Georgia Institute of Technology

Research News

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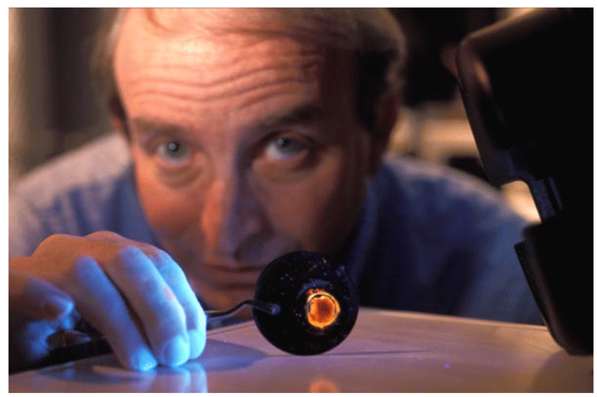
NOVEL GAS SENSORS BASED ON POROUS SILICON OFFER POTENTIAL FOR LOW-VOLTAGE, LOW-COST SENSOR ARRAYS INTEGRATED WITH ELECTRONICS

A new type of sensor based on porous silicon and a unique metallization process could offer enhanced sensitivity, reduced power demands and lower cost compared to existing technologies for detecting gaseous compounds important in environmental, food and biomedical applications.

Because they are based on silicon wafers, manufactured using integrated circuit production techniques and operate at room temperature using relatively low voltages, the new sensors could be integrated into electronic equipment and used to build sensing arrays. Developed by researchers at the Georgia Institute of Technology, the devices are described in a paper published in the February 15 issue of the *Journal of Applied Physics*.

"The sensors show a rapid and reversible response to low concentrations of these gases at room temperature," said James L. Gole, a Georgia Tech professor of physics. "They operate on a voltage much less than that of a watch battery and would be small enough to be taken into the field with a troop contingent or any other group concerned about the presence of harmful gases. The sensors are so simple that they could ultimately be mass-produced for pennies apiece."



James Gole shows photoluminescence of porous silicon under ultraviolet light. The effect may be important to producing low-resistance contacts.

Sensors based on porous silicon have been built before, but their practicality has been limited because of high resistance in the electrodes connected to the porous silicon and the power requirements of as much as 5 volts. Using a unique metallization process, however, Gole and his collaborators dramatically reduced the resistance of the electrodes built into the silicon, allowing their sensors to operate at between one and 10 millivolts -- a dramatic improvement over earlier sensors.

The new devices can detect ammonia, hydrochloric acid and nitrogen oxides at concentrations of between 10 and 100 parts-per-million -- if not lower -- compared to 100 to 1,000 parts per million for the higher-voltage sensors. Because the chemical reaction they use

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to detect the gases can be rapidly reversed, the new devices are reusable. And after long-term use, they can be regenerated with a simple chemical treatment.

The introduction of gases onto sensitive porous silicon surfaces causes dramatic changes in their conductance. Simple and inexpensive electronic equipment can be used to measure these changes. That could allow the sensors to be integrated onto a microelectronic chip and used as part of an "artificial nose" to detect a range of potentially toxic compounds.

The combination of low cost, low power consumption, room temperature operation and simple production for the Georgia Tech devices opens up new possibilities for sensing applications.

"We believe these sensors can be inexpensively built in arrays, which opens up interesting opportunities for mixture analysis in water quality, environmental sensing, food toxin detection and agricultural uses," said Peter Hesketh, the paper's co-author and a professor in Georgia Tech's School of Mechanical Engineering. "We also see the possibilities for biomedical analysis useful in blood analysis, pathogen testing and analyzing allergic reactions."

Production of the new sensors begins with a silicon wafer that is coated with a silicon nitride film deposited at about 250 degrees Celsius. Using integrated circuit fabrication technology, a pattern is then applied on the film using a photoresist. Reactive ion etching then selectively removes the silicon nitride, leaving a pattern of exposed silicon.

Next, a hybrid electrochemical process that Gole describes as a "semi-hydrous" etch forms micropores in the silicon with diameters of 1-2 microns and aspect ratios of up to 400. Multiple applications of the etch treatment can create pores of consistent size. On top of these micron-scale pores, the Georgia Tech researchers then fabricate a layer of material with pores of a nanometer-scale size.

A final electroless metallization process takes advantage of a unique property of porous silicon to produce low-resistance (~ 20 Ohm) contacts to which electrical leads can be attached. This overcomes one of the existing challenges in the fabrication of porous silicon devices: establishing low resistance electrical contact to the porous silicon structure.

Porous silicon has attracted considerable interest because it produces a strong orange-red photoluminescence when subjected to ultraviolet light. Though the exact mechanism for this is the subject of debate among physicists, the Georgia Tech team believes the same electronic excitation mechanism that creates the orange-red glow also helps improve the efficiency of the electroless metallization process -- thereby improving the conduction of the contacts.

The basis for the approach lies in the suggestion that the photoluminescence from porous silicon results from a surface based process and that this relatively long-lived photoluminescence can be used to enhance the rate of reduction of metallic ions from the electroless metallization solution in contact with the porous silicon surface.

The formation of surface-bound, electronically excited "centers" -- whose interaction and reaction capability greatly exceeds that for the unexcited surface -- provides an enhanced and controllable reduction capability for electroless solutions, the researchers argue.

The electroless processing technique produces contact resistances of as little as 20 Ohms. To facilitate electrical flow through the sensor, an aluminum film is deposited on the back of the wafer using screen printing and thermal annealing techniques.

Though initial testing suggests that the sensors have great promise, much work remains to be done on improving their selectivity, Hesketh notes. Techniques for calibrating them at lower concentration levels must also be developed.

In addition to Gole and Hesketh, the research team also included Lenward Seals, then a graduate student in the School of Physics, and Laam Angela Tse, a graduate student in the School of Mechanical Engineering.

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