Hydrogenated Diamond
A Low Cost Semiconductor Technology for IED Detection

A. Helwig, G. Müller, and *M. Eickhoff
EADS Innovation Works Germany, EADS Deutschland GmbH
D-81663 München
Germany
phone: +49-89-60728197; fax: +49-89-60724001

e-mail: andreas.helwig@eads.net

*Walter Schottky Institut
Technische Universität München
Am Coulombwall 3
D-85748 Garching
Germany.

ABSTRACT

Improvised explosive devices (IED) represent a new challenge as such explosives can be produced on-site from widely available and unsuspiciously looking raw materials. Compared to military high explosives, IE present much less a detection challenge, as IEs generally have much higher vapor pressures that can potentially be detected using miniaturized electronic nose devices. In this context we have been investigating novel kinds of sensitive layers which are sensitive and selective to acid and base vapors, likely to accompany on-site IED production.

1. INTRODUCTION

The 2006 transatlantic aircraft plot was an alleged terrorist plot to detonate liquid explosives carried on board several airliners traveling from the United Kingdom to the United States [1]. Recipes for liquid explosives can be obtained easily from open sources [2]. Such recipes tell that explosive materials for improvised explosive devices (IED) can be produced with little effort from unsuspiciously looking and widely available chemical base materials. TATP, for instance, requires acetone, H_2O_2 and sulfuric acid, i.e. transparent liquids looking like water upon visual inspection. The threat with IEDs is that explosive materials as such need not be transported over long distances through potentially many inspection points; rather such devices can be built on-site or close to the points of intended use from the raw materials themselves. Prevention of IED attacks therefore may be attained by air monitoring of confined spaces such as aircraft lavatories using miniaturized low-cost semiconductor sensors.

2. IED PRODUCTION

The IED materials of interest fall into two classes (TATP, HMTD, …) and (NG, DNT, EDGN,…). In both cases the backbone molecular structure of the explosives consists of hydrocarbons (acetone, hexamine, glycerine, glycerol,…). In the first group these hydrocarbons need to be treated to prepared peroxide-group containing di- or trimers of the base materials. In the second group of materials, HNO_3 / H_2SO_4 mixtures are used to attach nitro groups to the backbone hydrocarbon molecules [2]. The corresponding

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synthesis reactions are in all cases exothermic, which means, that relatively high and easily detectable vapor pressures of the raw materials, as well as intermediate and end products of the chemical synthesis products should be available for detection. With the likely concentration ranges being in the above-ppm range, threat detection with low cost electronic nose devices seems feasible.

3. ELECTRONIC NOSE DEVICES

Electronic nose devices are often based on arrays of metal oxide gas sensors with different cross sensitivity profiles [3]. Such sensors are sensitive enough to detect gases in the ppm concentration range and they distinguish gases according to their combustibility. For operation metal oxide gas sensors need to be heated to attain surface temperatures on the order of 400°C. In order to reduce the power consumption of such devices there has been a lot of research on micro-heater technologies to reduce their electrical power consumption [4].

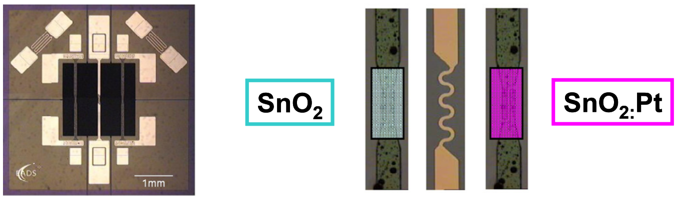

Fig.1: (left) micro-heater chip containing two different kinds of gas sensors and a fast-responding Pt-thermometer; (right) detail view onto the heater bridges.

