

Design of a contamination-free microfluidic device for Electrolyte-Gated Organic Field-Effect Transistor (EGOFET) biosensors

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Abstract

In this work a new microfluidic platform is designed and validated to remove analyte contamination problem in EGOFETs biosensors.

Introduction

In recent years, Electrolyte-Gated Organic Field-Effect Transistors (EGOFETs) were proved to be good candidates for the next generation of biosensors, given their ability to detect biomarkers at very low concentrations through a specific functionalization of the gate electrode, opening the possibility to treat patients at the early stage of the disease.¹ However, the use of EGOFETs as commercial biosensors is so far mainly limited by the poor reliability of the organic material, which is caused by different factors that are subject of numerous studies.² Among them, the unwanted doping of the polymer upon the exposure to different analytes is one of the most important operational limits. This problem arises because the organic material and the gate electrode must be immersed in the same buffer, thus when exposing the gate electrode to the analyte, the polymer may be contaminated, too. This issue is usually overcome with a removable functionalized gate that is taken away from the device, incubated in the buffer containing the analyte, rinsed and placed back in the device for the measurement.³ Despite this technique avoids any contamination of the polymeric material, it is evident that a transla-

tion of this configuration from a research level to a real diagnostic device is not possible. Aiming to solve this issue, in this work the concept of a contamination-free microfluidic device integrating an EGOFET biosensor is presented. A finite element simulation through COMSOL Multiphysics® software was performed to evaluate the diffusivity of a biomolecule such as BSA (Bovine Serum Albumin), in order to validate the design.

Materials and Methods

The main concept of this design is to separate the organic material and the gate electrode in two different chambers connected through a small bridge. The microfluidic platform consists in two inlets (one for each chamber) and one outlet, which is placed in correspondence of the gate chamber (Figure 1).

The blank buffer (*i.e.* without the analyte, thus not doping the organic material) is firstly loaded with a syringe from Inlet 1 until it fills completely the whole device. Then, a second syringe containing the buffer with the analyte is plugged in and starts filling the chamber from Inlet 2. Since Inlet 1 is still plugged with the syringe containing the blank buffer, this results in a high fluidic resistance: the buffer with the analyte will then flow straight to the outlet through the gate chamber, so that the organic material is always exposed to the same blank buffer. In the same way, it is possible to perform a rinse of the gate electrode by simply loading additional blank buffer from Inlet 1, which will pass through the gate chamber to the outlet.

To validate this design, a finite element simulation was performed exploiting COMSOL Multiphysics® software. The goal of the simulation was to prove if a target biomolecule (in this case BSA) would diffuse to the organic material during operation because of a concentration gradient. A 2D model of the chamber was used to lower the computational efforts and a laminar flow was imposed. A flow from Inlet 2 was imposed for 5 minutes, after which it was stopped to allow the incubation of the analyte on the gate. The values used in the simulation were: 3.3×10^{-3} m/s for the fluid flow (corresponding to 200 μ L/min in the 3D structure), 15 minutes for the incubation time, 1 nM for the analyte concentration and 1.5×10^{-12} m²/s for the isotropic diffusivity constant of BSA.⁴

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Key words: Microfluidics; simulation; biosensors; EGOFET.

Acknowledgments : The present work was performed in the framework of the POLITO BIOMed LAB, financed by Politecnico di Torino. The activity was also financed by DEFLECT ("Advanced platform for the early detection of not small cells lung cancer") project, financed by Piedmont Region in the framework of "Health & WellBeing" Platform project and by FOOD-DRUG-FREE project, financed by the Piedmont Region in the framework of the "FOOD-DRUG-FREE" Platform project.

Conference presentation: This paper was presented at the Third Centro 3R Annual Meeting - L'era delle 3R: modelli *in silico*, *in vitro* e *in vivo* per promuovere la ricerca traslazionale - 30 September - 1 October 2021, Evento online organizzato dal Politecnico di Torino.

