Benchmarking of Qualification Methodologies for New Package Technologies and Materials

Curtis Grosskopf[1], Feng Xue[2], David Locker[3], Sven Thomas[4], Jiayu Zheng[5], Masahiro Tsuriya[6]

IBM Systems Supply Chain Engineering, [1]Poughkeepsie, USA, [2]Singapore, [5]Shenzhen, China

[3]US Defense Department,

[4]Heraeus Deutschland GmbH & Co. KG

[6]iNEMI (International Electronics Manufacturing Initiative Inc.,), Tokyo Japan

***Abstract*— In common industrial practices, new integrated circuit (IC) package technologies are qualified using procedures and test conditions based on experience with the most similar technology previously qualified. While previous experience is important to consider, it cannot be the only criterion. Relying too much on experience may result in overlooking new failure modes and/or new wear out mechanisms. Current test standards may not capture the reliability risk in the new package or may overstress the technology in the new package. On the other hand, lack of understanding of the assembly processes, application environments, and use conditions of all potential end-users versus targeted end-users poses challenges when developing the appropriate reliability test plan for new package technologies/materials. With shorter development cycle time and more frequent introduction of new package technologies, a thorough qualification methodology is necessary to identify reliability weaknesses and prevent reliability escapes during the qualification of new package technologies and materials.**

Therefore, iNEMI conducted two industry surveys to assess potential gaps in common package qualification practices. The surveys were made available to the entire electronics supply chain, from device users to device suppliers, fabless device suppliers, design houses, package suppliers (OSAT), and fab suppliers. The surveys covered such topics as new package materials, new package technologies, end-user concerns, test conditions, new application spaces, and new qualification requirements. This paper discusses the findings generated from the survey results and presents the roadmap for developing a methodology for qualifying new package technology to address the gaps identified in the survey's responses.

Keywords: Package Qualification, New Package Technology, Benchmarking

I. Introduction

During the 2016 iNEMI Substrate & Package Technology Workshop in Singapore[1)], a major gap in the IC packaging industry was identified which was the lack of understanding of the assembly processes and application environments of all potential end-users when developing the reliability test methodology for new package technologies/materials. In general, the test plan generated only focuses on standard test methods and encompasses the requirements from customers or targeted end users, however current test standards may not capture all of the reliability risks for the new package or may over stress the new package. Test plan completeness is always questionable when planning to stress new package technologies/materials. Two examples of qualification "escapes" in recent years that the industry experienced for new package technologies were that Cu wirebond qualifications did not fully cover the variability in structure and strength of IC bondpad structures nor initially identified all of the new failure mechanisms associated with embedded IC packages. Moreover, field failures are rarely fed back to the original qualification team to allow for fail mode validation, root cause analysis, and improvements to the test plan; nor are the developers of new package technologies and materials rushing to help industry standards groups to develop new test methods or qualification standards for their new technologies and materials.

iNEMI officially started the industry project "Methodology for Qualifying New Package Technology" in July 2017, from a qualification methodology point of view, to address the gap identified above.

The purpose of this project is to develop a methodology for defining a qualification plan for new package technology and materials that addresses the gaps resulting from:

- Lack of understanding of the assembly processes
- Lack of understanding of the interactions of the materials and components within the new package
- Lack of understanding of the application environment
- Lack of understanding of the use conditions of all potential end-users
- Lack of understanding how variations of the manufacturing process could affect product quality and reliability

The project team completed a review of current industry qualification standards in October 2017 which is discussed in Section II of this paper. The project team completed the generation of the questions for the first survey in March 2018, of which the outline of the survey methodology was presented at IEMT2018 conference[2)]. The intent of the first survey was to understand what package qualification methods, tools, and best practices are used today and how users' requirements are obtained to ensure that a robust qualification plan is generated. The first survey was conducted from March to June 2018 and the results are discussed in Section III. Upon review and analysis of the responses to the first survey, it was determined that a follow-up survey was necessary to obtain more detailed information in a few key areas, specifically new package technologies and application spaces and is discussed in Section IV. The follow-up survey was conducted from Dec. 2018 to Jan. 2019 and a summary of its results are presented in Section V. Lastly, a summary of the project and its next steps are discussed in Section VI.

