NEMI TIN WHISKER USER GROUP

Interim Recommendations on Lead-Free Finishes for Components Used in High-Reliability Products
Updated March 2004

I. Executive Summary

The NEMI User Group consists of ten large manufacturers of high-reliability electronic assemblies that annually purchase many millions of dollars of components. NEMI formed the User Group to develop recommendations for lead-free surface finishes that could be used on components in high-reliability electronic applications in order to minimize risk of failures from tin whiskers. It is the consensus of the NEMI User Group that pure tin electroplating presents a high-reliability risk in these applications, and that there are cost-effective alternatives available to minimize this risk.

Events are pushing industry for hard decisions on issues for which the technical community has not formed any consensus on the most effective options. The NEMI User Group is very concerned that market pressures will create chaos, with high-end users demanding the highest degree of reliability and low-end users demanding the lowest possible costs. Only by working in concert can users effectively interact with providers to get the best of both low cost and high reliability.

This second interim report updates the report originally published by the group in June of 2003. It presents recommendations for lead-free finishes for a variety of applications. These recommendations reflect the best judgment of the NEMI User Group members, based on their own experiences and the available data. Fifteen whisker mitigation "facts" have been used in developing these interim recommendations. A number of the larger OEMs have already issued specifications similar to these recommendations and others are considering following suit.

The goal of the User Group is to define methods and tests that minimize the probability of tin whiskers creating functional or reliability problems with our products. This result is achieved by a combination of using known mitigation practices and some level of testing.

II. Background Statement

Pure tin electroplating has a long history of whisker formation and growth that has resulted in reliability problems for various types of electronic equipment. The predominant whisker mitigation strategy for more than 50 years has been the addition of lead (Pb) to the tin plating. Legislation that will eliminate the use of lead in electronic products sold in the European Union (due to be implemented on July 1, 2006) has led many electronic component suppliers to propose the removal of lead (Pb) from tin-lead plating, leaving essentially pure tin. This approach is the most convenient and least costly lead-elimination strategy for the majority of component manufacturers. However, for the high-reliability user community, the pure tin strategy presents reliability risks due to the whisker forming tendencies of pure tin and tin alloy plating.

This second interim report lists viable lead-free finish alternatives for various applications. The positions presented are based on the personal experiences of the members taken in conjunction with the available technical literature on tin whisker formation and growth. The User Group also recognizes the ongoing work on whisker formation and growth carried out under the auspices of several consortia, including the NEMI Modeling Project, the NEMI Tin Whisker Accelerated Test Project, and the University of Maryland's Computer Aided Life Cycle Engineering (CALCE) group. Particular acknowledgement is made to the NASA Goddard Space Center web site, which lists considerable background information on tin whisker problems and research.

It is the position of the NEMI User Group that there is no scientific consensus on whisker formation and growth fundamentals at this time. Nor is there a standard set of tests that can accelerate whisker formation and growth with any reasonable degree of certainty. Therefore, any claims for "whisker-free" tin-plating processes, or guaranteed lifetimes without a whisker failure, must be regarded with skepticism at this time.

III. General Guidelines for Migrating to Lead(Pb)-Free Finishes

There is a great deal of new information in the public domain on tin whisker formation and strategies for migrating to lead-free surface finishes. It is advisable to be fully aware of the available data and alternatives before making any decision. Each firm needs to evaluate the alternatives in terms of reliability risk and cost benefits for the market application.

The User should be advised that whisker experimentation has been notoriously inconsistent relative to growth rates, incubation times, and many other parameters. Nevertheless, certain whisker mitigation guidelines have been supported by the NEMI User Group:

1. Non-tin plating: Nickel/Palladium/Gold (or just plain Nickel/Palladium) should be strongly considered for lead-frame applications. This plating has more than a ten-year history (1992-2003+) of field application. Early solderability issues have been resolved. In addition, NiPdAu is not prone to whisker growth in most environments (gold has been observed to grow whiskers in certain environments). The NEMI User Group strongly recommends this plating for most lead-frame applications in retarding whisker growth. However, Users should be aware that molding compounds do not adhere as well to noble metals such as Pd and Au as they do to copper. As such, it may be more difficult for NiPdAu packages to achieve MSL 1 and 2 performance at the higher temperatures associated with SnAgCu Pb-free assembly. NiPdAu has also had corrosion in accelerated tests

using high hydrocarbon and sulfur atmospheres. This corrosion has not been noted in actual field conditions.