Received for publication: 9 July 2021.

Accepted for publication: 7 September 2021.

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Biomedical Science and Engineering 2021; 4(s1):191

doi:10.4081/bse.2021.191

Results

The simulations results are reported in Figure 2. It is possible to notice that at the beginning (Figure 2a) there is not BSA at all in the chamber. After 5 minutes of flow, the BSA at the targeted concentration (1 nM) is present only inside the gate electrode chamber, as expected (Figure 2b). Finally, after an incubation time of 15 minutes, it is clear that BSA did not diffuse into the other chamber, which validates the microfluidic design (Figure 2c).

Discussion and Conclusions

The developed microfluidic platform was proven to meet the requirement of the lack of contamination of the organic material. The great results must be also attributed to the low value of the diffusivity constant of BSA, which makes diffusion extremely

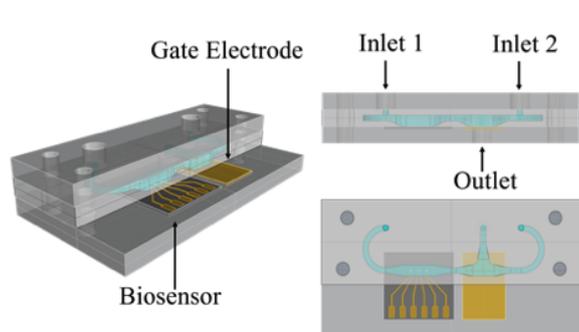


Figure 1. 3D model of the microfluidic platform.

slow. Further simulations may concern other relevant biomolecules to assess their diffusion, keeping in mind that the microfluidic platform may be tuned to different diffusivity constants by modulating the bridge length to ensure a more efficient separation between the two chambers.

References

1. Sensi M, Berto M, Gentile S, et al. Anti-drug antibody detection with label-free electrolyte-gated organic field-effect transistors. *Chem Commun* 2021;57:367.
2. Sharma A, Mathijssen SGJ, Kemerink M, et al. Proton migration mechanism for the instability of organic field-effect transistors. *Appl Phys Lett* 2009;95:253305.
3. Mulla M, Tuccori E, Magliulo M, et al. Capacitance-modulated transistor detects odorant binding protein chiral interactions. *Nat Commun* 2015;6:6010.
4. Xu T, Fu R. Determination of effective diffusion coefficient and interfacial mass transfer coefficient of bovine serum albumin (BSA) adsorption into porous polyethylene membrane by microscope FTIR-mapping study. *Chem Eng Sci* 2004;59:4569.

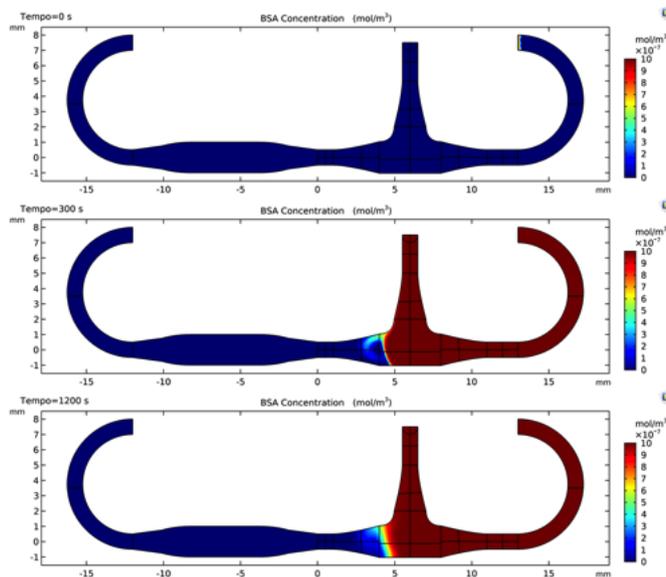


Figure 2. Concentration levels of BSA inside the chamber at the beginning (a), after injection (b) and after the incubation time (c).