The Transition to Pb-free Products

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Abstract
The NEMI 1998 Environmentally Conscious Electronics (ECE) Roadmap[1] identified that a gap existed in developing a Pb-free solder technology infrastructure in North America. In response, a number of projects have been completed to close this gap. The NEMI 2002 ECE Roadmap identified a number of new gaps focusing on the supply chain infrastructure required for converting to Pb-free products, including:

- The availability of components specified to meet higher soldering temperatures.
- The lack of standards for the exchange of "Materials of Concern" information.

The roadmap recommended that, to remain competitive, global electronics firms will need to:

- Develop, qualify, and introduce new materials, components, and processes in 2002-6 to enhance recycleability, improve energy efficiency, and reduce ecological impact.
- Develop and implement standards to enable efficient exchange of environmental attributes data in order to meet the requirements of European and Japanese regulations on electronics and automotive products.
- Educate the supply chain to the new materials requirements and end-of-life responsibilities.

This presentation will summarize the Pb-free projects that NEMI has completed to develop a Pb-free soldering technology base, highlight the status of the current projects to expand this technology base to address wave soldering, rework, and surface finishes for high-reliability applications, and then focus on the new initiatives being established to support the business/supply chain issues associated with the transition to Pb-free products and meeting the RoHS and WEEE requirements.

Introduction
NEMI's 1998 Roadmap identified the need for materials and processes that would allow manufacturers to eliminate lead from electronic assemblies. In 1999, NEMI organized its first lead-free project — the Lead-Free Assembly Project — with the goal of developing North American capability to produce lead-free products. Over the course of the next three years, the project team recommended an industry-standard alloy to replace tin-lead solders, and followed up with extensive testing to characterize the new materials and demonstrate reliability. This project moved the industry forward in knowledge and understanding of lead-free materials and processes. Follow-on projects have included efforts focused on tin whiskers, lead-free rework, and infrastructure issues related to requirements of pending legislation.

Phase I Project
In early 2000, NEMI recommended the use of Sn3.9Ag0.6Cu for reflow solder and, in coordination with NIST, did extensive testing to characterize this alloy in order to demonstrate reliability and help industry implement lead-free solutions. Since that time, many lead-free solder compositions were proposed by others, causing significant confusion and dispersion of resources within industry. Today, the debate has shifted from this wide variation of materials to discussion of the best SnAgCu alloy for industry to adopt.

Although the compositions of some of the alloys being commercialized vary slightly from the NEMI composition, the NEMI alloy is representative of the acceptable range of lead-free solders. Tin-silver-copper formulations with silver content between 3.5% and 4.1% and copper between 0.5% and 1.0% are virtually indistinguishable in terms of melting point and process features. The NEMI alloy provides a model system for industry that is extremely well characterized, and several NEMI members currently are using the alloy in production. Clearly, the NEMI focus on a single lead-free alloy has helped to accelerate industry convergence on standard solder formulations, manufacturing processes and, ultimately, the timely and cost-effective conversion to lead-free assembly.

A number of NEMI OEMs have made announcements in the past two years about new lead-free products that are in full production including Motorola, HP, and Intel. Several NEMI EMS providers have announced lead-free manufacturing capabilities, including Solectron, Celestica, Sanmina-SCI, and LACE Technologies.

Phase II Projects

A second phase of NEMI projects has continued to fill in knowledge gaps. These include the Lead-Free Assembly and Rework Project, Tin Whisker Accelerated Test Project, Tin Whisker Modeling Project and Tin Whisker User Group.

Lead-Free Assembly and Rework Project

This project is extending the Phase I project's work into new areas, including the issue of board rework with the higher temperature SnAgCu solder. The project's extensive testing of tools and processes to rework SnAgCu soldered components on thick boards (up to 0.130") found that assemblies built with existing tools and processes threatened to reach temperatures exceeding 260°C during rework. The team is developing new tools and processes with the potential for keeping component temperatures in the range of 245° to 250°C. Testing began in December on several assemblies, using two board thicknesses and a variety of representative components manufactured with the new procedures. When these tests are completed (September 2004), the project will begin failure analysis and statistical analysis of results.

