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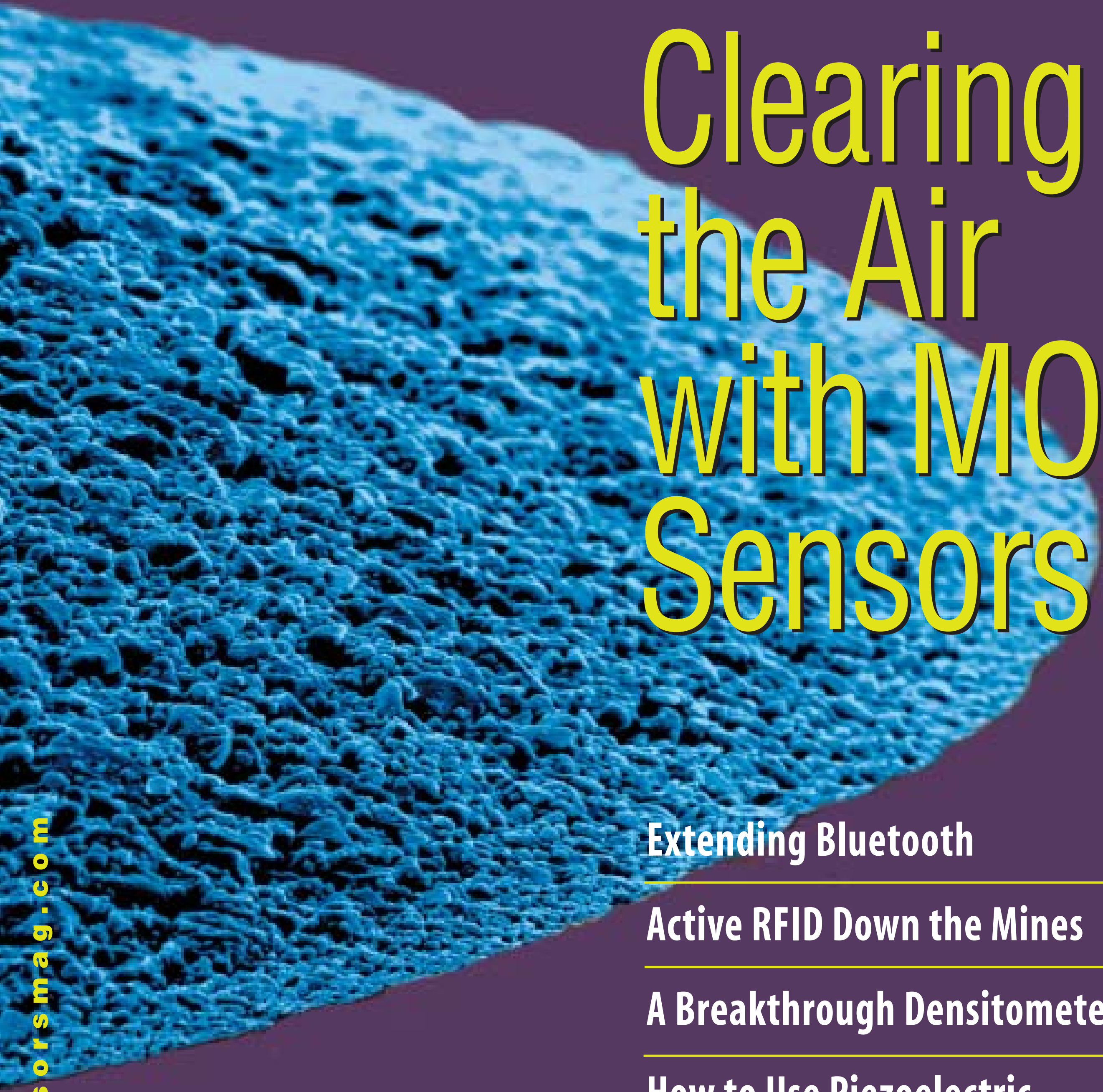

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MOS Air Quality Sensors Make Vehicle Cabins Safer

Tom Aiken, AppliedSensor

Federal and local emissions standards are cleaning up automotive exhausts, but they're not much help to occupants of a car that's stuck in traffic or passing a pulp mill. Here's a sensor that will clear the air.

