Optimization of Moisture and Thermal Mechanical End of Line Monitors (EOLMs)

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Abstract: This document outlines the application of a ten-step approach to evaluating moisture and thermal mechanical end-of-line monitors in an effort to optimize their reliability.

Keywords: Equipment Reliability, Process Monitors, Control Equipment, Cost Analysis

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1 EXECUTIVE SUMMARY

A ten-step approach was used to evaluate moisture and thermal mechanical end-of-line monitors (EOLM) for reliability. The purpose of applying this ten-step approach is to eliminate or reduce EOLM so that resources can be focused where they will be more effective. The 10 steps are as follows:

1. Define purpose of monitor and stakeholder
2. Review current monitor
3. Review other similar activities
4. Determine what can be replaced or enhanced
5. Define attributes of desired future state
6. Perform risk/benefit and cost analysis
7. Develop roadmap: today to future
8. Define deployment plan
9. Obtain customer/stakeholder feedback and buy-in
10. Execute

1.1 Conclusions

By using this ten-step approach it was determined that properly implemented in-line process monitors and controls, thorough qualifications, and wafer- and assembly-level reliability monitors should pose little or no risk to reliability since the in-line monitors are expected to identify the same defects that would have been found by the EOLM tests, except much earlier in the process. Benefits of eliminating EOLM testing for robust technologies are that it frees up resources such as reliability test equipment and does not consume shippable devices. The effort used in this program could then be directed towards optimizing existing in-line monitors and controls or putting new ones in place.

2 INTRODUCTION

A Process Monitors and Controls team was established under the direction of the SEMATECH Quality Council to determine and optimize monitors and controls that are used in manufacturing semiconductor products. An output of this team is a publication entitled *SEMATECH Process Monitors and Controls, Volume I* (SEMATECH Technology Transfer #98013449A-XFR), that documents an overall concept for process monitor and control systems and can help companies determine strengths and weakness of their systems. It also contains what are thought to be the best known methods for process monitor and control now being used in the industry. An appendix to this publication contains a ten-step approach that is recommended for optimizing monitors. This publication is endorsed by the SEMATECH Quality Council with the recommendation that member companies use the methodologies described in it to assess and improve their quality systems.

The ten-step approach was used to evaluate the high temperature operating life (HTOL) test that is used in EOLM for reliability. Using this approach, it was recommended that HTOL testing be optimized by reducing it to 168 hours or less from what had been a de facto industry standard of 1000 hours. To optimize moisture and thermal mechanical EOLM, this team takes the same ten-step approach and shows how it can be applied. However, companies are urged to conduct their own evaluation using the ten-step approach before implementing the changes being recommended by this team.

Following is the framework of how each of the ten steps was applied towards evaluating the EOLM tests. Steps 7 to 10 require additional individual company details and plans as these steps deal with the implementation of EOLM optimization.

3 TEN STEPS

3.1 Define Purpose of Monitor and Stakeholder

EOLM testing, in its present form, has been in use for approximately 25–30 years. The moisture and thermal mechanical tests that make up this testing include temperature humidity bias or 85/85, temperature cycling or thermal shock, highly accelerated stress testing (HAST), autoclave, and preconditioning (moisture/reflow sensitivity) for surface mount packages, which can be used before any of the other tests. The initial purpose of the reliability tests currently used for EOLM was to stimulate and precipitate known failure mechanisms and provide ongoing information about the probability of occurrence. As a result, the EOLM emerged as a lot acceptance test and provided a warning of problems to help detect major reliability excursions. It was also used to provide feedback on the effectiveness of improvements to process control and materials selection.

Some of the current perceived purposes of EOLM include providing customers data to use in quarterly reliability reports, providing feedback for continuous improvement efforts, verifying and supporting qualification assessments, deriving reliability statistics and failure rates to monitor reliability, supporting conformance to an industry practice and traditional measurement, giving customers a supplier assessment metric, and protecting the customer against failure wear-out mechanisms.

