NEMI Tin Whisker Modeling Project
Interim Report — July 21, 2003

As the electronics industry moves toward Pb-free soldering, new coatings for component leads are needed to replace the standard Sn-Pb coatings in current production. A simple manufacturing solution is to go to a 100% Sn plated terminal finish. However, pure Sn coatings have been shown to be prone to the growth of needle-like protrusions of pure Sn that are capable of bridging electronic circuits and causing electrical shorts. (For pictures and examples, see NEMI website at www.nemi.org/projects/ese/lf_hottopics.html). The purpose of this report is to provide a short status of the NEMI Tin Whisker Modeling Project as we approach the summer vacation period.

The NEMI Modeling Project has been actively engaged in tin whisker research since November of 2001. Even though the root cause of tin whiskers is not yet completely understood, the modeling group has made significant progress as summarized below:

1. The modeling group has supported the NEMI Tin Whisker Accelerated Test Project with two sets of experiments. A report on the second set of experiments is given in Boguslavsky (6) referenced below.

2. An annotated bibliography, published by G. Galyon (1), examined tin whisker publications over the last 50 years. The bibliography puts current research into a historical perspective and highlights areas in need of additional scientific investigation. Whisker theories currently under evaluation are categorized as:
    a. Cracked oxide theory
    b. Dislocation theories
    c. Recrystallization

3. A number of experiments were done by member companies and shared with the project team. The results of this work can be found below:
    a. At NIST, see Williams (1) & (2).
    b. At Cookson, see Dr. Xu (6) & (7).
    c. At TI, see Romm & Abbot (1).
    d. At IBM, see Galyon (2).

    This work was added to the NEMI database and factored into the overall conclusions.

4. NEMI co-sponsored a tin whisker workshop with NIST and TMS on March 2, 2003, to bring together the best researchers in this field to discuss latest findings and theories. The reports can be seen on the NEMI website at htttp://www.nemi.org/ newsroom /NEMI/NIST_TMS_workshop.html.

5. The project team has emphasized the use of FIB (Focused Ion Beam) microscopy to enhance the microstructural analysis of whiskers. (See Galyon (2) below).

6. The project team has defined a new experimental matrix intended to address:
    (a) Ultra-pure plating baths — can they prevent whisker formation?
    (b) Stress in the film - is stress a necessary condition for whisker formation?
    (c) Nickel barriers - why do nickel barriers work as a whisker mitigation practice in some cases?
    (d) The cracked oxide theory — does experimental evidence corroborate the theory?

7. The project has spun off a user group to define mitigation practices for reducing exposure to whisker-induced failures.

Several members of the project team have published papers in conference proceedings and presented their work in various workshops. The group has also conducted experimental work in cooperative efforts between the members of the group. The current Chairman, Dr. George T. Galyon of IBM Systems Group, has issued the following summary of the current committee position on the fundamental aspects of tin whisker formation and growth.

- The Modeling Project is proposing that tin whisker formation and growth is a recrystallization process. It is necessary for an as-plated microstructure to transform itself by recrystallization before whiskers can form. The project participants who have authored, or soon will author, papers on the subject of tin-whisker formation reflect this position.

- The role of stress in whisker formation is somewhat controversial. A majority of project members acknowledge the central role of compressive stresses in the film as a prerequisite for whisker formation. Some of the members believe that a positive stress gradient across the boundary of the whisker grain is a prerequisite for whisker growth. Some of the members feel that stresses are relatively unimportant, and that the driving force for whisker formation and growth is a delta in the free energy of the growing grains.

- The project team acknowledges the possible relevance of the cracked-oxide theory but notes that there is currently no direct evidence in support of a defect in the oxide layer being a necessary condition for whisker formation.

- The project team also acknowledges the possible relevance of some of the proposed dislocation-based mechanisms for whisker formation, but note that there is not any available data to show the actual existence of the proposed dislocation structures. In fact, recent publications strongly infer that no dislocation structures exist similar to those described in published dislocation models.

- Tin whiskers often represent a large volume of atoms which have apparently originated elsewhere in the deposit. Mass transport of atoms by diffusion is widely accepted as the mechanism feeding whisker growth. Studies by project

members have for the first time provided direct physical evidence of diffusion. Grain boundary depletion and remote grain subsidence in matte tin and subsurface voids in bright tin have been visualized and presented as this evidence. Thus the pathways of diffusion (grain boundaries) and potential sources of atoms (depleted grains and voids) have been visually identified.

During the summer of 2003 the Tin Whisker Modeling Project will be building hardware and beginning the test of a new experimental test design using laboratory equipment and coupons. The weekly meeting schedule will be reduced during this vacation period and the project will reconvene in the Fall of 2003 to continue the ongoing work, with an emphasis on proving/disproving the above theories. There will be a focus on the microstructural and stress analyses of tin films with and without a nickel underlay. The analyses will be done immediately after deposition and periodically thereafter. There will also be a focus on the effect of plating bath purity levels. FIB microscopy will be extensively employed as the tool of choice for microstructural analysis, and stress analyses will be done with the cantilever beam and the standard ASTM based XRD technique. TEM analysis will be attempted to determine whether dislocation structures are involved in whisker formation, and the role of an oxide layer on whisker formation will be independently assessed.

