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Trace detection of research department explosive (RDX) using electrochemical gas sensor

Praveen Kumar Sekhar*, Francesca Wignes

Nanomaterials and Sensors Laboratory, School of Engineering and Computer Science, Washington State University Vancouver, 14204 NE Salmon Creek Avenue, Vancouver, 98686, USA

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ABSTRACT

Scientific interest in the detection of the high-explosive research department explosive (RDX) continues to escalate from a national security perspective. In this article, selective and sensitive detection of trace RDX is demonstrated. The screening system is based on a concentrator front end and electrochemical potentiometric gas sensor as the backend. Preferential hydrocarbon and nitrogen oxide(s) mixed potential sensors with integrated heaters were used to capture the signature of the explosive. Quantitative measurements based on hydrocarbon and nitrogen oxide sensor responses indicated that the detector sensitivity scaled proportionally with the mass of RDX (down to 20 ng). The sensitivity was found to depend on the flow rate. The sensitivity was found to increase with increasing flow rate. A 42% increase in sensitivity was observed with a flow rate of 500 ml/min. This detection technique has the potential to become an orthogonal technique to the existing explosive screening technologies for reducing the number of false positives/false negatives in a cost-effective manner.

1. Introduction

The 2011 Department of Homeland Security (DHS) Progress Report [1] on 'Implementing 9/11 Committee Recommendations' places an important precedence on improving national security through robust explosive-screening technologies. The detector combination of Gas Chromatography (GC)–Mass Spectrometry (MS) is currently considered as a gold standard [2] for explosives detection. However, the high cost of GC–MS, their bulky size, and the need for an informed end-user has motivated investigations for new screening technologies, which are more cost-effective [3].

Present day commercial threat detection technologies are less capable than needed and suffer from numerous limitations (e.g., low sensitivity and false positives) when used outside well-controlled conditions [4–8]. In addition to sensor performance considerations, there is the matter of cost. For example, the tabletop systems used for screening carry-on baggage can cost around $65,000 [9]. The United States has more than 400 commercial passenger airports; if equally distributed, several thousand devices might be required, corresponding to a total capital cost for equipment of up to hundreds of millions of dollars. Installation and maintenance costs would be additional. At present, the scent-analysis ability of dogs is used as the baseline to gauge any instrumentation for detecting explosives. Further, dog's olfaction is sensitive enough to detect trace amounts of many compounds, but several factors have inhibited the regular use of canines for passenger screening. Dogs trained in explosives detection can generally only work for brief periods, have significant upkeep costs, are unable to communicate the identity of the detected explosives residue, and require a human handler when performing their detection role.

Chemical sensors, on the other hand have the potential [10] to mimic the incredibly accurate and versatile "canine-nose" system. In particular, electrochemical sensing [11–15] modality holds a great promise in offering portable, low cost, selective, sensitive, rapid and compact solution to threat detection. As probing the vapor phase (instead of solid or liquid) surrounding the potential threat may lead to improved means for explosives detection, electrochemical gas sensors could be a possible solution to screen a diverse palette of explosives.

Mixed potential sensors are a class of electrochemical devices that develop a non-Nernstian potential due to the difference in the kinetics of the redox reactions at each electrode/electrolyte interface upon exposure to various analytes [16,17]. The mixed potential strongly depends on the catalytic and electrocatalytic properties near the three phase interface (electrode/electrolyte/gas), which in turn depend on the operating temperature of the sensor. Unlike the state-of-the-art and commercially available trace

* Corresponding author.
E-mail address: praveen.sekhar@wsu.edu (P.K. Sekhar).

