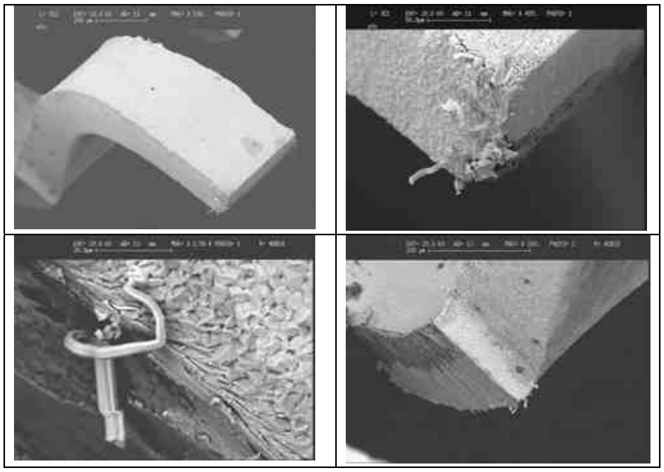

Figure 3: Sn plated, and corroded outer leads after trim and form and 4000 hours storage at 60ºC/90%RH

On the side of the plating technology supplier the question remains under which circumstances whisker formation is favored. Are there critical areas within the working range of the electrolyte which need to be avoided as whiskers are more prone to occur ? Are there physical parameters such as temperature or agitation accelerating the formation?

The Details of the Whisker Matrix and the Evaluation

For our extensive investigation the following physical and chemical electrolyte parameters were identified to potentially have an influence on the whisker formation tendency:

- Sn thickness
- Ni thickness (without, with 2 µm and with 0,5 µm)
- Ni bath type (Sulfamate and Sulfate)
- Current density
- Temperature
- Agitation
- Sn concentration
- MSA concentration
- Additive concentration
- Grain refiner concentration
- Post bake (150ºC for 1 hour)

Each parameter was varied individually while keeping the other default values unchanged. In the IC/leadframe application (no Ni interlayer) the common C194 base material was chosen. In the connector case Ni plated bronze pins were evaluated. Sn and Ni plating thicknesses were varied in the range of the layer thicknesses used in production. Extreme values on the low Sn side were chosen as these are known to be most critical for the isothermal storage conditions. After plating the samples were stored according to the NEMI recommendations valid at the time of the evaluations:

1. TCT from –55ºC to +85ºC – 1000 cycles
2. Isothermal at 30ºC/60%RH – 4000 hours
3. Isothermal at 60ºC/90%RH – 4000 hours

(RH – relative humidity)

After storage the tests were evaluated and the whisker propensity quantified. For each sample the maximum whisker length (MWL) and the whisker density or occurrence rate (OR) was compiled.

The OR classification ranges from 5 (no whisker) to 1 (abundant whisker formation).

The parameters were classified with respect to being functional, which means there is a dependence of the whisker formation with this parameter or even critical for the case that the MWL exceeded 40 µm.

Due to the extend (a total of 151 samples for the matt StannoPure HSM and 93 for the bright StannoPure HSB high speed Sn electrolyte were prepared) of the SEM photo documentation prepared during this study, we will refrain from displaying most of these pictures within this publication. The reader is asked to contact the authors for the details and the photos of the SEM surfaces investigation.

The details of the matrix with all parameters summarized can be found in appendix 1.

The Results of the Whisker Tests - High Speed Matt Tin Electrolyte/ StannoPure HSM

The matt Sn electrolyte StannoPure HSM chosen for this evaluation is widely used in the plating of ICs and connectors and has been tested and qualified by leading MNCs working in these fields of application.

Though all the relevant data is available for matt Sn layers plated on a Ni interlayer (connector case) as well, only the IC application will be discussed in detail here.

- **TCT 1000 (**–55ºC to +85ºC)

Table 1 and 2 compare the maximum whisker length found after TCT 1000 with and without post baking at 150^{o}C for one hour.

