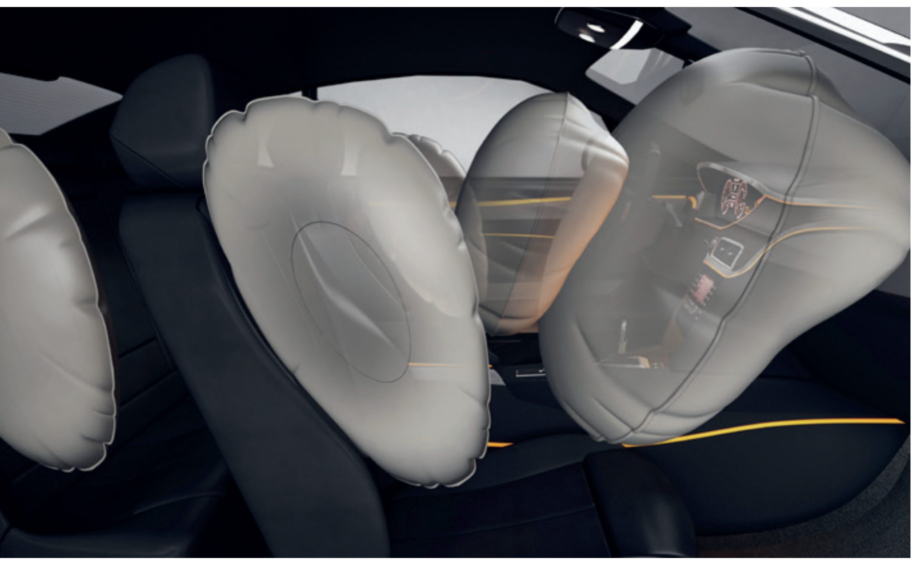
SMi PRESSURE SENSORS

Meeting New Automotive Pressure Sensor Requirements: A Design Approach

White Paper

Background

Automobiles are increasingly taking over functions once demanded of the driver, improving the safety, reliability and comfort of the automotive experience. Cars and trucks are constantly monitoring their environments, both externally and internally; sensors are what allow this to happen. In fact, for some types of sensor, the automotive sector represents not only the largest market, but also the fastest growing.



"Side airbags are an example of this, as are pedestrian-protection systems in the front bumper."

Pressure sensors fit into this category. Things the driver was once expected to do – monitoring the pressure in the tires, maintaining oil levels, keeping fluid levels in check – are now performed automatically, at greater frequency and accuracy than was previously possible. Some systems need to gather information so quickly that no human, or indeed any other type of sensor, is up to the task. Side airbags are an example of this, as are pedestrian-protection systems in the front bumper. For these reasons, the automotive sector now consumes 58% of the world's pressure sensor output, and the industry is enjoying an 6% annual growth rate.

Because the market is so attractive, one could assume that all pressure sensor manufacturers serve as automotive suppliers. However, the barrier to entry for prospective automotive suppliers is high. Suppliers must be prepared to receive or maintain TS16949 as well as ISO9001 certifications, and many manufacturers require ISO14001 Environmental compliance as well. These certifications require a constant commitment to quality and continuous improvement. Additionally, suppliers to the automotive industry must be prepared for audits by the end customers for their products. So despite the attractiveness of the market, the number of options presented to the automotive system designer remains limited.

An automotive supplier must understand the key attributes the automotive industry demands: reliability, lifetime, and cost. The sensor should work 100% of the time. It should operate reliably for 10-15 years, or 150,000-250,000 miles. Finally, given the automotive industry's cost consciousness, the sensor must be economical. These demands are all the more difficult because automotive pressure sensors operate in extremely hostile environments. As engines grow smaller and hotter, the operating temperature range of the sensors continues to expand. The Automotive Engineering Council recognizes this; in 2014 Grade 4 (operating temperature from 0°C to +70°C) was eliminated. Currently, Grade 0 is defined as operating temperatures from –40°C to +150°C, but automakers are already looking beyond this to applications where +165°C and higher are required. Even as the operating conditions continue to expand, performance is expected to improve, and increasing cost is not an option.

While these conditions and constraints pose formidable challenges, they are not insurmountable. Sound design protects the sensors and delivers reliability and long operational life. However, to better meet all of these requirements simultaneously, significant evolution in sensor design needs to occur.

Consider the performance limitations inherent in the sensors currently used for absolute pressure measurements in the automotive industry. Figure 1 illustrates a typical device (in this case, the SM9231 sensor from Silicon Microstructures, Inc.). This device consists of a silicon sensing wafer with glass wafers anodically bonded to the top and bottom. The top glass provides the absolute reference cavity located above the pressure-sensing membrane, which the bottom glass provides mechanical isolation between the sensing membrane and the package, as well as allowing additional bonding area on the bottom. The top glass is arranged to allow access to the bondpads on the silicon layer, while the bottom glass contains a hole to allow the pressurized fluid access to the underside of the pressure-sensing membrane.