II. CURRENT INDUSTRY STANDARDS OVERVIEW

Several commonly used industry standards used to qualify the package of IC devices (qualification plans, tests methods, and pass/fail requirements) are shown in Table 1. However, none of these industry standards address the entire process for qualifying a new package technology/material nor which industry best practices should be used; e.g., how to identify best material set, initiate Failure Mode and Effects Analysis (FMEA), assess all possible customer assembly and field conditions, and other best practices.

TABLE I. LIST OF COMMONLY USED INDUSTRY STANDARDS

Standard Number	Standard Title
JESD47[3)]	Stress-Test-Driven Qualification of Integrated Circuits
JESD94[3)]	Application Specific Qualification Using Knowledge Based Test Methodology
JEP150[3)]	Stress-Driven Qualification of & Failure Mechanisms Associated with Assembled Solid State Surface-Mount Components
AEC Q100[4)]	Stress Test Qualification for Integrated Circuits
IEC - 60749-43[5)]	Guidelines for IC reliability qualification plans
Mil-Std-883[6)]	Test Method Standard for Microcircuits
Mil-Std-750[6)]	Test Methods for Semiconductor Devices

III. SURVEY SCOPE AND RESPONDANTS

The first survey consisted of 7 sections covering the qualification requirements and methodologies used to develop and qualify new package technologies and new materials.

A total of 62 responses were received for the first survey. Figure 1 shows the composition of the respondents by their organization: 16% were from IC package assembly houses, 30% from OEM & EMS, and 36% from “Others” (including wafer fab foundries, fabless design houses, package material manufacturers, national institutions and universities). The respondents’ geographic information is also shown in Figure1.

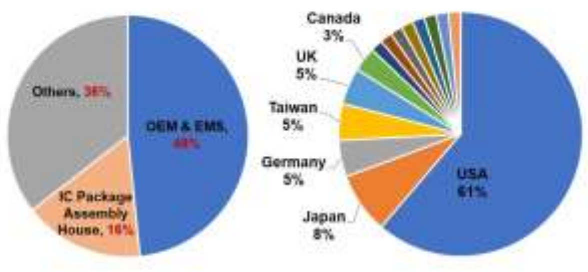

Fig. 1. First Survey Respondents by Organization and Geography

The follow-up survey attempted to obtain detailed information in a few key areas, specifically new package technologies and application spaces and received 92 responses. Figure 2 shows the composition of the respondents by their organization. The follow-up survey had a larger proportion of “Other” organizations (which includes device suppliers, package material manufacturers, fab suppliers, etc.), increasing from 36% up to 63%; and a smaller proportion of device users (both OEM and EMS) and package suppliers (OSAT), decreasing from 64% down to 37%.

