Advanced testing technology for emerging automotive applications

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The IC content in automobiles has been steadily increasing for the last twenty years. Emerging automotive applications in the areas of mobile connectivity, automotive safety and electrically powered vehicles are expected to drive that content well beyond its current historic level. Many of these new applications, especially those in the area of automotive safety and electrical power will require extremely high levels of performance and reliability in harsh operating environments. FormFactor and Texas Instruments recently collaborated in a study designed to address some of the testing challenges presented by these new applications. This paper discusses select results from the study.

Automotive semiconductor growth

The automotive sector is one of the fastest growing segments in the semiconductor industry. According to an IC Insights report [1], the ICs used by the automotive industry are expected to expand at a compounded annual growth rate of 6.7% from 2014 to 2019. As shown in **Figure 1**, the automotive segment is predicted to grow faster than any other semiconductor market segment during that time period, such as communication, computer and consumer end-applications.

One of the main reasons for this notable automotive segment growth is that the automotive industry, worldwide, is undergoing some profound changes that are driving an increased dependence on semiconductors. The demand for increasingly versatile electronic systems listed below is believed to be a key driver behind this growing use. These include:

Automobiles with mobile connectivity. Consumers are demanding expanded access to mobile digital content while driving. This trend has required the development of application-specific ICs that can provide a safe and secure merger of the two sectors.

Environmentally friendly cars. The slow, but steady growth of the electric car market is also helping to drive increased semiconductor demand from the automotive industry. Application-specific semiconductors play a critical role in delivering the high energy requirements needed to make electric vehicles a practical and environmentally friendly alternative to those powered by internal combustion engines.

Increased automotive safety. The trend of including advanced driver assistance systems (ADAS) in automobiles, which provides automated driving assistance in difficult conditions, has also helped drive automotive IC content specifically designed to provide the high reliability sensing and reaction capabilities required by ADAS systems.

Gartner projects [2] that the increasing semiconductor content in automobiles will drive the worldwide automotive semiconductor market from its all-time high of $30 billion in 2014 to $40 billion by 2019. This level of growth makes the automotive market highly attractive to many semiconductor manufacturers, because it is seen as being steadier and less cyclical than the consumer and mobile semiconductor markets. This highly positive growth outlook is, in part, predicated on the assumption that the future vision of driverless and fully automated cars will soon become reality.

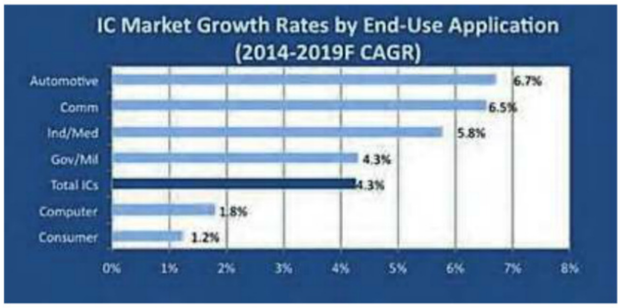


Figure 1: IC Market growth rates by segment, 2014-2019. SOURCE: IC Insights, Inc.

Emerging auto IC test applications

These new automotive electronic systems will require specialized ICs that have been tested to guarantee the highest levels of performance and reliability [3]. These various applications will require a range of ICs including these examples:

Advanced driver assistance systems (ADAS). This application provides the latest technology advancements for driver awareness and safety. It requires processors with digital signal processing (DSP) capabilities to enable multiple vision and radar systems for applications like lane departure warning, rearview and surround view camera systems, collision warning and avoidance, as well as blind spot detection. It also requires a fully integrated system-on-chip (SoC) for ultrasonic parking assistance, FPD-Link connecting standard cameras and megapixel cameras via thin, as well as light and cost-optimized cables, which can reduce the weight and complexity of the wiring harness without sacrificing performance. **Figure 2** highlights some of the ADAS

Figure 2: Some of the latest automotive applications requiring leading-edge IC technology.

functions currently being produced for that sector by Texas Instruments [3].

Body electronics and lighting. The central body controller supervises and controls the functions related to the car body, such as lights, windows and door locks. It also serves as a gateway for controller area network (CAN) and local interconnect network (LIN). TI's portfolio of products includes solutions for power management, signal-chain, interfacing, load drivers, RFID functions, and DSP/microcontrollers. Figure 3 shows ICs designed to address some of these applications [3].