2. Adding lead (Pb) to tin (Sn) plating mitigates whisker formation (that is no longer a viable strategy for most products after July 1, 2006 due to pending EU, California, and Chinese regulations).

3. Adding a nickel (Ni) underlay between tin plating and a copper (Cu) base metal mitigates whisker formation (this will be a key User Group recommendation) as the under-layer plating may mitigate whisker formation by alleviating the compressive stress in the tin film which is thought to be one of the driving forces for tin whisker growth. The thickness, porosity and ductility of the nickel plating also are very important to ensure an effective barrier layer for the copper. It is important to ensure these parameters are met even after lead forming. Similarly, the control of the tin-bath impurities, particularly copper, is important to make this under-layer effective. Components that use nickel under plating should have a porosity free nickel thickness of a minimum of 1.27µm with 2µm thickness recommended.

4. Fusing tin (Sn) plating mitigates whisker formation. Fusing is a reflowing operation usually done by dipping the tin-plated surfaces into a hot oil bath. Some User Group members recommend fused tin.

5. Immersion tin is a chemical displacement process that results in a relatively thin (<20 micro-inches or .5 microns) and stress free tin film. Whiskers have been grown on immersion tin by NEMI team members, but the whisker lengths appear to be limited to <20 microns. For some applications, immersion tin is a suitable minimum risk selection that has been successfully used by some of the NEMI User Group companies.

6. Hot dip tin is a molten tin bath process that is not prevalent in lead-frame construction intended for electronic components, but it has been used for structural steel parts, connectors and devices such as relays. Hot dipping is considered to be whisker-free.

7. Annealing/heat treating (150C for 1 hour) of matte tin plated copper alloy lead-frames has shown promise as a tin whisker mitigation technique. However, the data is still not at the level that the User Group is ready to provide blanket endorsement of this technique. It may be accepted by users once more significant test data is compiled.

8. Matte tin is a tin film with lower internal stresses and larger grain sizes than so-called bright tin. Many current suppliers tout a proprietary version of this type of tin as whisker-free. The NEMI User Group does not support these claims at this time. The claims are at best premature and should be considered with skepticism. This is also the position of the NEMI Modeling Project. Matte tin films are less

prone to whisker formation and growth than so-called bright tin films. For the purposes of this document, matte and bright tin finishes are defined by the following:

Parameter	Matte Sn	Bright Sn
Carbon Content	.005%-0.050%	0.2%-1.0%
Grain Size	1µm-5µm	0.5µm-0.8µm

9. Tin-bismuth alloy finishes are controversial when used in conjunction with eutectic tin-lead solder. When added to tin in amounts of 2-10% by weight, bismuth is considered to be an effective whisker suppressant. There is a low melting point ternary eutectic formed between tin-lead-bismuth with a melting point at 96^{o}C. However, it is not thermodynamically possible to form this ternary eutectic with small (1-5% by weight) additions of Bi to Sn-Pb. There is a ternary tin-lead-bismuth peritectic that is thermodynamically viable for small additions of Bi and this peritectic has a melting point of 135^{o}C. With lead-free solder, tin-bismuth is a viable candidate for component finishes. With eutectic tin-lead solder, it will be necessary to control the bismuth content of the finish between 3-5% so as to have enough bismuth to suppress whisker formation without getting into the compositional range of the ternary eutectic. In addition, keeping the Bi content low is required to retain solderability of formed leads.

10. Industry data indicates that thicker tin finishes show a lower propensity for tin whiskers and/or a greater incubation time before tin whiskers occur. The User Group recommends tin thickness for components without a nickel or silver under layer be 10 µm nominal (8 µm minimum preferred) or thicker. Components that use nickel under plating should have a porosity-free nickel thickness of a minimum of 1.27µm with 2µm thickness recommended. Components using silver under plating should have a minimum silver thickness of 2µm.

11. The macro stress level of the tin deposit has an impact on tin whisker growth. Tin deposits that have tensile stress as plated and remain tensile with aging are preferred. Tin deposits that are compressive during service life are not preferred.

12. In limited testing thus far, bias voltage (and/or current flow) has been shown to have an impact on tin whisker growth. The extent and impact of bias is yet to be fully understood. At this point, it is a concern area for the User Group members.

13. An acceptable plating for alloy 42 (Fe-42Ni) lead frames has not been proven at this time. Some alternatives that show promise are low porosity NiPdAu and Sn(1-4%)Bi plating..

