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XXXV Cycle

Organic transistors for health science applications

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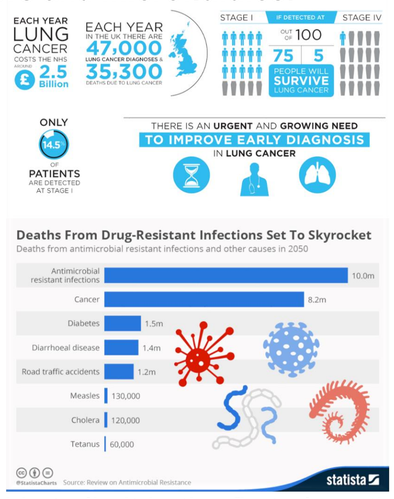
Research context and motivation

- Nowadays there is an always increasing demand of new and diffused sensing elements able to constantly monitor our world. Thanks to the exploitation of nanotechnologies, it is in fact possible to get access to new relevant information, as well as to create tools able to process the data with a lower cost and in a less amount of time.
- In the frame of two different projects, this work is aiming to provide new tools for the detection of relevant molecules exploiting **organic transistors** and **microfluidics**.
- The first project is called DEFLeCT ("Digital technology for lung cancer treatment"). Lung cancer is by far the deadliest kind of tumor in the world and currently there is not a screening procedure to identify it at early stages, yet. Thus, this project aims to develop a platform for the recognition of non-small lung cancer cells at an early stage to guarantee better treatments and a higher patient's life expectancy.



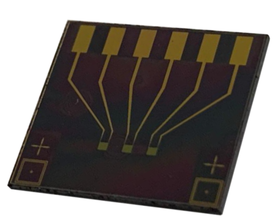
- The second project is called FDF ("Food Drug Free"). Antibiotic resistance has been recognized as the "illness of this century" and it is expected to kill more people than cancer by 2050. The only effective way to prevent its spread is to limit in the first place the use of antibiotics, especially in the farming sector. The goal of this project is to provide a fast and portable analysis tool capable of detecting the presence of antibiotics in raw food - such as honey, milk and eggs – when they exceed the limits dictated by law.

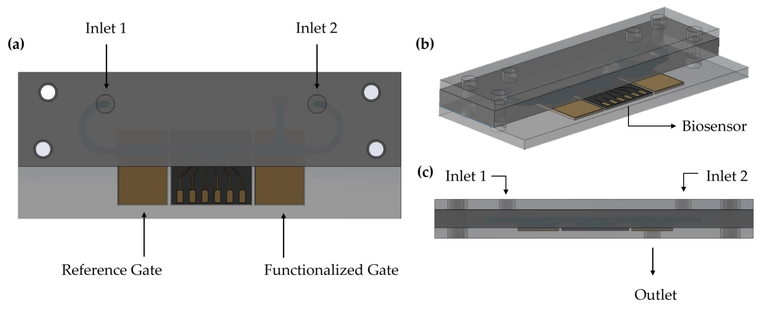
Addressed research questions/problems

- The main idea is to develop a unique tool to detect different kind of targets - more specifically proteins and some antibiotics families -, which could have quite dissimilar characteristics, thus increasing the complexity of the project.
- Given the final applications, all the targets of interest will be dispersed in an aqueous-based medium, which means that the sensing platform should allow liquid handling and manipulation.
- The new sensing platform should be portable and disposable, thus cheap and requiring a low amount of power. At the same time, it should be quite rapid while guarantying a high sensitivity.

