Nanomonitors for Energy Systems

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ABSTRACT

Recent advances in trace gas species sensing using nanotechnology show great promise for detecting chemical species by the principle of chemiresistivity. This principle measures changes in resistance associated with the adsorption of chemical species onto nanomaterials. Existing chemiresistive sensors are limited in sensitivity and selectivity and typically operate in mild environment. The goal of this proposed work is to understand and tailor the performance of trace gas species nanomonitors in terms of sensitivity; specificity and stability using nanoporous ceramic and metal doped ceramic membranes supported on microelectrode arrays (MEA). The nanoporous pseudo-membrane behaves as a series of inter-connected resistors resulting in signal amplification, thereby enhancing the nanomonitor sensitivity. The material chemistry and particle-pore characteristics of the nanoporous composite are designed to achieve the specificity and stability in the extreme environment. We address multi-disciplinary issues such as device design and fabrication as well as nanomaterials synthesis and processing to successfully develop the proposed nanomonitoring technology.

These sensors have a wide range of applications: power conversion, energy storage, and energy harvesting devices all require sensors for optimization and reliable performance.

Keywords: gas sensors, chemiresistive, trace gas, selectivity,

1. INTRODUCTION

The energy industry generates a large amount of pollution, including the generation of toxic gases and greenhouse gases from fuel combustion, nuclear waste from nuclear power generation, oil spillages in the petroleum industry, etc. These pollutants are responsible for polluting the environment which affects human health. It is very necessary to control these pollutants. Inorder to control these pollution gases it is necessary for continuous monitoring of these pollution sources.

There are various kinds of monitoring systems or sensor systems such as surface acoustic wave gas monitoring systems [1], micro-cantilever based monitoring systems [2], optical gas monitoring systems like chemiluminescence based monitoring systems [3], and electrochemical gas sensors like metal and metal oxide based gas sensors, semi-conductor based gas sensors, polymer based gas sensors, nanomaterial based gas sensors [4], etc that are already available. All these gas sensors are either highly costly or they are limited in issue like sensitivity, selectivity and operating temperature. For example, chemiluminescence gas sensor is highly selective and sensitive towards a particular analyte but it is highly expensive and not portable. Coming to electrochemical gas sensors, these are not capable for selective detection of a particular analyte even though they are cost effective and portable. Performance of all these sensors will also depend on the operating temperature. At high temperatures, some of these sensors may not have the same sensing characteristics/capabilities when compared to room temperature. Since, it is necessary to have a high operating temperature at most of energy systems it is necessary to develop a cost effective monitoring which can monitor various harmful analytes with high sensitivity and selectivity.

Here we present a electrochemical nanomonitor which is cost effective and with improved sensitivity and selectivity. The selectivity of this electrochemical nanomonitor is improved by employing nanoporous ceramic and metal doped ceramic membranes[5-7]. These nanoporous ceramic membranes are placed on a microelectode array (MEA) pattern which helps in monitoring the electrical properties of the membrane due to the adsorption of trace gas analytes. Due to the application of ceramic membranes in these monitoring systems these nanomonitors can work effectively at elevated temperatures.

2. NANOMONITORS

2.1. Principle of Operation

In the electrochemical nanomonitoring systems there are various kinds of detection mechanisms such as chemiresistive, potentiometric, voltammetric and amperometric. In the present application we employed chemiresistive detection mechanism due to its simplified electrical circuitry and ease of operation.

The principle of operation of the chemiresistive nanomonitor is based on the measurement of resistance change associated with the adsorption/reaction of trace gas analyte by/with the nanoporous material matrix[8,9]. The prototype nanomonitor functions based on the chemiresistive principle, where variations in the resistance of a analyte gas sensitive nanocomposite is observed and measured due to selective adsorption/reaction of analyte by/with the nanocomposite and the analyte gas molecules that in turn decreases/increases the number of free electrons resulting in a concentration dependant resistance increase/decrease.

