Integrated Hydrogel-Porous Silicon Structures for Non-Invasive Biosensing

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I. Introduction

Hydrogels are water-infused, biodegradable polymer networks. They make cheap and environmentally friendly materials that interface well with human skin. Alginate/Acrylamide hydrogels are particularly useful because of their uniquely malleable yet supportive structure. These characteristics make them an ideal medium for supporting Meso-Porous Silicon membranes and simultaneously assimilating into a wide range of tissues. (Fig. 1)

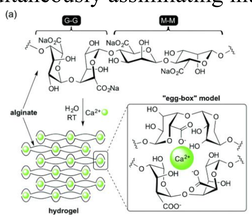


Figure 1. Structure of alginate, a water-soluble biopolymer obtained from brown algae and composed of (1 → 4)-β-D-mannuronic acid (M) and (1 → 4)-α-L-guluronic acid. Formation of hydrogels from alginates occurs upon coordination with Ca^{2+} ions through a well-established "egg-box" model.

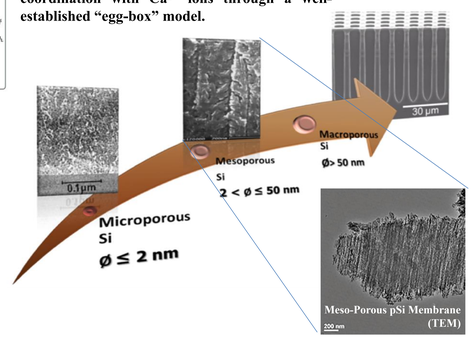


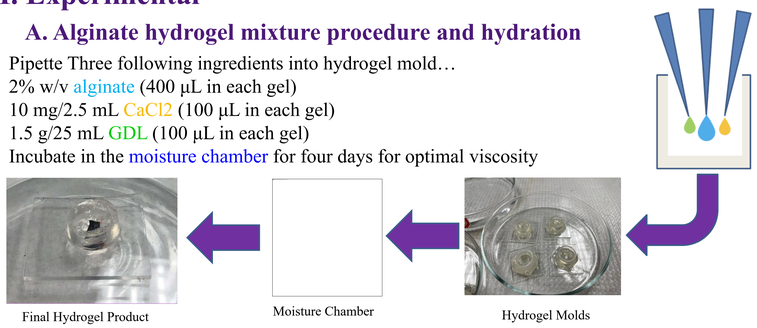
Figure 2. Porous Silicon classifications (SEM) from microporous to macro-porous in function of the average pore diameter (Ø). (Greman Laboratory, University of Tours, France)

Porous silicon is utilized to measure and conduct electrical signals throughout the hydrogel system. Porous silicon is a highly porous form of the classic semiconductor common to nearly all modern electronic devices. These membranes exhibit measurable current values as a function of voltage, which we will use to detect bioelectrical stimuli such as the concentration of physiologically relevant ion species such as sodium, potassium, and calcium.

II. Experimental

A. Alginate hydrogel mixture procedure and hydration

- Pipette Three following ingredients into hydrogel mold…
- 2% w/v alginate (400 µL in each gel)
- 10 mg/2.5 mL CaCl2 (100 µL in each gel)
- 1.5 g/25 mL GDL (100 µL in each gel)
- Incubate in the moisture chamber for four days for optimal viscosity

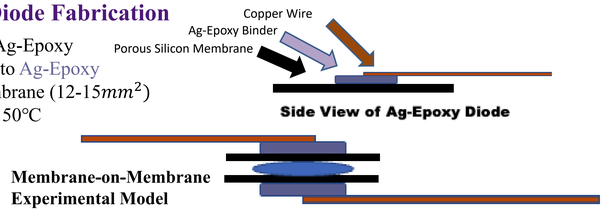


B. Porous Silicon Etching Process

- Meso-Porous Silicon wafers (**Figure 2**.) are etched from doped silicon placed in a HF/Ethanol solution in a process termed Anodization described by Leigh Canham PhD. in *Handbook of Porous Silicon (2018)*

C. Porous Silicon Diode Fabrication

- Mix 1:1 Part A & B of Ag-Epoxy
- Dip 0.25mm Cu wire into Ag-Epoxy
- Place flat onto pSi membrane (12-15mm^2)
- Heat for 10 minutes @150°C
- Cool for 10 minutes



III. Results

A. Current/Voltage Measurements (pSi + $NaCl_{(aq)}$ only)

Initial experiments focused on the innate conductivity of pSi diodes. An electrochemical cell is setup with a small separation between the two diodes. To connect the circuit, 5 µL of H_2O with varying salt solution concentrations is pipetted into the gap. (Figure 3.) A voltage sweep was performed and the measured current in this configuration reaches a plateau in the 30 µA range. (Figure 4.)