	Level		
	Low	Medium	High
Sn thickness	5		10
CD	10	10	20
Temperature	15	10	15
Agitation	10		10
Sn content	10	10	10
MSA content	15	10	20
Additive content	10	10	10
GR content	10	10	20

Table 1: High speed matt Sn layer plated on C194 without post bake – Evaluation of MWL after TCT 100

	Level		
	Low	Medium	High
Sn thickness	0		20
CD	10	20	25
Temperature	20	20	15
Agitation	15		20
Sn content	10	20	15
MSA content	20	20	25
Additive content	10	20	10
GR content	10	20	20

Table 2: High speed matt Sn layer plated on C194 after post bake (150^{o}C/1h) – Evaluation of MWL after TCT 1000

Table 3 and 4 compare the maximum whisker occurrence rate after TCT 1000 with and without post baking at 150^{o}C for one hour.

	Level		
	Low	Medium	High
Sn Thickness	4,0		1,0
CD	2,0	1,0	0,5
Temp	1,0	1,0	1,0
Agitation	1,0		1,0
Sn Content	0,5	1,0	1,0
MSA Content	0,5	1,0	1,0
Add Content	1,0	1,0	1,0
GR Content	2,5	1,0	0,5

Table 3: High speed matt Sn layer plated on C194 without post bake – Evaluation of OR after TCT 1000

	Level		
	Low	Medium	High
Sn Thickness	5,0		2,0
CD	2,0	2,0	2,5
Temp	1,5	2,0	1,0
Agitation	2,0		2,0
Sn Content	1,0	2,0	1,0
MSA Content	0,5	2,0	2,0
Add Content	1,0	2,0	2,0
GR Content	3,0	2,0	0,5

Table 4: High speed matt Sn layer plated on C194 after post bake (150^{o}C/1h) – Evaluation of OR after TCT 1000

The following conclusions with respect to the TCT 1000 storage of this matt Sn layer are drawn from the data summarized in the previous tables.

No whiskers longer than 25 µm were found, thus with respect to the working range of the bath the TCT storage condition is not critical. However it can be witnessed from the OR data no mitigating effect of the post bake is found. In contrary, the whisker density and maybe even the maximum whisker length (MWL) will slightly increase with the thermal post-treatment applied.

Current density, Sn thickness and grain refiner concentration are functional parameters with respect to the TCT 1000 storage condition. At a low Sn thickness of 3 µm the abundant whiskering found for 10 µm will disappear.

- **Isothermal at 30ºC/60%RH** – 4000 hours

Table 5 and 6 compare the maximum whisker length found after 4000 hours at 30ºC/60%RH. Again the data compares the whisker formation tendency with and without post baking at 150^{o}C for one hour.

	Level		
	low	medium	high
Sn thickness	30		20
CD	25	20	20
Temperature	25	20	25
Agitation	50		20
Sn content	15	20	15
MSA content	20	20	35
Additive content	20	20	20
GR content	50	20	20

Table 5: High speed matt Sn layer plated on C194 without post bake – Evaluation of MWL after 4000 hours at 30ºC/60%RH

	Level		
	low	medium	high
Sn thickness	0		0
CD	0	0	0
Temperature	0	0	0
Agitation	0		0
Sn content	15	0	10
MSA content	10	0	0
Additive content	0	0	0
GR content	15	0	10

Table 6: High speed matt Sn layer plated on C194 after post bake (150^{o}C/1h) – Evaluation of MWL after 4000 hours at 30ºC/60%RH

Table 7 and 8 compare the maximum whisker occurrence rate a after 4000 hours at 30ºC/60%RH with and without post baking at 150^{o}C for one hour.