14. Since a full understanding of the tin whisker growth mechanism is still lacking, collecting data on the characteristics of tin platings is critical to help increase the knowledge level on parameters affecting tin whisker growth. The NEMI

document "Tin Whisker Growth Tests" (available at http://www.nemi.org/projects/ese/tin_whisker.html#mod) defines data collection requirements for tin finishes. The User Group recommends data collection in accordance with that document.

15. Other material sets and combinations will be considered if they are provided along with strong technical arguments as to why they are efficacious in reduction of tin whiskers, and are backed up with tin whisker test data. The whisker test procedures used by the supplier shall also be specified.

IV. Lead-Frame Finishes

Lead-frames are the metal tabs that electrically connect the chip die to the printed circuit board. The majority of current lead-frames are made of copper or a copper alloy. In addition, some lead-frames are still made of an iron-nickel alloy (e.g. alloy 42). Typically, the lead-frames are purchased without a finish (or plating) and processed at the manufacturing site into a package. Tin lead-frame platings are done after the molding operation. The predominant lead-frame finish today is a tin-lead alloy. About 10% of the lead-frame finishes are Ni/Pd/Au which are purchased in a pre-plated form by the assembly manufacturer.

The tables below (I-VI) reflect the best judgment of the NEMI User Group members, based on available data. The risk assessments are not meant to represent the mitigation strategies that have been, or will be, adopted by their respective companies, although they do illustrate the opinions of an influential engineer/scientist in each company. A “Y” is a zero risk (highly recommend) position. An “M1-M9” is a risk position with 9 being high risk and 1 being low risk. “N” indicates an unacceptable risk, and a blank indicates that there is no opinion.

Table I. ICs with fine pitch lead-frames (125-200 micron gap between leads)

Finish	Co. A	Co. B	Co. C	Co. D	Co. E	Co. F	Co. G.	Co. H	Co. I
Ni/Pd/Au	Y	Y	Y	Y	Y	Y	Y	Y	Y
Sn over Ni	Y	Y	M	Y	M4	M	M2	Y	M2
Fused Sn	Y	N	Y	N	M4		M3	Y	
Immersion Sn	Y	Y	M	M	M7			Y	
Hot Dip Sn	N	N	Y	N	M4		Y	N	Y
Bright Sn	N	N	N	N	N	N	N	N	N
Satin Bright Sn	N	N	N	N	N	N	N	N	N
Matte Sn	N	M	N	M7	M5	M	N	N	M9
SnBi	N	N	N	M6	N	N	N	N	N
SnCu	N	N	M	N	M5	M	N	N	N

Table II. ICs with wide-gap lead-frames (>200 micron gap between leads)

Finish	Co. A	Co. B	Co. C	Co. D	Co. E	Co. F	Co. G.	Co. H	Co. I
Ni/Pd/Au	Y	Y	Y	Y	Y	Y	Y	Y	Y
Sn over Ni	Y	Y	M	Y	M4	M	M2	Y	M2
Fused Sn	Y	N	Y	M	M4		M3	Y	
Immersion Sn	Y	Y	M	M	M7			Y	
Hot Dip Sn	Y	N	Y	Y	M4		Y	Y	Y
Bright Sn	N	N	N	N	N	N	N	N	N
Satin Bright Sn	N	N	N	N	N	N	N	N	N
Matte Sn	N	M	N	M6	M5	M	N	N	M8
SnBi	N	N	N	M5	N	N	N	N	N
SnCu	N	N	M[7]	M8	M5	M	N	N	M9

Tin-copper alloys are not satisfactory finishes because copper enhances whisker formation and growth when included as an alloying element in tin plating.

The NEMI User Group specifically advises potential users to realize that component finishes are not always melted into the solder during an assembly operation. Some part of the component lead-frame may remain non-wetted after a solder assembly operation. This is an important fact that users must take into account. A non-wetted (or as-plated) film is susceptible to whisker formation and growth due to the built-in stress state. It is true that whisker formation is inhibited if the finish is completely absorbed or reflowed into the solder. However, complete absorption or reflow of the finish should not be relied upon.

V. Separable Connectors

A separable connector is defined as a make/break connector with a mating end and an end that attaches to a wire utilizing a crimp barrel or some kind of metallurgical joining operation. Compliant (press fit) pins are a special sub-class of separable connector that utilizes a pin design that is inserted into a plated through hole (PTH) on a printed circuit board (PCB).