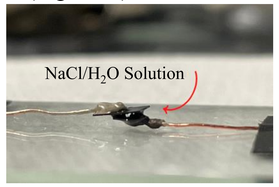


Figure 3. PSi Diode and Salt Solution electrochemical cell

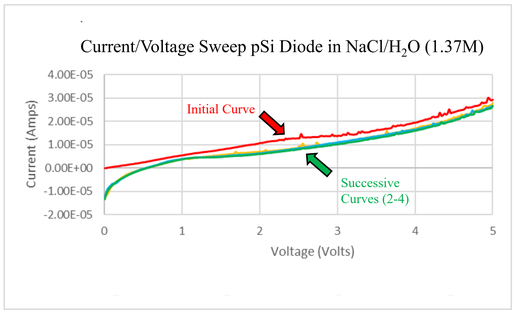


Figure 4. Current/Voltage trace of pSi diode Control experiment

The focus of recent experiments is centered on integrating porous silicon membranes into various aqueous environments and hydrogels to test how variations in ion concentration affect the current flow as a function of applied voltage. In each experiment, an electrochemical cell is created by placing two porous silicon membranes parallel each other 2-3 mm apart in hydrogel. (**Figure 5.**)

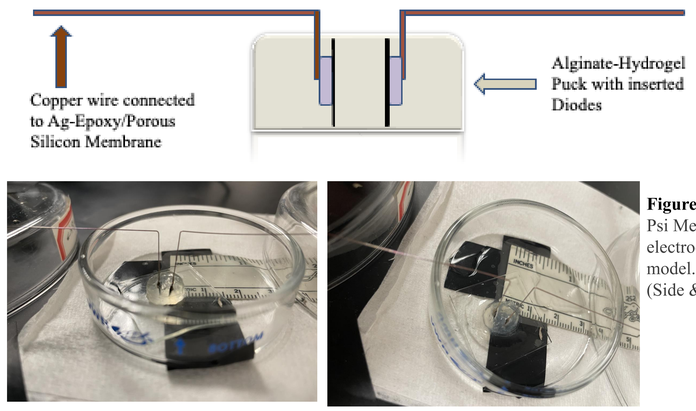


Figure 5. Psi Membrane electrochemical cell model. (Side & Top view)

B. Current/Voltage Measurements (pSi + Hydrogel)

- For measurement conditions similar to part A, current is recorded as the voltage sweeps from zero to five volts. In hydrogels, this results in a much larger measured current, with an average of 3-4 mA when a 5V bias is applied. (**Figure 6**.)
- Additions of NaCl solution (5µL – 1.37M) were pipetted into the hydrogel to test current sensitivity in response to changes in ion concentration. (**Figure 7**.)

Acknowledgments

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III. Results (Continued)

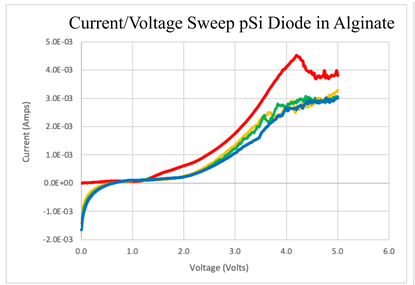

Figure 6.

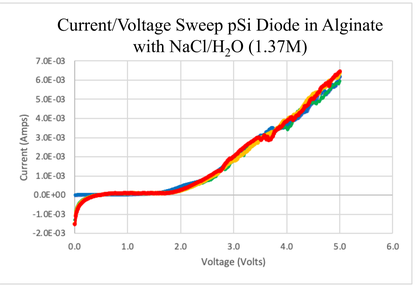

Figure 7.

C. Observations

- The placement of the Porous Silicon Diodes in the Hydrogel mold increases the current readings around 100-fold. (µA to mA)
- The addition of ions via NaCl approximately doubled measured current response to ~5.5-6.5 mA.

IV. Conclusions

- Hydrogels allow for greater ion exchange between the diodes and greater current measurement.
- Porous Silicon diodes are sensitive to ion flux in the hydrogel medium.

V. Future Work

- Refine Hydrogel/pSi design to increase sensitivity of current readings to ion concentrations during voltage sweeps
- Explore usability time of Porous Silicon Membrane diodes in Hydrogel media and effect of Sodium ions remaining in micropores of diodes after trials.

VI. References

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