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Noble Metal Decorated Graphene Sensor for Detecting Hydrogen at Room Temperature

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Summary:
This study reports the development of a Pd functionalized graphene-based chemiresistor device for the detection of hydrogen at room temperature. This low-cost graphene device can operate and detect hydrogen efficiently at room temperature and hence has a very low power unlike pellistor-based sensors. Our preliminary data clearly reveal that the sensor can detect hydrogen at concentrations ranging from 0.01 % to 1 % hydrogen in air. This shows the potential of a graphene chemiresistor to be used for detection of hydrogen leaks in, for example H_2-based cars emerging to replace combustion engines.

Keywords: Gas chemiresistor, graphene, hydrogen sensor, chemical sensor.

Background, Motivation an Objective

With the rapid development of diverse technologies, the world is currently experiencing a severe energy crisis. Though non-renewable energy sources are utilized to solve energy shortages, there is an urgent need for green energy to promote the development of a more sustainable environment [1]. Hydrogen is one among the three major energy sources along with solar and nuclear, and it helps to reduce air pollution and global warming due to its zero-emission nature. Furthermore, due to its high abundance and recyclable nature, hydrogen has always been a suitable option for the global green energy system. Although hydrogen has numerous advantages in energy development and other industrial applications such as fuels, transportation, storage, its colourless and odourless properties along with its asphyxiating nature make it extremely difficult for humans to detect leaks. The lower explosive limit (LEL) is 4% hydrogen in air and so is a major fire hazard. Therefore, retaining hydrogen safety as primary consideration, it is very important to design gas sensors with high sensitivity and rapid response time to assure human safety. A plethora of materials have been investigated for the development of hydrogen sensors including nano metal oxides, conducting polymers, carbon nanotubes, graphene and hybrid materials based on combinations of the aforementioned components [2]. Among these materials, metal oxides semiconductors and Pt pellistors are commonly used as the active material in the fabrication of resistive and thermal hydrogen sensors and have been shown to exhibit enhanced sensitivity with a very short response time. However, the main disadvantage is that they can only operate at high temperatures and so require high power consumption. One of the most important considerations in the practical use of hydrogen sensors is that it should be able to function at a possible low temperature to avoid explosions. Recently, graphene-based sensors have grown in popularity for detecting harmful and toxic gases at room temperature because of their ultra-high surface to volume ratio and superior physisorption [3]. Traditionally scalable production of large area graphene devices requires transfer from a copper growth substrate to the product substrate. This process can lead to cracks in the graphene film and can lead to metal and organic residues which damage device performance and increase variability. Paragraf's devices are made from directly deposited graphene. This results in no contamination from polymers or catalysts, and high quality graphene material. However, pristine graphene has been shown to have poor response, but the nanoparticle loaded graphene has shown an enhanced response with excellent sensitivity due to catalytic effect [4]. Here, we investigate the response of a graphene chemiresistor functionalized with a thin layer of palladium (Pd) against a reference uncoated graphene chemiresistor.

Description of the New Method or System

Graphene devices were produced at Paragraf Ltd using proprietary techniques for deposition of graphene directly onto a metal oxide substrate. The graphene was patterned to produce a 94 µm channel contacted through passivated metal

tracks. Dies were cleaved and mounted onto a bespoke PCB with epoxy coated wirebonds contacting the device. For hydrogen sensing studies, pristine and palladium loaded graphene (deposited via e-beam evaporation, 1Å/s, 1 nm) chemiresistor devices were compared

Fig. 1 shows a photograph of the graphene chemiresistor device attached to a small PCB and the pads wire-bonded via an ultrasonic wedge bonder.

Fig. 1. Functionalized graphene chemiresistor *mounted on a carrier PCB for sensor response measurements*

The graphene sensors were placed in a customized chamber, which passes constant current through the source-drain channel to measure its resistance. Up to 8 devices can be tested simultaneously in the automated gas test station, under the control of a National Instruments LabVIEW Virtual Instrument. Graphene resistances were measured using an NI USB 6343 data acquisition system (DAQ) and standard PC computer.

Results

The sensing performance of both pristine and Pd decorated graphene was investigated in the concentration range of 0.01 % to 1 % of hydrogen at RT (Figures 2a and 2b). The response data show that pristine graphene has shown no response to hydrogen in all the concentration range, while the Pd decorated one responded very well in the measured range. The exposure time of hydrogen was set to 5 minutes. The sensor response is defined using the following equation.

$$Response\ (\%) = \left[\frac{R_g - R_a}{R_a}\right] \times 100 \qquad (1)$$

Where R_a is the resistance value measured in air and R_g is the resistance measured in the gas.

The resistance of the Pd decorated graphene sample was found to increase with an increase non-linearly in hydrogen (see Fig 2c). Further studies on the effect of humidity and interfering gases on the sensing response of Pd decorated graphene towards hydrogen are in progress and will be presented in the conference.

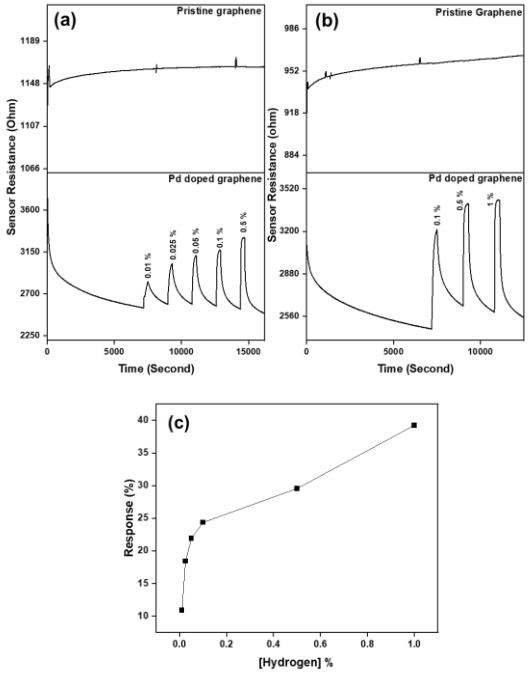

Fig. 2. Time series resistance plots of pristine and Pd decorated graphene at (a) low concentrations (b) high concentrations (c) Plot of sensor response (%) versus % concentration of hydrogen at RT.

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