There are tradeoffs between performance and operating temperature range for sensors of this sort. The temperature coefficient of offset and temperature hysteresis are limited by the thermal mismatch between the silicon and the top and bottom glass. To achieve both high performance as well as an extended operating temperature range, it would be preferable to avoid thermal mismatches in the region of the mechanical membrane.

The location labeled 'A' in Figure 1 represents a stress concentrator at the glass/silicon interface. Under extreme pressures, or extreme rates of pressure change, the acute angle formed at this interface could become a failure site.

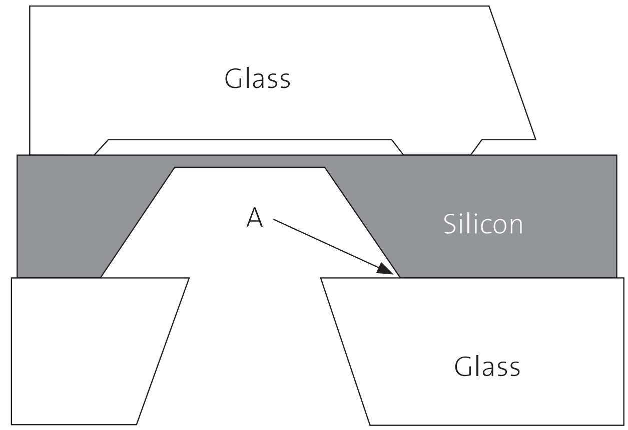


Figure 1: Current backside absolute pressure sensors for the automotive market (cross section)

Realiability

While out-of-the-box performance is important, reliability is the true hallmark of the automotive sensor. In order to ensure reliability for the most demanding automotive applications, SMI looks for shifts in offset and span resulting from the following stress conditions:

- Electrostatic Discharge up to 2kV
- High temperature operating life of 150°C and maximum operating voltage for 2000 hours
- 2000 Temperature cycles from –55°C to + 150°C
- Drop testing
- Vibration testing
- Pressure cycling

A New Design

These problems can be eliminated with modified sensor design. Consider a sensor consisting of a thick silicon base layer with a cavity etched in the back to form the membrane. A second silicon wafer is bonded to the top surface, forming the absolute reference cavity between the two wafers. This design provides several advantages. First, thermal mismatch between silicon and glass is avoided. Second, there are no glass/silicon interfaces exposed to pressure from the backside, eliminating the possibility of a glass/silicon interface failure. Silicon-to-silicon fusion bonding results in an absolute pressure cavity with lower pressure inside than anodic bonding can provide. It also forms a stronger bond than glass-to-silicon anodic bonding. No acute angles are formed by the etching or bonding processes.

In addition to removing the glass-silicon interface with an acute angle, this design benefits from an overpressure stop realized by carefully controlling the thickness of the reference cavity. When pressures reach about 2.5X FS, the membrane makes contact with the cap silicon, preventing further motion and providing additional protection against cracking or damage when overpressures are encountered.

Burst Pressure	**SMI SM98 (New Design)**	**SMI SM92**	**Merit HM Series**	**Epcos C32 Series**	**Amphenol NPR Series**
Burst Pressure Specification, Multiples of Full Scale Pressure	15X (10bar)	5X	5X	3X	2.5X

Table 1: Burst pressure specifications of old designs vs. new design

Figure 2 shows a variation of the device described in which the backside cavity is etched with DRIE rather than a wet etch (in this case, the SM9820 sensor from Silicon Microstructures). Other advantages of this design include the small die size that can be achieved, increasing the number of die per wafer.

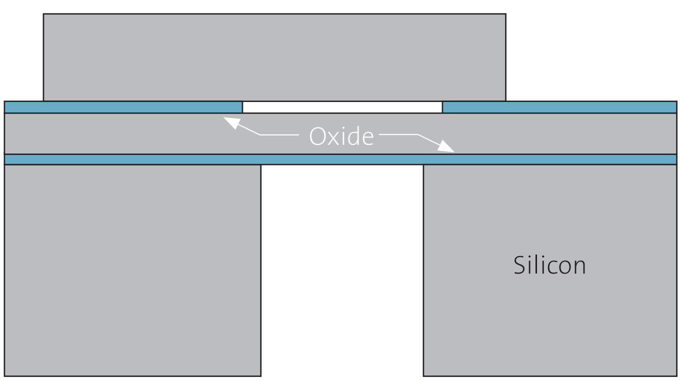


Figure 2: Redesigned backside absolute pressure sensor for the automotive market (cross section)

Devices using these design improvements are currently being commercialized, and have been thoroughly evaluated. Dramatic improvements in burst pressure have been demonstrated. Table 1 shows improvements in burst pressure using the new design, compared to published values of older design. The burst pressure resulting from the new design shows about a 300% improvement over the current generation of sensors.