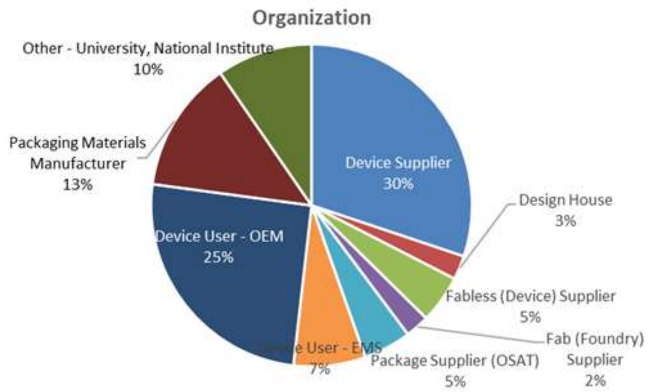

Fig. 2. Follow-up Survey respondnets by Organization Type

IV. FIRST SURVEY RESULTS

A. Current Methodology to Develop New Packages/Materials

As shown in Figure 3, the results from the first survey show that 75% or more of all respondents use the following three practices, tools, or methods: ensure that their customer's requirements are covered by their own qualification plan which is based on their internal methodology, perform a technology assessment prior to performing the product qualification, and perform FMEA. In addition to that, more than 50% of all respondents also use the following two practices: computer simulations (FEM - Finite Element Modeling) and extend the duration of their qualification stresses until fails are observed (Test to Fail). Only one practice, the use of special test ICs during reliability stress testing was performed by less than 50% of all respondents.

Figure 3 also shows how each group of respondents; OEMs, IC packaging houses, and “other”, responded to these questions. The overall usage for all respondents for each practice is shown on the bottom of the chart while each group’s usage of a specific practice is noted by the % value in each group’s color in each bar. IC packaging house stated that they used all six of the listed practices at a rate of 75% or higher. OEMs, on the other hand, only had use rates of 75% or higher for three practices: using FMEA, technology assessment prior to product qualification, and ensuring that customer requirements are included in the qualification plan. However, only 20% of OEMs use specially designed test ICs instead of product ICs and only 44% perform computer simulation/ FEM as part of their internal qualification methodology. These differences may be due to the fact that many OEMs are not involved at the beginning of evaluating new package technologies and materials.

Fig. 3. Practices used to qualify new package technology/materials

B. Types of New Technologies/Materials

Discrepancies were also observed between OEMs and IC packaging houses with respect to which new technologies have been implemented or are planned to be implemented (Figure 4 and Figure 5). IC packaging houses reported much higher implementation rates of new technologies. In some cases, the difference was 2x to as high as 8x, as noted in Figure 5. This difference in implementation rates may be due to OEMs not being aware of the new technologies within the devices they procure. Another possible reason for the discrepancy could be that some new technologies are only used in niche markets outside of the OEM's product set.