Hybrid/electric power train systems. ICs also provide analog and embedded processing solutions for improved performance and safety throughout the hybrid/electric power train systems. Solutions include battery management and charging systems, fully integrated plug-in electric vehicle management systems, and start/stop functionality. Figure 4 highlights a TI ASIC designed for such applications [3].

Infotainment and cluster. Applications are widely used in designing cluster, head unit, human-machine interface (HMI) display or other infotainment system components [3].

Safety. ICs are now being used in a wide range of automotive safety applications that include stability control and anti-lock braking systems; electric power steering systems; airbag, occupant detection and alarm systems; and ADAS [3].

Stringent automotive IC test requirements

ICs used in automotive applications must adhere to the highest performance and quality standards to ensure the safety of both the driver and passengers. As a result, ICs used in these applications must be tested more rigorously and under more extreme conditions than ICs used in most mobile and consumer applications as noted in the following paragraphs.

Harsh outdoor environment. The electronics incorporated into an automobile, or one of its subsystems, will be expected to operate in a much wider range of temperatures than most mobile consumer devices will experience. A smartphone, for an example, is practically attached to our hands most of our waking hours and, more often than not, is used in an air-conditioned environment. In contrast, cars are used in an outdoor environment. A car's interior can experience a temperature range of -40 to 125°C. In addition, the "hidden" electronics that are mounted under the hood and control the engine, electric power steering, airbag deployment and anti-lock brakes often operate at ambient temperatures of 150°C or higher.

- Three TPS92630 connected together by FAULT bus to drive 9 LED strings with 100mA current each string
- Car battery directly connected and full test in Qualified Automotive EMC Lab
- Ideal results for Tail Light, Stop Light and Turn Light

Figure 3: TI provides a range of ASICs to meet body electronics and lighting needs.

- Operates from a single 12V automotive supply (7V to 40V operational range)
- Drives 3-phase Brushless DC (BLDC) motors up to 60W with no position sensors required
- Easy to get started with MotorWare software

Figure 4: TI's 60W brushless DC motor drive.

"Zero defect" expectance to ensure highest level of safety. When it comes to the electronics it deploys, the automotive industry expects zero defects, both for safety and economic reasons. IC manufacturers participating in that sector are expected to use a defective parts per million (DPPM) design methodology and manufacture their products using a zero-defect process technology that minimizes early life failures and ensures long mean-time-between-failure (MTBF). Even a 1ppm IC failure rate can translate to a 1.5% or 15,000ppm failure rate at the automotive level—a rate that can result in a massive recall and serious economic distress for an automotive manufacturer. As a result, automotive IC suppliers are strongly motivated to achieve a goal of zero defects if they want to maintain or grow their share of the automotive IC market.

Automotive probe card requirements

The need for zero defects and the harsh automotive environment create certain challenges for back-end wafer test probing. FormFactor and TI have worked together to address some of these challenges by leveraging FormFactor's latest vertical MEMS probe card product Katana™. The two biggest issues concern maintaining thermal agility for wide temperature range probing, and ensuring minimum pad damage with no dielectric punch-through. This section will discuss those challenges and how they were addressed.

Thermal agility for wide temperature probing. The various effects of wide temperature probing are summarized below. This study shows that the new probe card can achieve stable electrical and mechanical performance at both cold and hot temperatures. This allows customers to use the same probe card design over a wide temperature range, resulting in a significant reduction in cost-of-test.

1) X,Y and Z movement of probes: Because of the safety nature of many of the semiconductor applications used by the automotive industry, the industry demands that the ICs intended for its use are broadly tested over a wide temperature range (-40 to 140°C) to ensure reliable performance. Thermal stresses due to high temperature (140°C) not only cause the wafer pads to shrink, but also add to the testing complexity by affecting the X, Y and Z position of the probes testing the wafer [4,5].

Thermal stress acts on various components of a probe card including printed circuit boards (PCBs), mechanical hardware and probe head components (such as guide plates, metal stiffeners and probes). As a result, the probe position can change, negatively affecting test accuracy [4,5].

It was found that the most effective way to minimize the effects of high temperature in wafer testing is to modify probe card construction. The necessary modifications include, selecting MEMS probe materials that are minimally affected by temperature change, as well as implementing scaling in the probe head design that negates temperature effects on the other probe card components. Various steps taken during IC production, including introduction of soak times (placing the probe card near the wafer for a short period prior to testing to attain thermal equilibrium), realignment of the probe card, changing the distance between chuck and the probe card, and changes in the stepping pattern, can all reduce the effect temperature has on probing accuracy [4, 5].

