A Collaborative Approach for Automotive Electronics

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Collaboration along the supply chain, focused on common issues that emerge out of the dynamic electronics market and changing automotive ecosystem, will identify and drive improvements in the interest of the whole supply chain.

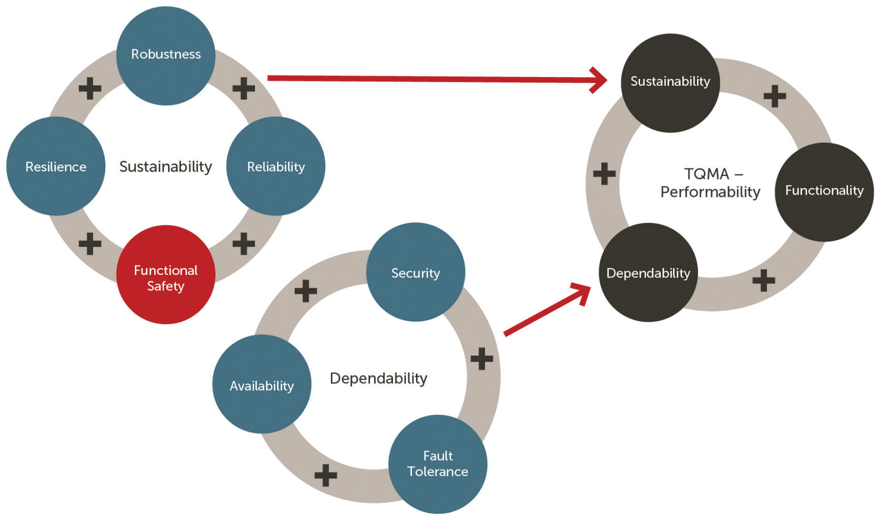

Figure 1. Total quality management [4].

Automotive demand growth for semiconductors historically has been strong. Between 2010-2019, the market grew at a 7% compound annual growth rate (CAGR). Although automotive semiconductor sales declined approximately 10% in 2020 from the impact of COVID-19 [1], sales are expected to bounce back 18% in 2021 [2]. In the long-term, it is estimated that automotive semiconductors will grow a healthy 7% annually from 2019-2026, and by 2030, nearly 50% of the costs to manufacture a car are currently projected to be related to electronics. This is being driven by the electrification of vehicles and the increasing level of autonomous driving. It also has made the automotive industry increasingly focused on the quality and performance of chips that go into vehicles. As we move into a more electrified and automated reality, sustainability of the system, including robustness, resilience, reliability, and functional safety, are all concerns of automakers. Functional safety is of upmost importance, as best described by the automotive zero fail strategy that was historically called "zero defect strategy." Protecting drivers against the unintended consequences of a system malfunction goes well beyond the standard practices of routine testing, software simulations, and electronic system modeling. State-of-the-art electrical test coverage for Systems on a Chip (SoCs) is going up to 99.4 % [3], leaving 0.6 % of billions of transistors untested. Now, more than ever, automakers must dig deeper into their supply chains to identify and eliminate the root causes of potential hazards, some of which may be created during semiconductor manufacturing.

To truly address functional safety from a systems perspective, it is essential that the automotive industry and semiconductor manufacturers start working jointly on quality assurance and creating frameworks that improve functional safety from the beginning of the process (design) to the end of the process (the useful life of the automobile).

Functional safety impact on the semiconductor manufacturing ecosystem

The fast change of the in-vehicle electronics architecture from distributed electronic control unit (ECU) networks towards vehicle cloud computing is a consequence of immediate functional and security needs. What is often underestimated in trying to accommodate those needs are the challenges of maintaining high quality standards when introducing new technologies originating from non-automotive domains. Total quality management comprises three parts: dependability, functionality, and sustainability (Figure 1).

Recently the Automotive Electronics Council (AEC) released an updated version of their Automotive Zero Defects Framework, AEC-Q004. The purpose of the document is to identify best practices, methods and tools that all members across the automotive semiconductor supply chain can use to drive toward zero defects [5]. The content focuses on manufacturing, testing, reliability, and continuous improvement methods. However, the document does not cover the intersection of these areas. A systems engineering approach that looks at the totality of all the manufacturing and assembly processes can best identify the pareto analysis of optimization opportunities to achieve lowest defect levels with reasonable efforts.

