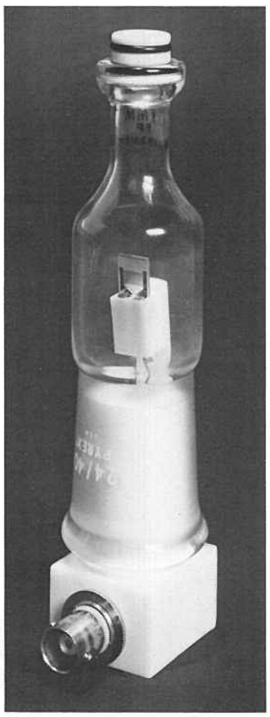
The Solid-State Nitrogen Dioxide Sensor

Inventors: Dipen N. Sinha, Mechanical and Electrical Engineering Division, Stephen F. Agnew, Isotope and Nuclear Chemistry Division, and William E. Christensen*



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The Solid-State Nitrogen Dioxide Sensor is compact, and it responds to nitrogen dioxide in seconds.

In large, industrial cities, a reddish-brown haze frequently envelops and smothers people and buildings alike. Nitrogen dioxide—a poisonous gas released by automobiles, certain industrial operations such as smelting and refining, electric power plants that burn coal and oil, and photochemical reactions produced by the interaction between sunlight and various pollutants—is responsible for the color of the haze. When released into the atmosphere, nitrogen dioxide causes people to experience severe coughing, chest pains, and feelings of suffocation; it can gradually damage their lungs. Monitoring and controlling nitrogen dioxide releases into the atmosphere are thus most important to human health.

Emissions of nitrogen dioxide into the atmosphere also mark the beginnings of an environmentally harmful process, acid rain. Water vapor from the clouds reacts with nitrogen dioxide gas and produces acids. The acidity of rain depends on the concentrations of those acids. In spite of acknowledged deficiencies in the scientific understanding of acid rain, specialists agree that acid rain is a form of pollution that can have serious atmospheric and biospheric consequences. Being able to measure and control the content of nitrogen dioxide emissions into the atmosphere has, clearly, an overwhelming environmental significance.

It is precisely in the context of health-related and environmental needs that a number of companies have made nitrogen dioxide sensors commercially available. However, these sensors are slow and bulky, require frequent recalibration, are not always selective to nitrogen dioxide, and are expensive. Unlike them, the Solid-State Nitrogen Dioxide Sensor developed at Los Alamos responds to nitrogen dioxide in seconds and is miniature in size; monitors nitrogen dioxide in real time and requires no recalibration because it returns to base line after each measurement; is highly selective to nitrogen dioxide and therefore free of interferences from other gases emitted into the atmosphere; is entirely solid state; and is remarkably inexpensive. Having understood the significance of the Los Alamos technology, *Research and Development Magazine* granted the inventors a 1990 R&D 100 Award; the awards are given annually for the one hundred most significant technical innovations of the year.

The Invention—Features and Advantages

The Solid-State Nitrogen Dioxide Sensor detects the gas by monitoring changes in the *electrical conductivity* of a thin polystyrene film. Although normally an electrical insulator, polystyrene film becomes somewhat conducting when exposed to nitrogen dioxide gas; the change in conductivity depends on the concentration of the gas and is the result of two condensed molecules of nitrogen dioxide undergoing a process of self-ionization, which implies that the molecules become one stable ion pair. It is the underlying chemistry of the polystyrene film that makes the sensor extremely specific to nitrogen dioxide gas. In fact, the whole idea of using an insulator to detect nitrogen dioxide is unprecedented; it opens up new avenues for research.

To provide a very large film/electrode contact area in a small space, the sensor features an *interdigitated-electrode system*. This means that a very long electrode is squeezed into a small area by following a pattern that looks much like that formed by the interlocked teeth of a gear. An enlarged contact area between the electrode and the film results in an approximately 40,000 times increased sensitivity of measurement over the sensitivity observed with a conventional contact area, which features a parallel design of the electrodes. This large amplification in measurement sensitivity allows changes in the film's conductivity to be detected easily with off-the-shelf, inexpensive, integrated circuits. The interdigitated-electrode design allows the sensor to be miniaturized.