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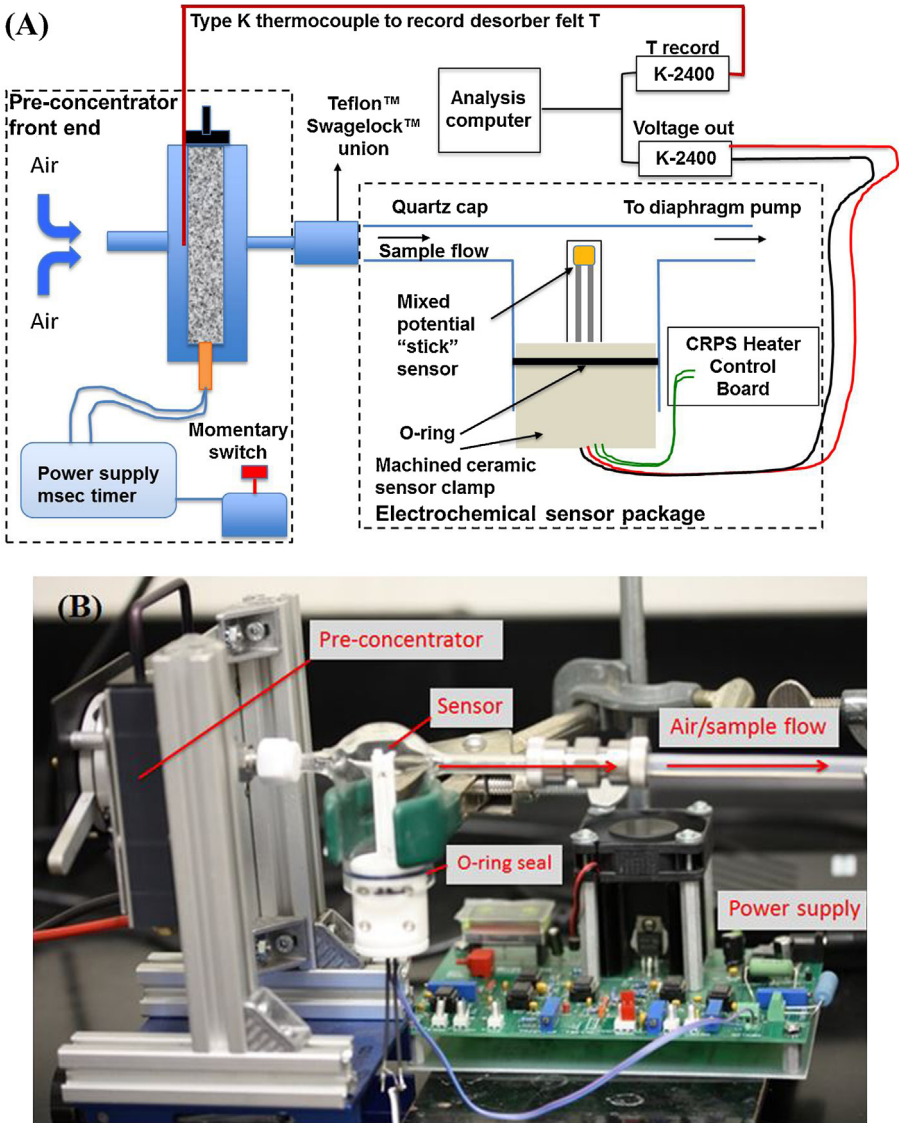

Fig. 1. Illustration and photographs of the experimental arrangement used for explosives detection by an electrochemical gas sensor. (A) Experiment schematic, and (B) Photograph of the sensing set-up.

explosive detection systems (such as Ion Mobility Spectrometer), the mixed potential based gas sensors offer a low-cost alternative for screening a diverse palette of explosives with high specificity. The mixed potential based gas sensors leverage the fact that the inevitable gas-phase decomposition of explosives that are made up of C, H, N, O involve highly predictable and readily-measurable 'breakdown' components such as NO, NO_2, CO, CO_2, C_3H_6, NH_2, NH_3, etc. [18]. The focus of this article is to demonstrate the trace detection of research department explosive (RDX) using selective hydrocarbon (HC) and NO_x mixed potential gas sensor.

RDX is 1000 times less volatile than 1,3,5-trinitrotoluene (TNT), corresponding to a parts-per-trillion vapor pressure under ambient conditions. Compared to other explosives, trace detection of RDX is challenging. However, trace detection of RDX has been reported exploiting surface stress [19], luminescence [20], fluorescence [21], calorimetric [22], colorimetric [23], photoacoustic [24], and opto-electronics [25] based transduction methods. Though detection limits of 1 ng have been reported [26], there is a lack of interference testing and experiments to test the suitability of the techniques in field conditions. Further, the potential cost of deployment of the investigated techniques seems comparable to the cost of existing explosives detector.

Reports on electrochemical detection [27] of RDX looks promising due to the possibility of system miniaturization and reduced field deployment cost. As mentioned earlier, the mixed potential gas sensor work driven largely for the need a new types of emissions monitoring sensors for the lean-burn automotive and heavy vehicle markets to meet new emissions standards – has produced a number of advances in durability, cost, and selectivity.

In this work, a planar mixed potential sensor with integrated platinum heater is used in the selective HC and NO_x detection mode. The front end houses a state-of-the-art preconcentrator system [28] (a hand-portable sample collection and preconcentrator device), which, when combined with an appropriate method of detection, is capable of detecting vanishingly faint odors (parts per trillion) of explosives, drugs, and other chemicals. Apart from RDX, TNT and Pentaerythritol tetranitrate (PETN) are used as the analytes to gauge the discrimination capability. Acetonitrile, methanol, and Vitamin E ($C_{29}H_{50}O_2$) are used as negative controls.

2. Experimental

The experimental set-up for explosives detection is shown in Fig. 1A and B. The planar sensor was mounted into custom made