Respectfully submitted: Dr. George T. Galyon, Chairman

NEMI Modeling Committee Members

Dr. George T. Galyon- IBM Systems Group / Chairman
Ms. Maureen Williams – NIST / Co-Chair
Mr. Chris Johnson - NIST
Dr. William Boettinger – NIST
Dr. Carol Handwerker – NIST
Dr. Kil-Won Moon – NIST
Dr. Don Abbott – Texas Instruments
Mr. Douglas Romm – Texas Instruments
Dr. Chen Xu – Cookson Electronics
Mr. Neil Brown – Shipley Company
Mr. James Martin – Shipley (retired)
Dr. Sudarshan Lal – FCI Electronics
Mr. Nhat (Nick) Vo – Motorola
Dr. Valeska Schroeder – Hewlett-Packard
Mr. Jack McCullen – Intel Corporation
Dr. Benihan Huang – Indium Corporation
Mr. Ron Gedney – NEMI
Dr. Irina Boguslavski – NEMI consultant
Mr. Peter Bush – SUNY at Buffalo
Dr. B. Radhakrishnan – Oak Ridge National Laboratory
Dr. Gene Ice – Oak Ridge National Laboratory
Prof. William Mayo – Rutgers University

Project Member Publications/Presentations/NEMI Reports

Dr. Irina Boguslavsky

1. I. Boguslavsky, "Whisker Fundamentals Modeling Group DOE," Tin Whisker Forum, APEX 2002, San Diego, CA: January 24, 2002.
2. I. Boguslavsky, "The Effect of Operating Parameters and Test Conditions on the Whisker Performance of Pure Tin As a Lead-free Solderable Finish," Proceedings of the American Electroplaters and Surface Finishers Society (AESF) SUR/FIN 2002 Conference, Chicago, IL: June 2002, p. 43.
3. A. Shirafisi, I. Boguslavsky, M. Toben, "Belt and Re-work Strippers for Lead-free Solders," Proceedings of the American Electroplaters and Surface Finishers Society (AESF) SUR/FIN 2002 Conference in Chicago, IL: June 2002, pp. 69-74.
4. I. Boguslavsky, "Whiskers: Truth and Mystery," NASA/Industry Workmanship and Technologies Meeting (formerly the NASA Technical Workmanship Committee): September 11, 2002.
5. I. Boguslavsky, "Whiskers: Truth and Mystery," NEMI/IPC Lead-Free Symposium, Montreal, Canada: September 19, 2002.
6. I. Boguslavsky, P. Bush, "NEMI Tin Whisker Test Group: Phase 2 DOE Results," IPC Annual Meeting, New Orleans, LA: November 7, 2002.
7. I. Boguslavsky, "NEMI Sn Whisker Modeling Group, Part 1: Overview and Results," IPC Annual Meeting, New Orleans, LA: November 7, 2002.
8. I. Boguslavsky, P. Bush, "Recrystallization Principles Applied to Whisker Growth in Tin," APEX 2003, Anaheim, CA: March 31, 2003, pp. S12-4-1 – S12-4-10.
9. P. Bush, G. L. Jones, I. Boguslavsky, "Relationships of Copper Diffusion and Surface Oxide Formation to Tin Whisker Growth," NEMI Workshop on Tin Whiskers, APEX 2003, Anaheim, CA: April 1, 2003.
10. I. Boguslavsky, P. Bush, "Practical Aspects of Whisker Studies, NEMI Workshop on Tin Whiskers," APEX 2003, Anaheim, CA: April 1, 2003.
11. I. Boguslavsky, P. Bush, E. Kam-Lum, M. Kwoka, J. McCullen, N. Vo, "NEMI Sn Whisker Project," Tin Whisker Joint Meeting: NEMI, JEITA & SOLDERTEC, Tokyo, Japan: May 15, 2003.

Ms. Maureen Williams

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2. M.E. Williams, C.E. Johnson, K.W. Moon, G.R. Stafford, C.A. Handwerker, and W.J. Boettinger, "Whisker Formation on Electroplated Sn-Cu," Proceedings of the American Electroplaters and Surface Finishers Society (AESF) SUR/FIN 2002 Conference in Chicago, IL: June 2002, pp. 31-39.
3. M.E. Williams, I. Boguslavsky, "NEMI Sn Whisker Project," Proceedings of the IPC/NEMI Symposium on Lead-Free Electronics, Montreal, Canada: September 19, 2002, pp.37-41.
4. M.E. Williams, "NIST Sn Whisker Activities," CALCE Pb-free Forum at the University of Maryland: October 10, 2002.
5. M.E. Williams, I. Boguslavsky, "NEMI Sn Whisker Project Overview and Progress Report," CALCE Pb-free Forum at the University of Maryland: October 10, 2002.
6. M.E. Williams, I. Boguslavsky, "Part 1 of Fundamental Modeling Group Progress Report and Future Work," IPC/NEMI Workshop, New Orleans, LA: November 7, 2002.
7. M.E. Williams,"TMS/NEMI/NIST Whisker Workshop Report," NEMI Whisker Workshop, APEX 2003, Anaheim, CA: April 2, 2003.

