Low-Power Hazardous-Gas Sensing Integrates with Consumer Electronics

Commercial chemical sensing technologies face severe limitations. Poor sensitivity makes it difficult to detect very low gas concentrations (less than 100 ppb), and poor selectivity may generate a false-positive signal when interfering gases are present. For example, a toxic-gas sensor for hydrogen sulfide (H_2S) with poor selectivity may alarm in the presence of a flammable gas like hydrogen. The size of many electrochemical sensors and their power requirements make them unsuitable for integration with consumer electronics. This is about to change.

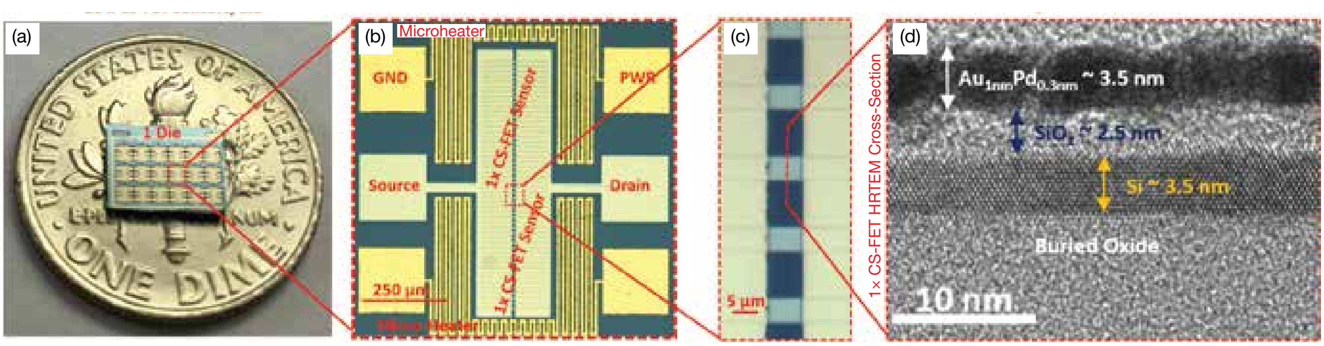
With funding from the National Science Foundation and Chevron, researchers at the Univ. of California, Berkeley (UC-Berkeley), led by Ali Javey, have developed a highly sensitive, low-power gas-sensing platform that is based on a silicon chemical-sensitive field-effect transistor (CS-FET). This platform has demonstrated a large responsivity — with a nearly two orders of magnitude change in sensor current baseline — that ensures high-fidelity signal readout. In addition, the platform has very low limits of detection and fast response times (<20 sec). These metrics are critical for meeting workplace regulations for permissible exposure limits, and for detecting flammable or explosive gases quickly.

Each CS-FET is constructed of inexpensive silicon and has three terminals: a source, a gate, and a drain. When a fixed voltage is applied to the drain terminal, current flows between the drain and the source. This current flow is controlled by the gate terminal, which (unlike the source and drain) is electrically floating — *i.e.,* not connected to ground. The gate contains metal and/or metal-oxide nanoparticles that are engineered to interact with only one specific gas. An interaction between that specific gas and the gate changes the gate's work function, which in turn changes the source-drain current flow, creating a positive detection. Conceptually, the CS-FET's structure resembles that of transistors found in electronic devices.

The Javey Lab has created CS-FETs sensitive to hydrogen sulfide, nitrogen dioxide, ammonia, hydrogen, and other gases. Because the transistor is inexpensive, highly scalable, and easy to mass-produce, it holds a tremendous advantage over other semiconductor materials such as graphene, carbon nanotubes, and transition-metal-dichalcogenides. Its small size and low power requirements make it ideal for integration with personal mobile electronics.

The H_2S CS-FET in Figure 1 has a low detection limit of 1 ppb H_2S and a detection range of 1 ppb to 10 ppm. Approximately 3 nW of power is needed to operate this sensor. The chip also contains microheaters adjacent to the gas sensors that, when switched on for a few seconds, can enhance recovery. The inclusion of these microheaters can also prevent unwanted ambient-induced poisoning, a common issue seen in other types of gas-sensing technology. Over time, such poisoning effects can slow down sensor response and/or make sensors insensitive to the target gas.

The researchers have formed a spin-off, Serinus Labs, Inc., to commercialize the patent-pending CS-FET gas sensors for several target markets, including consumer electronics, industrial safety, and automotive applications. Serinus Labs is funded by Small Business Innovation Research (SBIR) grants from the NSF and NASA to develop sensors for critical applications in food security and space technologies, respectively. CEP



▲ **Figure 1.** (a) Image of a single CS-FET die on a dime. (b) Optical microscope image of a single H_2S CS-FET sensor (where GND = ground terminal, PWR = voltage terminal). (c) Enlargement of the individual silicon channels in the H_2S sensor. (d) Cross-sectional transmission electron microscope image taken across an ultrathin silicon channel. Source: Fahad *et al., Science Advances,* 2017.

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