Nanosensors for the Evaluation of Hazardous Environments

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Applications and Transformations

Abstract:

Astronauts in a space vehicle or in an extra planetary environment, as well as ground-based personnel working within or nearby spacecrafts can potentially be exposed to lethal amounts of hazardous gases. Space vehicles often use hydrazine and similar gases as fuel for some small engines. These gases can be extremely dangerous even in concentrations as low as tens of parts per billion. It is therefore important to be able to detect, identify, and quantify the presence of a gas, especially when its existence could result in serious injury or death.

Introduction:

The use of small and sensitive nanosensors can allow for the placement of multiple devices over a large area, thus allowing for a more precise and timely determination of a gas leak. ASRC Aerospace and its research partners are developing nano sensors for the detection of various gases, including but not limited to: H_2, NH_3, N_2O_4, hydrazine, and others. Initial laboratory testing has demonstrated the capability to detect the gases in concentrations lower than parts per million and testing is ongoing to evaluate the sensitivity at level three orders of magnitude smaller. Testing and development is continuing to improve the response and recovery times, and to increase the sensitivity of the devices. Different coatings and electrodes are currently being evaluated to determine the optimum configuration for the detection and identification of a variety of gases.

The small footprint of the nanosensors allows for several devices, each responsive in a different way to different gases, to be placed into a single substrate. Multiple devices embedded into a single substrate results in increased reliability and in a decrease in the frequency of periodic calibrations. The use of different coatings for individual elements of a multi-channel sensor allows for the identification of different gases. The characterization of these sensors is being accomplished by the use of a custom multi-channel signal conditioner amplifier built on a small multi chip module. This device is used to process the output of the sensors and to deliver a signal that can be remotely monitored and analyzed. All the data is digitized and transmitted over the same cable pair used to power the amplifier. Multiple outputs can be connected to a single cable pair in order to minimize the added weight and expense associated with cabling in a spacecraft.

Monitoring of the environment is not limited to the detection of gas leaks, and it will become increasingly important as longer duration space missions are planned and executed. A multitude of sensors need to be developed and qualified for space flight under realistic operating conditions, and as such, development activities in the nano sensor field will continue for years to come.

ASRC Aerospace, a NASA prime contractor at the Kennedy Space Center in Florida, is working on the development of nanosensors for use at the launch pads and possibly on future space vehicles.

Objective:

Gas sensors are indispensable to monitor the quality of the environment in areas where hazardous gases might be present. A typical launch environment for space vehicles involves the use of H_2, NH_3, N_2O_4, N_2, He, hydrazine, and others. The Space Shuttle uses liquid hydrogen and liquid oxygen as the fuel and oxidizer respectively to power its three main engines.

Because of the potential hazards associated with these gases, it is important to ensure that no gas leaks are present. From the beginning of the Space Shuttle program, mass spectrometers have been used to monitor for cryogenic fuel leaks. Mass spectrometry is a proven technology that can be used to monitor all necessary gas constituents at the required limits of detection [low part per million (ppm)]. However, the size, weight, and power requirements of the mass spectrometers is such that all the monitoring is done on the ground, and not in the vehicle itself.

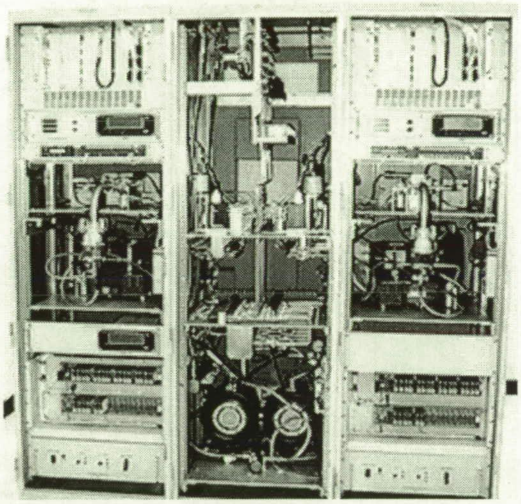

Figure 1. Typical Mass Spectrometer unit.

One of the drawbacks of remotely sensing for gases is that gas samples have to be transported to the mass spectrometer through long transport lines (about 115 m long) because the size of the Space Shuttle Orbiter. This means the samples being analyzed are tens of seconds old by the time they reach the mass spectrometer. The use of small sensors, with sensitivity and selectivity similar to that achieved by the mass spectrometer, can result in a more timely analysis of the gas samples, especially when such sensors are physically placed in the area of interest.