	Level		
	low	medium	high
Sn thickness	4		4
CD	4	4	4
Temperature	3	4	3
Agitation	4		4
Sn content	4	4	4
MSA content	4	4	4
Additive content	4	4	4
GR content	4	4	4

Table 7: High speed matt Sn layer plated on C194 without post bake – Evaluation of OR after 4000 hours at 30°C/60%RH

	Level		
	low	medium	high
Sn thickness	5		5
CD	5	5	5
Temperature	5	5	5
Agitation	5		5
Sn content	4	5	4
MSA content	4,5	5	5
Additive content	5	5	5
GR content	4,5	5	4,5

Table 8: High speed matt Sn layer plated on C194 after post bake (150°C/1h) – Evaluation of OR after 4000 hours at 30°C/60%RH

The following conclusions with respect to the storage of this matt Sn layer for 4000 hours at 30°C/60%RH are drawn from the data summarized in the previous tables.

All whiskers longer than 20 µm were found on the stamping edge of the leadframe (Figure 3a). After post bake the base material stress is released and a homogeneous IMC is formed, leading to an almost negligible whisker formation (Figure 3b). Grain refiner and agitation are critical factors for whisker formation, if no post bake is applied.

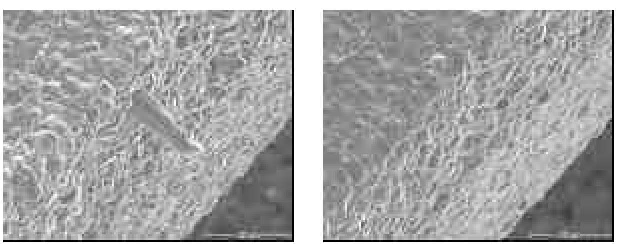

Figure 3: Whisker at stamping edge of the LF (left) and a corresponding sample after post bake (right)

While there will always be agitation exerted the transportation of the IC strips through the cell, the grain refiner should be monitored. The 50 µm whisker was found at a grain refiner concentration of 5 ml/l, well outside the working range of the electrolyte (lower limit 15 ml/l).

- **Isothermal at 60°C/90%RH** – 4000 hours

Table 9 and 10 compare the maximum whisker length found after 4000 hours at 60°C/90%RH. The data compares the situation found with and without post baking at 150°C for one hour.

	Level		
	low	medium	high
Sn thickness	15		5
CD	5	5	0
Temperature	10	5	5
Agitation	5		5
Sn content	5	5	0
MSA content	5	5	5
Additive content	5	5	5
GR content	5	5	5

Table 9: High speed matt Sn layer plated on C194 without post bake – Evaluation of MWL after 4000 hours at 60°C/90%RH

	Level		
	low	medium	high
Sn thickness	0		0
CD	0	0	0
Temperature	0	0	0
Agitation	0		0
Sn content	0	0	0
MSA content	0	0	0
Additive content	0	0	0
GR content	0	0	0

Table 10: High speed matt Sn layer plated on C194 after post bake (150°C/1h) – Evaluation of MWL after 4000 hours at 60°C/90%RH

Table 11 and 12 compare the maximum whisker occurrence rate after 4000 hours at 60°C/90%RH with and without post baking at 150°C for one hour.

	Level		
	low	medium	high
Sn thickness	4		4
CD	4	4	5
Temperature	4	4	4
Agitation	4		4
Sn content	4	4	5
MSA content	4	4	4
Additive content	4	4	4
GR content	4	4	4

Table 11: High speed matt Sn layer plated on C194 without post bake – Evaluation of OR after 4000 hours at 60°C/90%RH

	Level		
	low	medium	high
Sn thickness	5		5
CD	5	5	5
Temperature	5	5	5
Agitation	5		5
Sn content	5	5	5
MSA content	5	5	5
Additive content	5	5	5
GR content	5	5	5

Table 12: High speed matt Sn layer plated on C194 after post bake (150°C/1h) – Evaluation of OR after 4000 hours at 60°C/90%RH

The following conclusions with respect to the storage of this matt Sn layer for 4000 hours at 60°C/90%RH are drawn from the data summarized in the previous tables.