An actual purpose of the EOLM testing is to provide data for quarterly reliability reports and to facilitate long-term failure rate assessments.

What stakeholders want from these monitors is a clear and sufficient demonstration that the product still meets or exceeds the reliability that was established at the time of the last qualification or major process change. By definition, a monitor is a system for warning of changes in reliability, not a control of reliability.

The stakeholders for EOLM include both the supplier and the customers. More specifically, the internal stakeholders for the supplier include the following organizations: Reliability Engineering, Manufacturing Operations and Engineering, Product Engineering, Development Engineering, Marketing, Internal Customers, and Quality. The organizations from the customers side include Component/Materials Engineering, System Reliability Engineering, Procurement, Incoming Quality, Board-Level Manufacturing Engineering, and External Customers.

3.2 Review Current Monitor

EOLM tests are implemented by taking a sample of finished product and subjecting it to long-term tests such as 1000 hours of 85/85 testing or 1000 cycles of temperature cycling. At intermediate intervals and/or at the end of the test, electrical testing is done to check for failures. Failed parts are subjected to failure analysis to determine what has caused that failure. This allows the appropriate corrective action to be taken to prevent that failure mechanism from occurring again. These EOLM tests are a subset of current qualification tests.

A downstream effect of the current monitor is when the results are known; the product has probably already been assembled by the customer and may even have been shipped to his customer. This type of process does not benefit either the supplier or the customer and demonstrates why EOLM is no longer effective in today’s marketplace, which requires much faster feedback.

An upstream influence of the current monitor is that it does not provide any new information on failure modes that are not already determined during qualification. If new modes were to be found, this might indicate that the qualification needs to be more comprehensive.

The reliability of the device is actually determined during design and manufacturing, which includes both wafer fab and final packaging. EOLM testing in its present form does very little to control these processes. Its major purpose is to provide data to the customer.

3.3 Review Other Similar Activities

EOLM data is used to publish quarterly reliability reports for customers. Published data may be made available in a real-time database, web site, or written report.

To make this data available, the necessary reliability equipment is needed. To complete the 1000 hour or 1000 cycle tests, this equipment is in use for long periods of time. The same reliability equipment is also used for qualification testing, which is much more critical. The qualification testing is closely related to EOLM testing; however, it is used to demonstrate the reliability of a new product or process change. This testing is usually either fully or at least partially completed before the product is shipped. For EOLM, the product is shipped well before the final results are obtained.

EOLM testing looks for defects caused during either wafer fabrication or packaging. In-line process monitors can be used to find many of the same defects while providing much faster feedback to correct the source of the defect. Also, since the first implementation of EOLM, many significant improvements have been made within the industry in the materials, processing, equipment, and general operating systems used to manufacture semiconductor devices. (Some of these improvements are explained in the appendices.) All of these improvements have helped to drive the failure rates down to their current low levels. However, many of the same EOLM tests that are still being run were first implemented before these improvements when failure rates were much higher.

In some cases customers use actual field performance data to calculate failure rates in lieu of EOLM data.

3.4 Determine What Can Be Replaced or Enhanced

The current EOLM tests are clearly reactive, especially those taken out to 1000 hours or 1000 cycles. These tests are an attempt to monitor reliability after a device has already been manufactured and perhaps even sent to the customer. Taking steps to design in reliability and then monitor it using process controls during manufacture is a much better method of improving reliability compared to performing the long-term EOLM tests. In addition, a thorough qualification program could also be used to ensure the reliability of the product before it is made ready for manufacture. Wafer- and assembly-level reliability monitors can also be used to find problems much earlier in the manufacturing process.

High leverage opportunities for reliability improvement have already been implemented (see the appendices). Additional opportunities will surely become available in the future and should help to drive defect and failure rates even lower than they are now. It is thought that for technologies/package types with low failure rates, in-line process monitors could be used in place of the EOLM tests. Examples of some of these process monitors are shown in Appendix A. It would be up to design/engineering teams at each company to determine the appropriate monitors or controls that would replace the selected EOLM tests.