Separable connectors usually have a nickel underlay beneath a film of gold, tin-lead, or pure tin. Gold, or pure tin, with a nickel underlay is considered by the NEMI users group to be of minimal risk relative to whisker formation. There is currently a motion before the European union to make compliant pin technologies exempt from the lead-free requirements of the RoHS directive.

Compliant pins typically utilize a tin-lead plating to achieve reasonable insertion forces. Members of the User Group have performed testing on lead free compliant pins and shown that the insertion forces and retention forces increase when the Pb is removed from the finish. This increase in insertion force is acceptable in most applications. The increase is most strongly linked to the switch from bright tin/lead coatings to matte tin coatings. Bright tin coatings have demonstrated insertion forces that are statistically equivalent or lower than bright tin lead, however bright tin is more susceptible to whisker growth.

Table III (below) summarizes the NEMI User Group's ratings for separable connector finishes relative to concerns about whisker formation and growth.

Table III. Separable Connectors

Finish	Co. A	Co. B	Co. C	Co. D	Co. E	Co. F	Co. G.	Co. H	Co. I
Ni/Pd/Au	Y	Y	Y	Y	Y	Y	Y	Y	Y
Sn over Ni	Y	Y	M	Y	M3	M	M	Y	M3
Au over NI	Y	Y	Y	Y	Y	Y	Y	Y	Y
Fused Sn	Y	N	Y	M	M3		M	Y	
Immersion Sn		Y	M	M	M6		M		
Hot Dip Sn		N	Y	Y	M3		M		Y
Bright Sn	N	N	N	N	N	N	N	N	N
Satin Bright Sn	N	N	N	N	N	N	N	N	N
Matte Sn	N	M	N	N	M4	M	N	N	M9
SnBi	N	N	N	N	N	N	N	N	N
SnCu	N	N	M	N	M3	M	N	N	M9

VI. Bolted Connectors

Bolted connectors are typically annular rings (ring lugs) that are bolted down onto a base metal, often with a Belleville washer assembly to maintain a high torque level over time. Clamping pressure on tin plating will accelerate whisker formation and growth several orders of magnitude. Each application must be considered relative to exposure to sensitive electrical componentry. For example, bolted connections in the air stream leading to electrical componentry should be considered a sensitive location. Whisker forming materials should not be used in sensitive locations.

Belleville washers are typically heat-treated steel (some are beryllium copper) that are mechanically plated with zinc or tin. These coatings avoid the inclusion of embrittling hydrogen ions generated with electrolytic processes. In the combined experience of the NEMI User Group, there have been no instances of whisker formation on mechanical plating of any type. However, it should be noted that there are no known technical articles on mechanical plating with respect to whisker formation.

Ring lugs and standard washers do not require mechanical plating for embrittlement reasons. Nonetheless, mechanical plating is appropriate for these parts. Tin over nickel and aluminum coatings are also acceptable. Hot dip and fused tins are generally not available for these parts. Noble metals (e.g. Ni/Pd/Au) would also work, but would be unnecessarily costly, and should not be considered for these applications.

Table IV: Bolted Connectors

Finish	Co. A	Co. B	Co. C	Co. D	Co. E	Co. F	Co. G.	Co. H	Co. I
Ni/Pd/Au	Y	Y	Y		Y	Y		Y	
Sn over Ni	Y	Y	M		M3	M		Y	
Mech. Zn	Y								
Mech. Sn over Zn	Y								
Aluminum	Y								
Fused Sn	Y	N	Y		M3			Y	
Immersion Sn	Y	Y	M		M6			Y	
Hot Dip Sn	Y	N	Y		M3			Y	
Bright Sn	N	N	N		N	N		N	
Satin Bright Sn	N	N	N		N	N		N	
Matte Sn	N	M	N		M4	M		N	
SnBi	N	N	N		N	N		N	
SnCu	N	N	M		M3	M		N	

VII. Bus Bars/Heat Sinks

Bus bars and heat sinks are often made with a plated copper or copper alloy. These parts are of particular interest because they are usually in close proximity to electrical circuitry. Whiskers on these assemblies can cause problems if they dislodge and short electrical circuitry. It is, therefore, prudent to avoid using plating material that is susceptible to whisker formation and growth. If possible, it is advisable NOT to plate bus bars and heat sinks. In non-corrosive environments, the base copper metallurgy will tarnish slightly over time, but the basic function of the piece will be unaffected. Localized plating to enhance solderability or contact resistance should utilize whisker-free plating. Table V summarizes the opinions of the NEMI User Group.

