Packaging ICs to survive the automotive environment

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Electronic systems in cars and trucks represent some of the harshest application conditions for integrated circuits (ICs). The packaging for these ICs must withstand a variety of tests that go well beyond conditions prevalent in consumer, commercial and industrial qualifications.

To survive these tests and operate reliably over their expected lifetime in a variety of vehicles and systems, assembly processes for automotive ICs have several unique aspects to ensure packaging reliability and durability. The extent of unique processing and tests depends upon the vehicle system where the IC is employed.

Getting electronics into production vehicles

Some electronics in vehicles are obvious, while others are somewhat hidden. The obvious systems include infotainment systems, digital displays, instrument cluster, voice/data communications, back-up warning, adaptive cruise control, advanced driver assistance systems (ADAS), cabin environmental controls, navigation systems, lane departure warning, and others in the passenger compartment.

The hidden vehicle systems include engine control, cylinder deactivation, electric power steering, electronic throttle control, airbag deployment, transmission control, anti-lock brakes, electronic stability systems, and more. Many of these hidden systems are mounted under the hood of the vehicle where the ambient temperature can be 150˚C or higher.

Vehicle electronics growth

Over 50 different electronic systems can be found in today's high-end vehicles that implement the most advanced technologies. In fact, the number of automotive electronic systems is increasing due to government safety mandates and consumer demand for more convenience and comfort features.

In addition to the increasing electronic content, the number of vehicles sold is increasing globally, especially in China and emerging markets. In the last decade, new vehicle sales in China have grown at a rate of almost 12% per year.

Increasing vehicle sales and higher electronic systems penetration are driving the automotive IC market, which is approximately $24B in 2015, with a 5-year CAGR of about 9% to 10% (**Figure 1**). Over 70% of the automotive total available market (TAM) is in the area of analog (including linear regulators, power components, DC-DC converters, LED drivers and interface components, such as USB drivers) and microcontrollers (MCUs).

The automotive market is an attractive segment for most semiconductor companies as it provides a more stable application base compared to cyclical mobile or consumer applications, longer product life cycles, and higher returns on investment. However, there are barriers to entry with very high expectations of quality, reliability, handling and processing, all of which must be achieved at reasonable costs. There are also continuously evolving quality and reliability requirements that drive significant capital purchases. Working with the right outsourced semiconductor assembly and test (OSAT) partner can help address many of these challenges effectively.

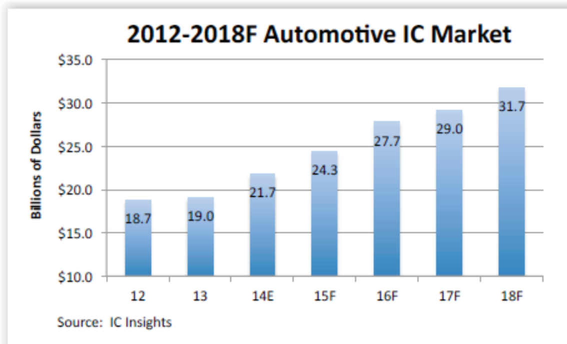


Figure 1: Market experts forecast consistent growth for automotive ICs. SOURCE: IC Insights.

AEC-Q100	Ambient Operating Temperature Range
Grade 0	-40°C to +150°C
Grade 1	-40°C to +125°C
Grade 2	-40°C to +105°C
Grade 3	-40°C to + 85°C

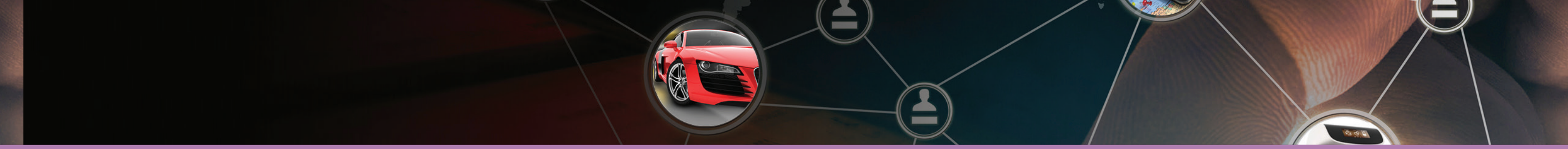
Table 1: AEC-Q100 grades vary based on the operating environment temperature range.