Current Efforts:

ASRC Aerospace Corporation and the Center for Nanotechnology at NASA Ames Research Center have reached an agreement to jointly develop, manufacture, and test nano devices. The effort includes:

- Developing, testing and evaluating nano sensors and other nanotechnology based devices.
- Investigating new technologies leading to more sensitive and more accurate sensors.
- Identifying applications and requirements for nano sensors for ground support and space applications.

A 32-channel miniaturized signal conditioner was designed and incorporated to a 32-channel nanosensor. The complete system is easily deployed and installed, while minimizing the requirement for multiple power and signal wires. The 32-channel sensor has been designed so every sensing element can be coated with a different nano material in order to optimize the response to different gases while using a single device.

Results:

The initial effort has concentrated on developing a sensor and optimizing its response to gaseous N2O4 and NO2. Different coatings continue to be tested so the optimum configuration can be selected.

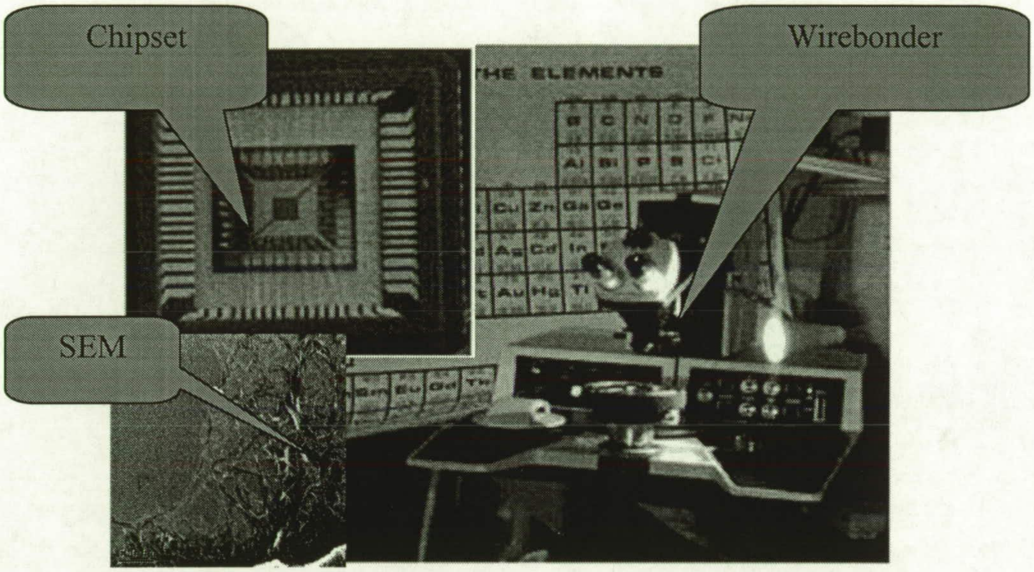

Figure 2. Development setup

The system has been designed to allow for 32 sensing elements in a single chip, while requiring only 3 wires to power and collect the information from all the sensing elements.

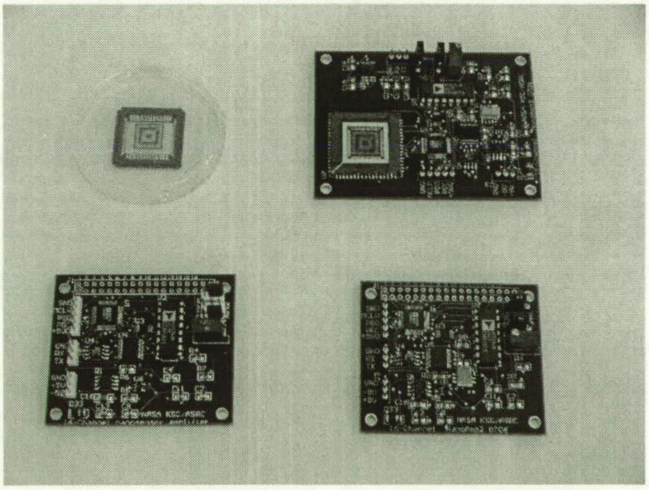

Figure 3. Sensor and signal conditioning amplifier

Initial testing of the sensors was conducted for various gaseous NO_2 concentrations and different relative humidity conditions, with some initial results shown in Figure 4. Several coatings have been tested to date, with IDE gap sizes of 8, 12, 25, and 50-mm.