No whiskers longer than 15 µm grew during 4000 hours at the heat/humidity storage condition. No corrosion whisker was formed. This was successfully avoided as the samples were kept clean after plating and no Cu or other more noble elements were exposed on the sample surface. All whiskers found developed at the stamping edge of the frame.

After post bake no whiskers were observed, again through the stress relaxation within the material and/or the formation of a homogeneous IMC. The Sn thickness may be a functional parameter. If only the samples without post bake are considered.

If corrosion can be avoided the heat/humidity storage is the least dangerous storage condition. Practically with corrosion occurring at the Cu/Sn interface this storage condition is most severe and dangerous. However beyond the influence of the matt Sn plating electrolyte.

- **Nickel Interlayer Type and Thickness at 30ºC/60%RH**

The investigations done with respect to the connector application included the dependence on the type of Ni plating bath used and determination of the whisker propensity at low Ni thickness. As a Ni layer may be critical during the trim and form process the lower Ni thickness chosen was around 0.5 µm. A Ni Sulfamate layer of that thickness will not crack during the bending operation.

In table 13 a comprehensive summary of the results after for 4000 hours at 30ºC/60%RH is given. With corrosion avoided this is clearly the most stringent of the three NEMI storage conditions.

	Level		
	low	medium	high
Sn/Ni thickness	0	0/0	0
CD	0	0	0
Temperature	0	0	0
Agitation	0		0
Sn content	0	0	0
MSA content	0	0	0
Additive content	0	0	0
GR content	0	0	0

Table 13: High speed matt Sn layer plated on a Ni interlayer – Evaluation of MWL after 4000 hours at 30ºC/60%RH

As no whiskers were found the whicker density rate table is not required. A Ni layer is a stronger mitigating measure to prevent whisker growth than a post bake.

It was found that even down to a Ni thickness of 0.5 µm no whiskers were detected. Thus plating a thin Ni diffusion barrier may also be practical in the assembly houses without a large risk of cracking by bending.

Ni Sulfamate was finally compared to the Watt's type Ni electrolyte (Sulfate based). Figure 4 shows representative SEM images at different magnifications taken from the Watt's Ni + Sn plated samples

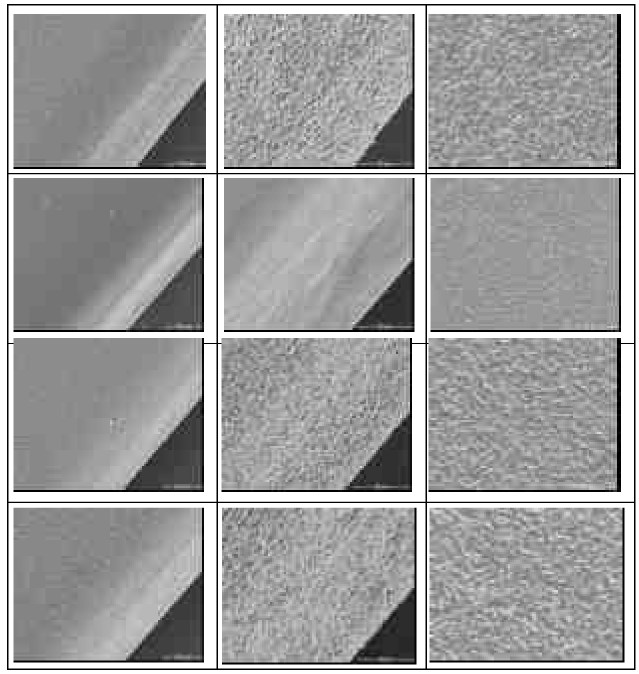

Figure 4: Matt Sn layers on Watt's Ni (2 µm) at different Sn thicknesses/current densities after 4000 hours storage at 30ºC/60%RH; from top to bottom row: 8µm/15Asd; 1µm/15Asd; 8µm/5Asd; 8µm/20Asd

As in the case of Ni Sulfamate no whiskers were found under no circumstances.