AEC-Q100 grades

The Automotive Electronics Council (AEC) has established AEC-Q100, "Failure Mechanism Based Stress Test Qualification for Integrated Circuits" [1], to provide standardized test methodologies for reliable, high-quality electronic components.

Many of the tests in AEC-Q100 are performed by the IC suppliers themselves, but packaging-related tests may be performed by an OSAT as part of the IC qualification. The test requirements vary from "under-the-hood" applications, to passenger compartment, and other vehicle locations. The part operating temperature grades are shown in **Table 1**.

The grades reflect different application profiles from under the hood to inside the cabin mounting locations and apply to IC products including microelectromechanical



systems (MEMS) sensors, power devices, signal conditioning, MCUs and more. While Grade 1 is most commonly used in automotive, Grade 0 is for the more stringent applications, while Grades 2 and 3 are more equivalent to commercial qualifications.

Special considerations for automotive ICs

Semiconductor suppliers are not always aware that a particular IC will end up being used in an automotive application – especially if it's a catalog IC being used in Grade 2 or Grade 3 applications such as after-market infotainment. If an IC is designed explicitly for an automotive application, however, steps must be taken to ensure that it is handled and processed differently than a standard commercial or industrial IC. Even a 1ppm component failure rate translates into a 1.5% or 15000ppm failure rate at the car level. To ensure the highest safety standards, we need to have a goal of zero defects.

When a product is identified for automotive use, IC suppliers, especially those familiar with automotive requirements, usually have specific expectations for processing and handling during the assembly process.

Supplier management

Early in the development process of an automotive IC, one of the major considerations is business continuity planning with respect to raw materials. For instance, there have been major disruptions in the lead frame supply chain with recent accidents and some lead frame suppliers exiting the business. Supplier selection, redundancy, and process audits per automotive standards such as VDA6.3, are very important to ensure continuity and quality of supply for automotive ICs.

Automotive controls

In addition to ensuring that factories have automotive certifications such as TS16949, automotive products should be subject to tighter controls on the factory floor. Among other things, these controls might include designated automotive equipment (**Figure 2**), specially trained operators, error-proofing systems and hands-free processing systems. Designated automotive lines are usually equipped with higher end models of machines that are maintained at a different standard and subject to tighter C_{pk} process capability requirements. Certified operators are specially trained to handle automotive devices and have to meet certain minimum requirements to achieve and maintain certification. Process control automation can help ensure that automotive devices are processed only on designated automotive equipment by certified operators.

Additional process steps

Depending on the application profile, automotive devices could have additional process steps compared to a standard commercial IC to ensure the highest quality and reliability. These typically include more stringent visual inspections during assembly and 100% open-short testing at the end of the assembly process. Some of the other additional process steps could be direct plasma cleaning before wire bonding to ensure a higher quality bond and plasma cleaning before mold.

Safe launch

Safe launch is a process during the pre-production phase where manufacturers or assemblers inspect the process at each step and verify that the particular step is done correctly before the product moves to the next one. This ensures that any issues with production processes are identified and addressed during the pre-production phase itself, before high-volume production starts. Safe launch is even more important for advanced packages such as flip-chip ball grid array (FCBGA), flip-chip chip-scale package (fcCSP), system-in-package (SiP), etc., which are relatively new to automotive applications. For example, during the assembly process of FCBGA packages, safe launch could include examining cross sections at several different locations after the solder ball attach process to make sure that the metallurgy of the solder joints is robust. Although this represents extra work and time during pre-production runs, the benefit is better quality and a more robust process. It also gives more confidence to both semiconductor suppliers and Tier 1 suppliers about going into production with new technologies.

AEC-Q100 qualification

AEC-Q100 consists of a suite of tests but only a subset of these tests is directly related to the package and assembly. Some of these are "in process" tests such as wire bond shear (WBS), wire bond pull (WBP), and others that an OSAT can perform. As shown in **Figure 3**, the reliability tests in test group A are the most applicable to an OSAT.