Adopted methodologies

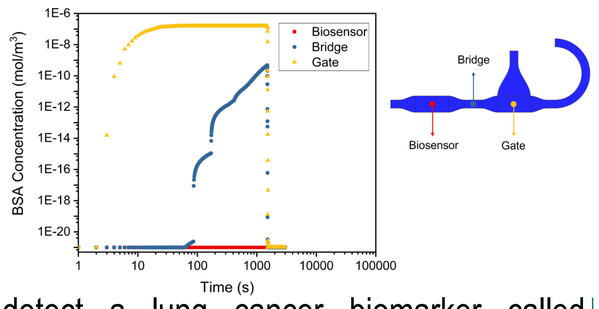
- A modular configuration was chosen for the sensing platform, which is constituted by three parts: the sensing unit, the functionalized electrode and the microfluidic structure.
- The sensing unit is the core of the platform and it is constituted by an **Electrolyte-Gated Organic Transistor** (EGOT), whose current can be modulated by the specific binding of an analyte onto an electrically active surface. It operates directly in liquid through the application of low voltages (less than 1 V) and it has **P3CPT** as the active material.
- The gate electrode acts as the functionalized electrode. It is physically separated from the sensing unit - thus allowing an accessible functionalization protocol –, while the electrical contact is guaranteed through the electrolyte. A thiol-based chemistry is exploited for the functionalization in addition to antibodies or aptamers (depending on the target).
- The microfluidic structure integrates all the other parts and ensure the access to the sensor unit, as well as the correct liquid handling, which is displaced through external motorized syringe.



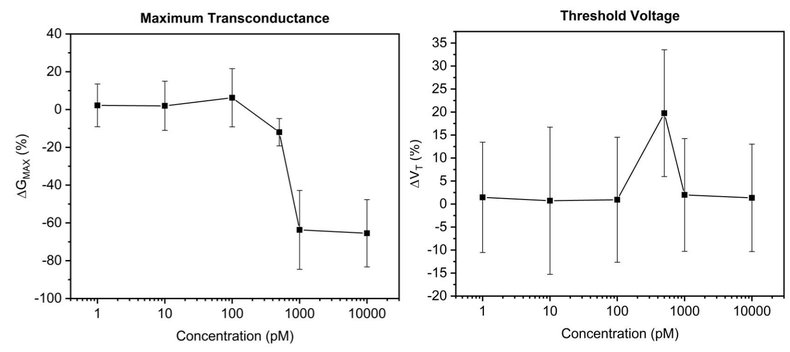


Novel contributions

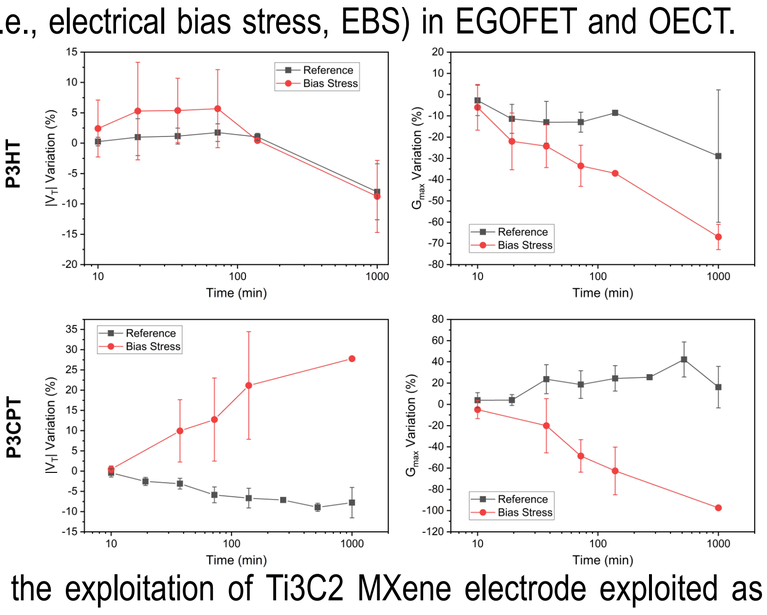
- In the state of the art, the analyte incubation onto the functionalized gate is made externally in order not to contaminate the sensor with the same analyte, which makes impossible to exploit these systems in real sensing application. In this work a novel microfluidic configuration consisting in two separate inputs was designed to avoid this problem. As proven by the fem simulations, during a standard operation protocol the analyte never contaminates the sensing element, ensuring a reliable readout of the measurement.