The Results of the Whisker Tests - High Speed Bright Tin Electrolyte/ StannoPure HSB

While bright tin layers are becoming increasingly popular in connector plating they are so far no alternative for the IC/LF industry. Previous data and experiences showed that their whisker propensity is much stronger than that of matt Tin layers and that the whisker's maximum length can even be in the mm range.

In many cases these experiences stem from electrolytes which were controlled merely by the brightness of Hull cells and not by quantified analytical results. With analysis procedures available one is now in the position to run these electrolytes on a constant brightener and carrier level.

In the course of our extensive investigations the propensity of a high speed bright tin electrolyte was investigated as well. Its whisker propensity can thus directly be compared to the matt version.

The bright Sn electrolyte chosen for this evaluation is widely used in the plating of connectors and has been tested and qualified by leading MNCs.

The matrix designed for the investigation of the bright Sn deposit plated directly on C194 was somewhat less elaborate, the details are found in appendix 2. However it contained knowingly critical parameters as such as

Current density

Temperature

Brightener concentration
Carrier concentration
Post bake

Within this evaluation no whiskers longer than 40 µm were found. Furthermore, in contrary and most surprisingly, the whisker formation during TCT 1000 was found to be much less pronounced. Also different to the matt Sn layers a quite positive and mitigating influence of a Ni interlayer during TCT 1000 was found.

Figure 5 compares the matt Sn to the bright Sn version at standard parameters, with and without a Ni interlayer.

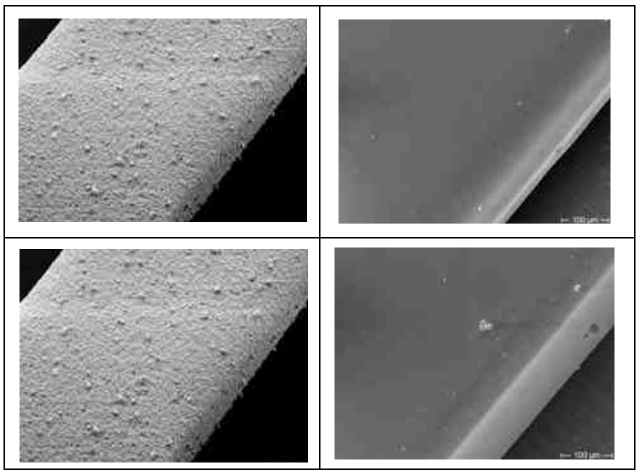

Figure 5: Comparison of matt (left side) and bright (right side) tin layers after TCT 1000, 15 Asd,, 8-10 µm Sn, with (top row) and without (bottom row) Ni interlayer

These excellent results are accompanied by the fact that within the extensive Ni interlayer matrix carried out on the bright tin bath (see Appendix 3), not a single whisker was found after isothermal storage. The numerical results and the corresponding SEM information can be obtained from the authors upon request.

Further advantages of bright over matt tin layers have recently also been described by Tyco [3]. In this interesting publication it was demonstrated that whiskers formed (during heat/humidity, corrosion!) in regions of increased pressure (by connectors) or on bent connector areas are more prone to occur with matt tin.

Conclusions

Matt Sn Electrolyte/ StannoPure HSM

1. Within the range investigated (for all physical and chemical parameters), only a shortage of grain refiner appears to be a critical condition for whisker formation. This is only found during room temperature storage, and not during heat/humidity or TCT 1000.
2. Without corrosion occurring the most severe condition is room temperature storage. It is thus most likely that any documented incident of whisker formation at heat/humidity was caused by corrosion and not by process parameters out of range.
3. The Sn thickness is clearly a functional parameter for the propensity of whisker formation. While for the TCT 1000 storage condition no whiskers will occur at low thickness, this condition will lead to longer whiskers during isothermal storage.
4. A post bake is an effective means to reduce the whisker formation during the subsequent isothermal storage at room temperature or at elevated heat and humidity. A post bake is not effective to reduce the whisker propensity during thermal cycling. The data acquired even indicates a generally higher whisker density or occurrence rate and potentially longer whiskers.
5. A Ni interlayer is more effective to suppress the whisker formation during isothermal storage. No whiskers are found with a Ni interlayer of 1-2 µm.
6. A Ni interlayer as thin as 0.5 µm can effectively prevent the whisker formation during isothermal storage. Ductile Ni Sulfamate layers will not crack at these thicknesses during the trim and form process.
7. Watt's Ni layers are equally suitable to mitigate whiskering during isothermal storage. No difference was found as compared to Ni Sulfamate. The influence of current density and Sn thickness was investigated and no whiskers were documented.