Tin Whisker Accelerated Test Project

NEMI's Tin Whisker Accelerated Test Project is an open program that is working to devise industry standard tests to help predict the propensity for tin whisker growth. Comparing test results from two rounds of NEMI experiments with Soldertec of Tin Technology Ltd (Europe), and the Japan Electronics and Information Technology Industries Association (JEITA), the three groups concluded that thermal cycling accelerates whisker growth. Based on this conclusion, the NEMI project submitted definitions of tin whiskers and measurement techniques to JEDEC for consideration as industry standards. Their recommendation includes three environmental test conditions. A third round of experiments is in progress to verify test methods for various plated electronic products. The team is also preparing a test matrix to determine the effects of electrical bias on whisker growth, and plans a fifth round of experiments that will attempt to measure acceleration factors by utilizing specific test conditions.

Tin Whisker Modeling Project

This NEMI project is attempting to understand why whiskers form, and how to control them. The group continues to pursue an understanding of the mechanism(s) that cause tin whiskers to form. The team has published, and continues to update, an annotated bibliography of tin whisker literature, written by project chair George Galyon (IBM). They are also developing a consensus position on whisker theories. A set of experiments is currently underway to look at stress, crystal orientation and material movement within tin film, using carefully prepared laboratory samples (to avoid the variations seen in commercial processes).

Tin Whisker User Group

NEMI formed the Tin Whisker User Group to develop recommendations for lead-free surface finishes for components that would minimize the risk of failure from tin whiskers in high-reliability electronic applications. Although the modeling project has made significant progress, the root cause of tin whiskers is not yet totally understood. Thus, this initiative is developing mitigation strategies to reduce the immediate risk. The Tin Whisker User Group has published interim recommendations for lead-free finishes based on the mitigation strategies shared by various companies. Recommended practices include: use of nickel-palladium or nickel-palladium-gold instead of tin; use of a nickel underlay; heat treatment (150°C for one hour) or reflow the tin coating. Mitigation practices are continuously refined as new information becomes available, and the project's recommendations are available on the NEMI website. The team has also recently published a document defining test conditions and criteria necessary for user acceptance of pure tin or high tin content tin alloy finishes. This document is also available on the NEMI website.[2]

Phase III Projects

The 2002 NEMI Roadmap highlighted the need for development of standards for collection, documentation and transmittal of material content data of components, assemblies and systems, as required by the European Union's RoHS (Restriction on use of certain Hazardous Substances) and WEEE (Waste from Electrical and Electronic Equipment) Directives. The RoHS Directive will ban several substances from electronic products sold in Europe,

beginning in July 2006; and the WEEE Directive requires manufacturers to mark products and provide hazardous material data to recyclers by July 2005. Manufacturers will be expected to prove conformity, which will require IT systems and audit trails that can cover the entire supply chain and manufacturing cycles. These systems must be able to track materials content and provide aggregate percentages at subassembly and whole unit levels.

In order to help industry meet these requirements, NEMI sponsored a series of gap analysis meetings to define infrastructure gaps and identify several transition issues that could be addressed effectively through industry collaboration. This process led to the creation of the RoHS Transition Task Group to further define areas for standardization and develop implementation projects. This work will build on what is being addressed by other industry groups, such as EIA, AeA and IPC.

NEMI is actively organizing four projects under the RoHS Transition Task Group:

- Assembly Process Specifications
- Component and Board Marking
- Component Supply Chain Readiness
- Materials Declarations

RoHS Assembly Process Specifications Project

As part of the ongoing industry effort to develop a lead-free soldering process, there is a need for component standards that accurately reflect the "real world" conditions that will be encountered during soldering operations. Before these standards can be developed, a process must be fully defined that covers all aspects of assembly (SMT, wave solder, rework, manual rework, etc.). This definition must include the soldering temperatures for all component types, taking into account the solder joint, package materials and the PCB. The Assembly Process Specifications Project is working to define the lead-free assembly process and determine the component specifications required for successful implementation of lead-free soldering. In addition to developing a process definition document, this project plans to identify industry standards that will need to be modified to reflect the lead-free process. The team is working with the standards-making bodies to modify IPC-610 and JEDEC 020B for lead-free processing.

