Driving growth, safety, and quality in automotive electronics

Sophisticated electronic systems continue to increase their impact across today’s automotive sector. Radar, LiDAR, and a host of new artificial intelligence (AI)-based systems are becoming the norm as vehicle makers seek to improve safety, performance and efficiency on the road to fully autonomous vehicles. Linde Electronics describes ways that the automotive manufacturing supply chain can meet tight performance standards in pursuit of global market opportunities.

By: Dr. Paul Stockman, Head of Market Development, and Greg Shuttleworth, Technical Quality Manager, Linde Electronics
In 1913, Henry Ford revolutionized manufacturing with the inauguration of the first assembly line to produce automobiles, which reduced the time to make a new car from 12 hours to 2.5 hours, and more importantly, drove down the cost by 65%. Semiconductor manufacturing has been a beneficiary of this approach, as increasing automation has been complementary to the geometry shrinking forces responsible for Moore’s Law. Both industries manufacture on a very high volume: there were approximately 87 million passenger vehicles and 87 million 300mm equivalent wafers fabricated in 2017. Today, robotics drives both industries to further cost reduction and improved quality.

More and more, these industries are connected, as electronic systems and semiconductors become a larger part of the total automotive bill of materials, and automotive applications become a larger percentage of the total semiconductor market. At the same time, electronics are responsible for a larger portfolio of car functions, progressing rapidly towards an anticipated revolution of fully automated driving vehicles. While electronics become more safety critical in vehicle operation, the quality requirements of the semiconductor components are increasing in ways the industry has not seen before. We can see in the daily financial news the competing headlines between large strategic plays in automated driving investments and developments punctuated by reports of crashes by test vehicles and private owners pushing their cars into uncharted levels of self-driving.

In this article, we look first at the expanding market and drivers that are linking the growth of the semiconductor and automotive businesses. Next, we evaluate the status of automotive semiconductor quality requirements and the developing needs for further specifications. Finally, we look further into the supply chain to examine the role that semiconductor process materials play in enhanced requirements for safety and quality.

**Market overview**

Electronic systems and passenger vehicles are both significant contributors to the global economy, representing about 2% each of global GDP, and their growth is increasingly interdependent. According to NXP, electronic systems represent more than one-third of the bill of materials for new cars. The chips themselves, including OSDs (optical, sensors, and discretes) now average nearly (USD) $500 per vehicle. From the semiconductor industry perspective, automotive ICs and OSDs are 13% of application sales, and growing almost twice as fast as the overall industry. Just like PCs and smartphones, we expect the chip value of the overall electronics assembly to increase as the applications become a more critical part of vehicle operation.

This growth potential has attracted attention from many of the major players in semiconductor manufacturing as they try to both directly benefit from the higher multiples of the automotive sector, and to influence what kinds of chip designs will control future vehicles.

Many recent mergers and acquisitions have been viewed through the lens of increasing the acquirer’s position in automotive applications: NXP’s acquisition of Freescale, which had a larger share of automotive chip sales, and Qualcomm’s pending takeover of NXP. Likewise, On Semiconductor increased its share by acquiring Fairchild, and Infineon has bought Wolfspeed and International Rectifier for silicon carbide technology important for power control in electrified vehicles.

![Figure 1: Growth of automotive, semiconductor and vehicle markets](adapted from IC Insights)
Even more strategic plays have been pursued in the past year by Intel and Samsung. Intel has made a portfolio of automotive acquisitions, capped recently by the $15 billion purchase of Mobileye for chip designs that support assisted and autonomous driving for customers like Tesla and BMW. For its part, Samsung purchased Harman for $8 billion. Known best for its premium car audio offerings, Harman’s products also include automotive navigation, communication, and cybersecurity. It brings with it a customer portfolio of most of the major vehicle manufacturers in Europe, Japan, and the United States.

