Influence of Planar Organic Electrochemical Transistor Device Geometry in the Characterization of Barrier Tissue

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Introduction:

The interfacing of electronics with biological systems, using novel organic materials that are easily processed, have soft mechanical properties, and the ability to conduct both ions and electrons, has led to endless applications in the field of bioelectronics. Organic electrochemical transistors (OECTs) are one application of this innovative technology [1].

Our aim for this project was to take various geometric aspects of the OECT, diagramed in Figure 1, and evaluate the effects the variable had on the electrical characteristics of the transistor and in the characterization of barrier tissue. Planar OECTs offer the advantages of a simple fabrication process — cells can be seeded directly on top of the transistor and the electrical and optical characterization can be correlated since the device is fully transparent. The p-type semiconductor poly(3,4-ethylened ioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) was used as the active layer for the gate and the channel. The contacts were made of gold [2]. When a positive voltage was applied to the gate, the cations, from the cell media, were pushed into the PEDOT:PSS channel layer. The film was thus dedoped, becoming less conducting.

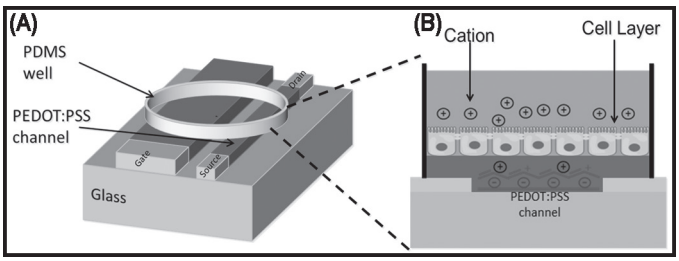

Figure 1: (A) Schematic of the planar OECT with PEDOT:PSS gate and channel on the same plan. (B) Cross section of the OECT sensor with cells grown on it. The presence of this cell layer modulates the flux of ions that can penetrate in the PEDOT:PSS channel.

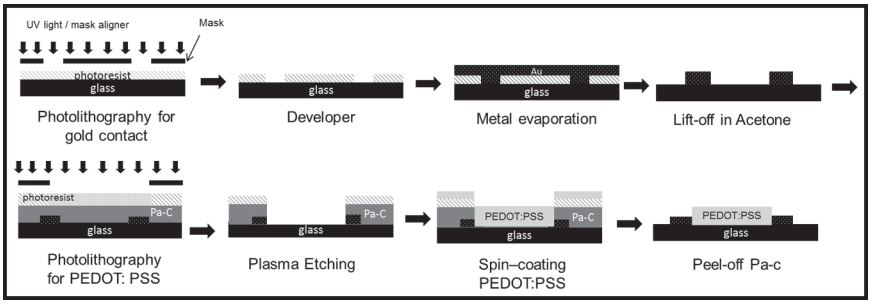

Figure 2: Organic electrochemical transistor fabrication process.

Madin-Darby canine kidney (MDCK) epithelial cells were grown on top of the transistors imitating barrier tissue, which regulates the passage of ions, nutrients, and pathogens through both transcellular and paracellular transportations. Barrier tissue integrity was electronically measured by the OECT and the optimal device geometry was determined.

Device Fabrication:

For the fabrication of planar OECT, shown in Figure 2, glass substrates (75 mm × 25 mm) were obtained, cleaned, spin-coated with S1813 photoresist, and patterned with the desired device geometry using photolithography. The substrates were developed in MF-26 developer. Using the metal evaporator, 10 nm of chromium and 100 nm of gold, was deposited on the surface. Acetone and sonication was used to remove the photoresist and excess gold, leaving patterned substrates. A 2 μm layer of Parylene C was deposited. Then AZ-9260 photoresist was spin-coated. The substrates were again exposed to UV-Light for PEDOT:PSS patterning. With the plasma etcher, areas without photoresist were removed. PEDOT:PSS was deposited on the substrates with the spin coater and the Parylene C layer was then peeled off, removing photoresist and PEDOT:PSS that was not attached to the glass substrate. The substrates were hard baked for 30 minutes at 140°C and PDMS wells where attached to each pixel on the transistor.

Characterization of OECT:

For the electrical characterization of the OECT, a probe station and a Keithley 2612 Source Meter were used. The channel current modulation under a pulsed gate was measured and the highest modulation was expected.