It should be noted that silver (Ag) plating, while frequently utilized for bus bars and heat sinks, is susceptible to corrosion effects in sulfurous environments.

Table V. Heat Sinks/Bus Bars

Finish	Co. A	Co. B	Co. C	Co. D	Co. E	Co. F	Co. G.	Co. H	Co. I
Ni/Pd/Au	Y	Y	Y	Y	Y	Y		Y	
Sn over Ni	Y	Y	M	Y	M2	M		Y	
Fused Sn	Y	N	Y	M	M2			Y	
Immersion Sn	Y	Y	M	M	M6			Y	
Immersion Ag	Y								
Electroplate Ag	N								
Hot Dip Sn	Y	N	Y	Y	M2			Y	
Bright Sn	N	N	N	N	N	N		N	
Satin Bright Sn	N	N	N	N	N	N		N	
Matte Sn	M7	M	N	M4	M2	M		M7	
SnBi	M5	N	N	M3	N	N		M5	
SnCu	N	N	M	M6	M2	M		N	
Ni	Y	Y	Y	Y	Y	Y		Y	

VIII. Printed Circuit Boards (PCBs)

The surface coating on PCB lands (made of copper) are designed to protect the base metal against oxidation that could result in poor solder joints during the assembly operations. HASL (hot air solder leveled) tin-lead coatings have been the coating of choice for most of the last 50 years. To comply with legislation, alternative Pb-free surface finishes must be considered. These finishes include OSPs, immersion gold over electroless nickel, Pb-free HASL, immersion silver, and immersion tin. Of these surface finishes, immersion tin is susceptible to the formation of pure tin whiskers and immersion silver is susceptible to the formation of silver sulfide dendrites. Both tin whiskers and silver sulfide dendrites can create electrical shorts, however, the formation mechanisms and the required environmental conditions are different. For all of these finishes, individual processes vary tremendously relative to film quality, corrosion resistance, shelf life, etc., and the user should work closely with the process provider to evaluate each particular process. Aside from whisker and dendrite growth, other aspects of the surface finishes will affect selection, including cost, shelf life, solderability, manufacturability, and technical limitations with certain assembly processes, component types, and board designs.

Table VI summarizes the assessments of the individual members of the NEMI Users Group relative to the above PCB finish processes.

Table VI. Printed Circuit Boards

PCB Finish	Co. A	Co. B	Co. C	Co. D	Co. E	Co. F	Co. G.	Co. H	Co. I
SnCu HASL	M5	Y		M7	Y		M		M5
Immersion Sn	M5	Y	Y	M5	M5		Y	Y	Y
Immersion Au Electroless NI	Y	Y	Y	N	Y		M	N	M5
Immersion Ag	Y	Y	Y	M2	M5		Y	Y	Y
OSP (e.g. Entek)	Y	Y	Y	Y	Y		N	M5	M7

IX. Future Work

The NEMI User Group is currently meeting regularly to consider comments on this position statement based on new data, and is working on a user acceptance requirements document.

X. NEMI Contacts

Parties interested in participating in NEMI operations on these matters should contact Ronald W. Gedney (703-834-0330 or rgedney@AOL.com) for information. There are currently three ongoing NEMI project teams focused on tin whisker issues:

a. Tin Whisker Modeling Project - Chairman; Dr. George T. Galyon / IBM Corp.
b. Tin Whisker Accelerated Test Project-Chairman, Nhat Vo/Motorola Corp.
c. User Group - Chairman; Joe Smetana, Alcatel

In addition to the committees on whisker fundamentals and testing, there are also ongoing NEMI committees dealing with lead-free assembly operations and materials.

XI. NEMI User Group members

Dr. George T. Galyon	IBM eSystems Group
Mr. Ronald Gedney	NEMI consultant
Mr. Richard Charbonneau	Chairman, NEMI ECE TIG (formerly of Storage Tek)
Mr. Richard Parker	Delphi Electronics & Safety
Dr. Valeska Schroeder	Hewlett Packard
Dr. Richard Coyle	Lucent
Mr. Joseph Smetana	Alcatel
Ms. Vicki Chin	Cisco
Dr. Bob Hilty	Tyco Electronics
Mr. Sean McDermott	Celestica
Mr. David Love	Sun Microsystems