3.5 Define Attributes of Desired Future State

In-line process controls (see Appendix A), thorough qualifications, and wafer- and assembly-level reliability monitors are some of the controls that should be in place before considering to reduce or eliminate EOLM testing. The most robust technologies would then require minimum or no EOLM testing. Technologies that demonstrated problems during initial qualification would be monitored with the appropriate EOLM tests until enough improvements are made to allow the EOLM to be either reduced or eliminated.

Qualification processes will need to have broader scope to include risk analysis and reliability validation to production and ramp-up. The actual validation tests, test conditions, sample sizes, and frequency of testing will be determined case by case by the qualification team based on the results of the risk analysis. This system will allow for more timely feedback into manufacturing for corrective action and will make better use of the resources associated with EOLM testing.

It is thought that this optimization should currently apply to all of the EOLM tests except moisture preconditioning, until better process monitors can be found for it. It should be possible though to pull samples for this monitor earlier in the process and use accelerated moisture conditions to get results faster than the current method of waiting for completed devices before starting testing using standard moisture conditions.

3.6 Perform Risk/Benefit and Cost Analysis

If in-line process monitors and controls (see Appendix A), thorough qualifications, and wafer- and assembly-level reliability monitors are implemented properly, very little or no risk should be associated with the new system. The in-line monitors should identify the same defects that would have been found by the EOLM tests, except much earlier in the process. Another way of looking at this is that the current EOLM tests only monitor the quality and reliability that is already built into the product; they do very little to actually control quality and reliability. Therefore, eliminating the monitors will not reduce the quality and reliability. The broadened qualification system should also help to ensure that any new failure mechanisms are detected during the qualification that might otherwise be detected only during the EOLM.

Also, it is known that defect and failure rates have greatly decreased over the time since when EOLM was first implemented[1] [2]. Shown below is EOLM data from several SEMATECH member companies taken during 1996–1997.

Table 1 Combined Data of SEMATECH Members*

	Temp Cycle	**Autoclave**	**85/85(THB)**	**HAST**
Totals	66/270,775	12/254,402	42/189,701	0/21,390
Failure Rate	0.02%	0.005%	0.02%	0

* Data show failures/total samples taken.

Individual sample sizes are usually in the range of 50–100 devices. These sample sizes are much too small to give any resolution of the failure rates as contained in the above ranges. The great majority of samples taken show 0 failures. This does not allow the data to be used to drive continuous improvement programs and makes it very ineffective for use with many of the perceived purposes for EOLM listed in Section 2. To make the results of these tests more useful, the sample sizes would have to be increased. This would require additional good devices to be destructively tested, additional capacity in the form of reliability equipment and load boards, and additional labor both for shop personnel to perform the tests and engineers to evaluate the test results.

The defect rates shown above are so low that shifts in them cannot be detected using the current sample sizes. It would therefore be much better to use in-line monitors that can detect shifts in the defect levels. A minor risk with the new system may be that the customer will no longer have the long-term EOLM data for the robust technologies.

Benefits of eliminating EOLM testing for robust technologies are that it frees up resources such as reliability test equipment and does not consume shippable devices. The effort used in this program could then be directed towards optimizing existing in-line monitors and controls or putting new ones in place. The cost of the new system must be determined by each company. There will clearly be a cost saving for any EOLM testing that is eliminated or reduced. However, this must be compared to the cost of implementing the necessary in-line monitors or controls. Some companies may already have all of the necessary monitors or controls while others may have to spend money to implement them. Whether or not the new system saves money is really secondary; more important is that the new system will focus resources where they should be much more effective.