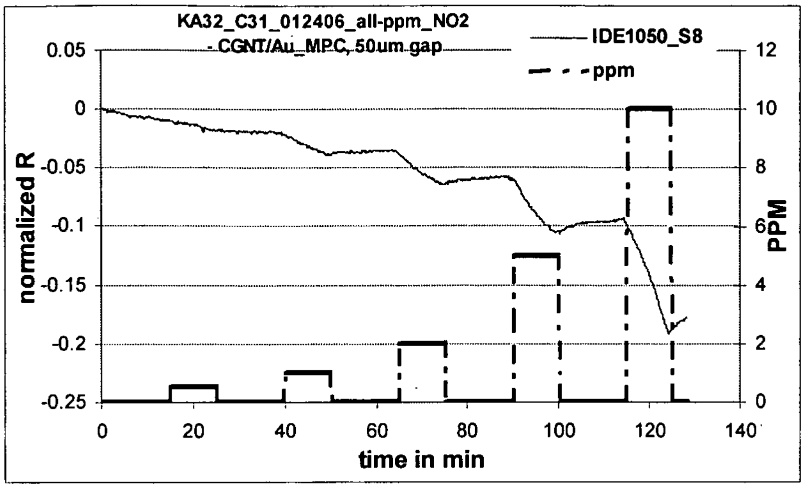

Figure 4. Changes in normalized resistance in the presence of various gas concentrations.

Although the initial work has concentrated on the detection of NO_2 and N_2O_4, the effort is not limited to those gases. Following the completion of the initial development and testing of these sensors with the aforementioned gases, testing will start with H_2 and NH_3 as well as hypergolic fuel (hydrazine) and hypergolic oxidizer (nitrogen tetroxide, which is analyzed as nitrogen dioxide).

Another gas of interest is monomethyl hydrazine (MMH). Evaluation of MMH will be conducted pending the results with hydrazine. The sensors are being evaluated under a wide variety of environmental conditions, including various temperatures, humidity, and gas concentrations. The initial evaluation is revolving around the reproducibility of the sensors in the analysis of several hydrazine concentrations (3 concentrations) at constant temperature and humidity. The final objective will be to optimize individual responses to various gases, and to integrate the sensors onto a single substrate.

Summary:

The development of miniaturized sensors is important for current and future space programs as it will allow for more precise and focused measurements. We have presented some of the development work currently in progress at ASRC and its development partners. Results to date are very encouraging, including both the sensitivity and selectivity obtained with the sensors for hazardous environments.

Monitoring of the environment, not limited to the detection of gas leaks, will become increasingly important as longer duration space missions are planned and executed. The will drive the need for the development of a multitude of sensors which would have to be qualified for space flight under realistic operating conditions. As such, development activities in the nano sensor field are expected to continue for years to come.

The use of nanosensors will provide NASA with a cheaper and more reliable way to detect gases during the launch process and ground support operations. The technology has potential to be used in flight and on other planetary surfaces for long time habitation missions on the surface of the moon or nearby planets.

The commercial applications of miniaturized nano scale detection devices have potential markets in homeland security, medical device monitoring, environmental monitoring, and eventually on everyday life applications.

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Nanosensors for the Evaluation of Hazardous Environments

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Introduction

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- Personnel living in a space environment as well as technicians and engineers preparing spacecraft for launch can potentially be exposed to small amounts of hazardous gases.
- It is important to be able to detect, identify, and quantify the presence of a gas, especially when its presence could lead to a fatal situation.
- The use of small and sensitive sensors can allow for the placement of these devices over a large area, thus allowing for a more precise and timely determination of a gas leak.

Objective

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- Gas sensors are indispensable to monitor the quality of the environment in areas where hazardous gases might be present. A typical launch environment involves the use of H_2, NH_3, N_2O_4, N_2 , He, hydrazine, and others.
- The Space Shuttle uses liquid hydrogen and liquid oxygen as the fuel and oxidizer, respectively, to power its three main engines.
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Legacy Systems

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- Mass spectrometry is a proven technology that can be used to monitor all necessary gas constituents at the required limits of detection [low part per million (ppm)].
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Legacy Systems (cont.)