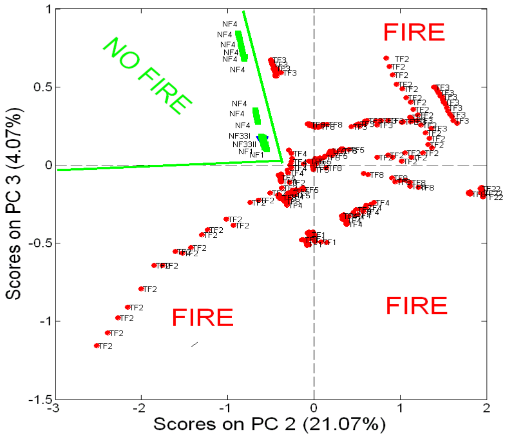

Fig.2: Response of the above gas sensor array towards different fire and non-fire scenarios applied in a range of fire detection tests.

Fig.1 presents an example from EADS where two micro-strip heaters and a rapidly responding Pt thermometer have been integrated into a single silicon chip. The two micro-heaters in turn carry undoped and Pt-catalyzed SnO_2 as sensitive layers [5].

The first one mainly corresponds to heavily oxidizing gases such as O_3, NO_2 and H_2O_2 and the other to H_2 and a wide range of hydrocarbon species including acetone. Both sensors can be heated to operation temperature by a DC electrical power in put of about 100mW. A further reduction by roughly a factor of

10 is possible by applying millisecond heating transients with low duty cycles [6]. Devices, as simple as those shown in **Fig.1**, can be successfully applied to detect smoldering fires in buildings and in other confined spaces. The data in **Fig.2** show that the discrimination power of such a simple two-sensor array is sufficient to distinguish different fire from non-fire scenarios.

Considering the broad range sensitivity of metal oxide sensors and their high sensitivity to gases such as O_3 and NO_2, as well as acetone, miniaturized electronic nose devices are potentially also capable of detecting the illicit production of IEDs in confined and visually unobservable spaces such as aircraft lavatories. Further considering that a low false-alarm rate is of paramount importance, we have been searching for novel sensing materials, which are able to detect acid and base vapors, which accompany IED production, in a background of combustible gases that are easily detected at heated metal oxide surfaces.

4. HYDROGENATED DIAMOND SENSORS

A novel material which holds promise in this respect is hydrogenated diamond (HD) [7]. HD can either be a single crystal or a CVD-deposited thin film in which the surface dangling bonds are terminated by hydrogen. Once operated at room temperature, thin layers of water (~1nm) tend to form on the HD surface by condensation of water molecules from the ambient atmosphere. The interesting feature of HD is that HD, in principle, is electrically insulating and that the adsorbed water layer produces a p-type surface conductivity, which is sensitive to gases in the ambient air that exhibit the potential of electrolytic dissociation. With water-solubility and electrolytic dissociation being the main criteria for detectability, HD sensors are far more selective than metal oxide ones, which probe gases with regard to their combustibility. This latter fact is illustrated in **Fig.3**. **Fig.4** shows in more detail that besides NH_3, also low concentrations of NO_2 can be detected using room-temperature operated sensors. The conductivity change in this latter case is opposite to the NH_3 one. **Fig.5** shows that in addition to NO_2 all other kinds of nitrogen oxides can be detected as well. HD sensors therefore exhibit a remarkable selectivity to nitrogen-containing gases, i.e gases that are likely to accompany the production of IE materials.

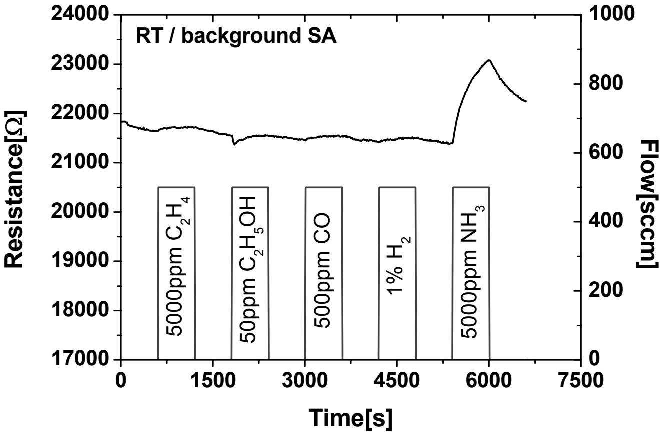

Fig.3: Room temperature response of a HD sample towards a range of combustible gases diluted into a background of synthetic air (SA). A selective response to NH3 is observed.