Commercially available nitrogen dioxide sensors are not solid state. However, a number of solid-state nitrogen dioxide sensors exist in experimental stages at various laboratories, but they all require heating to high temperatures (approximately 300 degrees Celsius) to function. Our sensor does not. This feature is significant because it implies that the sensor does not require a large power source. The Solid-State Nitrogen Dioxide Sensor can be battery operated and is thus well suited for remote monitoring of toxic gases.

Applications and Spinoffs

Researchers at Los Alamos are interested in further developing the Solid-State Nitrogen Dioxide Sensor,

* *William Christensen contributed to this invention while a student in the Department of Energy's Science and Engineering Research Semester (SERS) Program.*

for which they can already foresee various applications with a great environmental significance. For instance, multiple sensors—each incorporating a different method of detection and, therefore, each being able to detect a different gas—could be integrated in a package and used to obtain an *instant* in-field analysis of toxic gas; this analysis is most important for atmospheric and industrial pollution monitoring. The multiple-sensor package could gradually find its way into homes, where it could be used as an early-warning safety device for harmful gas in much the same way that the familiar smoke detector is used.

Because it can be battery operated, the Solid-State Nitrogen Dioxide Sensor can be used in remote monitoring of atmospheric nitrogen dioxide and in monitoring of gases emitted from industrial operations. For example, when used in industrial alarm systems, the sensor allows a speedy response to gas leaks, which is essential to safe industrial operations.

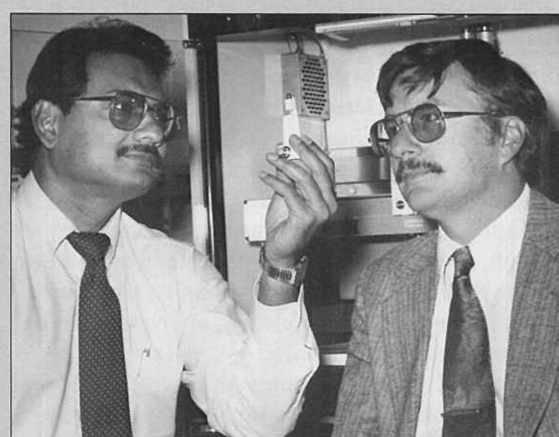
On the basis of the same process, but with modifications and further development in selectivity, a sensor can be developed that will detect *in situ* various water contaminants, such as the carcinogenic chlorinated hydrocarbons. This sensor will be inexpensive, automated, and completely integrated. Much like the Solid-State Nitrogen Dioxide Sensor, the sensor for water contaminants can give a measure of contaminant concentration by indicating a change in electrical conductivity. There are, of course, other methods currently available for detecting water contaminants (for example, liquid or gas chromatography); however, they are time consuming, expensive, and unsuitable for field use.

Instead of relying on the conventional semiconducting properties of organic films, our sensor introduces insulating polymers as sensing materials. This marks a completely new approach to technologies in solid-state gas sensing and thus opens up a previously unexplored area of research and development.

The Laboratory has applied for a patent on the technology and is seeking industrial collaboration to develop a commercial product.

INVENTOR Dipen Sinha's specific interest in the field of sensors and devices led to the discovery of the Solid-State Nitrogen Dioxide Sensor, which received an R&D 100 Award in 1990. Sinha received his B.Sc. in physics with honors from St. Xavier's College in Ranchi, India, and two years later his M.S. in physics from the Indian Institute of Technology in Kharagpur, India. After earning his Ph.D. in physics from Portland State University, Oregon, Sinha spent three years as a postdoctoral fellow at Los Alamos. He then worked as a senior member of technical staff with Rockwell International Corporation in Anaheim, California. In 1986, Sinha joined the Laboratory as a staff member in the Mechanical and Electrical Engineering Division. He specializes in solid-state devices and sensors, high-temperature superconductors, high-speed electrical measurements, and various ultrasound techniques.

Inventor Stephen Agnew played a major role in explaining the chemical processes involved in developing the sensor. In 1976, Agnew earned his B.A. from Evergreen State College, Washington, and in 1981 his Ph.D. in chemical physics from Washington State University. He came to Los Alamos as a postdoctoral fellow in 1982 and has remained at the Laboratory as a staff member in the Isotope and Nuclear Chemistry Division. His research interests include infrared and Raman spectroscopic studies of polymer thin films and dispersions as well as use of polymer films in developing solid-state sensors.



Dipen N. Sinha (left) and Stephen F. Agnew

Working under Dipen Sinha's supervision, William Christensen contributed significantly to the numerous experiments carried out in developing the sensor.

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