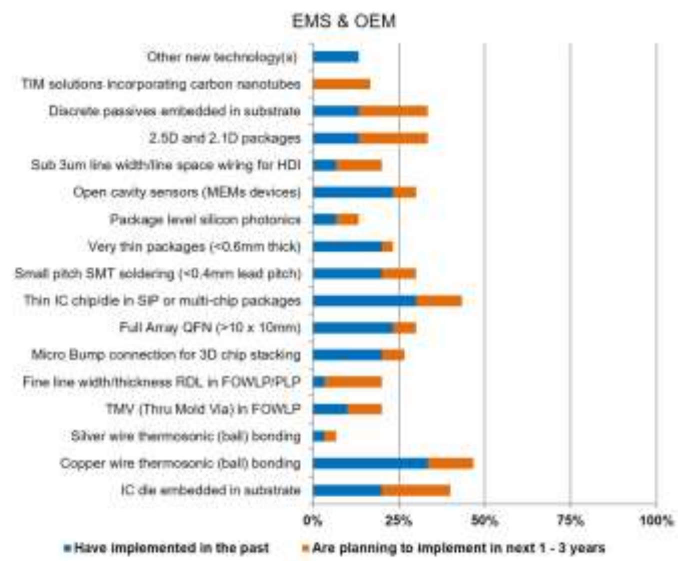

Fig. 4. OEM New Technology Implementation

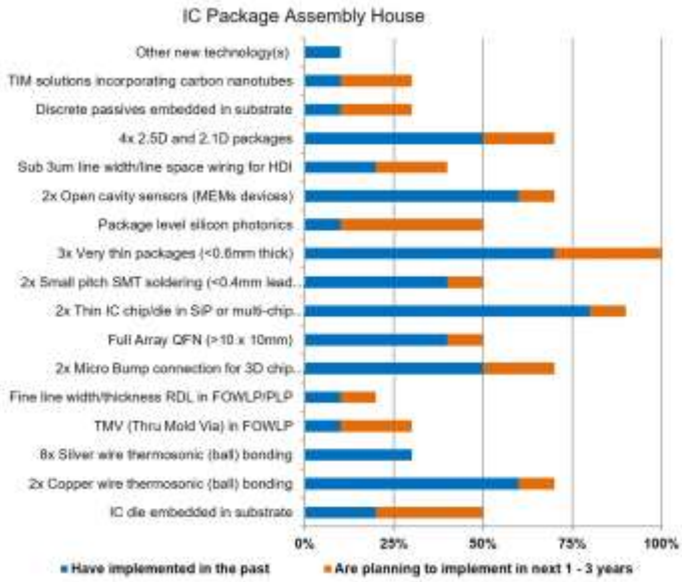

Fig. 5. IC Packaging House New Technology Implementation

C. Practices to Determine the Duration of Stress Test

Figure 6 shows the current qualification practices that the industry is using to determine the duration of the stress tests being performed. Approximately 40% of the respondents from each of the three sectors responded that they test beyond the expected field life and that they test to failure when qualifying new technologies. Testing to failure is the only way to determine whether acceleration models for past products also apply to a new technology. Incorporation of testing to failure in the qualification of new technologies indicates a significant recognition by the industry that new technologies may require new acceleration models compared to previous technologies. However, it also implies for the need for the remaining 60% to possibly reconsider their current practices when qualifying new technologies.

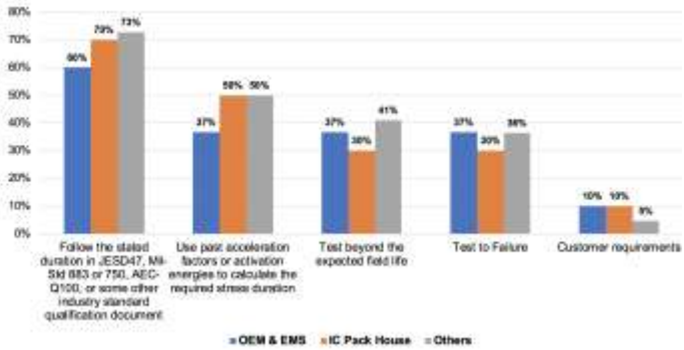

Fig. 6. Practices to Determine the Duration of Stress Test

D. New Test Methods to Develop to Better Address Relevant Failure Mechanisms

Figure 7 shows the percentage of respondents who use industry standard test methods, but at conditions or to durations not stated in the standard or use a test method that is not defined in an industry standard. When reviewing the other responses in the survey for the roughly 70% of respondents who answered "No" to both questions, 36% stated that the application space requirements of their product exceeded those stated in the corresponding qualification standard, and 61% saw a need for the industry to develop new test methods to better address relevant failure mechanisms. This suggests that even though a company may use standard test methods, they still see the need for better test methods and more appropriate stress conditions and durations. It suggests that the industry is aware of issues and opportunities exist to better align qualification methodologies with application requirements.

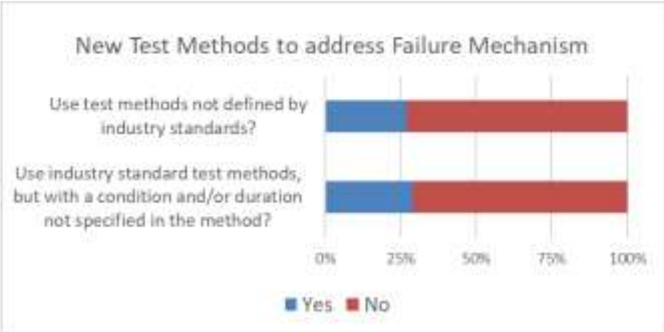

Fig. 7. Use of Test Methods beyond Industry Standards

E. *Qualification Report from Suppliers*

Figure 8 shows the response on whether suppliers provide all the necessary information in their qualification report to their customers (OEMs) which would allow them to verify that the new package technology/material will meet their end user's requirements. Only 24% of the respondents stated they did; 63% stated they did not; and the remaining 13% included responses of "occasionally", "sometimes", and "varies from supplier to supplier". This represents a major disconnect between what is provided and what is required.

