Platinum nanoparticle chemical sensors on polyimide substrates

E. Skotadis¹, D. Mousadakos¹, K. Katsabrokou¹, S. Stathopoulos¹, D. Tsoukalas¹

¹School of Applied Mathematics & Physics, National Technical University of Athens, Hroon Polytexeioy 9, Athens 15780, Greece

Abstract

A gas sensor formed by a Platinum (Pt) nanoparticle film and a poly(2-hydroxyethyl methacrylate) (PHEMA) polymer layer is discussed in this paper. The Platinum nanoparticles which have been produced by a modified magnetron sputtering technique are deposited on flexible polyimide substrate. The substrate has been initially patterned with gold interdigitated electrodes (IDEs). A second layer of PHEMA polymer has been delivered on top of the Pt nanoparticles using an ink-jet micro printer. By taking advantage of PHEMA’s known susceptibility in alcohol or humidity vapors, chemical gas sensors of varying sensitivity can be produced by controlling the nanoparticle deposition time. As a result an inexpensive alternative to gas sensors using conventional silicon technology can be realized.

1. Introduction

Metallic or semiconducting nanoparticles have been widely used in the area of chemical sensing. Their unique chemical and electrical properties and the possibility to use their molecular capping as a gas sensitive layer renders them as ideal candidates for biological or chemical sensing applications [1]. In our case platinum nanoparticles without any prior chemical modification (“naked” NPs) have been produced using a modified magnetron sputtering system and have been
Nomenclature

NPs nanoparticles
PHEMA poly(2-hydroxyethyl methacrylate)
IDEs inter digitated electrodes

deposited on top of flexible polyimide substrates. These substrates have been patterned with gold IDEs so as to facilitate the electrical characterization of the devices. A layer of PHEMA polymer, which acts as the gas absorption layer [2], has been deposited on top of the nanoparticle layer by means of ink-jet printing. The polymer’s swelling affects the inter nanoparticle distance, inducing a change in the resistance of the device. As a result an inexpensive alternative to gas sensors using conventional silicon technology can be realized expanding results previously reported by this group [3].

2. Experimental

Polyimide substrates having a thickness of 120 μm have been patterned with gold interdigitated electrodes having electrode gaps of 5 μm and 30 μm using conventional optical lithography, the e-gun evaporation of gold and lift-off. As a second step gas phase synthesized platinum NPs were deposited on the polyimide substrates at room temperature using a modified magnetron sputtering technique, where the NP size and surface density can be controlled through the experimental parameters. The NP density was controlled by adjusting the deposition time, which in this case was 13.5 min. Finally 1000 drops of ethyl-lactate solution with 0.5% PHEMA concentration were deposited onto the devices using a 5 Hz printing frequency, resulting in the chemical sensor that can be seen in figure 1. The devices were characterised electrically using an HP4041B picoampere meter. The gas sensing experiments have been performed in a small volume chamber (approximately 4 mm²) where temperature and humidity have been carefully controlled, using humidity as a test gas.

Fig. 1. (a) Microscope image of polyimide chemical sensor; (b) Optical image of flexible polyimide substrate patterned with gold IDEs.
3. Results/discussion

Platinum or gold NPs having unique physiochemical properties (chemical inertness, stability, electron transfer properties, etc.) constitute ideal candidates for chemical or biological sensing applications. On the other hand sputtering is a well known room temperature vacuum technique for the synthesis and deposition of metallic NPs that allows control over the size and density of the produced nanoparticles [4].

In our case by controlling the nanoparticle deposition time, NP films of varying surface density can be produced which can lead to devices of varying base resistance and ultimately of varying sensitivity [3], something that we observed in the case of polyimide sensors as well. The incorporation of flexible polyimide substrates in the sensor’s design has not significantly affected the fabrication process. As can be seen in figures 2(a) and 2(b) sensors having an electrode gap of 5 μm and 30 μm and a base resistance of 30 Ω and 50 Ω respectively, have a well-established chemi-resistive response when exposed to vapours of humidity. The sensors exhibit a fast response and relaxation time, while they are able to detect concentrations of humidity in the range of 5000 ppm to 20000 ppm (corresponding to the detection of relative humidity in the range of: 12% to 47%). It is also worth noting that the sensor having an electrode gap of 5 μm exhibits higher sensitivity when compared to its 30 μm counterpart in agreement with previous results [5].

Fig. 2. (a) Transient resistance response in humidity for a sensor having an electrode gap of 30 μm; (b) Transient resistance response in humidity for a sensor having an electrode gap of 5 μm; (c) Relative resistance response in Humidity.
4. Conclusions

In the past it has been demonstrated by this group that by using conventional oxidized silicon substrates and varying densities of platinum NPs, chemical gas sensors of different sensitivity can be produced. Moreover the sensitivity of the sensors has been connected to their overall resistance which is a measure of the density of the nanoparticle film. In this paper inexpensive polyimide substrates have been successfully incorporated in the sensor’s design without significantly affecting the fabrication process of the sensor, showing promising results regarding the sensor’s chemical response to humidity.

A first approach on the use of polyimide substrates for chemical sensing has been established. Further improvement and study of the device could result in a cost effective sensing device on a par with conventional silicon sensors.

Acknowledgements

This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program “Education and Lifelong Learning” of the National Strategic Reference Framework (NSRF) - Research Funding Program: Heracleitus II: “Investing in knowledge society through the European Social Fund” that supports the author E. S.

References