**Primary drivers**

While we may think of semiconductors as being rather recent introductions, associated with many of the comfort, convenience, and infotainment options now available, computer chips have long been an integral, if unseen, part of the cars we drive.

- **Operations and environmental controls**
  In 1968, just ten years after the modern IC industry was born, Volkswagen introduced an electronic control unit (ECU) manufactured by Bosch for regulation of fuel injection. As emission and fuel efficiency requirements became more stringent, ECUs were made standard on most vehicles manufactured. Controllers have proliferated in cars ever since: engine temperature, electronic steering and braking, automatic transmissions, as well as controls for smaller parts like wipers, mirrors, and illumination. Airbag sensors/actuators and anti-lock brakes have made driving safer.

- **Convenience, comfort and infotainment**
  More obvious in modern cars are the proliferation of many electronic functions, which have a higher density than our connected offices and homes. Conveniences and comfort functions are almost everywhere accessible in the vehicle: power windows, climate control, charging ports, remote operations, as well as those actually related to driving like cruise control and passive seatbelt use indicators. More recently, infotainment offerings have also quickly advanced from radio and recorded media players to include multiple display screens for indicators, controls, navigation, and entertainment in addition to connectivity for the vehicle and the devices we bring inside it. As a safety feature, the US National Highway Traffic Safety Administration has required rear-view cameras for vehicles less than 4500 kg sold after May 2018.

- **ADAS to full autonomy**
  The basics of ADAS (advanced driver assistance systems) are already in premium vehicles today: adaptive cruise control, lane departure warnings, and drowsy driver detection are just a few of the controls and sensors available. However, these are just the beginning of what is anticipated to be a rapidly advancing revolution in driving technology, which will transform the operation of driving from one where the driver is assisted passively by various electronic information and controllers, to one where the vehicle operates fully autonomously, that is independently, of any occupant in the vehicle.

  The roadmap to full autonomous driving is populated not only with significant developments in technology, but also with safety protocols. Various automotive authorities have created stages on this roadmap, such as the SAE (Society of Automotive Engineers) characterization in Figure 2. Common protocols among autonomous vehicles will need to be agreed to benefit from information sharing between vehicles.

  To achieve fully autonomous driving, sensors and controllers are just the beginning of the electronics requirements. Extreme amounts of data will need to be received, prioritized, analyzed, and shared in real time. Intel estimates that cars will generate data at a rate of nearly 0.75 Gb/s, or around
4 Tb per average 90-minute usage per day, rivaling the fastest broadband connections available today. Processors like emerging GPUs for artificial intelligence are thought to be the likely means of dealing effectively with data-rich processing, which gives companies like Nvidia and AMD and the foundries that supply them access to this emerging application. And autonomous vehicles will need to receive and share relevant data with each other, which will require new levels of cloud connectivity and capacity, explaining the strong early investment in ADAS from cloud giants like Baidu, Google, and Microsoft.

Electrification
In a development roadmap roughly parallel to autonomous driving, electrification of powertrains will also transform the automotive industry and become a new growth application for semiconductors. Already available from established and new automobile manufacturers either as fully electric vehicles or as hybrid electric motor-combustion engine models, electrified vehicles have roughly double the semiconductor content per vehicle. The adoption of electric vehicles is driven by environmental concerns – the reduction of greenhouse gas, NOx, and particle emissions – as well as improvement of sales of combustion engines by major economies like India, China, and much of Europe by 2040. Already, 3% of vehicles sold in 2017 were electric.

Diverse electronics content
Automotive electronics is an application that cannot be defined by specific technologies or applications, which benefits almost all sectors of the semiconductor industry. Currently, it is characterized by a very large portfolio of products based on mostly mature technologies, spanning from discrete, optoelectronics, MEMS and sensors, to integrated circuits and memories.

Figure 3 shows the distribution of silicon content from an analysis of an early electrified car in 2014. Important to note is that this car has no autonomous driving capability. If all vehicles made today had the same level of electronics intensity as this example car, the semiconductor content would require the equivalent of 600,000 wafer starts per month of 300mm fab capacity.