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[1] Pallab K. Chatterjee, William R. Hunter, Ajith Amerasekera, Sian Aur, Charvaka Duvvery, Paul E. Nicollian, Larry M. Ting, Ping Yang "Trends for Deep Submicron VLSI and Their Implications for Reliabililty," *Proc. 33rd IRPS* 4, Fig. 6 (1995)

[2] Julie Spicer England, Robert W. England "The Reliability Challange: New Materials in the New Millennium, Moore's Law Drives a Discontinuity," *Proc. 36 IRPS* 3, Fig. 8 (1998)

3.7 Develop Roadmap: Today to Future

The actual roadmap will vary for each company that decides to reduce EOLM testing. Before reducing or eliminating EOLM, companies may want to consider having in place or planning to put in place the following conditions and/or equipment:

- Routine monitoring of in-line SPC metrics for the detection of maverick lots.
- Wafer-level reliability tests to measure and control wear-out mechanisms. This could include wafer-level thermal shock testing, passivation layer monitoring, and high temperature bakes.
- Assembly-level reliability tests to measure and control package-level reliability.
- A robust qualification/certification methodology to ensure the initial quality and reliability of the product before the start of production through ramp-up to high volume production. This should make use of extensive data collection, root cause analysis, corrective action, and risk assessment.
- Periodic reviews of baseline data to ensure that product design rules are still being met.
- Checking of back-up data received from customers and suppliers such as customer line fall out, customer returns, and failure reports. This is to verify that the customer is not seeing any higher than expected failure rates or any unknown or unexpected failure mechanisms.
- Quality operating systems such as ISO or QS to ensure consistent operating practices with the rest of the industry.
- Preconditioning monitors moved as far upstream in the process as possible to provide data that can be correlated to any board mounting issues that may be found.
- The general industry and technology improvements listed in the appendices.

It should not be necessary to have all of these in place before starting a reduction in EOLM testing. Also, the above list should not be considered complete since additional items could also be considered.

3.8 Define Deployment Plan

Each company must develop its own specific plan for executing the roadmap that it develops. Some companies are now planning to implement this program towards the middle of 1998.

3.9 Obtain Customer/Stakeholder Feedback and Buy-in

This step will have to be completed by each company. The actions in this step include determining if the customer supports the proposal and determining what information the customer needs to support the proposal.

3.10 Execute

This step will have to be completed by each company.

4 CONCLUSIONS

The SEMATECH members believe there is merit in applying this ten-step approach to eliminating or reducing EOLM so that they can focus resources where they will be much more effective. Each company can now develop its own specific plan for executing the optimization. Several companies are planning to start implementing this program towards the middle of 1998.

APPENDIX A
In-Line Process Controls

Moisture Related Failure Mechanisms	In-Line Controls	Comments
Corrosion	Wafer moisture test	Provides information related to contamination of wafer surface
	Passivation integrity	Wafer inspection for pin hole density and cracking
	Contact angle	A measure of wafer cleanliness
	Phosphorous controls	Monitor of phosphorous used in wafer processing
	Wafer packing and storage controls	Prevention of contamination on wafer surfaces
	Raw materials controls	Supplier partnerships apply controls to the quality of raw materials to minimize contamination
	Construction analysis	Analysis of all materials used in the assembled product for identification of potential risks
	Mold flow modeling and design	Optimization of mold parameters to ensure adhesion
Delamination	In-line C-SAM monitors	Scanning acoustical microscopy inspection after molding
	X-ray monitoring	D/A void and encapsulation void monitoring
	Plasma clean process controls	Monitors of energy, exposure time, gas flow and pressure
	In-line preconditioning	Pre-conditioning completed in-line after mold