Semiconductor manufacturing monitoring systems are designed to detect defects that cause electrical disturbances. The root cause of these defects can come from anywhere within the fab. For many years there were several means to detect these defects using inspection and test equipment. However, as the number of total potential contaminants has increased and the size of the potential contaminants has decreased, it is even more difficult to detect them, Figure 2 [6]. While great advances have been made in inline defect inspection, the advances are not moving at the pace of the semiconductor industry. Today's robust monitoring strategies are unable to identify potentially critical contaminants of interest and trying to find them with an inspection strategy would come at a significant cost and negative impact to throughput. The landscape has shifted from predictable to pervasive defectivity where not only size, but also variety of contaminants are threats to be mitigated.

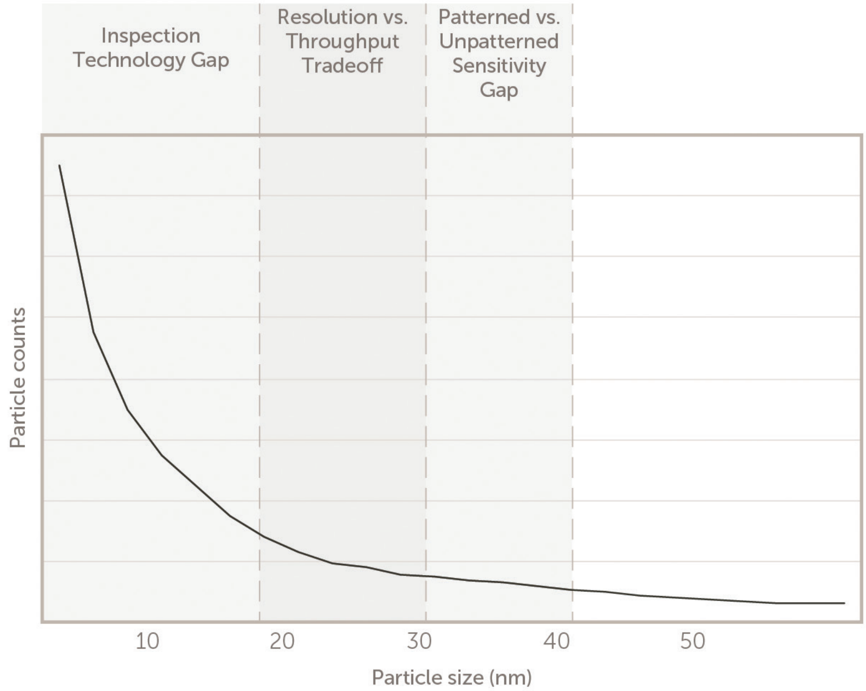

Figure 2. The defectivity power law, showcasing the relationship between the size and number of particles [6].

Monitoring strategies have typically been optimized to find killer defects. Detection of these defects is done via advanced optical detection methods during wafer processing complemented by electrical post wafer manufacturing parametric monitoring (PCM) and fast wafer level reliability (*f*WLR) monitoring [7] on test structures, as well as functional testing (product) at wafer level. Inspection and inline tests measure certain, but not all defect types. Wafer level stress tests at the end of the manufacturing line target latent defect density control. Burn-in and high temperature operating life (HTOL) are used to assess the failure rate of devices at different times in their useful lives. Burn-in tests are used to screen devices that are likely to fail early, and are specifically applied when a new process technology is launched. HTOL applied during semiconductor product qualification is intended to determine first premature failure rates [8] and general intrinsic construction flaws that would lead to failures during a specified time window – ideally, but not necessarily covering normal operating life.

Yield and reliability are related and are proportional for all defects. The proportion is dependent on many factors including individual die size, total defect density, defect size distribution, layout density, and environmental stresses. In a perfect system, a fab would be able to measure and monitor that proportion if they could measure and identify all the factors with a high statistical certainty. In reality, testing is limited because of the high cost, significant delays required to test all devices, and limited access to devices in the chip [3]. Testing simply cannot compensate for all sources of defectivity. And worse, total costs increase if one does not discover until the end of the entire process that the manufactured goods do not meet quality standards.

