Challenges in automotive package development

By Shaun Bowers [Amkor Technology, Inc.]

Automotive package development in outsourced semiconductor assembly and test suppliers (OSATS) is a natural extension of the market forces that established the OSAT market in the 20th century. The motivation to re-use technology, cross-pollinate approaches, standardization, and a lower barrier to entry for new package types all apply to automotive as well as standard OSAT packaging services. The trend to adopt new and varied package types to automotive applications is a direct response to the market forces that are increasing the semiconductor content in automobiles at an exponential rate. Whether a future car is considered a rolling smartphone, a rolling supercomputer, or a rolling artificial intelligence (AI)-enabled taxi, the quantity of integrated circuits per vehicle will continue to increase as carmakers rely on sensing, CMOS and solid-state devices for safety, performance, infotainment and vehicle autonomy functions.

Although the market forces outlined above push suppliers to adjust the way they approach automotive package development, the core objectives to address reliability and device performance have stayed static. Material selection, bond integrity, adhesion promotion and stress management remain the core of the package development objectives no matter the package format or function (**Figure 1**).

Figure 1: Automotive development methodology. SOURCE: Amkor Technology, Inc.

How package development activities are directed to address the market will greatly influence the ability to accelerate the adoption of new automotive packages. To become an automotive powerhouse, OSATS must change the way data is analyzed, adjust the test vehicle (TV) design and experimental approach, and dedicate resources specifically to automotive testing and analysis.

Automotive testing and test to failure

Failure mechanism (FM)-based testing is widely acknowledged as the accepted methodology to determine automotive fit for use. The use of the Automotive Electronics Council's (AEC's) AEC Q100, Q006 and Q101 specifications is common to evaluate new materials and semiconductor package types for automotive applications. Because copper (Cu) wire is mechanically more rigid, has low resistance, and is slower to develop intermetallics vs. gold (Au) wire, the use of Cu in automotive applications is ideal. The evolution of Cu wire bond has had many iterations (**Figure 2**), including how to form the bond, what materials to use, and what environment in which to keep the device to ensure bond integrity.

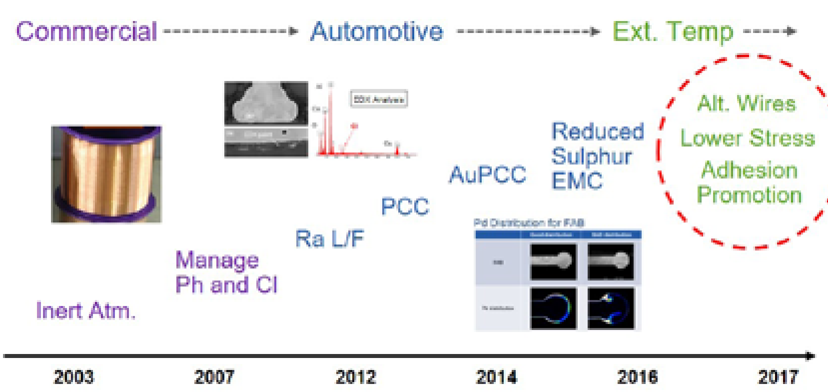

Figure 2: Evolution of Cu wire. SOURCE: Amkor Technology, Inc.

As the survivable number of cycles (per AEC Q006 testing) is extended for Cu wire, key challenges in automotive package development start to be revealed. With a more capable material and an extended test spec, the amount of data on time to failure becomes rare due to the length of the test. It is not uncommon for some devices to exceed two or three times the defined envelope in AEC Q006, so failures in devices put into reliability testing nine months ago, have yet to occur.

In many ways, development and manufacturing groups are at odds for automotive applications. The manufacturing group does not want to see failures, but the development group needs to see them to learn, validate assumptions and make improvements. The only option seems to be to wait. This is in conflict with the market forces that want to adopt new packages quickly.