Traditional JEDEC and AEC-Q100 Test group A have various tests including pre-conditioning, temperature cycling (TC), temperature humidity bias (THB), unbiased highly accelerated stress test (HAST) and high-temperature storage life (HTSL). **Table 2** shows the differences between the standard JEDEC conditions vs. Grade 0 and Grade 1 automotive reliability test conditions. An OSAT must have reliability labs with capability and equipment to perform these tests.

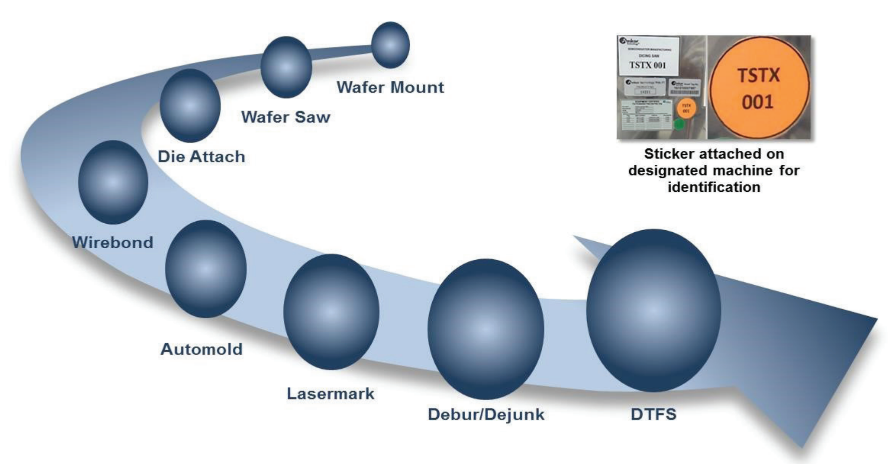


Figure 2: Typical wire bond assembly process steps and special identification label for designated automotive equipment.

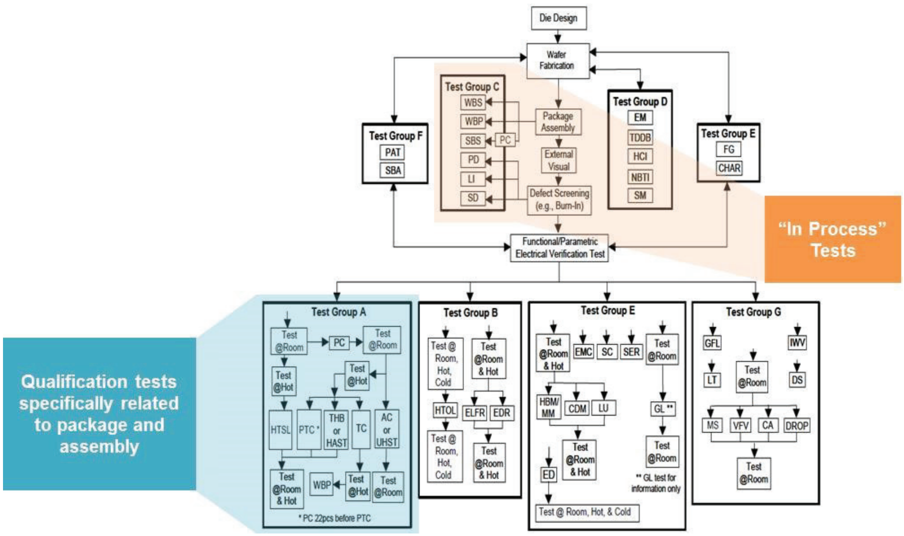


Figure 3: AEC-Q100 qualification test flow [1].