RoHS Component and Board Marking Project

One of the issues surrounding the transition of the electronics industry to lead-free assembly is marking of components, boards and end products. This NEMI project is working to develop recommendations for industry standards related to lead-free component identification. Project deliverables will include specifications for a labeling and marking standard (excluding point-of-sale/retail box marking) for components, cards and motherboards, both in raw material and finished product form. The team will also make recommendations for part identification, including numbering nomenclature, change management and visual identification, based on best practices. As the specifics of the RoHS legislation and implementation become better defined, the Component and Board Marking Project will develop recommendations for a RoHS-compliant standard (which covers elimination of lead as well as other materials).

There are several marking schemes being used by industry and, as lead-free manufacturing proliferates, so does the number of marking schemes. JEDEC JESD97 has been approved as a lead-free component and board marking standard. This standard is being released along with a NEMI white paper summarizing the standard.

RoHS Component Supply Chain Readiness Project

The objective of this project is to assess and influence readiness of the component supply chain to support RoHS product conversions. The group will be looking at RoHS content compliance and lead-free process compatibility, focusing on board-mounted components and PCBs for mainstream electronics and high-reliability applications. The first step is to develop component compliance and compatibility criteria. For the purpose of this study, the following criteria are being used when evaluating material content for RoHS compliance:

- Lead content <0.1% by weight at raw homogeneous material level
- Cadmium content <0.01% by weight at raw homogeneous material level
- Hexavalent chromium content <0.1% by weight at raw homogeneous material level
- Mercury content <0.1% by weight at raw homogeneous material level
- PBB & PBDE content <0.1% by weight at raw homogeneous material level

In this instance, “homogeneous” is defined as a unit that cannot be mechanically disjointed in single materials. Additionally, the following uses of lead are exempt from this definition: lead in glass of cathode ray tubes, electronic components and fluorescent tubes; lead as an alloying element in steel containing up to 0.35% lead by weight, aluminum containing up to 0.4% lead by weight and as a copper alloy containing up to 4% lead by weight; lead in high melting temperature type solders (i.e. tin-lead solder alloys containing more than 85% lead); lead in electronic ceramic parts (e.g. piezoelectric devices).

The survey also evaluated components compatibility with lead-free processing temperatures.

Based on these criteria and the suppliers’ indicated timing, the group will then evaluate the readiness of the supply chain. The final function of this group will be to address identified roadblocks, whether

through their own efforts or by leveraging ongoing projects from other industry consortia.

RoHS Materials Declarations Project

Material composition disclosure is becoming a critical issue for the electronics supply chain due to the proliferation of laws and regulations that ban the use of certain chemicals in electronics (e.g., lead). Companies need to know that the products they are purchasing do not contain banned or restricted materials, and global efforts are under way to standardize how the electronics industry will declare hazardous and other materials in products and components. The Electronic Industries Alliance (EIA), European Industry Association (EICTA) and the Japan Green Procurement Survey Standardization Initiative (JGPSSI) have drafted a Material Composition Declaration Guide, which is currently in the JEDEC voting process.

The NEMI Materials Declarations Project is running pilot tests to identify issues relating to the Material Composition Declaration Guide, focusing on the legally banned and restricted materials summarized in Annex A of the guide. Various materials declaration tools are being compared for accuracy, cost, and required effort, with pitfalls and issues being reported. Based on information from these tests, the project team will then recommend a standard for materials declaration process and toolset. The goal is to develop an automated reporting process with minimal supply chain impact.

Conclusion

Some have compared the transition of the electronics industry to meet the requirements of the RoHS Directive with the transition of the information technology industry to meet the needs of Y2K. Many well-established systems in the manufacturing infrastructure are impacted. This article has highlighted the many projects that NEMI has undertaken to support industry's transition. New needs are continually being identified to accomplish this transition. As we write this paper we are initiating two new projects: Pb-free Wave Soldering Assembly Process and Substrate Surface Finishes for Lead-Free Assembly.

The successful execution of the transition by the world-wide supply chain will be a major challenge during the next two years.

References

1. "National Electronics Manufacturing Technology Roadmaps, December 2002" (2002), National Electronics Manufacturing Initiative, Herndon, Virginia, USA.

2. Information about NEMI's lead-free, tin whisker, and RoHS transition projects can be found at http://www.nemi.org/projects/ese/lf_hottopics.html