Automotive development groups have ways to adjust to this new reality, however. The long time to data dictates the adoption of aggressive test vehicles to force early failures in the testing of materials and designs. It necessitates the addition of purposeful variability to obtain meaningful A vs. B data from the experimentation (**Figure 3**). The benefit is that once success in aggressive testing schemes is achieved, it is easily adopted along a broad package envelope.

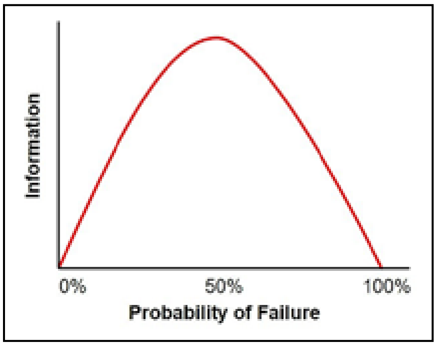

Figure 3: The use of purposeful variability for more meaningful data. SOURCE: "The Principles of Product Development Flow," Donald G. Reinertsen

Automotive design rules

The transition from Au to Cu wire in automotive products has also introduced the requirement for destructive analysis into the testing schedule (**Table 1**). Instead of merely testing electrical response as in Q100, the Q006 test procedure requires destructive analysis of the devices after the environmental testing for devices with Cu wire.

Ensuring bond integrity after temperature cycling (TC), highly-accelerated stress testing (HAST) and high-temperature storage (HTS) requires new design best practices (**Figure 4**). Ensuring that the device has no delamination in critical areas post-testing requires new materials best practices. Accepting that bond integrity,

	Read Point	Mold Compound Delamination Acceptance Criteria	Electrical
Qualification Requirements	T0	No delamination at first (ball) or second (stitch/wedge) bonds unless otherwise agreed between supplier and user.	All components passing production test
	Post MSL PC	No delamination at first (ball) or second (stitch/wedge) bonds unless otherwise agreed between supplier and user.	All components passing production test
	1X for AEC Q100 grade X or AEC Q101	No delamination at first (ball) bond. If any (stitch/wedge) bond delamination found – no heel cracks.	All components passing production test
	2X for AEC Q100 grade X or AEC Q101 (TC included if no BLR performed)	Evaluate the severity of any bond delamination found per Sections 5.2 and 5.3.	All components passing production test
Minimum CSAM sample size: EITHER the same 11 components per lot through each readpoint (preferable) OR 22 random components per lot at each readpoint.			

Table 1: AEC Q006 delamination criteria.

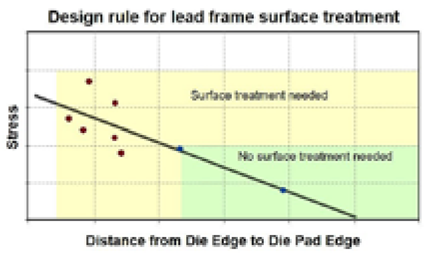

Figure 4: Automotive design rule example—roughened surface.

stress management and adhesion promotion all play roles in these best practices, then new design elements must be adopted early in the development process. The data gained from the aggressive test vehicles allows the validation of the new design elements. Determining when to use a certain technology or material can be tied directly to the results of the testing.

Automotive materials

With the aggressive TV and design-of-experiment (DOE) regimen established, it is now possible to perform A vs. B experiments on different materials. This allows the demonstration of the reliability response for items such as Au palladium- coated copper (AuPCC) vs. alloy wire selection, effect of ionic and/or corrosive materials within compounds, and the effect of roughened surfaces and mechanical design elements. The net result is that the findings enable confidence in material sets for devices specifically targeted to automotive applications.

The time elements of this testing remain lengthy and onerous. Although difficult, it is advantageous to develop accelerated testing to achieve results sooner. The industry has looked at increasing amplitude (temperature), frequency and order of operation to shorten the time to data (**Figure 5**). All of these have merits and boundaries, but accelerated failure mechanism testing will shorten the time to data. If adopted and agreed upon, this will allow more development cycles in the given timeframe, and make iterative approaches easier to analyze.