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- One of the drawbacks of remotely sensing for gases is that gas samples have to be transported to the mass spectrometer through long transport lines (about 115 m long) because the size of the Space Shuttle Orbiter.
- This means the samples being analyzed are tens of seconds old by the time they reach the mass spectrometer.
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Current Efforts

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- ASRC Aerospace Corporation and the Center for Nanotechnology at NASA Ames Research Center have reached an agreement to jointly develop, manufacture, and test nano devices.
- The effort includes:
  - Developing, testing and evaluating nano sensors and other nanotechnology based devices.
  - Investigating new technologies leading to more sensitive and more accurate sensors.
  - Identifying applications and requirements for nano sensors for ground support and space applications.

Current Efforts (cont.)

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- The nanosensors and a miniaturized signal conditioning amplifier will be incorporated into a single device.
- The complete system will be easily deployed and installed, while minimizing the requirement for multiple power and signal wires.
- The sensor will be designed so every sensing element can be coated with a different nano material in order to optimize the response to different gases while using a single device.

Results

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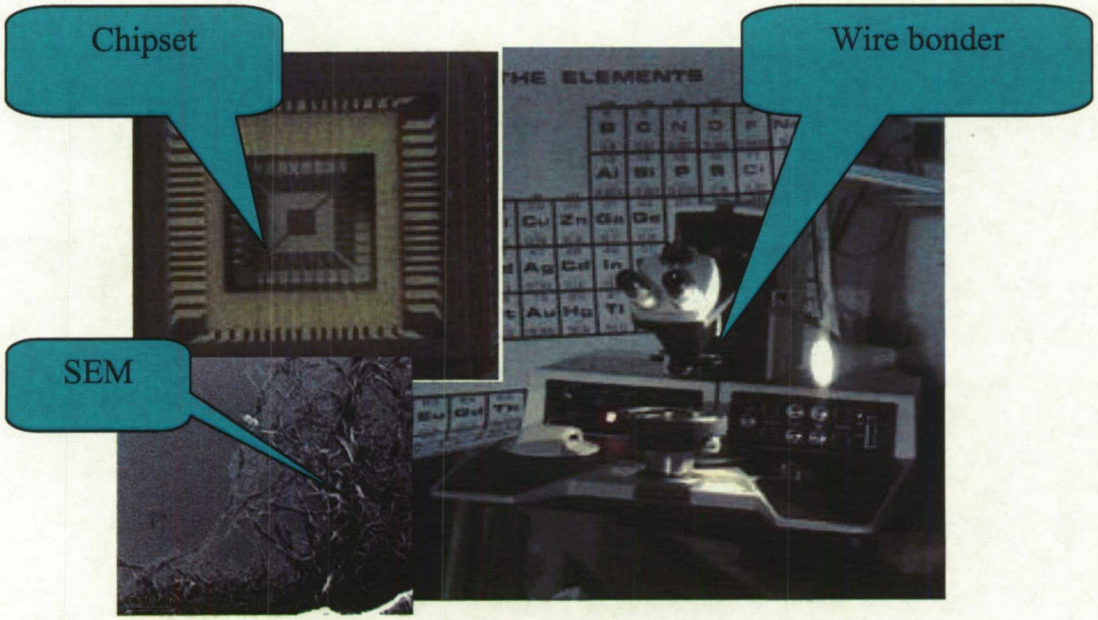
- The initial effort has concentrated on developing a sensor and optimizing its response to gaseous N_2O_4 and NO_2. Different coatings continue to be tested so the optimum configuration can be selected.