It was found that it was possible to control the movement of probes by introducing effective scaling in the probe head design to compensate for heat-induced PCB stiffness and the thermal expansion of the mechanical hardware. **Figure 5** highlights the production data showing the X, Y and Z movements at a temperature range of -40°C and 140°C. It also shows the relative chuck height. The correction in X, Y and Z (Cx, Cy and Cz) are relative to the scale on the left side of the graph (in µm). The absolute planarity (Z) and auto Z are relative to the scale on the right side of **Figure 5** (chuck height in µm). The black dotted lines represent a new wafer and the green dots (INDEX) represent a new die. During the initial setup, the Auto Z (electrical contact) shown by the red dotted line is attained and the relative chuck height value is stored. Temperature causes X, Y and Z movements on the probe card and the prober performs the optical alignment to change the value of the absolute chuck height (Z) with respect to corrections [6].

The soak process is not used in the process described above to compensate for the effects of temperature—instead, the optical alignment method is used to provide correction to the movement. Optical alignment by the prober is done every 6 minutes in the first hour and every 15 minutes after the first hour. This schedule accounts for the fact that in the first hour, the movement in the Z direction is tremendous and therefore, the correction Cz is of higher magnitude. Therefore, the frequency of the alignments is more in the first hour until the probe card attains thermal equilibrium and has stable movements. As shown in **Figure 5** at 140°C, the correction Cz is about 60µm until the thermal equilibrium is achieved.

Figure 5 also shows that X, Y and Z optical movement is under 10µm for the data collected across 35 wafers at -40°C, and that the X, Y and Z optical movement is under 20µm for the data collected across 9 wafers at 140°C. This demonstrates that only a minimal correction is needed in all directions to compensate for the thermal effect. As a result, once the vertical MEMS Katana probe card achieves thermal equilibrium, probe movement is minimal for both cold and hot temperature.

2) Stable CRES with increase in temperature. The other major challenge to probing with a wide temperature range (especially at high temperatures) is maintaining stable contact resistance (CRES). Generally, an increase in temperature will cause the aluminum pad to soften and oxidize, resulting in an aluminum oxide formation on the pads, which degrades probe tip contact performance. This situation requires aggressive cleaning and, in turn, reduces the lifetime of the probe card. The new product provides a unique anti-wear probe tip material (PA2 material) to extend product lifetime, while achieving stable CRES by gently scrubbing through aluminum oxide.

Minimum pad damage/no dielectric punch-through. Probe-induced dielectric cracking or punch-through is an ongoing test industry issue. Damage to Cu/low-k devices during fabrication, wafer probe, and assembly is a long-term reliability concern. Current leading-edge process technologies are using low-k materials, which tend to have a lower modulus of elasticity and easily fracture, resulting in a greater probability of cracking.

In automotive applications, it is common to rate wafer probe cards according to a certain number of probe tip touchdowns on wire bonding pads. The tests conducted at TI used an 11-touchdown standard to ensure the highest reliability and to confirm that no dielectric cracking or punch-throughs occurred during probing.

When it comes to vertical probe technologies, two key factors — probe contact force and scrub mark size — have been shown to significantly affect pad cracking.

1. Desired probe force: FormFactor's Katana pointed tip probe, used in the study, delivered a probe force ranging between 1.8 grams and 2 grams at a production overdrive of 75µm. The graph in **Figure 6** shows 1.9 grams of probe force measured for the data collected for 1.5M touchdowns for 6 probes.

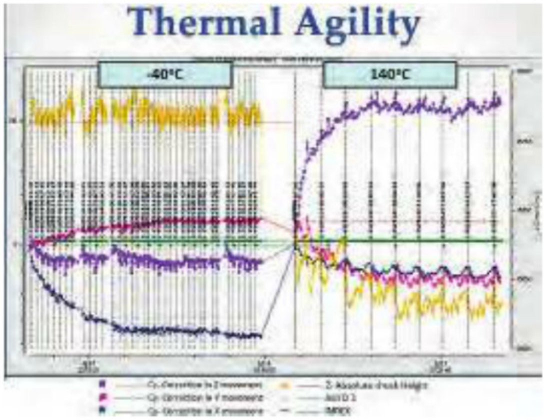


Figure 5: X, Y, Z movements at a wide temperature and relative chuck height.