Table1 gives a quick overview of advantages and disadvantages of various techniques that can be employed in various nanomonitors. It shows that the issues with the present chemiresistive detection mechanism are poor selectivity and moderate sensitivity. But dealing with these two issues and employing chemiresistive detection mechanism we can achieve a cost effective, portable nanomonitor.

Sensing Principles	**Sensitivity**	**Selectivity**	**Cost**	**Portable**
Chemiluminescence	High	High	High	No
SAW	High	High	High	No
Micro Cantilever	High	Poor	Moderate	No
Chemiresistive	Moderate	Poor	Low	Yes

Table1 Overview of various detection mechanisms that can be employed in the nanomonitoring systems [1-3,8,9].

Figure 1 shows the simplified equivalent circuit of the chemiresistive nanomonitor. In this technique a simple Wheatstone bridge was employed for detecting the change in electrical resistance of the nanoporous membrane. The MEA with the nanoporous membrane is connected to one leg of the Wheatstone bridge and the entire MEA will act as a resistor. Whenever the nanomonitor chip is exposed to the analyte gas there will be change in the electrical resistance of the nanoporous membrane. This change in electrical resistance results in imbalance of the Wheatstone bridge. So, there will be a corresponding change in voltage at the output terminals of the circuit which could be measured using a two probe measuring device.

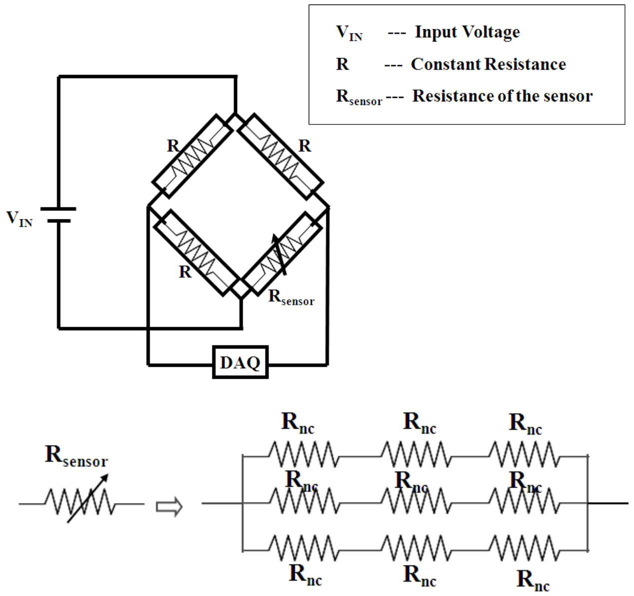

Figure 1. The equivalent circuit of the entire chemiresistive nanomonitor and equivalent resistance of the nanoporous composite. The resistor R_{sensor} in the Wheatstone bridge circuit is the resultant resistance of the nanoporous composite.

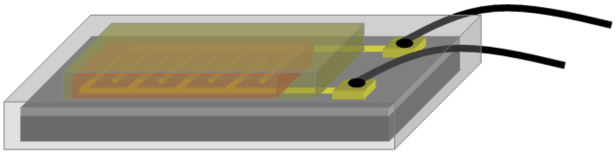

Figure 2. Shows the schematic representation of the chemiresistive nanomonitor chip. Each microelectrode array is comprised of an interdigitated geometry with 20 digits. Each digit is ~200µm in width and 2mm in length with 300µm spacing.

3. EXPERIMENTAL TEST BED

The experimental test bed consists of a 200 liter glass chamber in which chips are placed and tested with all the gases. The nanomonitor chip in the chamber is connected to a simple wheat stone bridge circuit, which changes the voltage level at its output depending on the change in the resistance of the chip. The output of the Wheatstone bridge is connected to an analog to digital converter, which is connected to a PC using an USB cable. The DAC converts the analog signals from the Wheatstone bridge to a digital signal and send those digital signals to PC. Gas concentrations are monitored by standard air quality monitoring instrumentation. Signals from the Wheatstone bridge and gas monitoring instruments are fed into the data acquisition system and are continuously monitored.

