

Development of a transistor-based gas sensor for biomedical applications

Dieu-Linh NGUYEN¹, Thi-Thu VU², Benoît PIRO¹

¹ ITODYS Laboratory, CNRS UMR 7086, Université Paris Cité, 15 rue Jean-Antoine de Baïf, 75013, Paris, France

² University of Science and Technology of Hanoi (USTH), Vietnam Academy of Science and Technology (VAST), 18 Hoang Quoc Viet, Cau Giay, 100000 Hanoi, Vietnam

Corresponding author: piro@u-paris.fr

Summary:

In this PhD's project, we aim to fabricate a transistor-based gas sensor for screening and analysis of human volatile organic compounds (VOCs) which are exhaled or emitted from human body odor. With the use of porous polyaniline (PANI) as the channel material, decorated with catalytic nanoparticles (PdNPs, PtNPs), the response of the sensor while being exposed to targeted gas molecules is relatively high.

Keywords: Gas sensor, gas sensor array, printed electronics, organic electrochemical transistors, biomedical application, volatile organic compounds.

Title

Development of a transistor-based gas sensor for biomedical applications.

Background, Motivation and Objective

The human body can generate a variety of volatile organic compounds (VOCs), which could be exhaled gas or emitted gas from body odor [1], [2]. The profiles of human VOCs can reflect underlying pathological and metabolic processes, subtle alterations of their compositions and concentrations might indicate some health conditions, such as lung cancer, diabetes, kidney dysfunction, and inflammatory diseases [2], [3]. Therefore, human VOCs have emerged as non-invasive biomarkers for health monitoring and early diagnosis. The use of gold-standard, traditional analytical methods like gas chromatography-mass spectrometry (GC-MS) might offer good selectivity and sensitivity; however, they are limited by their specialized operations, complications, and high cost. Therefore, with an emerging interest in the development of point-of-care devices, we would like to develop a compact gas sensor array that could operate like an electronic-nose system by combining the arrays of selective sensing transistors, with pattern-recognition or machine learning algorithms to study the complex VOCs mixture. Among several gas sensing platforms such as chemiresistors, optical-based sensors, electrochemical sensors, we would like to investigate a sensor array that is transistor-based. Owing to the advantages of signal amplification, low operating

voltage, and room-temperature operation conditions. Within this context, we study a sensor array that is based on organic electrochemical transistors (OECTs) using conducting polymers as the channel material, and with some catalytic NPs (PdNPs, PtNPs) for hydrogen gas and ethanol gas detection, respectively.

Description of the New Method or System

The sensor array composed of 8 side-gate transistors was fabricated by photolithography and gold evaporation. Thereafter, the PANi channel and catalytic NPs were electrodeposited by cyclic voltammetry approach. For the electrical characterizations and gas sensing studies, the sensor array was operated in the form of a solid-state transistor, with an acidic gel electrolyte deposited on top of each transistor, covering all the gate and the channel. The gel electrolyte was printed by direct ink writing method using a Kelenn DMD100 ink-dispensing printer. A 3D-printed gas chamber was installed for gas sensing experiments. Preliminary results indicate that the gas sensor shows a promising response to hydrogen and ethanol, with high sensitivity.

Results

Polyaniline (PANI) nanofibers were electrochemically deposited on the channel by cyclic voltammetry approach with a deposition staircase of -0.2 V to 0.8 V; 50 mV/s, 5 cycles in 0.1 M aniline in 0.5 M H₂SO₄ solution. Also, PdNPs catalytic NPs were electrodeposited by scanning from the same CV staircase in 2 mM PdCl₂ in 0.1 M

$\text{H}_2\text{SO}_4 + 0.2 \text{ mM HCl}$ solution. To increase the working area of the gate electrode, PANi was also deposited on the Au gate; thus, the gate capacitance will increase, that will further improve of the gating effect of the OECT. For all the electrical characteristic and gas sensing studies, an acidic gel of PVA and H_2SO_4 (1 M) was printed on the side-gate transistors by direct ink-writing method. Electrical studies on PANi-based OECT (with PANi redox active gate) exhibits the ambipolar signature of PANi, which resulted from the redox-state switching of PANi itself with varying gate voltage applied. After the decorations of NPs, although the inhibit the gating effect of the system, they promotes better selectivity towards gas molecules. Preliminary tests on gas sensing study were conducted with a 3D printed gas chamber with H_2 gas collected from a PEM Hydrogen generator machine (provided by Domnick Hunter). The gas sensing was studied by monitoring I_{DS} as a function of time while applying a fixed drain voltage (V_{DS}) bias and gate voltage (V_{GS}) bias at 0.2 V. Initial studies with PdNPs@PANi-based sensor on the array exhibited a high selectivity with high response% value to hydrogen gas. The response% was calculated by:

$$\text{Response} = \frac{I_{\text{air}} - I_{\text{gas}}}{I_{\text{air}}} \times 100\%$$

Figure 1 below shows significant responses of H_2 on PdNPs@PANi-based sensor. PdNPs are known to exhibit a selective sensing activity towards hydrogen based on the spill-over effect. As a reducing gas, H_2 will be adsorbed on PdNPs, dissociated into H atoms, forming PdHx

and released electrons. The electrons released from PdNPs then will reduce PANi, making PANi become deprotonated, and decrease the conductivity of the material. Thus, the I_{DS} obtained while being exposed to H_2 decreased. The PdNPs@PANi-based sensor exhibited response% of 97%, with an estimated response time of 20s and recovery time of 50s.

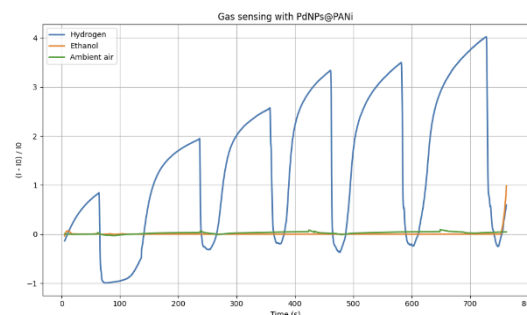


Fig.1. Normalized signal of gas sensing study with PdNPs@PANi transistor with hydrogen, ethanol, and ambient air.

References

- [1] P. C. Moura, M. Raposo, and V. Vassilenko, "Breath volatile organic compounds (VOCs) as biomarkers for the diagnosis of pathological conditions: A review," *Biomed. J.*, vol. 46, no. 4, p. 100623, Aug. 2023, doi: 10.1016/j.bj.2023.100623.
- [2] A. Amann *et al.*, "The human volatilome: volatile organic compounds (VOCs) in exhaled breath, skin emanations, urine, feces and saliva," *J. Breath Res.*, vol. 8, no. 3, p. 034001, Jun. 2014, doi: 10.1088/1752-7155/8/3/034001.
- [3] N. Nasiri and C. Clarke, "Nanostructured Chemiresistive Gas Sensors for Medical Applications," *Sensors*, vol. 19, no. 3, p. 462, Jan. 2019, doi: 10.3390/s19030462.