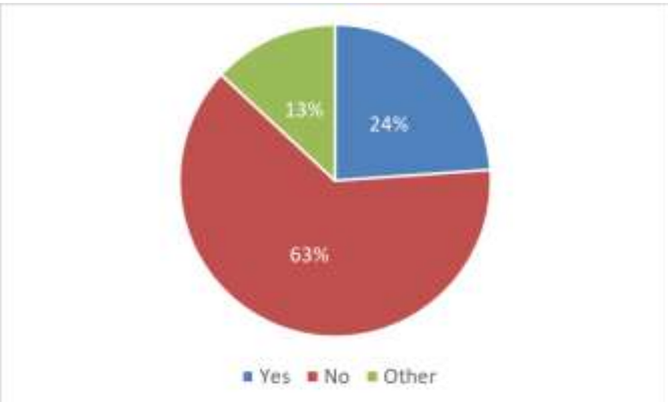

Fig. 8. Response on Supplier Support

F. *Qualification Plan Given by Business Partner*

The last part of the survey attempted to gather information on how qualification plans were generated. We attempted to understand if customer requirements were incorporated and if the qualification plan included input from customers. Unfortunately, there were not enough responses for any of the groups (device users (OEM and EMS), device suppliers, fabless device suppliers, OSATs, foundries, and design houses) to be able to make any comparisons or conclusions.

While the survey results provided key insights into current industry practices and validated the gap identified by the iNEMI workshop, a few "surprising" and even "contradicting" observations were made in analyzing the survey responses, e.g., the lack of qualification reports and the difference in opinion between packaging houses versus OEMs on rate of implementation of new package technologies and materials. For the questions that covered application use conditions, several recommendations were made, but it was not clear how widely held those recommendations were within the industry. Therefore, the project decided to conduct a follow-up survey.

V. RESULTS OF FOLLOW-UP SURVEY

The follow-up survey attempted to address the deficiencies and gaps identified by the previous survey, thus it focused on verifying responses and gathering detailed information in these five areas; A) test methods, B) qualification standards, C) application temperatures (both use and junction), D) new application spaces and E) package qualification methodology tools and best practices.

A. *Needs Identified with Test Method*

The first set of questions in the follow-up survey asked respondents whether they agreed with recommendations from the first survey that the industry should generate four new test methods. The results as shown in Figure 9 ranged from 53 to 73% in support of the generation of new test methods that would calculate the percentage of intermetallic compound (IMC) formed for Cu thermosonic ball bonds, evaluate a material's capability to protect an IC from radiation, evaluate the adhesion strength for stacked die, and evaluate package warpage as a function of absorbed moisture. As all four test methods were supported by more than 50% of the respondents, this project will recommend to the appropriate standards bodies that all four topics warrant consideration for new test methods.