SMI's Grizzly Family

The Grizzly family consists of several related designs, based on the design improvements discussed here. The SM99 is for pressure ranges from 1 to 8 Bar absolute; the SM98 covers the range from 10Bar to 50Bar, while the SM97, in limited release, is a more robust version of the SM98 for extreme overpressure applications.

The Grizzly measures absolute pressure (i.e., pressure compared to vacuum) with pressure introduced from the backside of the die; this serves to protect the sensing elements from the medium being measured. Therefore, the Grizzly devices are called harsh environment, backside absolute sensors.

Each version of the Grizzly also has an on-board thermometer and has bondpads laid out along one side for easier in-package integration with signal processing chips. In contrast to many automotive backside absolute sensors available today, there is no need for a bottom glass constraint wafer. Finally, each member of the family is available with optional backside gold for eutectic bonding.

The Grizzly design allows for substantial reductions in die size. Figures 1 and 2 show a comparison between SMI's SM92 sensor, currently built into hundreds of thousands of cars, and the SM98, an equivalent device from the Grizzly family. The overall area of the chip is 67% smaller, while eliminating the topside and bottomside glass allow a 59% reduction in thickness.

The smaller size allows for smaller packaging, which also provides a cost advantage.

Key parameters of the SM98 family are shown below:

Characteristic	Minimum	Typical	Maximum	Units
Span (FS p_{RANGE}), 10 and 20 Bar		80		mV
ESD (HBM)			2kV	
Offset	–20		+20	mV
TC Span		–17.7		% FS/100°C
TC Offset		0.5		% FS/100°C
TC Resistance		32.9		% RB/100°C
Linearity		±0.03		% FS
Bridge Resistance		5.3		kΩ
Pressure Hysteresis			±0.10	% FS
Temperature Hysteresis			+0.2	% FS
Diode Forward Voltage		0.63		V
Change in Diode with Temperature		–2.2		mV/ºC

Only devices that show <1% shift in both span and offset earn the AccuStable™ rating.

Performance Advantages

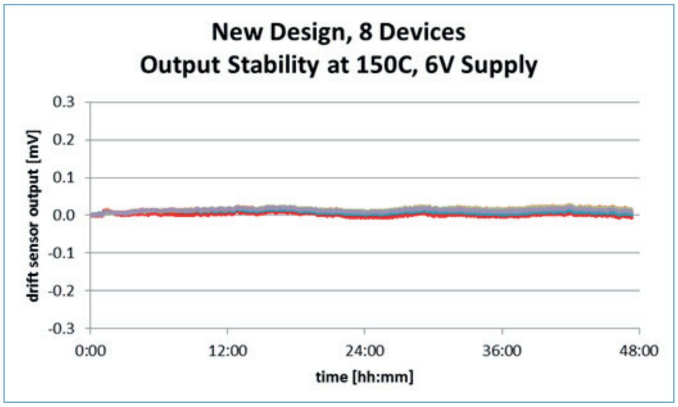


Figure 3: 48-hour stability test of new design. Y-axis is in millivolts

Performance over temperature has also been improved. By eliminating the glass/silicon interfaces, improvements in high-temperature stability and temperature hysteresis were expected, and this has been confirmed experimentally. The thermal hysteresis of the new design was <0.2% when measured across the entire operating temperature range of –40°C to +150°C. Figure 3 shows output over a 48-hour test at maximum operating temperature and operating voltage.

Conclusions

The challenges facing the automotive system designer are considerable, and grow more difficult generation by generation.

While the current generation of harsh-environment pressure sensors have performed well, the industry now requires a revolutionary rather than evolutionary improvement in sensor performance. This necessitates an entirely new design. This paper has described one such design that appears to.

About the Author

Dr. Justin Gaynor is the Program Management Officer for Silicon Microstructures, Inc., a subsidiary of The Elmos Group. He received his Ph.D. from Virginia Polytechnic Institute in Materials Science and Engineering and in 2014 became a certified Project Management Professional (PMP). He has been at SMI since 2010 and collaborated with lead designers Dr. Fernando Alfaro and Rick August and principle engineer Dolly Tactac on the development of the Grizzly family.