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Percolation Networks of Polypyrrole for Vapour Sensing of Improvised Explosive Devices

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Summary:
Using chemiresistive vapour sensors based on a percolation network of polypyrrole (PPy) significantly increases the sensitivity compared to more traditional PPy thin film based sensors. At the optimum, close to the percolation threshold, an LOD of 18 ±2 ppb ammonia was achieved. The sensors are also highly sensitive to vapour emitted by the ammonium nitrate/fuel oil (ANFO) mixture, which is commonly used in improvised explosive devices (IEDs).

Keywords: Chemiresistor, vapour sensing, conductive polymer, percolation network, ammonium nitrate/fuel oil (ANFO)

Introduction

Vapour sensing plays an important role in many safety, security, and healthcare applications. Therefore, it is perhaps surprising that despite modern technologies sniffer dogs are still considered the gold standard in vapour sensing. Achieving high sensitivities often remains challenging. Furthermore, existing technological solutions often require relatively large pieces of equipment, or pre-concentration steps [1].

Especially for the detection of improvised explosive devices (IEDs) small sensors with a fast response time are of high importance. Furthermore, they have to be easy to use and if possible be made on flexible or wearable substrates. Conductive polymer (CP) based chemiresistive vapour sensors offer an interesting solution because of the large range of materials available. Furthermore, they are relatively cheap and easy to process, and their small scale makes it possible to use them in small scale devices.

Concept and methods

Traditional conductive polymer based chemiresistors tend to make use of a conductive polymer thin film. Here we demonstrate that by using a percolation network of conductive polymers we can significantly improve the sensitivity compared to a more traditional thin film based sensor. When a sensor is operated close to the percolation threshold, a small number of chemical interactions causes a large change in the resistance of the sensor. This allows for a much higher sensitivity than thin film based sensors that by definition operate in the flatter region of the percolation curve.

The sensors consist of glass substrates with Pt interdigitated electrodes (IDEs). Au nanoparticles (NPs), created between the IDEs by dewetting an Au thin film, are used as nodes in the electrochemically grown PPy network [2][3]. Sensors consisting of various PPy coverages, corresponding to various points along the percolation curve, were created and exposed to 100-700 ppb ammonia. Furthermore, the optimized sensors were exposed to unknown concentrations of vapour emitted by ammonium nitrate/fuel oil (ANFO) samples.

Results

Upon exposure to ammonia the sensors displayed an instantaneous and reversible increase in resistance, where the magnitude of the resistance change is dependent on the ammonia concentration (fig 1a). A comparison of the limits of detection (LODs) of sensors with different polymer coverages shows that there is an optimum at resistances corresponding to the steep part of the percolation curve, close to the percolation threshold. At lower resistances, corresponding to thin film sensors, the LOD is higher. At resistances higher than the optimum the absolute sensor response is higher as well, but due to an increase in noise the sensitivity decreases when the sensor is too close to the percolation threshold. At the optimum we've achieved a LOD of 18 ±2 ppb.

The optimized sensors where also exposed to unknown concentrations of vapour emitted by various ANFO samples, based on different types of fertilizer. The sensing responses to the fertilizer and ANFO samples were similar to the responses to ammonia, which is consistent with

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the sensor response being caused by ammonia emitted by the fertilizer. The sensors do not respond to diesel. By comparing the sensor response to a calibration curve created with the ammonia sensing experiments the ammonia concentration detected as a result of the exposure to ANFO could be deduced. For example, 160 ppb ammonia resulting from an ANFO sample was easily detected. Furthermore, it was found that different fertilisers give different sensing responses.

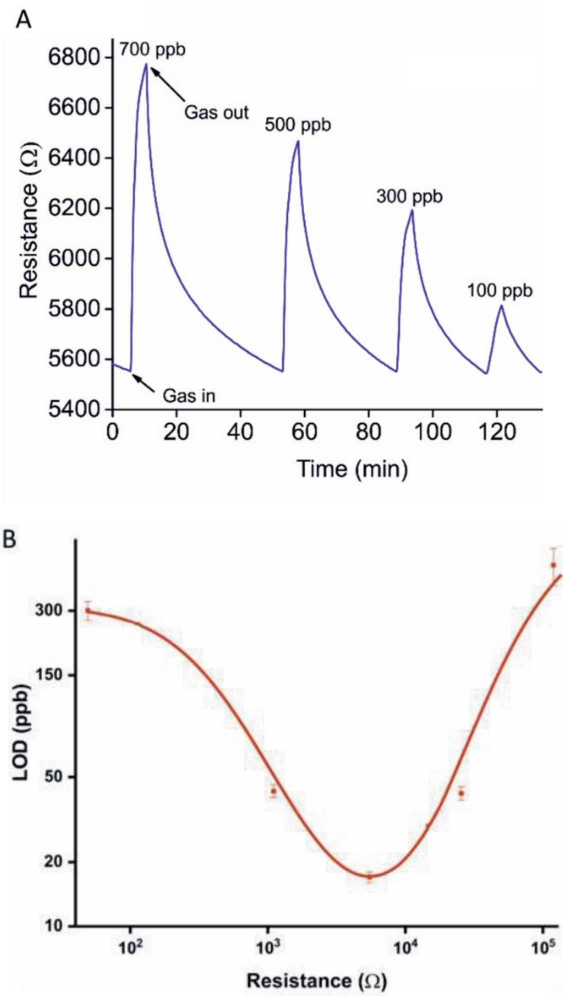

Fig. 1. A) Resistance change as a function of time upon exposing a sensor based on a percolation network of PPy to 700, 500, 300, and 100 ppb of ammonia. The sensor response is instantaneous and reversible. B) The limit of detection (LOD) for sensors with different starting resistances, corresponding to different points along the percolation curve. A LOD of 18 ±2 ppb was achieved at the optimum, which is found at a resistance value corresponding to the steep part of the percolation curve.

Summary and outlook

By using a percolation network of ammonia the sensitivity was significantly improved compared to more traditional thin film based sensors. Sensors operating this way can achieve ppb level sensitivity, making them especially interesting for the detection of IEDs. We have also successfully used sensors based on a percolation network of PPy to detect vapour emitted by ANFO, which is commonly used in IEDs.

Further work includes extending this work to different sensor materials and analyte vapours. And, to improve the potential for practical implementation of these sensors, the development of an integrated device and the development of these sensors on flexible substrates.

References

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