Thermo-Mechanical Failure Mechanisms	**In-Line Controls**	**Comments**
General	Stress modeling (FEA)	Evaluation of stress levels for die/package combination
	In-line cross-section	Evaluation of package integrity
	Construction analysis	Analysis of all materials used in the assembled product for identification of potential risks
Passivation/thin film cracking	Die design rule controls	Rules established for die metal layout to minimize stress related issues
	Passivation monitoring	Wafer inspection for pin hole density and cracking
Die cracking	Backgrind controls	Downfeed controls employed at the SAW operation to minimize wafer cracking
	Saw controls	Controls and monitors employed at the SAW operation to minimize wafer cracking and chipping
Bond lift/cratering	In-line bond pull	SPC monitoring of the bonding process
	Bond process controls	Controls employed at the bonding operation to minimize bonding problems
	In-line ball shear	SPC monitoring of the bonding process
	In-line X-ray	Post assembly inspection for wire sweep
Lifted die	In-line die shear	SPC monitoring of the D/A process
	In-line X-ray	Post assembly inspection for D/A voiding
Package cracking	Auto-mold process controls	Process controls at the molding operation for consistency of mold parameters and device handling
	Tooling controls	CONTROLS employed at the trim and form operation to minimize defects attributed to this operation

APPENDIX B
Material Improvements

Over the last 20 years the semiconductor industry has significantly improved the materials used in wafer fab processing and in assembly processing. These material improvements have had a dramatic effect on the moisture and temperature cycling performance of the finished IC components.

Phosphorous glasses have also been improved by reducing the level of extractable phosphate, which was a source of Al corrosion during 85C/85% RH w/bias (THB) testing and during autoclave testing. The move to barrier metals such as TiW as part of the bond pad construction has all but eliminated the silicon chipout problem that occurred during temperature cycling. Improvements in passivation overcoats and scribe-line seals have been effective in eliminating mobile ion/inversion issues and have prevented ionic contaminates from reaching circuit metal and causing ionic leakage or corrosion. The industry has converted from pure Al metallization to Cu doped Al and/or implemented the use of metal capping technologies to reduce metal deformation resulting from mechanical stress and to prevent electromigration. Metal grain size is being controlled to minimize stress voiding and to optimize electromigration performance. For large die applications, die corner design rules, such as slotted metal, no active circuitry in the corner areas, no active circuitry under bonding pads, etc., are being used to reduce the effect of package shear stress on metal deformation/cracking and on passivation overcoat/interlevel dielectric cracking.

Numerous material improvements in assembly have had a favorable impact on moisture performance and temperature cycling capability. The most dramatic improvements have occurred with the molding compounds or plastic encapsulants used on ICs. Twenty years ago, the industry was using silicone molding compounds, anhydride cured epoxy molding compounds, phenolic cured epoxidized phenolic novolac (EPNs), and phenolic cured epoxidized ortho-cresol novolac (EOCNs). Although the silicone encapsulants were clean, they had poor adhesion properties, poor tensile/flexural strengths, and high moisture permeation rates. The epoxy formulations offered better adhesion performance and higher strengths, which were much more compatible with lead frame trim/form processes and customer board insertion processes.

In the 1970’s, the epoxy formulations had hydrolyzable chloride values that were in the 400–1000 ppm range and water extractable chloride levels in the 17–160 ppm range. During 1981–1983, mold compound formulators started using the purer low chloride epoxy resins from the Japanese resin suppliers. This lowered the hydrolyzable chlorides to the 130 ppm level and the water extractable chlorides to the 0.5–10 ppm range. These cleaner resin systems had a favorable impact on THB and autoclave performances. In the 1970’s, autoclave failures for the EPN and EOCN formulations typically occurred within 48–96 hours. With the cleaner resins in the early 80’s, the times to failure increased to 168–240 hours. As these cleaner epoxy resins were moved into the epoxy die attach formulations along with improvements in their hardener and catalyst systems, the autoclave failures moved out to 500–1500 hours. The continual reduction of chloride levels and other ionic contaminants in mold compounds and die attach materials have effectively reduced the need for THB and autoclave as an EOLM. With continued improvement in epoxy resin cleanliness, the levels of hydrolyzable chloride and water extractable chloride that are being observed in the current mold compounds are 20–70 ppm and 0.5–10 ppm, respectively.