Results

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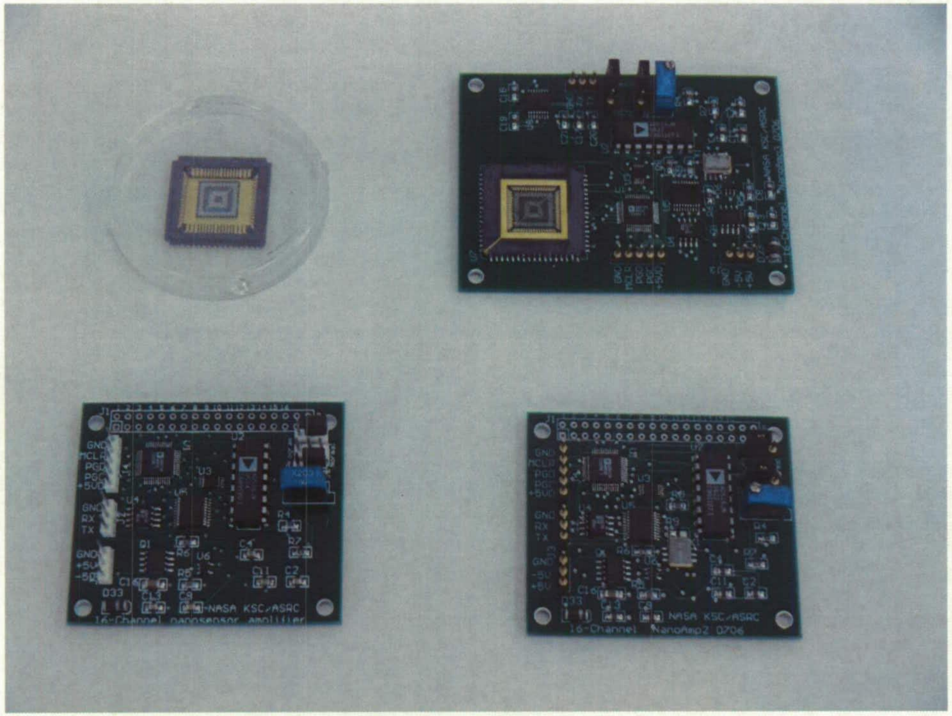

Results (cont.)

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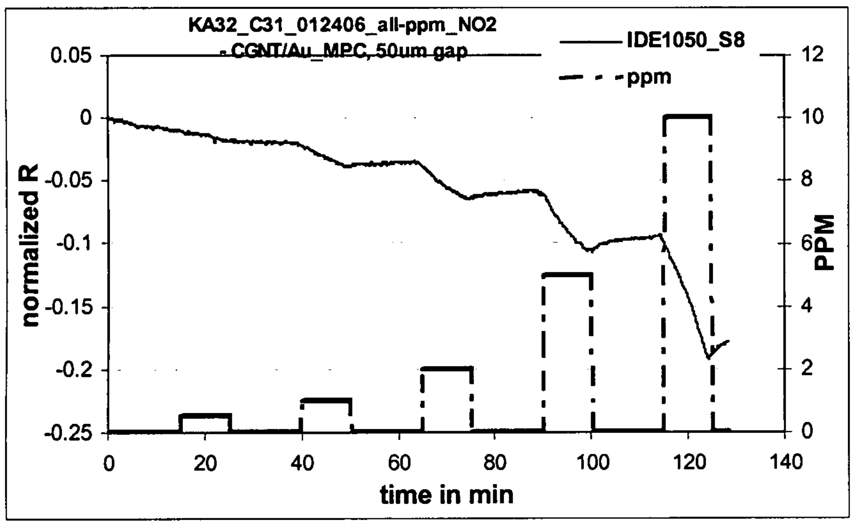

Changes in normalized resistance in the presence of various gas concentrations.

Results (cont.)

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Results (cont.)

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- The sensors are being evaluated under a wide variety of environmental conditions, including various temperatures, humidity, and gas concentrations.
- Initial evaluation is revolving around the reproducibility of the sensors in the analysis of several hydrazine concentrations (3 concentrations) at constant temperature and humidity.
- The final objective will be to optimize individual responses to various gases, and to integrate the sensors onto a single substrate.
- Multiple sensors in a single device will result in increased reliability and selectivity.

Summary

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- The development of miniaturized sensors is important for current and future space programs.
- We have presented some of the development work currently in progress at ASRC and its development partners.
- Results to date are very encouraging, including both the sensitivity and selectivity obtained with the sensors.
- Monitoring of the environment, not limited to the detection of gas leaks, will become increasingly important as longer duration missions are planned and executed.
- A multitude of sensors need to be developed and qualified for space flight under realistic operating conditions, and as such, development activities in the nano sensor field will continue for years to come.

Summary (cont.)

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- The use of nanosensors will provide NASA with a cheaper and more reliable way to detect gases during the launch process and ground support operations.
- The technology has potential to be used in flight and on other planetary surfaces.
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