Enhanced quality
Until now, the automotive electronics market has been the preserve of specialized semiconductor manufacturers with long experience in this field. The reason for this is the specific know-how required for quality management. As applications proliferate, become safety critical, and progress towards leading-edge processes, enhanced quality protocols will be required.

A component failure that appears harmless in a consumer product could have major safety consequences for a vehicle in motion. Furthermore, operating conditions of automotive electronics components (temperature, humidity, vibration, acceleration, etc.), their lifetime, and their spare part availability are differentiators to what is common for consumer and industrial devices.

Currently, some of the most technologically advanced vehicles integrate around 450 semiconductor devices. As they become significantly more sophisticated, the semiconductor content will drastically increase, with many components based on the most advanced semiconductor technology available. Introducing artificial intelligence will require advanced processors capable of computing a massive amount of data stored in high-performance and high capacity memory devices. This implies that not only the most advanced semiconductor processes will be used, but that these will need to achieve the highest degree of reliability to allow a flawless operation of predictive algorithms.

It is expected that smart vehicles capable of fully autonomous driving will employ up to 7,000 electronic components. In this case, even a failure rate of 1ppm, already very low by any standard today, would lead to 7 out of 1,000 cars with a safety risk. This is simply unacceptable. The automotive electronics industry has therefore introduced quality excellence programs aimed at a zero-defect target. Achieving such a goal requires a lot of effort and all constituents of the supply chain must do their part.

The automotive electronics industry is one of the most conservative in terms of change management. Long established standards and documentation procedures
Typical operating conditions for different electronics market segments

<table>
<thead>
<tr>
<th></th>
<th>Consumer</th>
<th>Industrial</th>
<th>Automotive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>0 to 40°C</td>
<td>-10 to 70°C</td>
<td>-40 to 160°C</td>
</tr>
<tr>
<td>Operation time</td>
<td>2 to 5 years</td>
<td>5 to 10 years</td>
<td>Up to 15 years</td>
</tr>
<tr>
<td>Humidity</td>
<td>Low</td>
<td>Environment</td>
<td>0% to 100%</td>
</tr>
<tr>
<td>Supply</td>
<td>Average 1 year</td>
<td>2 to 5 years</td>
<td>Up to 30 years</td>
</tr>
<tr>
<td>Tolerated failure rate</td>
<td>&lt;10%</td>
<td>&lt;&lt;1%</td>
<td>Target: 0% failure</td>
</tr>
</tbody>
</table>

Figure 4: Typical operating conditions for different semiconductor applications

ensure traceability of design and manufacturing deviations. Qualification of novel or modified products is generally costly and lengthy. This is where material suppliers can offer competence and expertise to provide material with the highest quality standards.

What does this mean for a material supplier?

As a direct contact to its customer, the material supplier is responsible for the complete supply chain from the source of the raw material to the delivery at the customer’s gate. The material supplier is also accountable for long-term supply in accordance with the customer’s objectives.

There are essentially two fields where the material supplier can support its customer: quality and supply chain.

Given the constraints of the automotive electronics market, material qualification must follow extensive procedures. While a high degree of material purity is a prerequisite, manufacturing processes are actually more sensitive to deviations of material quality, as they potentially lead to process recalibration. Before qualification starts, it is critical that candidate materials are comprehensively documented. This includes the manufacturing process, the transport, the storage, and, where appropriate, the purification and transfill operations. Systematic auditing must be regularly performed according to customers’ standards. As a consequence, longer qualification times are expected. Any subsequent change in the material specification, origin, and packaging must be duly documented and is likely to be subject to a requalification process.

Material quality is obviously a critical element that must be demonstrated at all times. This requires the usage of high-quality products with a proven record. Sources already qualified for similar applications are preferred to mitigate risks. These sources must show long-term business continuity planning, with process improvement programs in place. Purity levels must be carefully monitored and documented in databases.