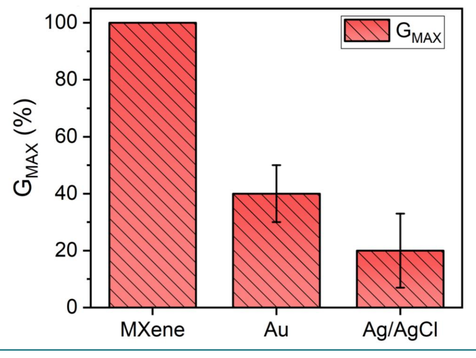
- The sensing platform was exploited to detect a lung cancer biomarker called **Angiopoietin-2** (Ang-2). For the first time with an electrochemical-based sensor, this biomarker was detected at **concentration lower than 1 nM**. While the threshold voltage did not change, the maximum transconductance showed an abrupt decrease in the region between 0.5 nM and 1 nM, meaning that the transduction mechanisms is prevalently given by a change in the system capacitance.



- A major work was done for the understanding of the root causes of the sensor instabilities caused by the applied voltage (i.e., electrical bias stress, EBS) in EGOFET and OECT. It resulted that EBS decreases transistors performance thanks to the **creation of trap states**. This effects is more dramatic on OECTs, since the carboxylic groups favor polymer oxidation. Interestingly, EBS effects are partially reversible in P3HT (EGOFET) while totally irreversible in P3CPT (OECT), always related to **oxidative events**.



- The last contribution concerned the exploitation of Ti3C2 MXene electrode exploited as gating material to enhance the sensing unit sensitivity. It was found that the interesting MXenes properties – such as ion intercalation, high conductivity and surface micro structurizations – increased dramatically the gate capacitance, thus **increasing its current modulation of about 60% and 80% than gold and silver-chloride electrodes**, respectively.



Future work

- Study of the polymers and electrodes capacitances through electrochemical measurements (i.e., C-V, EIS).
- Biosensing tests with MXene as gate electrode and functionalized P3CPT to obtain ultra-sensitive biosensors.

List of attended classes

- 01UKHKI – Applied spectroscopic methods (15/06/2020, 27h, 45 credits)
- 01UJTIU – Control and data acquisition automation in scientific experiments (15/2/2021, 10h, 17 credits)
- 01UNRRV – Entrepreneurship and start-up creation (03/07/2020, 40h, 67 credits)
- 01SZPKG – Introduzione alla microscopia elettronica (29/09/2020, 22h, 37 credits)
- 01MLHKG – Microscopia a scansione di sonda per la fisica e l'ingegneria (19/06/2020, 42h, 70 credits)
- 01SFURV – Programmazione scientifica avanzata in Matlab (27/04/2020, 28h, 37 credits)
- 01QSXRU – The measurement of electrical impedance (10/03/2021, 10h, 17 credits)

Submitted and published works

- Segantini, M., Martiri, A., Meschini, S., "*Analysis of road accidents fatalities: The impact of socio-economic factors and innovative solution strategies*", CERN IdeaSquare Journal of Experimental Innovation, 4 (2), pp. 2-6, 2021.
- Segantini, M., Parmeggiani, M., Ballesio, A., Palmara, G., Frascella, F., Marasso, S.L., Cocuzza, M., "*Design of a Portable Microfluidic Platform for EGOT-Based in Liquid Biosensing*", Sensors, 22 (3), art. no. 969, 2022.
- Segantini, M., Ballesio, A., Palmara, G., Zaccagnini, P., Frascella, F., Garzone, G., Marasso, S.L., Cocuzza, M., Parmeggiani, M., "*Investigation and Modeling of the Electrical Bias Stress in Electrolyte-Gated Organic Transistors*", Advanced Electronic Materials, 8 (7), art. no. 2101332, 2022.

Politecnico di Torino

PhD program in
Electrical, Electronics and Communications Engineering