Stringent air quality standards have forced U.S. automakers to regulate automotive emissions, but not much attention has been paid to the air inside the vehicle's cabin other than ensuring that it remains at a comfortable temperature. Now, with recent advances in sensor technology, vehicle manufacturers are gaining a competitive advantage by offering luxury vehicles with interior air that is not only climate controlled, but also free of harmful pollutants and unpleasant odors. These new air quality sensors, located under the vehicle's hood near the fresh air inlet, act as an "electronic nose" to detect gases such as CO, NO_2, and a wide range of volatile organic compounds (VOCs).

While most of these gases may not concern the average new car buyer, it's easy to sell the health and safety benefits of clean cabin air once the detrimental, and in some cases life-threatening, effects of dirty cabin air are explained. For example, levels of exhaust gases at major metropolitan intersections, on congested freeways, in tunnels, or behind high-polluting vehicles such as trucks or old cars, can be 100–1000 times higher than peak concentrations of pollutants in typical air. Some fume peaks can contain exhaust gas concentrations up to 10,000 times higher than the surrounding air. And if that weren't disturbing enough, a recent study by Germany's Federal Environmental Agency reported that ~14,000 deaths per year are caused by the carcinogenic effect of diesel fumes.

MOS Improves Sensor Efficiency

The application of an air quality sensor in a vehicle is really quite simple. Mounted in the air intake of the HVAC (heating, ventilation, and air conditioning) system, the sensor sends a signal to the fresh air inlet door to close when gases and VOCs are detected and automatically reopen when the quality of the outside air returns to an acceptable level (see Figure 1, page 41). Although a driver could close the air inlet manually, forgetting to reopen it could cause the windows to fog or lower the oxygen level in the cabin—and compromise the safe operation of the vehicle. Furthermore, many of the most harmful gases are odorless, making them virtually undetectable to humans.

The basic air quality sensor design has been around for several years, but improved materials and processes, combined with new MEMS designs, have produced a metal oxide semiconductor (MOS) sensor that provides higher sensitivity, higher stability,

In the cover image, the tin oxide grains of the MOS gas sensor's polycrystalline thick film layer are at 200 × magnification; here, they are at 1000 ×.

and a response time that is several seconds faster than human reaction. One example is a new MOS device developed by AppliedSensor for Texas Instruments' Sensors and Controls Division (www.ti.com) that uses tin oxide-based thick films deposited onto silicon micromachined substrates (microsensors). As shown in Figure 2 (page 42), the substrate is equipped with electrodes that enable extremely accurate measurement of the resistance of the sensing layer. To ensure quick, sensitive, and selective detection, heaters are incorporated into the substrate that can heat the sensing layer to ~400ºC.

Figure 1. The Air Classification Module, mounted in the air intake of the HVAC system, protects occupants of a vehicle by automatically closing the fresh air inlet door when the sensor detects noxious gases and VOCs.

Operating Principles

Chemical. Changes in the composition of the ambient atmosphere create a corresponding change in the resistance of the sensing layer, allowing the sensor to detect a wide range of toxic and explosive gases even at very low concentrations. The sensing layer is a porous thick film of polycrystalline tin oxide (SnO_2). In normal ambient air, oxygen and water vapor-related gases are absorbed at the surface of the SnO_2 grains. For reducing gases such as CO, a reaction takes place with the preabsorbed oxygen and water vapor-related gases that decreases sensor resistance (see Figure 3, page 42). Conversely, oxidizing gases such as NO_2 and O_3 increase the resistance. The magnitude of change depends on the microstructure and composition/doping of the base material on the morphology and geometrical characteristics of the sensing layers and substrate, as well as on the temperature at which the sensing takes place. To detect a wide variety of different gases or classes of gases, the sensor can be tuned to detect alterations in any of these parameters.