The process related part of functional safety is certainly related to reliability and consequently to yield, defect density levels and types. Not every defect type is electrically relevant, however this may also change with increasing electrical fields and temperature induced by higher device densities or environmental factors. An efficient and cost-effective way to address both yield and functional safety is the holistic smart fab approach that optimizes processes where test, inspection, and contamination control intersect, Figure 3.

Historically, defectivity control and test management in automotive semiconductor manufacturing facilities add significant costs to the finished product. However, because defect causes and types have changed, they now become also more yield relevant for non-automotive products. Consequently, the effort and cost gap between automotive and non-automotive product lines can be reduced as contamination control strategies represent cost-effective measures for leading-edge technologies. A world-class defect reduction strategy requires high baseline yields and lower incidence of excursions. By creating a contamination control system that addresses the air in the fab, the wafer surroundings, and the process chemistries, both high baseline yields and fewer excursions can be achieved.

Following recommendations for liquid, gas, and air filtration systems from the IRDS (International Roadmap for Devices and Systems), fabs focused on filtration that had a retention rating of hard particles at one half to one-quarter of the identified critical dimensions. However, latent defects do not fall within this size range, nor do they fall within the visible range of the monitor's sensitivity, Figure 4. What cannot be observed cannot be managed, and therefore these defects were largely ignored. However, as noted in Figure 2 there are more of the smallest defects than there are of the largest defects.

As measures to keep-up with yield expectations for leading-edge technologies have turned out to be also essential to achieve automotive compliance, it is now the best time for automakers to address their requirements. Installation of corresponding measures in the interest of automotive quality can potentially reduce overall fab costs across all product lines. Therefore, now more than ever, it is in the best interest of the semiconductor fab and the automaker to identify areas where more stringent contamination control is needed in order to address safety relevant latent defects.

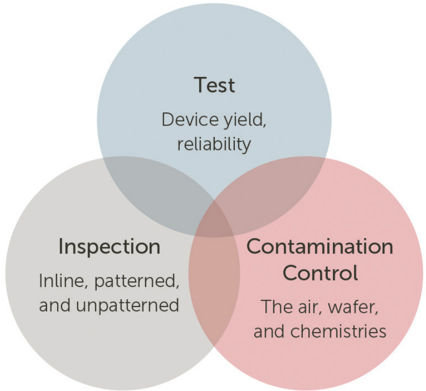

Figure 3. Addressing functional safety where test, inspection, and contamination control intersect.

Defining and future-proofing your contamination control strategy

In order to identify the optimization potential of individual fabs, it is best to start with an assessment of a fab's current contamination control strategy by creating benchmarks. Benchmarking is a tool to assess the maturity of the fab ecosystem. It must be performed with great care and relies on a disciplined and uniform set of criteria applied across factories and regions. Figure 5 highlights a summary of several benchmark results across technology nodes. The example presents the variety of awareness and preparedness across technology nodes. Comparing contamination control levels at a location or across locations together with yield and process monitoring data provides an opportunity for a fab to make data-driven strategic decisions about where to invest in contamination control.

However, choosing the right filtration or purification strategy to solve existing problems is only the beginning of this journey. Sustaining and scaling a contamination control strategy over a long term is the next step. A proactive, sustainable strategy includes planning routine preventive maintenance of the optimized contamination control solutions. Designing quality into the system can have dramatic, positive

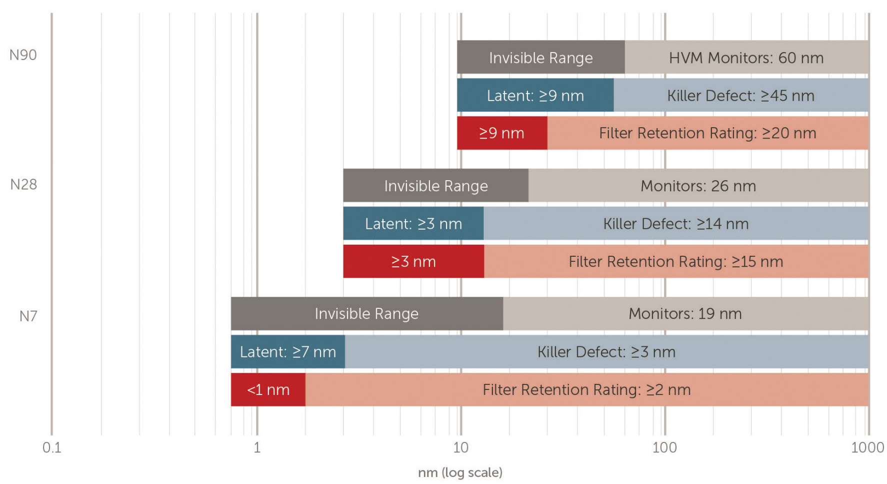

Figure 4. A comparison of the ability to detect particles, the size of killer and latent defects, and liquid filtration retention ratings typically used at 90 nm, 28 nm, and 7 nm nodes.