Stress	Standard JEDEC Conditions	AEC-Q100 Grade 0	AEC-Q100 Grade 1
Pre-conditioning	MSL 1: 85°C/85% RH for 168 hours, unlimited floor life MSL 2: 85°C/60% RH for 168 hours, 1 year floor life MSL 2a: 30°C/60% RH for 696 hours, 4 weeks floor life MSL 3: 30°C/60% RH for 192 hours, 1 week floor life	Min Level 3, per J-STD-020	Min Level 3, per J-STD-020
Temperature Cycling	Condition A: -55°C to 85°C Condition B: -55°C to 125°C Condition C: -65°C to 150°C	-55°C to 150°C for 2000 cycles	-55°C to 150°C for 1000 cycles -65°C to 150°C for 500 cycles
Temperature Humidity Bias	THB: 85°C/85% RH for 1000 hours	Pre-condition before THB: 85°C/85% RH for 1000 hours	
Unbiased HAST	Unbiased HAST: 130°C/85% RH for 96 hours, or 110°C/85% RH for 264 hours	Pre-condition before Unbiased HAST: 130°C/85% RH for 96 hours, or 110°C/85% RH for 264 hours	
High Temp Storage Life	Condition A: +125°C Condition B: +150°C Condition C: +175°C	175°C for 1000 hours or 150°C for 2000 hours	150°C for 1000 hours or 175°C for 500 hours

Table 2: AEC-Q100 qualification tests within an OSAT company's scope.

Figure 4 shows the tests that Amkor typically performs for AEC-Q100 qualifications. Based on equipment availability, or in some cases the equipment's capability, alternate tests may be acceptable. For example, instead of unbiased HAST, autoclave or temperature humidity (without bias) are acceptable tests. These tests are used to characterize the bill of materials (BOM) for AEC-Q100 Grade 1 and Grade 0 applications. Different package families are evaluated to determine the most robust the most robust bill of materials (BOM) to qualify for Grade 0 and other grades.

Special BOM considerations

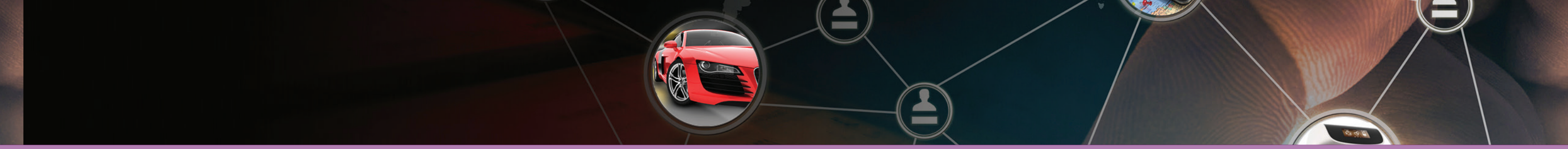
In addition to special processing, automotive applications frequently require special material sets or BOM. For lead frame products, some of the main material considerations are: wire type, epoxy mold compound (EMC), die attach (DA) materials, and lead frame design features.

Lead frames with roughened surfaces are often used to enhance EMC adhesion. Roughened lead frames can be used in combination with unique design features that are etched or stamped onto the lead frame surface to improve delamination performance.

A critical component in being able to achieve aggressive year-on-year cost reductions is to use copper wire on wire bond products. Traditionally, gold has been the wire of choice, but due to cost and high-temperature performance where Kirkendall voiding is observed between the gold and aluminum interface, most new wire bonded automotive devices are using copper wire. Most major IC suppliers are either already qualified, or are in the process of qualifying copper wire for automotive applications. Lead frame, chip-scale package (CSP) and ball grid array (BGA) packages are in volume production for infotainment and engine control applications, and there is also increasing acceptance in other applications such as powertrain and chassis. Safety applications, however, have been slower to adopt the use of copper wire.

The use of copper wire is not without its own set of challenges. Apart from the usual workability challenges of Cu wire, recent industry testing [2] has raised some concerns related to Pd coated copper (PCC) bond wire for very stringent automotive applications. In these studies, HTSL testing performed at above 150˚C showed degradation of bond pull test (BPT) results seen over time, as well as cracks at the stitch bond area. While PCC wire passes the AEC-Q100 Grade 0 min levels, there are some concerns regarding the margin in very stringent applications where the IC must operate at temperatures over 150˚C for extended periods of time.

Further evaluations are necessary to validate the findings of the above-mentioned study and determine the right material set to achieve robust performance for AEC-Q100 Grade 0 and beyond. Amkor has ongoing evaluations to determine appropriate BOMs for various products. The evaluation matrix for lead frame products consists of variations of wire type, EMC and lead frame design features. The primary goal of these evaluations is to develop a BOM recommendation for AEC-Q100 Grade 0, with secondary goals of extended testing beyond the Grade 0 limits, to achieve zero delamination and meet other stringent automotive criteria.