Bright Sn electrolyte/ StannoPure HSB

8. Bright tin electrolytes can exhibit similar low whisker propensity like their matt counterparts. Especially on Ni interlayer's the electrolytes give almost whisker free deposits within the entire working range.
9. Under certain conditions, i.e. during TCT 1000, it was found that their tendency towards whisker formation is much lower. It is very likely that bright tin layers are more resistant to oxidation and that corrosion whiskering is reduced, if not entirely suppressed.
10. The strong whisker tendency found for bright Sn deposits in former times may be related to inadequate analytical procedures in place.

References

[1] IC Packaging Materials, Electronic Trend Publications Inc., p. 2-2, 2006

[2] M. Dittes, P.Oberndorff, P.Su, P. Crema; ETCT NEMI workshop, June 1, 2005

[3] R. Hilty, IPC/JEDEC 11th Conference on Lead-Free, Boston, Dec. 7, 2005

Appendices

Appendix 1

	Sn Thickness	**CD [A/dm?]**	**Temperature**	**Agitation**	**Metal content**	**MSA content**	**Additive**	**Grain Refiner**	**post bake**
C 194 -1	10 µm	15	40°C	yes	70 g/L	190 g/L	50 mL/L	20 mL/L	yes/no
C 194 -2	**3 µm**	15	40°C	yes	70 g/L	190 g/L	50 mL/L	20 mL/L	yes/no
C 194 -3	10 µm	**5**	40°C	yes	70 g/L	190 g/L	50 mL/L	20 mL/L	yes/no
C 194 -4	10 µm	**40**	40°C	yes	70 g/L	190 g/L	50 mL/L	20 mL/L	yes/no
C 194 -5	10 µm	15	**24°C**	yes	70 g/L	190 g/L	50 mL/L	20 mL/L	yes/no
C 194 -6	10 µm	15	**50°C**	yes	70 g/L	190 g/L	50 mL/L	20 mL/L	yes/no
C 194 -7	10 µm	15	40°C	**no**	70 g/L	190 g/L	50 mL/L	20 mL/L	yes/no
C 194 -8	10 µm	15	40°C	yes	**30 g/L**	190 g/L	50 mL/L	20 mL/L	yes/no
C 194 -9	10 µm	15	40°C	yes	**90 g/L**	190 g/L	50 mL/L	20 mL/L	yes/no
C 194 -10	10 µm	15	40°C	yes	70 g/L	**100 g/L**	50 mL/L	20 mL/L	yes/no
C 194 -11	10 µm	15	40°C	yes	70 g/L	**230 g/L**	50 mL/L	20 mL/L	yes/no
C 194 -12	10 µm	15	40°C	yes	70 g/L	190 g/L	**30**	20 mL/L	yes/no
C 194 -13	10 µm	15	40°C	yes	70 g/L	190 g/L	**70**	20 mL/L	yes/no
C 194 -14	10 µm	15	40°C	yes	70 g/L	190 g/L	50 mL/L	**5**	yes/no
C 194 -15	10 µm	15	40°C	yes	70 g/L	190 g/L	50 mL/L	**30**	yes/no