impacts on both yield and total cost of ownership. Machine learning (ML) algorithms can be applied to contamination control databases for big data analysis. Routine planned filter and purifier maintenance could be one specific performance metric. Combining this information with inline inspection data, inline test data, as well as manufacturing process history can develop patterns for process deviation identification that can be used as a new metric for enhanced statistical process control (eSPC). These proactive steps also ensure that a high yielding process remains that way.

Being able to analyze a fab's contamination control strategy enables fab management and unit process owners to holistically decide how to improve total quality without relying solely on inspection and testing. By focusing on designing a system for quality, fabs can increase yield and reduce latent defects, all while controlling costs and time for manufacturing.

Carefully designing a sustainable quality system can also help to ensure the fab's future-proof readiness for further introduction of new designs and materials. Semiconductor manufacturers have long worked to reduce the time it takes to achieve high yielding processes. While trying to ramp yield, requirements for the allowed total number of particles dramatically reduces. Unfortunately, the size of the particles to be identified has become much smaller than the sensitivity of the instruments to detect them, leaving a significant gap in a fab's ability to identify potential latent defects. Building a robust platform of contamination control creates a foundation where the inspection and test equipment can be used to interrogate new designs and materials without sacrificing the quality of standard products. Redistributing the efforts of contamination control, inspection, and test, can optimize the system to achieve faster yield ramps.

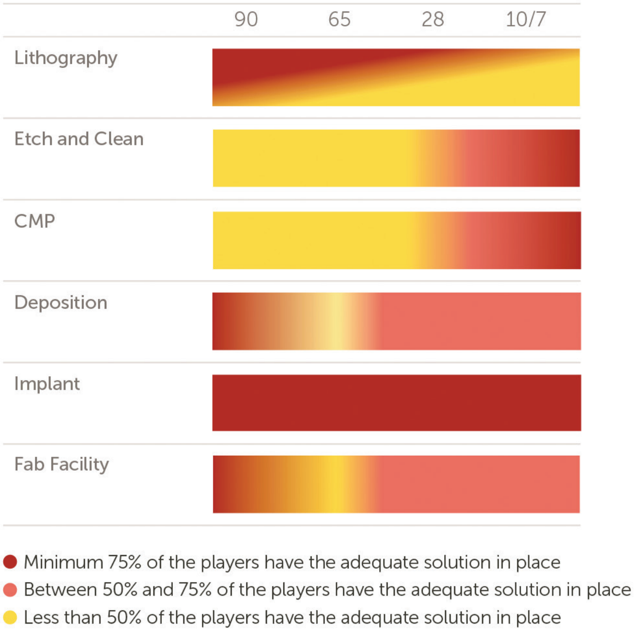

Figure 5. Comparison of contamination control awareness across different technology nodes and unit processes.

Conclusion — a New Collaborative Approach

As consumers push automakers to design cars with features known from the consumer electronics and telecommunication sectors, automakers push semiconductor manufacturers to deliver new designs that are functionally compliant and meet the highest quality levels. Now, both industries must acknowledge that the time to do both simultaneously while also focusing on newest functional safety directions towards autonomous driving poses significant challenges. An important fraction of those challenges can be addressed directly by the described holistic approach.

Collaboration along the supply chain, focused on common issues that emerge out of the dynamic electronics market and changing automotive ecosystem, will identify and drive improvements in the interest of the whole supply chain. Together, we need to connect, collaborate, and align. The GAAC (Global Automotive Advisory Council) has been founded to create a discussion space for all members of the supply chain, from chemical manufacturers to automotive designers. This work is an example that functional safety improvement potentials can go down far into the supply chain. Without such initiatives, potential is wasted, and with it benefits are created for all stakeholders.

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