When analyte gas is pumped into the test chamber, the active sensing area on the nanomonitor chip reacts with the analyte gas molecules resulting in the change in electrical resistance of the chip. This change in the resistance causes an imbalance in the Wheatstone bridge which results in change in the voltage level at the output of the Wheatstone bridge.

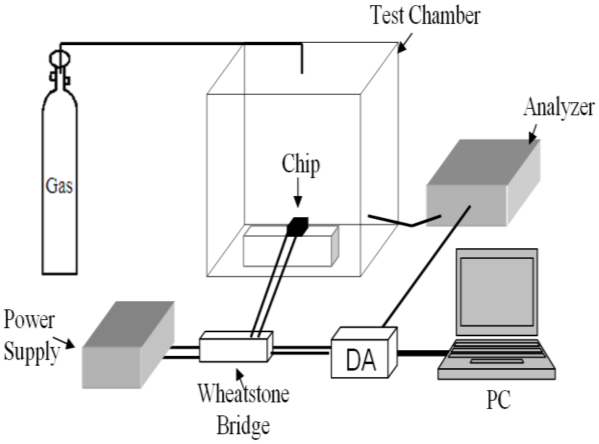

Figure 3 Shows the schematic of Experimental Test Bed. The test bed consists of glass test chamber in which the nanocomposite is tested, a chemiluminescence trace gas analyzer which is used for monitoring the analyte gas concentration level in the test chamber and electrical circuit which is used for monitoring the change in electrical resistance of the nanocomposite when it is exposed to analyte.

4. RESULTS AND DISCUSSIONS

When the nanomonitor chip is exposed to analyte gas there will be a change in electrical resistance which results in the change in the output voltage of the circuit. Figure 4 shows the graph between the percentage change in output voltage of the nanomonitor circuit vs. time. From the graph we can observe that when then the nanomonitor chip was exposed to the gas analyte the resistance of the chip changes (increases in this case) due to the adsorption of the gas molecules by the nanomaterial on the chip. Also, we can observe that the change in voltage level is more for the nanomonitor which is exposed to 2ppm of NO when compared to the change in voltage level of the nanomonitor which is exposed to 1ppm. This is because the change in voltage level is proportional to the number of gas molecules observed by the nanomaterial.

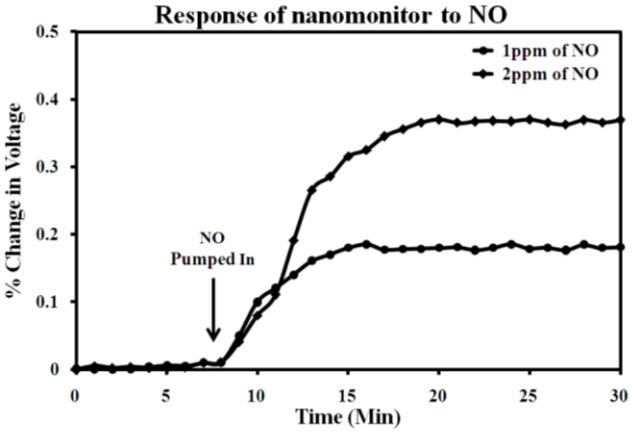

Figure 4 Shows the response of nanomonitor various concentrations of Nitric Oxide (NO). The graph shows that there is an increase in resistance whenever the nanomonitor chip is exposed to NO. The change in resistance is proportional to the concentration of the NO pumped in.

5. FUTURE WORK

We anticipate improving the sensitivity by upgrading the electrical conditioning and amplifying circuitry, which can increase the signal to noise ratio as well amplify the response coming from the sensor prototype. The selectivity of this nanomonitor can be improved by coating the nanoporous membrane with polymers or materials that are specific towards a particular gas analyte.

6. REFERENCES

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