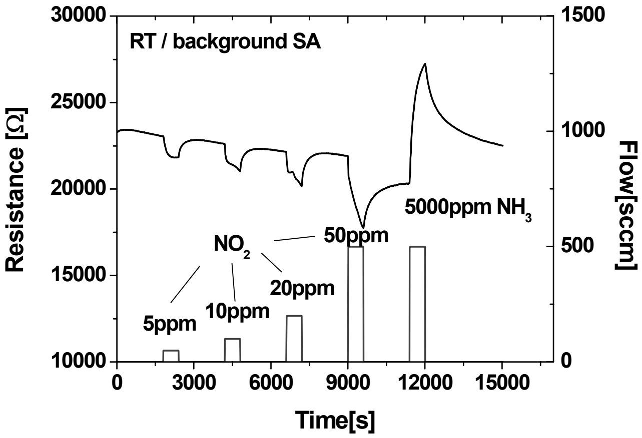

Fig.4: Room temperature response of a HD sample towards different concentrations of NO_2. The response towards a high-concentration NH_3 pulse is shown for comparison.

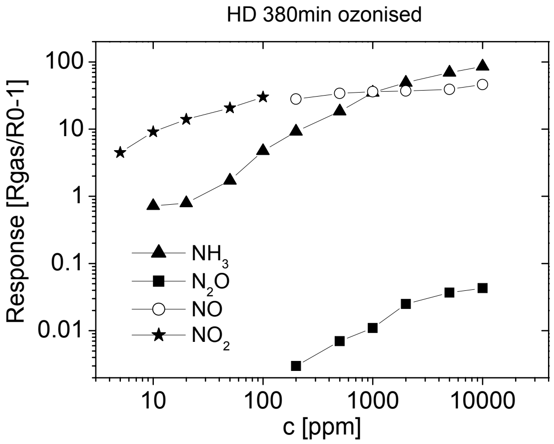

Fig.5: Response of a HD sample with a partially oxygenated surface towards a range of nitrogen-containing gases.

The data above have been obtained in a laboratory environment using a gas test rig. The data in **Fig.6** show a result of a test in a chemical laboratory in which a HD sensor was exposed to acid and base vapors emitted from a chemical laboratory workbench. These latter results clearly support the fact that HD sensors are able to sense acid and base vapors, likely to be emitted during on-site IED production.

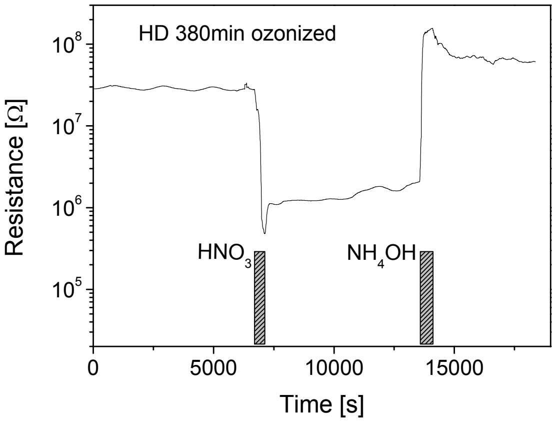

Fig.6: Response of a HD sample with a partially oxygenated surface towards acid and base vapors, generated in a clean-room environment.

Further experiments to be reported on elsewhere [8] show that the speed of response and recovery of these room-temperature operated sensors can be considerably enhanced using low-cost LED light sources.

On the whole, therefore, our results indicate that on-site production of IED devices in confined places, inaccessible to visual observation, can be monitored using miniaturized low-cost semiconductor gas sensors.

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