State-of-the-art analysis methods must be used. When necessary, containment measures should be deployed systematically. Given the long operating lifetime of automotive electronic components, failure can be related to a quality event that occurred a long time before.

Because of the necessary long-term availability of the electronics components and the material qualification constraints, manufacturers and suppliers will generally favor a supply contract over several years. Therefore, the source availability and the supply chain must be guaranteed accordingly.
Material suppliers are implementing improved quality management systems for their products to fulfill the expectations of their customers, in terms of quality monitoring and traceability. Certificate of analysis (COA) or consistency checks are not sufficient anymore; more data is required. In case deviation is detected, the investigation and response time must be drastically reduced and allow intervention before delivery to the customer. Finally, the whole supply chain must be monitored.

Several tools must be implemented to maintain a reliable supply chain of high-quality products: statistical process and quality controls (SPC/SQC), as well as measurement systems analysis (MSA), allow systematic and reliable measurement and information recording for traceability. Implementing these tools particularly at the early stages of the supply chain allows an “in-time” response and correction before the defective material reaches the customer’s premises. Furthermore, some impurities that were ignored before may become critical, even below the current detection limits. Therefore, new measurement techniques must be continuously investigated to enhance the detection capabilities.

Finally, a robust supply chain must be ensured. It is imperative for a material supplier to be prepared to handle critical business functions such as customer orders, overseeing production and deliveries, and other various parts of the supply chain in any situation. Business continuity planning (BCP) was introduced several years ago to identify and mitigate any risk of supply chain disruption.

Analyzing the risks to business operations is fundamental to maintaining business continuity. Materials suppliers must work with manufacturers to develop a business continuity plan that facilitates the ability to continue to perform critical functions and/or provide services in the event of an unexpected interruption. The goal is to identify potential risks and weaknesses in current sourcing strategies and supply chain footprint and then mitigate those risks.

Because of the efforts necessary to qualify materials, second sources must be available and prepared to be shipped in case of crisis. Ideally, different sources should be qualified simultaneously to avoid any further delay in case of unplanned sourcing changes. Material suppliers with a global footprint and worldwide sourcing capabilities offer additional security. Multiple shipping routes must be considered and planned to avoid disruption in the case, for instance, of a natural disaster or geopolitical issue affecting an entire region. Material suppliers need to be aware and monitor regulations specific to the automotive electronics industry such as ISO/TS16949 (quality management strategy for automotive industries). This standard goes above and beyond the more familiar ISO 9001 standard. By understanding the expectations of suppliers to the automotive industry, suppliers can ensure alignment of their quality systems and the documentation requirements for new product development or investigations into non-conformance.

Future of automotive electronics

With the increasing automation of future vehicles, new and more advanced semiconductor technologies will be used and vehicles will become supercomputers and data centers on wheels. Most of these components (logic or memory) will be built by manufacturers relatively new to the automotive electronics world—either integrated device manufacturers (IDM) or foundries.

In order to comply with the current quality standards of the automotive industry, these manufacturers will need to adhere to more stringent standards imposed by the automobile industry. They will find support from materials suppliers like Linde that can deliver high-quality materials associated with a solid global supply chain with acquired global experience in automotive electronics.

Figure 6: Enhancing material quality requires expanding traditional quality focus
Linde: Enabling a smarter and safer driving future

When it comes to driving a supercomputer on wheels, there is no room for failure.

Semiconductor manufacturers need to know that the materials used to produce the chips for their automotive customers are of the highest quality and are from a provider with a long history of offering reliable materials.

Linde is experienced in working with semiconductor companies that manufacture automotive electronics to achieve zero-defect through our precise analysis and qualification.

We have a robust supply chain in place and design a business continuity plan for you to ensure the materials you need are available.

Partner with Linde and experience a high-quality, reliable ride.

electronicsinfo@linde.com