Besides the improvements in the purity of the raw materials that go into the epoxy mold compound formulations, the fillers that are used in these compounds have changed dramatically. In the 1970's, the fillers used in most formulations were either crystalline silica, fused silica, or a blend of the two. In a few cases, tubular alumina was blended with the silicas to improve the thermal conductivity of the encapsulant. However in the mid-80's, die sizes started to grow significantly and circuit densities increased. Filler induced defects (FID) were becoming more of a problem, and the larger die were seeing problems related to package stresses (corner shear stress and warpage/compressive stress). As part of the solution to these issues, spherical fused silica fillers were incorporated into the formulations for large die applications. The reduced surface area of the spherical fillers allowed more filler loading in the formulation and this lowered the expansion coefficients and stress of the plastic encapsulant. Since package stress is a function of both the expansion coefficient and the modulus, mold compound suppliers started putting low stress additives in the formulations to improve the temperature cycling performance for the large die applications. Memory products experienced a unique problem in that the alpha radiation emitted by the standard fillers caused the memory cells to lose bits of information (soft error issue). To resolve the memory problem, ultra clean fused silica fillers with a uranium content less than 1 ppb were used for these applications.

Heading into the 1990's, the focus for applications was on VLSI die in the quad flat packages (QFPs) with high pincounts. With corner shear stress continuing to be the major issue, the industry moved to the ultra low-stress mold compounds that were based on the multifunctional epoxy resin (MF) chemistry. These formulations had high glass transition temperatures (Tg's in the 180°C range versus EOCN formulations with Tg's of 150°C), which expanded the range of the lower alpha 1 expansion coefficient and provided lower stress over a wider temperature range. The expansion coefficient properties were optimized by maximizing the filler loading for these compounds (80% filler). To achieve even lower stress, the formulations also had low stress additives to lower the modulus of the encapsulant. These low stress additives were either silicones or organic rubbers. Because of the number of bonding wires and the length of the wires for the larger packages, the mold compound formulations used low viscosity resins to minimize wire sweep issues. To obtain the lowest melt viscosity in the molding operation, most of the formulations also used spherical fillers or a blend of spherical and flake fillers. To provide additional improvements in wire sweep, the industry moved to gold wires whose dopant levels had been optimize to minimize wire sweep and wire sag while maintaining good loop control. Through these continual improvements in package materials, the large die applications have been able to achieve the temperature cycling performance that has been typical of the very small die.

From 1993 to now, the emphasis on plastic encapsulant has been on improved adhesion to reduce delamination and popcorning of the thin packages, such as TQFPs, TSSOPs, etc. Although the industry has not observed a strong correlation between delamination and reliability problems for all package families, some supporting data seem to indicate that delamination was more of an issue for large die in the thinner packages. This coupled with more customers acquiring scanning acoustical microscopes (SAMs) and becoming aware of delamination increased the priority for improving the delamination performance. To achieve a significant improvement in encapsulant adhesion for the thinner packages, the industry, again, moved to a new epoxy chemistry—biphenyl epoxy resins. The biphenyl epoxy formulations provided better adhesion, lower moisture absorption, higher strength at solder reflow temperatures, and lower melt viscosities, which allowed even higher filler content (85%). The higher filler loading provided lower expansion coefficients both below and above the glass transition temperature. This was particularly important for the biphenyl epoxy encapsulants, which have low Tg’s (100°C–120°C). Because of the low stress properties that were achieved by the lower expansion coefficients and the significant improvement in adhesion performance, low stress additives were not required in these formulations. Without the low stress additives, the biphenyl epoxy encapsulants were able to maintain their robust strength properties at solder reflow temperatures.

Today, because of customer demands, the industry is seeking to improve delamination performance on all package families. While in many cases the need is based on emotion instead of a real reliability issue, customers are taking the position that “although [they] do not know if delamination is causing a problem, [they] argue that delamination cannot be good.” Therefore, the semiconductor industry is responding by implementing programs to improve delamination performance for all packages. The most informative test procedure for meeting the current requirement is the IPC/Jedec J-STD-020 joint document for classifying the moisture capability of surface mount packages. While the standard moisture tests and temperature cycling tests will continue to be used in the characterization and qualification phases of a new package or a package improvement program, the control and monitor of the surface mount package families will rely more on delamination performance at time 0 and after preconditioning/reflow using SAM.