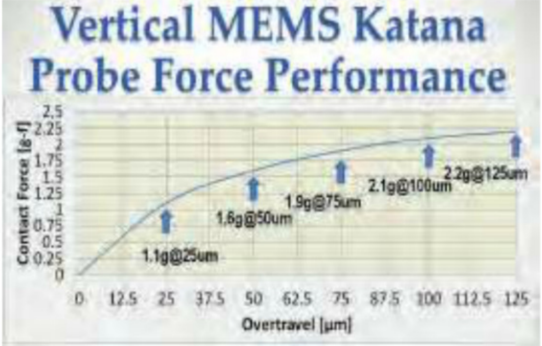
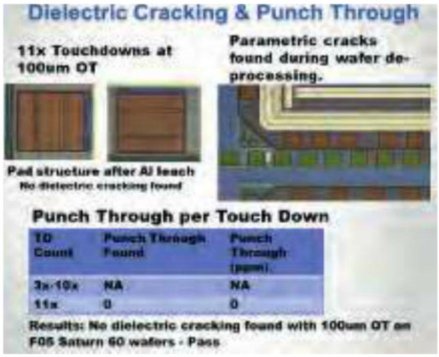


Figure 6: Probe force performance of FFI's Katana Vertical MEMS probe after 1.5M cycles.

	TD1	TD2	TD3	TD4	TD5	TD6	TD7	TD8	TD9	TD10	TD11
FormFactor Katana Technology	No	No	No	No	No	No	No	No	No	No	No
Other vertical pointed tip technology	No	No	No	Yes, under pads cracked							

Table 1: A comparison of FFI under-pad cracking results with that of alternative vertical pointed tip probe technology.


Dielectric Cracking & Punch Through

11x Touchdowns at 100um OT

Parametric cracks found during wafer de-processing.

Pad structure after Al leach
No dielectric cracking found

Punch Through per Touch Down

TD Count	Punch Through Found	Punch Through (ppm)
3x-10x	NA	NA
11x	0	0

Results: No dielectric cracking found with 100um OT on F05 Saturn 60 wafers - Pass

Figure 7: The Illustration highlights the FFI probe's ability to test even highly sensitive dielectric materials without damaging the dielectric layers.

Figure 8: FFI's Katana vertical MEMS probes demonstrate small probe mark size at production overdrive.

2. Consistent probe mark size: The new MEMS fabricated pointed tip probe card used in the study provides a consistent 13µm probe tip size. In contrast, a typically mechanically-shaped pointed tip probe card can have tip size variations from 10µm to 20µm throughout the usage and on-line cleaning cycles. Such probe tip size variations impose a difficult balancing act to minimize pad cracking, while maintaining adequate probing pressure to ensure contact stability. Additionally, frequent and laborious offline tip-reshaping is also required to maintain tip size in the range, adding further maintenance cost.

   FormFactor's Katana MEMS pointed tip probe, by contrast, has a constant probing pressure on the pads. This allows the wafer probing process to operate in the normal prober mode, while the other mechanically-shaped pointed tip products would require a 5SVC (5 speed variable control) prober mode to minimize impacts of high probing pressure variation. The 5SVC mode reduces the speed and acceleration of the prober chuck movement to minimize pads damage at the expense of increased test time. Therefore, the low constant pressure advantage of the Katana MEMS fabricated pointed tip probe minimizes pad cracking, while also reducing the test time and frequent offline maintenance required to reduce cost of test.

Table 1 and Figures 7 and 8 show the results from a study conducted on a TI test chip that is highly susceptible to dielectric pad cracking. The study found no dielectric punch-throughs after 11 touchdowns using FormFactor's MEMS pointed tip product, while the mechanically shaped pointed tip product showed cracking after 3TDs even with 5SVC prober mode.

Summary

Emerging automotive applications in the areas of safety, connectivity and electrical power are likely to be the next big area of growth for the semiconductor industry. Many of these new applications, however, present unique challenges for wafer probing, due to formidable dynamics like wide temperature ranges and stringent under-pad cracking requirements to ensure "zero defect" IC performance goals. This study — a collaboration between Texas Instruments and Form Factor — found that low-force vertical MEMS probe technology and advanced probe card construction design techniques can help to overcome the challenges, while improving production flexibility and uptime.

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Biographies

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