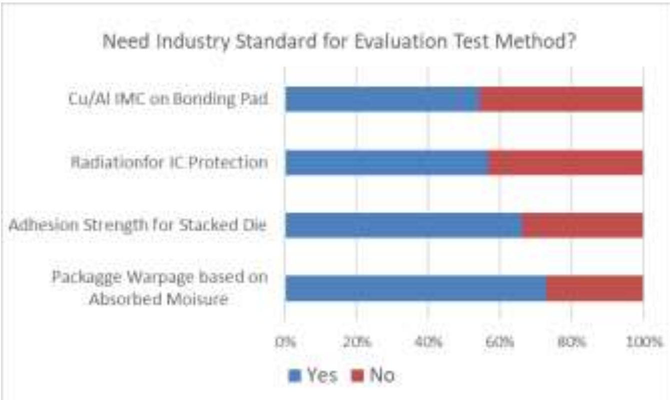

Fig. 9. Needs Test Method

B. *Needs Identified Qualification Standards*

The next set of questions in the follow-up survey asked respondents whether they supported the generation of five new qualification standards that covered Package on Package (PoP) technology, products/packages susceptible to atmospheric sulfur, open cavity packages for SMT sensors (pressure, humidity/moisture, etc.), devices in application spaces that require sequential package stress testing, and substrate-based packages with imbedded ICs and passives. Figure 10 shows that the support for the formation of all five topics varied between 52% and 67%. As all five qualification standards were supported by more than 50% of the respondents, this project will recommend to the appropriate standards bodies that all five topics warrant consideration for new qualification standards.

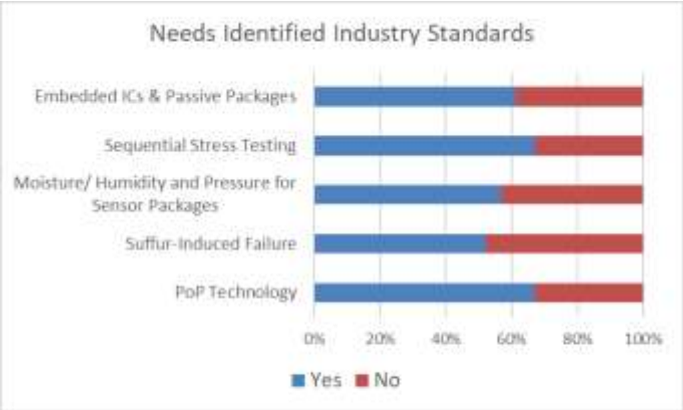

Fig. 10. Needs Identified Industry Standards

C. *Application Temperatures*

There were a few responses to the first survey that stated that there were applications for electronics that were at temperatures below 65ºC or above 150ºC (both junction and use), but very few details were provided, thus the follow-up survey attempted to validate those statements and gather detailed information about that applications. As shown in Figure 11, 50% of the respondents confirmed that applications existed where the maximum junction temperature may go above 150ºC and/or use temperatures are above 150ºC. Applications with very high use temperatures included down hole drilling (e.g., oil wells), automotive underhood (e.g., gearbox, tire control), and products that may at times see junction temperatures above 150ºC include RF power amplifiers. However, only 20% stated they were aware of applications in which the use temperature went below minus 65ºC, these included space, Mars, Antarctica, and computers at cryogenic temperatures (e.g., quantum computers). For the applications for which use conditions have already been documented, this project will recommend to the appropriate standards bodies that they should reconsider the current temperature limits. For those applications that are not yet defined in standards today, this project will recommend to the appropriate standards bodies that if they plan to define any of these application spaces that they consider these temperature limits.

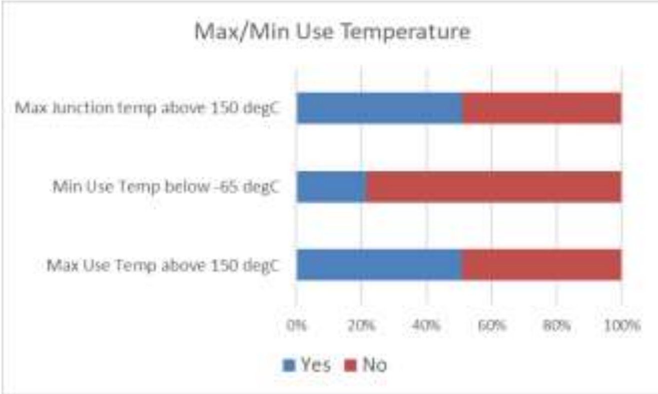

Fig. 11. Max/Min Temperature for Use Contion

D. *New Application Spaces*

This project initially identified 12 distinct application spaces covered by multiple qualification standards and respondents to the first survey recommended the need for five more. The follow-up survey assessed the industry's support for these five new application spaces; wearable electronics, undersea, down hole (in well) drilling, automotive – immersed in engine fluids, and space – beyond earth orbit. As all five applications are quite unique and some are even niche, many of the respondents could not provide an opinion, thus as shown in Figure 12 many answered, "Not Sure", ranging from 38 to 56%. Wearables had the largest support at 48% and undersea had the lowest at 22%. The level of non-support was low for all five, with the highest level only at 22%. Even though the level of support was below 50% level for all five questions, the level of non-support was even lower, thus this project will recommend to the appropriate standards bodies or industry organizations that most of these new application spaces warrant their consideration to be added to their qualification documents.