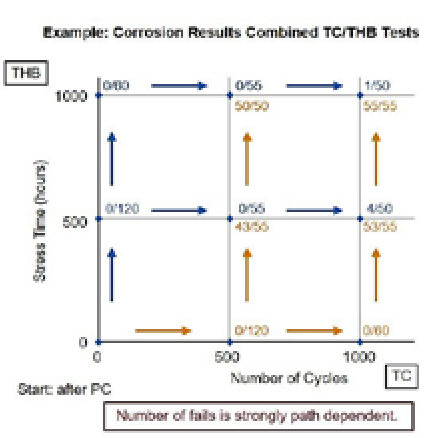

Figure 5: Graph of test order and effect on FM testing. SOURCE: Infineon Technologies

New package types not covered by Q100 and Q006

As the automotive market matures, it will command the use of nontraditional form factors that are common in other, less rugged applications (**Figure 6**). In some cases, the specifications and documentation are lagging the technical capabilities. For example, it is possible for wafer-level chip-scale packaging (WLCSP) to pass AEC Q100 testing, as the testing schemes are directed towards showing failure modes common to traditional wire bond technology. However, passing Q100 does not necessarily mean that the package type is good for automotive applications. In WLCSP, it is rather easy to pass post-test delamination criteria because there is no mold interface. WLCSPs are commonly underfilled on a printed circuit board (PCB), thereby creating the interface in question. In this example, AEC testing is required to be done on the device (e.g., preconditioning +TC), but board-level reliability (BLR) testing might be more appropriate. This is one area where standards groups need to adapt to technology and consider different failure modes as a part of that effort.

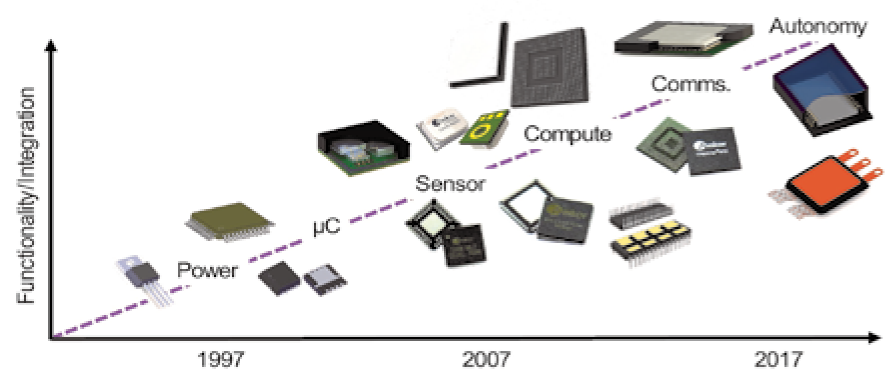

Figure 6: Adoption of package types over time in automotive applications.

Future areas of interest/development for automotive applications

Looking forward to the future, two things are certain: 1) the automotive market will continue to grow and expand into new packaging types, and 2) the OSAT industry will be relied upon to bring these to market. Automobiles will continue to integrate functions dominated by sensing, CMOS and solid-state electronics applications like computing, communications, environmental/mechanical sensing and AI. As a result, a host of package types can be expected to be developed and deployed in automobiles such as WLCSP, flip-chip ball grid array (FCBGA) and embedded packaging along with more traditional laminate and lead frame packages.

Development activities will continue to be focused on bond integrity, adhesion promotion, materials and stress management. Whether the bonding approach uses copper pillar bumps (CuP), alloy wire, hybrid wire, lead-free solder or other emerging techniques, bond integrity remains a key area of analysis. Testing requirements will involve destructive testing; therefore, adhesion promotion and stress management will be key to meeting the environmental reliability envelope of a vehicle application. Significant energy is expected to be spent to eliminate the failure-creating intermetallic compounds (IMCs) altogether, and to develop accelerated tests that enable more frequent cycles of learning. Development groups will need to adjust to keep up with the breadth and pace of automotive package development, and the OSAT community is uniquely positioned to create the required innovations.

Biography

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