Based on the material improvements over the last 20 years, the conventional EOLMs that have been used have become obsolete. The move to the SAM/preconditioning/reflow/SAM test as an in-line monitor and EOLM should be more effective for meeting today’s needs.

APPENDIX C
General Operating System Improvements

Over the last 10–15 years, the general operating systems that the semiconductor industry uses have significantly improved, which has reduced the need to run end-of-line monitors. Such improvements have been as follows:

- **Traceability**. Using either inked or laser written trace codes on the packages, it is now possible to trace the origin of a unit through all assembly and fab processes/equipment. In this manner, the industry has been able to track failures back to the origin of the problem and eliminate the cause.
- **Stress/modeling/package design rules**. It is now possible to predict the stresses that will cause package failures using modeling. In this manner, packages can be designed and materials selected that give the maximum margins for reliability performance, reducing the need for continuous monitors.
- **Design of Experiments**. By selecting the variables of a process in a statistical and systematic manner, it is possible to find the window of performance for that process. In this manner, the right process conditions can be selected that give the maximum reliability margins.
- **Better characterization/quals**. Running extensive package characterization tests before qualification, with maximum sample size, and out to failure has enabled the industry to define the reliability window that a package can operate in. Having a known and wide window beyond the EOLM conditions has reduced the need to run such monitors.
- **Supplier partnerships**. It is also necessary to extend the controls that the industry has implemented to suppliers. This has been done by developing close relationships with the supplier and “teaching” them, where necessary, how to implement process controls.
- **Analytical tools**. With better analysis tools such as SAMs, delamination can now be detected immediately after preconditioning. This tool can be used as part of the characterization to develop the best process conditions/materials and also can be used for in-line monitors. In this manner, monitors can be moved upstream from the EOLM.
- **Construction analysis**. By doing destructive analysis of packages and looking for items such as delamination, poor bonds, weak bond strength, die tilt, bond sweep etc., as part of the characterization effort, this information can be fed back to the assembly line as part of continuous improvements.
- **Rapid process control feedback**. By using in-line checks such as preconditioning SAM analysis, bond pull strength, bond shear strength, visual inspection, warpage checks, etc. and feeding this information back rapidly to the line by using statistical process control (SPC) techniques, problems can be rapidly detected and corrected without the need to find these during EOLM.
- **Material review board/change control board**. By managing changes to materials and processes in a controlled manner, including material review boards with experienced experts then detailed characterizations, DOEs and qualifications can be used to ensure changes do not degrade the reliability of the packages.

- **Cleanroom operations**. By assembling parts in cleanroom conditions, contamination can be all but eliminated as a cause for reliability failures, further enhancing the reliability and control of the process.
- **Statistical Process Control**. By using statistical techniques to define the control limits for processes, and plotting the data such that the assembly areas can take corrective actions when processes are going out of control, abnormal situations that can lead to EOLM failures an be reduced.

APPENDIX D
Process/Equipment Improvements

Mold Flow Design. The design of encapsulation molds have improved to provide better and more predictable laminar flow. This ensures reduction in pin-holes, voids, and wire sweep.

Lead Finish Process Improvements. Lead finish equipment and process controls provide better chemical stability and more controlled cleaning.

Plasma Cleaning. This is used for specific applications to improve adhesive coupling of laminated materials or composites.

Passivation/Planarization. This changes the passivation integrity to reduce cracking and pin hole occurrence.

Bond Process/Equipment Control. This reduces over bonding and low strength bonds.

D/A Process/Equipment Control. This is to reduce the occurrence of die cracking.

Backgrind Control. Here the improvements have been in better quality of grinding media, down feed controls, and tape strength adhesive reducing die cracking.

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