Appendix 2

	Sn Thickness	CD [A/dm?]	Temperature	Agitation	Metal content	MSA content	Carrier	Brightener	Postbake	PostDip SN
HSB-C18	8 µm	**20 A/dm?**	30°C	yes	70 g/L	190 g/L	20 mL/L	5 mL/L	no	no
HSB-C19	8 µm	**5 A/dm?**	30°C	yes	70 g/L	190 g/L	20 mL/L	5 mL/L	no	no
HSB-C20	8 µm	15 A/dm?	**45°C**	yes	70 g/L	190 g/L	20 mL/L	5 mL/L	no	no
HSB-C21	8 µm	15 A/dm?	30°C	yes	70 g/L	190 g/L	**30 mL/L**	5 mL/L	no	no
HSB-C22	8 µm	15 A/dm?	30°C	yes	70 g/L	190 g/L	20 mL/L	**10 mL/L**	no	no
HSB-C23	8 µm	15 A/dm?	30°C	yes	70 g/L	190 g/L	20 mL/L	5 mL/L	**yes**	no
HSB-C24	8 µm	15 A/dm?	30°C	yes	70 g/L	190 g/L	20 mL/L	5 mL/L	no	**yes**

Appendix 3

	Sn Thickness	Ni Thickness	CD [A/dm?]	Temperature	Agitation	Metal content	MSA content	Carrier	Brightener
HSB-C1	5-6 µm	2 µm	15 A/dm?	30°C	yes	70 g/L	190 g/L	20 mL/L	5 mL/L
HSB-C2	**1 µm**	2 µm	15 A/dm?	30°C	yes	70 g/L	190 g/L	20 mL/L	5 mL/L
HSB-C3	5-6 µm	**0,5 µm**	15 A/dm?	30°C	yes	70 g/L	190 g/L	20 mL/L	5 mL/L
HSB-C4	**1 µm**	**0,5 µm**	15 A/dm?	30°C	yes	70 g/L	190 g/L	20 mL/L	5 mL/L
HSB-C5	5-6 µm	2 µm	**5 A/dm?**	30°C	yes	70 g/L	190 g/L	20 mL/L	5 mL/L
HSB-C6	5-6 µm	2 µm	**20 A/dm?**	30°C	yes	70 g/L	190 g/L	20 mL/L	5 mL/L
HSB-C7	5-6 µm	2 µm	15 A/dm?	**21°C**	yes	70 g/L	190 g/L	20 mL/L	5 mL/L
HSB-C8	5-6 µm	2 µm	15 A/dm?	**45°C**	yes	70 g/L	190 g/L	20 mL/L	5 mL/L
HSB-C9	5-6 µm	2 µm	15 A/dm?	30°C	**no**	70 g/L	190 g/L	20 mL/L	5 mL/L
HSB-C10	5-6 µm	2 µm	15 A/dm?	30°C	yes	**30 g/L**	190 g/L	20 mL/L	5 mL/L
HSB-C11	5-6 µm	2 µm	15 A/dm?	30°C	yes	**90 g/L**	190 g/L	20 mL/L	5 mL/L
HSB-C12	5-6 µm	2 µm	15 A/dm?	30°C	yes	70 g/L	**100 g/L**	20 mL/L	5 mL/L
HSB-C13	5-6 µm	2 µm	15 A/dm?	30°C	yes	70 g/L	**230 g/L**	20 mL/L	5 mL/L
HSB-C14	5-6 µm	2 µm	15 A/dm?	30°C	yes	70 g/L	190 g/L	**10 mL/L**	5 mL/L
HSB-C15	5-6 µm	2 µm	15 A/dm?	30°C	yes	70 g/L	190 g/L	**30 mL/L**	5 mL/L
HSB-C16	5-6 µm	2 µm	15 A/dm?	30°C	yes	70 g/L	190 g/L	20 mL/L	**2 mL/L**
HSB-C17	5-6 µm	2 µm	15 A/dm?	30°C	yes	70 g/L	190 g/L	20 mL/L	**10 mL/L**