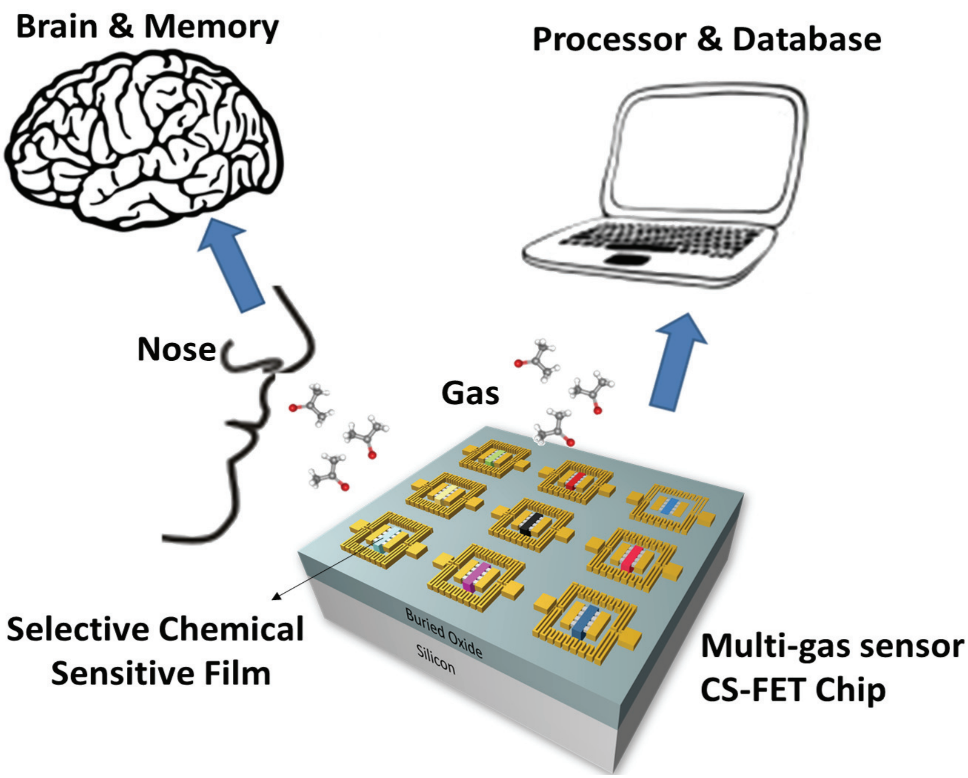
Berkeley Sensors and Actuators (BSAC)

University of California, Berkeley, Richard S. Muller, 510.642.0614, muller@berkeley.edu
University of California, Berkeley, Michael Cable, 510.643.5663, mdcable@berkeley.edu
University of California, Davis, David Horsley, 530.341.3236, dahorsley@ucdavis.edu

Chemical Sensitive Field Effect Transistor

Chemicals are all around us all. Sometimes they are toxic to our health. Knowing information about the chemical composition of our surrounding environment can allow us to take safety measures in attempts to protect our health; thus enabling preventive health-care to be practiced when needed more deliberatively. Current research on wearable technology indicates that vital information about our physiological state can be ascertained by measuring and quantifying specific chemicals in our breath and sweat. Because of this, there are increasing demands for sensitive, selective and low power chemical sensors that can be integrated with personal mobile consumer electronics.



The CS-FET is a low power gas sensor technology platform providing sensitive and selective multi-gas detection in a miniaturized, scalable single chip form-factor. Enabled by conventional silicon processing techniques, the CS-FET is a biomimicry of the human nose.

The chemical sensitive field effect transistor (CS-FET) is a new chemical sensor technology platform developed at the University of California's Berkeley Sensor and Actuator Center (BSAC). Based on silicon, the CS-FET is structurally similar to the nanoscale electronic transistor switches (or FETs) that are used in our computers, except that electrical gates are replaced by a chemical sensitive film. Nanoscale means very, very small; usually considered to be between 1 and 100 billionths of a meter. Large arrays of CS-FETs can be functionalized with a variety of materials that interacts with specific chemicals, where such specific chemical interactions are transduced into electrical signals. By conditioning these signals, CS-FETs can provide a comparatively more accurate composition of mixed chemicals in an environment than existing technology where selectivity is a problem. This mechanism of selective chemical detection in the CS-FET platform is biomimicry of the human nose. Depending on the specific chemicals, CSFETs can be tuned to detect parts-per-million (ppm) or even parts-per-billion (ppb) levels of chemicals. These concentration ranges are the administrative levels of many toxic chemicals for human health and environmental safety.

All existing chemical sensing technologies have several disadvantages. These include: poor sensitivity; poor selectivity; bulky size/form-factor, and; high power consumption. Chemical sensors that have such disadvantages are hard to integrate with consumer electronics, thereby limiting their use to very specific industrial applications. The CS-FET breakthrough, because of its small and scalable size and low power consumption, can be integrated with wireless technology and/or energy harvesters such as solar cells or thermo-electrics, for remote applications such as real-time environmental chemical mapping over large areas.

Small form-factor, low power consumption, highly sensitive and selective CS-FET sensor platform opens up a variety of possibilities in the chemical sensing applications. Broad area deployment of wireless integrated CS-FET sensor nodes will enable 24/7 real-time monitoring of target chemicals within that area. This space monitoring would be achieved with lower power consumption and/or at new spaces compared to the present chemical sensors. CS-FETs in portable devices can chemically provide information regarding the environmental conditions around us and/or our day-day physiological state.