Transducer. The changes in composition of the ambient atmosphere determine changes in the resistance of the sensing layers. In practice, the relationship between sensor resistance and concentration of the target gas usually follows a power law that can be described by:

$$R \approx k \times c^{\pm n} \qquad (1)$$

where:

c = concentration of target gas

k = a measurement constant

n has values between 0.3 and 0.8; the positive sign is used for oxidizing gases, while the negative sign is used for reducing gases

Figure 4 (page 42) shows a simple electrical circuit that can be used to measure sensor resistance, R_S. The heating voltage, V_H, is applied between 1 and 3 V, with typical values for both types of sensor ranging between 2 and 5 V. The measuring voltage, V_S, is applied between 2 and 4 V, with the recommended value not to exceed 5 V. To determine R_S, V_{out} is measured and R_L is known. The relationship between R_S and V_{out} can be described by:

$$R_s = R_L\left(\frac{V_s}{V_{out}} - 1\right) \qquad (2)$$

Typical Response Curves

The graphs in Figure 5 illustrate the typical behavior of a thick film MOS sensor that has been exposed to a series of CO pulses. The sensor resistance drops very quickly immediately after CO exposure. After the CO is removed, resistance quickly reverts to its original value. Response and recovery speed are determined by the operating temperature, the sensor layer type, and the gases involved. Quick recovery is essential for detection of multiple gases, as sensing instruments are blind during the recovery period.

▶

Expanded Applications for MOS Sensors

Auto manufacturers are now incorporating MOS sensors into new luxury passenger vehicles to monitor outside air quality, prevent noxious gases from entering the car cabin, and improve cabin air quality. But in an industry where costs are measured in fractions of a cent and products must be available in quantities of several million, the major automakers are looking to sensor manufacturers to improve reliability, production efficiency, and miniaturization before making air quality sensors a standard feature in economy-model vehicles. By using micromachining to improve the production and packaging of MOS sensors, AppliedSensor is achieving the requisite cost reductions and efficiency improvements. With continued improvements in sensitivity, stability, and life expectancy, OEMs will continue to find new applications for reliable, low-cost MOS sensors in packaging and food control, medical devices, security systems, process control, and other areas of industry. ■

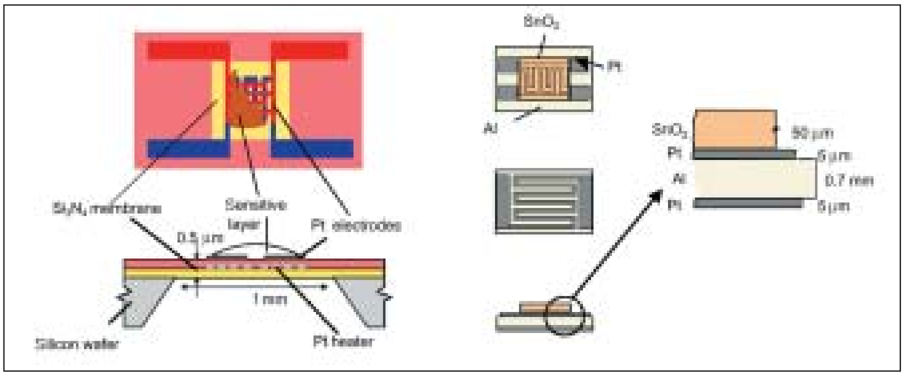

Figure 2. In the micromachined silicon sensor (left), a proprietary drop-coating method is used to deposit the sensing layer onto a thin membrane. The electrodes are on top of the membrane and a meander heater is inside it. The thick film sensor (right) consists of a ceramic substrate with electrodes on top and the heater on the back. The sensing material is screen-printed over the electrodes.