Mr. Chen Xu

1. C. Xu, Y. Zhang, C. Fan, A. Vysotskaya, and J. A. Abys, L. Hopkins, F. Stevie, "Understanding Whisker Phenomenon – Mechanisms Studies," SMTA International Proceedings 2002: Chicago.
2. Y.Zhang, C. Xu, C. Fan, J. A. Abys, and A. Vysotskaya, "Understanding Whisker Phenomenon, Part I," Proceedings of the Technical Conference, APEX 2002, San Diego, CA: January 2002.
3. C. Xu, Y. Zhang, C. Fan, and J. Abys, "Understanding Whisker Phenomenon, Part II," Proceedings of the Technical Conference, APEX 2002, San Diego, CA: January 2002.
4. C. Xu, Y. Zhang, C. Fan, and J. Abys, "Understanding Whisker Phenomenon: Driving Force for Whisker Formation," CircuitTree: May 2002, p10-21.
5. C. Xu, Y. Zhang, C. Fan, and J. Abys, "Understanding Whisker Phenomenon: Driving Force for Whisker Formation," CALCE Lead-Free Forum Workshop, College Park, MD: October 10, 2002.

6. C. Xu, “Stress in Electroplated Sn: Its Measurement and Implication in Spontaneous Whisker Growth,” NEMI/TMS/NIST Workshop, Tin Whiskers: Cause and Effect, San Diego, CA: March 2, 2003.
7. C. Xu, C. Fan, Y. Zhang, and J. Abys, “Whisker Prevention,” Proceedings of the Technical Conference, APEX 2003, Anaheim, CA: April 2003.

Dr. George T. Galyon

1. G.T. Galyon, “Annotated Tin Whisker Bibliography-February, 2003,” NEMI/NIST/TMS Tin Whisker Workshop, San Diego, CA: March 2, 2003. (www.nemi.org/newsroom/NEMI_NIST_TMS_workshop.html)

2. G.T. Galyon, L. Palmer, “Tin Whisker Microstructural Analysis,” NEMI/NIST/TMS Tin Whisker Workshop, San Diego, CA: March 2, 2003.

Mr. Nhat (Nick) Vo

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2. F. Wolfert and N. Vo, “Assessment of Pb-free Finishes for Leadframe Packaging,” IPC Elec. Circuits World Convention 2002: paper IPC56.
3. N. Vo, “Reliability of Pb-free Peripheral/Leadframe Packages,” Global SMT & Packaging, Vol. 1, Num. 3: October 2001, pp. 30-35.
4. N. Vo, “Pb-free Finishes for Leadframe Packages,” APEX 2002, San Diego, CA: January 24, 2002.
5. N. Vo, “Whisker Growth Evaluations of Tin-based Plating Finishes,” JEDEX 2002 Conference, Santa Clara, CA: March 25, 2002.
6. N. Vo, “Whisker Growth,” IPC 2002 Annual Meeting, New Orleans, LA: November 2002.
7. N. Vo and M. Tsuriya, “Whisker Assessment of Tin-based Finishes for Leadframe Packages,” Proceedings of EcoDesign2002 Japan Symposium, Tokyo, Japan: December 5, 2002, pp. B-5-1, 120-123.
8. N. Vo, “NEMI Tin Whisker Test Methods Standardization,” APEX 2003, Anaheim, CA: April 2, 2003.

Mr. Doug Romm, Dr. Don Abbott

1. D. W. Romm, D. C. Abbott, S. Grenney, and M. Khan, “Whisker Evaluation of Tin-plated Logic Component Leads,” Texas Instruments Application Report SZZA037A: February 2003.

Dr. Sudarshan Lal

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2. S. Lal, “Lead-free Developments of Electronic Connectors,” Proceedings, IPC Annual Meeting, Orlando, FL: October 2001, Paper S-05-5, pp. 1-14.
3. S. Lal, J. A. Kopec, & S. R. Angeli, “Lead-free Development of Electronic Connectors,” APEX 2002, San Diego, CA: January 2002, Paper S 01-1, pp 1-14.
4. S. Lal, “Lead-free Coatings in High-speed Electronic Connectors,” AESF-SUR/FIN Proceedings, Chicago, IL: June 2002, pp. 75-90.
5. S. Lal, “Managing Lead and Lead-free Transition in Electronic Connectors,” EEE/GFIE-GIXEL European Lead-free Conference, Paris: June 20, 2002.
6. S. Lal, “Managing Lead and Lead-free Transition in Electronic Connectors,” CALCE Lead-free Forum, Univ. of Maryland: October 10, 2002.
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8. S. Lal, J. Kopec and S. Angeli, “Lead-free Coatings in High-speed Electronic Connectors,” Plating & Surface Finishing, 2003 (Accepted for publication in September, 2003 issue — in press).
9. S. Lal, “Tin Whiskers and Minimization in Electrical Connectors,” AESF-SUR/FIN Conference, Milwaukee, WI: June 2003.