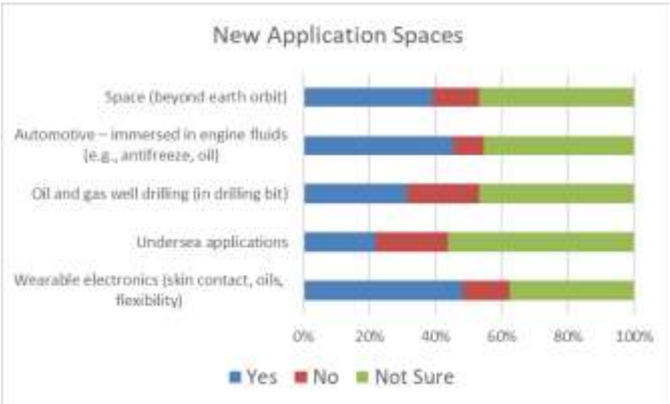

Fig. 12. New Application Spaces

E. *New Qualification Tools and Best Practices*

Lastly, the respondents were asked if they used any other qualification methods, tools or best practices as part of the assessment of new package technologies and materials. A few responses of note were digital imaging correlation and highly accelerated stress testing to expedite development. Though many comments were submitted, most of the recommendations were test methods, not necessarily additional best practices or novel ways to analyze the new technology or material. However, the list of comments when assessed as a group, suggested that when developing qualification plans for new technologies or materials, all possible interactions and use applications must be considered and addressed.

VI. Summary and Next Steps

The results of the two surveys highlighted that there is a discrepancy between supplier and customer knowledge on the use of new technologies and materials, as well as differences between field use conditions and the qualification stress conditions required to support the use conditions. This discrepancy highlights the need for greater sharing of information between companies, from end use conditions to qualification results. The awareness of what failure mechanisms could occur with new package technology and how best to test for those mechanisms, can be improved, and would greatly benefit from the generation of an industry guideline of best practices. A large percentage of the respondents had knowledge of the six qualification methods, practices, and tools that our surveys mentioned, though the level of usage varied between users and suppliers. This difference in understanding and use confirms the need for an industry guideline of best practices.

Respondents highlighted that application use temperatures are rising, with some going higher than the current 150°C upper limits; and a few going below the -65°C lower limits. Similarly, the fact that survey respondents, who are striving for zero defects, have extended their test durations indicates an awareness that improvements are needed to industry test methods and the requirements in qualification standards.

Lastly, device users pointed out a large discrepancy in what information was provided in a qualification report that they needed to assess whether a qualified device could be reliably used in their product versus what information was actually being provided. This last finding highlights the need for better communication across all members of the supply chain from end users back to package development teams.

The project team's next steps are to complete its analysis of the responses from the second survey and then begin the generation of a package qualification methodology (white paper) for new technologies and materials, referencing industry test methods, qualification standards, and industry best practices. The team plans to assess the completeness of the qualification methodology by reviewing the issues raised in the first survey for industry adoption of copper wirebonding and leadfree soldering and determining how well the methodology would have identified all of the issues during the qualification process.

It is the group's intent that this white paper will then be taken over by an industry standards body, so that it can be published and then maintained and improved over time.

Acknowledgment

The authors acknowledge the great contributions of the project team Phase 1 members: IBM, Ibiden, Wistron, iST, Intel and DYCONEX AG. We also appreciate the participation of the survey to have provided inputs.

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