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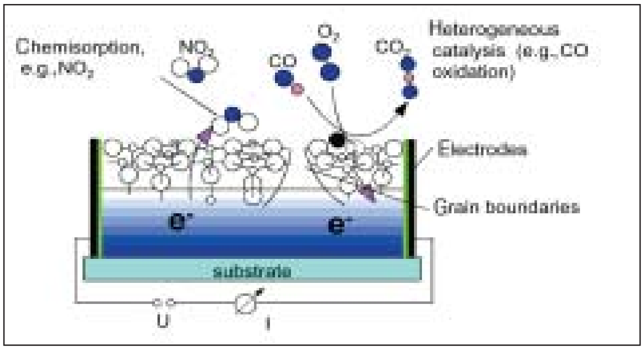

Figure 3. The metal oxide semiconductor (MOS) sensor consists of a sensing material and a transducer (substrate). Surface reactions at the sensitive layer change its resistivity. The transducer keeps the sensing material at an elevated temperature, and its resistance is measured.

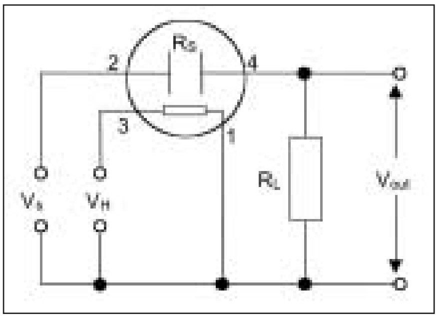

Figure 4. In this schematic of a MOS sensor's basic circuitry, V_H is the heater voltage, V_S is the test voltage, R_L is the load resistance, and V_{out} is the corresponding voltage drop used to determine sensor resistance.

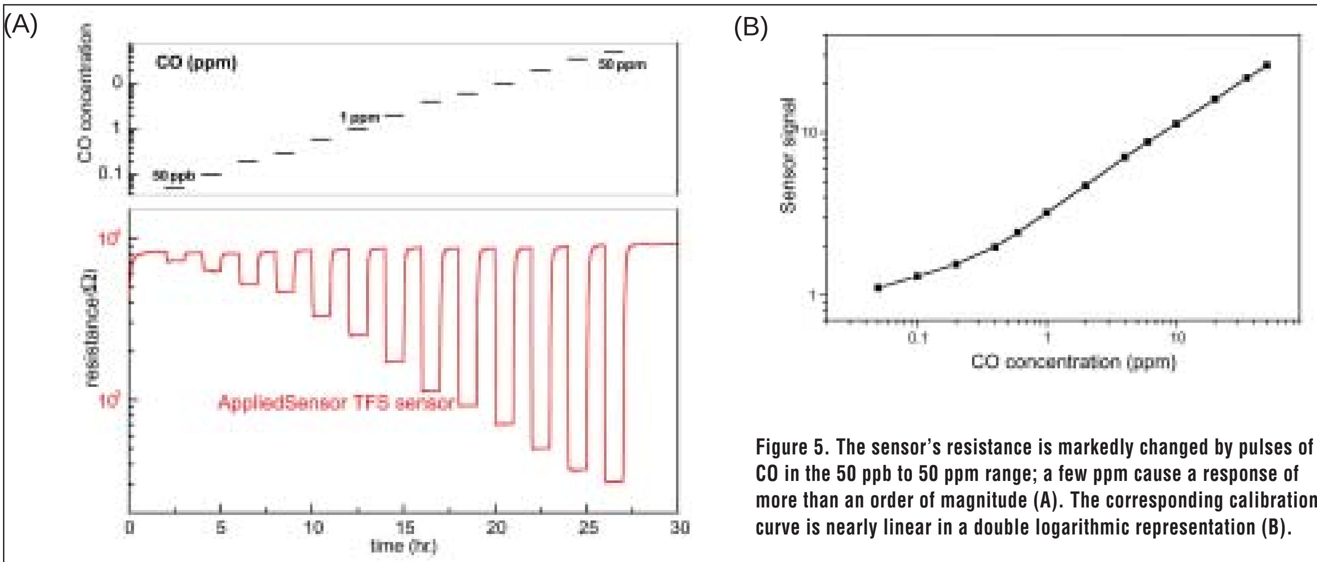

Figure 5. The sensor's resistance is markedly changed by pulses of CO in the 50 ppb to 50 ppm range; a few ppm cause a response of more than an order of magnitude (A). The corresponding calibration curve is nearly linear in a double logarithmic representation (B).

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