Talanta 160 (2016) 9–14

Contents lists available at ScienceDirect

Talanta

journal homepage: www.elsevier.com/locate/talanta

Fluctuation-enhanced sensing with organically functionalized gold nanoparticle gas sensors targeting biomedical applications

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ARTICLE INFO

Article history:
Received 13 March 2016
Received in revised form
27 June 2016
Accepted 28 June 2016
Available online 29 June 2016

Keywords:
Organically-functionalized gold nanoparticles
Formaldehyde detection
Fluctuation enhanced sensing
Flicker noise

ABSTRACT

Detection of volatile organic compounds is a useful approach to non-invasive diagnosis of diseases through breath analysis. Our experimental study presents a newly developed prototype gas sensor, based on organically-functionalized gold nanoparticles, and results on formaldehyde detection using fluctuation-enhanced gas sensing. Formaldehyde was easily detected via intense fluctuations of the gas sensor's resistance, while the cross-influence of ethanol vapor (a confounding factor in exhaled breath, related to alcohol consumption) was negligible.

1. Introduction

Numerous volatile organic compounds (VOCs) are produced inside the human body as a consequence of metabolic processes and the lighter blood-soluble VOCs (mainly nonpolar compounds) exchange in the alveoli and are released to the exterior through exhaled breath [1]. When a disease is onset, some VOCs are released in concentrations that are different from those in the normal state, and new VOCs can be also produced and utilized for non-invasive detection of the disease through exhaled breath analysis [1,2]. Formaldehyde is an interesting VOC for such biomedical applications and has been identified as a potential cancer biomarker in exhaled breath [3–5].

In medical applications targeting high-risk populations, screening for early diagnosis of a disease—which may then be easy to treat—by VOC detection requires cheap vapor sensors that are highly sensitive to the VOCs of interest and also tolerant for confounding compounds (e.g., ethanol vapor related to alcohol consumption). Sensors based on monolayer-capped gold nanoparticle (AuNP) films are of much interest and offer several advantages such as low detection limits for nonpolar VOCs, room temperature operation, small dimensions, and low cost [6]. These sensors' sensitivity and selectivity can be tailored by proper selection of their organic functionality, which provides the chemical sensing, while the gold nanoparticles produce electrical conduction through the film. Such sensors can be produced by use of various technologies and exhibit high sensitivity to selected gases—even to a group of the VOCs of present interest [3]. An overview of such gas sensors, based on gold nanoparticles doped with selected dopants (e.g., TiO_2, WO_3) and prepared by various technologies, can be found elsewhere [7–9]. The emerging technologies can be developed rapidly and they can be optimized with regard to cost, improved selectivity and way of gas sensing via DC resistance or the presented fluctuation-enhanced gas sensing.

Adsorption–desorption phenomena involving the sensing material and the sensed VOCs may result in changes of the gas sensor's electrical properties, such as its DC resistance [10] and/or resistance fluctuations [11,12]. Resistance fluctuations are expected to show the highest sensitivity to changes in the ambient atmosphere, because one can expect lower energy expenditure in order to induce fluctuations than to change the DC resistance, and consequently fluctuation-enhanced sensing can be extended to lower gas concentrations than DC-resistance-based sensing [13]. Moreover, DC resistance provides a single parameter whereas resistance fluctuations can be characterized, typically, by a power spectral density (PSD) which is a function of frequency and

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http://dx.doi.org/10.1016/j.talanta.2016.06.063
0039-9140/

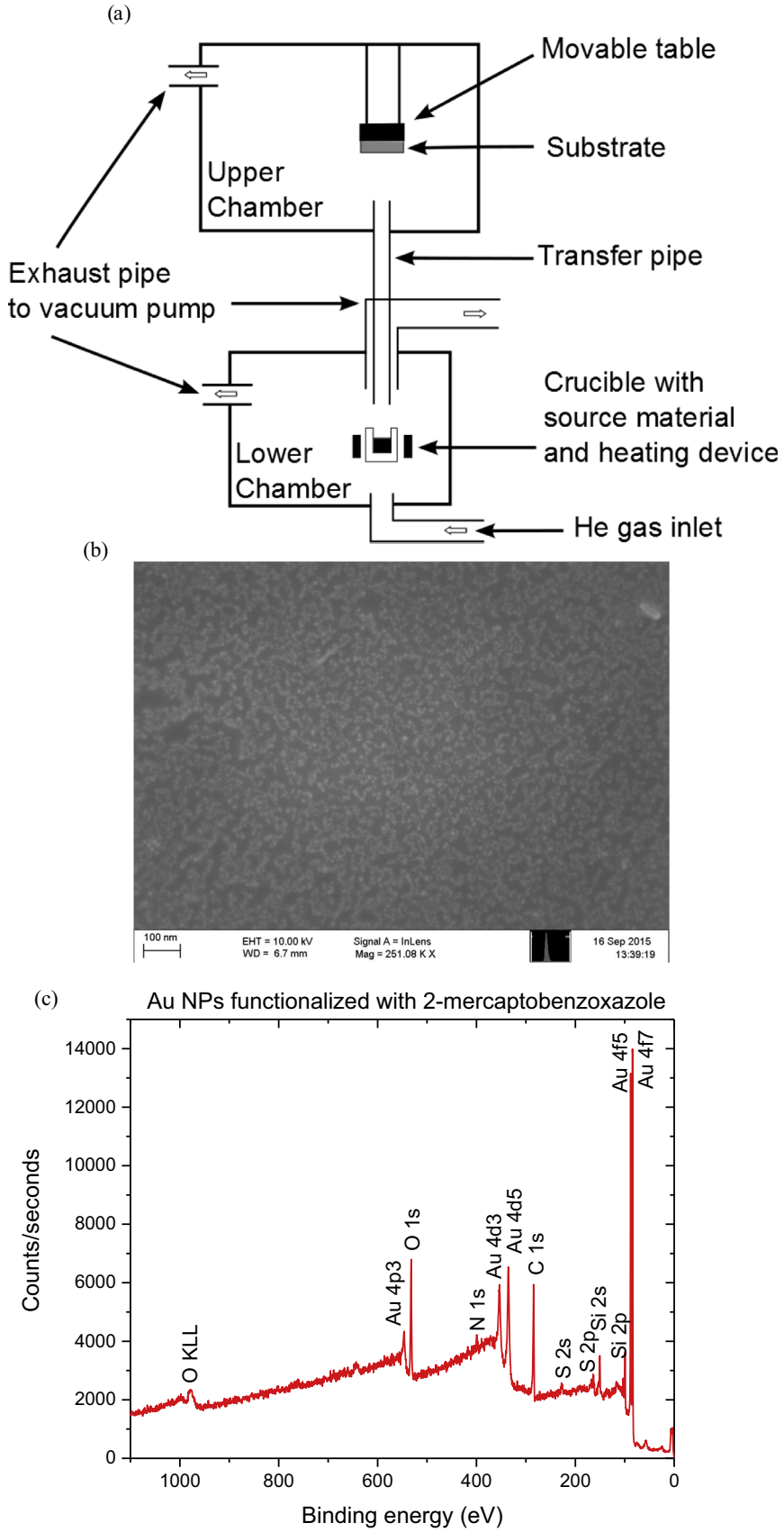

Fig. 1. (a) Schematic representation of the AGD equipment used for ultra-pure AuNP synthesis. (b) SEM image (top view) of a layer of AuNPs functionalized with 2-mercaptobenzoxazole. (c) XPS spectrum for a layer of functionalized AuNPs.