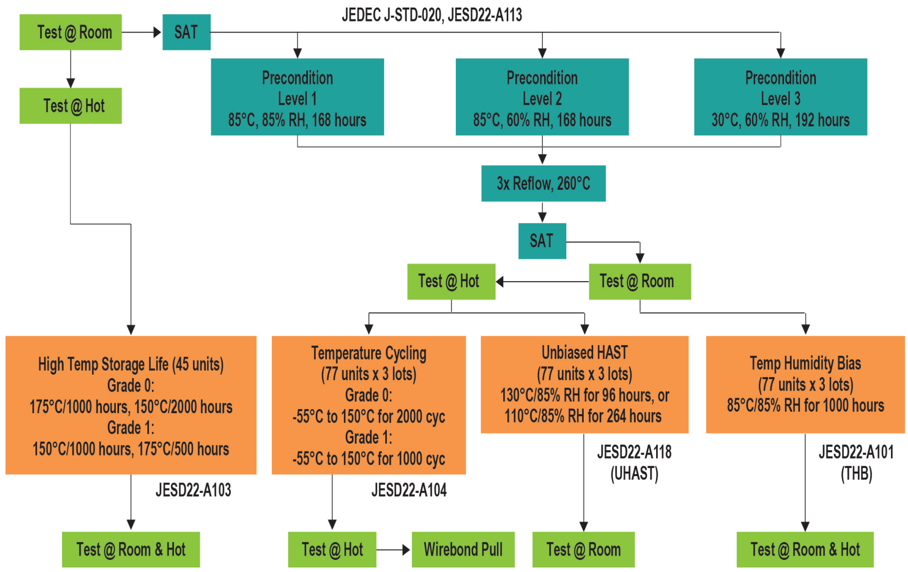


Figure 4: AEC-Q100 Group A tests performed by Amkor Technology®.

Some of the Amkor package families that are popular in automotive electronic systems include: SOIC, TSSOP, MLF®/QFN, TQFP, BGA, Stacked CSP, fcCSP, FCBGA and TMV®. Dual lead frame products such as SOICs and TSSOPs represent the highest volume. Quad lead frame packages, as well as BGAs, are popular for automotive MCUs. The increasing use of non-wire bond products such as CSP and through-mold via (TMV®) is occurring in infotainment and ADAS systems.

Evolving automotive packaging requirements

Increasing innovation in ADAS and infotainment is bringing advanced technologies to the automotive space at a much faster rate than ever before. Growing familiarity with smartphone technology is increasing consumer expectations in the car. Consumers now expect their car to seamlessly talk to their phones, and they want to be able to run the same apps that they are used to running on their phones, in their cars. New safety systems in the cars are slowly transitioning from driver assistance to highly automated, on their way to becoming autonomous. Autonomous operation requires automotive systems to continuously monitor the surroundings and take preventive actions in case an incident happens. In such a system, there are several sensors that feed real time data to a processor, where several algorithms are running and the processor feeds the results to actuators. Since these systems require real time processing, it is critical that the response time be as fast as possible. As a result, systems designers choose either SiP or fcCSP type of packaging to keep the processor and memory as close as possible to each other.

Assembly solutions for automotive IC packages

ICs provide the foundation for the technology inside the automotive electronic systems that deliver control features, convenience, connectivity and keep passengers safe and comfortable. To achieve the reliability that automakers demand, IC suppliers must approach IC packaging with considerably different packaging techniques. These include additional controls on the manufacturing floor, additional process steps during assembly, and using the right material set that has been proven to survive automotive reliability tests.

As an OSAT supplier with many years of automotive experience, Amkor Technology® has extensive understanding of the requirements of automotive OEMs and Tier 1 suppliers and can provide guidance and direction in assembling automotive products, especially to customers with limited automotive experience. Our joint venture with J-Devices is expected to expand and provide even greater assembly and test capabilities for automotive customers, as well as access to the Japanese automotive market.

Evolving packaging technologies from leaded to surface mount to MEMS, 3D and die-level packaging will continue to place even more stringent demands on IC packages in automotive applications. Working with a seasoned expert OSAT can mean the difference between survival and failure in automotive applications.

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Biography

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