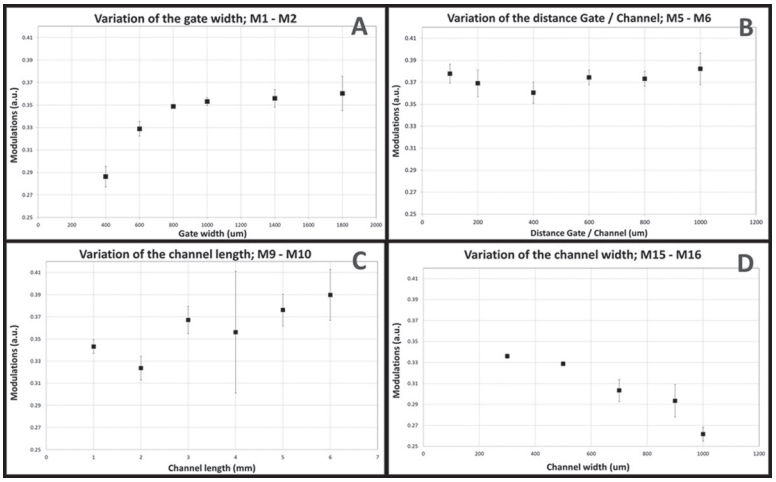

Figure 3: OECT electrical characterization, showing average and standard deviation of the modulation. A) Gate width variance (400-1800 µm), B) Distance between gate and channel variance (100-1000 µm), C) Channel length variance (1-6 mm), and D) Channel width variance (100-1000 µm).

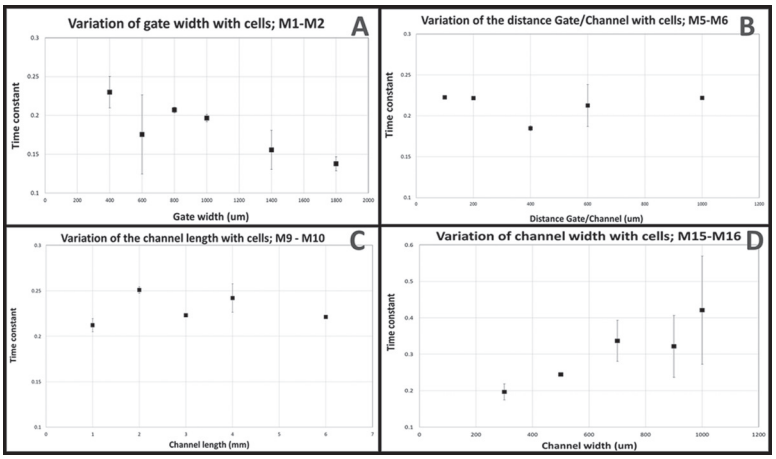

Figure 4: Characterization of barrier tissue. Average and standard deviation of Tau value are shown. A) Gate width variance (400-1800 µm), B) Distance between gate and channel variance (100-1000 µm), C) Channel length variance (1-6 mm), and D) Channel width variance (100-1000 µm).

Data for each varying parameter was obtained, the modulation graphed and standard deviation calculated (Figure 3). The same procedure was used for the characterization of the barrier tissue of MDCK cells at Day 6, according to OECT geometry. With MDCK cells, instead of modulation, the time constant Tau was used as a figure of merit representing the speed of the dedoping / doping of the channel layer. The highest Tau was expected and the data obtained was graphed in Figure 4 along with the standard deviation.

Results and Conclusions:

Varying geometric aspects of the OECT were evaluated, and the effects the variable had on the electrical characteristics of the transistor barrier tissue were observed. It was found that, initially, transistors without the layer of cells required a minimum gate width of 800 μm to dedope the PEDOT:PSS in the channel effectively (Figure 3A). From the graph of modulation versus the varying the distance between the gate and channel, in Figure 3B, it was concluded that this parameter had no effect on the success of the transistor. With an increase in channel length, an increasing trend was observed indicating that more charges were involved (Figure 3C). Increasing the channel width reduced the modulation because the ratio of the gate to channel did not remain consistent and there were not enough ions to fully dedope the channel.

In the presence of a cell layer, increasing gate width reduced the Tau value (Figure 4A) indicating that a larger gate was required in order to push ions through the cell barrier. Variation of the distance between the channel and gate and of the channel length did not have an effect on the Tau value (Figure 4B and 4C). Increasing the channel width improved the Tau value (Figure 4D) leading to the conclusion that with a larger channel covered with cells, it takes longer for the ions to be passed through the cell barrier.

Overall it can be concluded that in both sets of data, channel and gate width have a large and opposite effect on the OECT biosensor illustrating the importance of the (gate / channel) aspect ratio. An aspect ratio (area gate / area channel) of 8 is a good tradeoff between high enough modulation and Tau value, effectively dedoping the PEDOT:PSS while still monitoring small changes in the barrier tissue integrity. The distance between the gate and the channel does not affect the modulation or the time constant. When increasing the channel length, the modulation increases without increasing the Tau value, because there is an increase in the number of charges. The fact that the Tau value stays constant demonstrates the independence of the sensibility (represented by Tau) to the length and by extension to the area of the OECT.

Acknowledgments:

I would like to thank Professors George Malliaras and Roisin Owens, the Bioelectronics Laboratory, and Dr. Marc Ramuz for their guidance. I am grateful to the NNIN iREU Program and NSF for this research opportunity.

References:

[1] Jimison, L.H., et al., Measurement of Barrier Tissue Integrity with an Organic Electrochemical Transistor. Advanced Materials, 2012.

[2] Cicoira, F., et al., Influence of Device Geometry on Sensor Characteristics of Plana Organic Electrochemical Transistors, Advanced Materials, 2010.