> **Economic impact:** Because of the many advantages of the CS-FET sensor platform, such as small size, low concentration detection limit, good selectivity, and low power consumption, it will satisfy demands of many new applications; potentially replacing a considerable amount of present chemical sensing technologies. More significantly, wireless integrated CS-FET sensors should have huge economic impacts. A study shows that typically 50% of installation cost and 80% of installation time will be cut by changing wired connection to wireless connection of sensors used in industry. Global market size of hazardous fixed chemical detectors is roughly $1B; roughly $500M for portable detectors. In another report, the market size of wearable chemical sensors is expected to increase by about 30% every year in the next decade until 2025. Total market size of wearable sensors in 2025 will reach $3B. Chemical sensors will occupy roughly 30% of this.

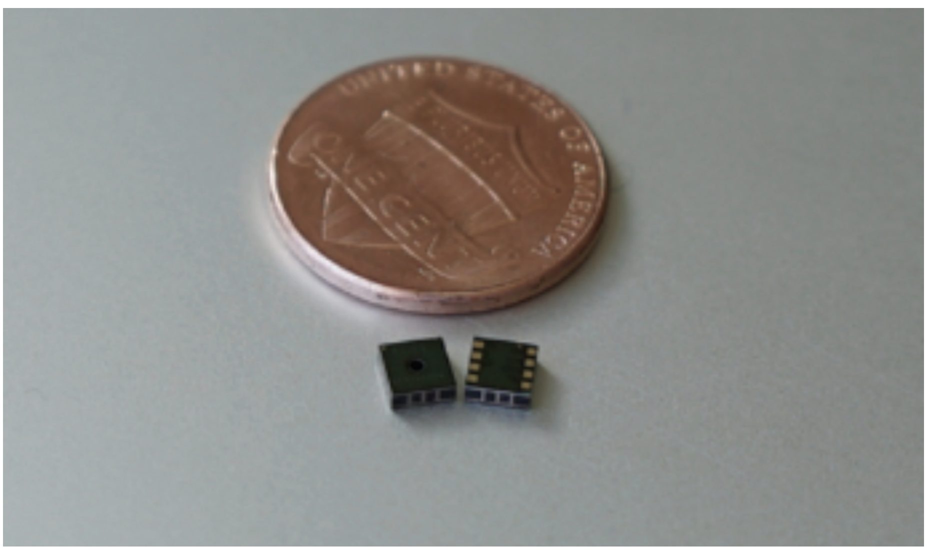
Due to similarity of the CS-FET to conventional field effect transistor (FETs) in computers, it will be possible to fabricate CS-FETs using existing and mature silicon processing techniques. This will definitely lower manufacturing costs. Current know-how in the semiconductor industry now can be transferred directly to CS-FET technology, which will drastically reduce R&D time/cost in Murata Manufacturing.

For more information, contact Ali Javey at University of California, ajavey@eecs.berkeley.edu, Berkeley, Bio https://www.eecs.berkeley.edu/Faculty/Homepages/javey.html, phone; 510.643-7263.

Ultrasonic Sensors for Consumer Electronics: MEMS Extension

Research at the Berkeley Sensor and Actuator Center (BSAC) has developed technology to make tiny, ultralow power ultrasonic sensors. These sensors use ultrasonic waves to detect objects and have applications in rangefinding, proximity, and presence detection. Multiple sensors can be used together to locate an object in three-dimensional space, enabling new user-interfaces such as gesture-based input. Because these sensors are ultra-low power, they can operate in small, battery-powered devices for months or years. The BSAC-developed ultrasonic sensor technology was licensed to Chirp Microsystems, a venture-funded start-up company that is working to commercialize it.

Ultrasonic sensors are widely used in everyday applications such as the parking-assist sensors in automobile bumpers. Relative to optical sensors, ultrasound has a number of advantages since it operates in all lighting conditions (total darkness to full sunlight), is insensitive to the color of an object, and it offers very precise range measurement. However, existing ultrasonic sensors are too big, too expensive, and too high power for use in most consumer electronic devices. The ultrasonic sensors developed by BSAC researchers operate at microwatt power levels, orders of magnitude lower than existing ultrasonic or optical sensors. BSAC's MEMS-based ultrasonic sensors are millimeters on a side, allowing them to fit into the smallest consumer electronic devices.



Two ultrasonic sensors compared to a penny.

MEMS based ultrasonic sensors have potential uses in consumer electronics devices such as laptops, tablets, and smart-phones. They may also be used in smart-home applications such as occupancy sensing. Because of their multiple potential applications in areas of extremely high consumer and industrial demand, their economic impacts should be substantial.

Economic impact: This technology is generating continuing interest and support from BSAC's industry members. This has led to another BSAC inspired startup, Chirp Microsystems (CM). CM has commercialized it and is currently sampling products based on this NSF I/UCRC supported breakthrough technology. Commercial impacts are expected to exceed $100M as measured by anticipated future valuations of Chirp. Chirp has been recognized by EE Times as "One of the 15 Startups to watch in 2015." A refereed paper from the Horsley/Boser research groups "3D Ultrasonic Gesture Recognition" received EE Times' designation as one of "5 Hot Papers" at the 2014 International Solid State Circuits Conference (ISSCC), the leading technical conference of the semiconductor industry. Because of their multiple potential applications in areas of extremely high consumer and strong industrial demand, their economic impacts should be substantial.

For more information, contact David Horsley at the University of California, Davis, dahorsley@ucdavis.edu, Bio http://faculty.engineering.ucdavis.edu/horsley/, 530.341.3236 or Bernhard Boser at the University of California, Berkeley, boser@eecs.berkeley.edu, Bio https://www.eecs.berkeley.edu/Faculty/Homepages/boser.html, 510.643.8350.