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Abstract

LIG/ZnO/Porphyrin-Functionalized EGFET-Based Electronic Tongue †

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Abstract: The use of laser cutter machines to produce porous graphene films is an innovative method for a low-cost production of flexible electrodes for electronics and sensing applications. Here, laser-induced graphene (LIG) is used to produce the gate electrodes of EGFET sensors. LIG electrodes and LIG electrodes functionalized with ZnO and metalloporphyrin-coated ZnO are used as elements of the electronic tongue. The array is tested in a classical experiment aimed at identifying complex food matrices, such as fruit juices. The results demonstrate the feasibility of the approach and provide a solid basis for further array developments.

Keywords: electronic tongue; extended gate FET; laser-induced graphene; ZnO; porphyrins

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1. Introduction

The use of field effect transistors as sensors for chemicals in solution is a staple of current chemical sensor technology. After the first introduction of the ISFET by Piet Bergveld in 1970, several variations on the theme have been proposed. Among them, the extended gate FET (EGFET) is particularly attractive because it makes use of standard commercial MOSFET devices which do not require the manufacture of the transducer itself. Thus, the sensor development can only be focused on the sensitive material. Recent implementations of the EGFET concept include the use of nanostructured inorganic materials for the non-enzymatic detection of glucose [1]. In this paper, we investigated the sensing properties of laser-induced graphene (LIG) electrodes as an extended gate. LIG was further functionalized by ZnO nanoparticles and metalloporphyrin-coated ZnO nanoparticles. A minimal array of four sensors was prepared and applied for the identification of fruit juices. The results show that EGFET devices and LSG electrodes provide a valid technological combination for the development of electronic tongues.

2. Materials and Methods

LIG electrodes were prepared on Kapton using a computer-controlled CO_2 laser cutter [2]. ZnO nanoparticles and metalloporphyrin-ZnO-capped nanoparticles were prepared by a hydrothermal method [3]. LSG electrodes and functionalized LIG electrodes were used as the gate electrodes of MOSFET devices. The common gate voltage was applied to a saturated calomel electrode. Figure 1 shows the electrical connections and the sensor bias circuits. Juices bought over the counter were used to test the identification capability of complex samples. Of the juices, 30 µL was added in 10 mL of a 1X PBS buffer solution. Each juice was measured four times in a random sequence.

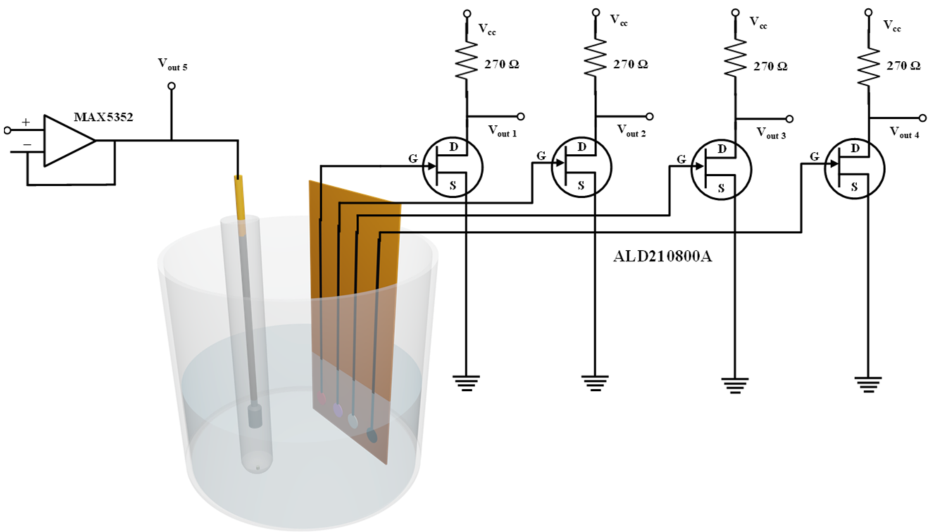

Figure 1. Experimental setup and electronic circuits.

3. Results and Discussion

Figure 2 shows a typical sensor signal. The time evolution of the signal depends on both the individual sensor response time and the diffusion time of the molecules from the drop of juice. To limit the discrepancies due to diffusion, the sensors were placed symmetrically in the container.

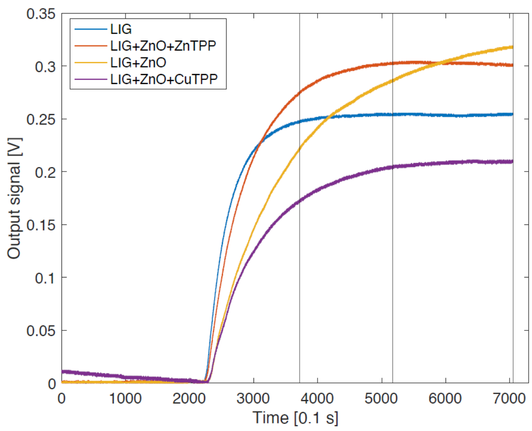

Figure 2. Example of normalized sensor signals during exposure to orange juice. Vertical lines indicate the times at which the features are calculated.

The response of each sensor was evaluated considering the steady signal and the signal evaluated at 30% and 60% of the total exposure time. Signals were normalized by subtracting the sensor signal immediately before the juice drop spiking. Eventually, three features per sensor were extracted.

Figure 3 shows the results of the principal component analysis (PCA) of the responses of sensors to four replicas of each sample. The score plot shows that despite a residual sparsity of the repeated measurements, the juices were correctly discriminated. The correspondent loading plot shows the implementation of the sensor array principles where each sensor points toward different directions. It is interesting to observe that the largest difference occurs between the bare LIG and ZnO, while the two metalloporphyrins provide a similar contribution to the first two principal components.

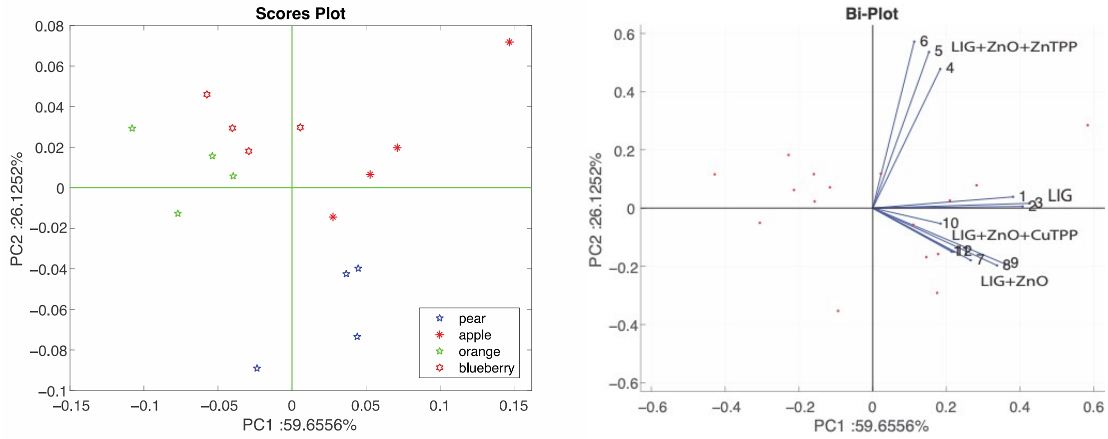

Figure 3. PCA of the sensor signals is represented by the first and the second principal components that account for about 85% of the total variance. Left side: score plot; right side: loading plot; each sensor is represented by three features.

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