Impact of Sensor Design on Hydrogel-Porous Silicon Structures Capable of Detecting Ion Concentrations in Human Sweat

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I. Introduction

Hydrogels are water-infused, biodegradable polymer networks. Alginate based hydrogels are particularly useful because of environmental abundance, along with their ability to interface well with human skin. The addition of acrylamide segments to the polymer chains adds stability and useful shelf-life to the material. These characteristics also make them an ideal medium for supporting porous silicon (pSi) membranes and simultaneously assimilating them into a wide range of tissues. (**Figure 1**)

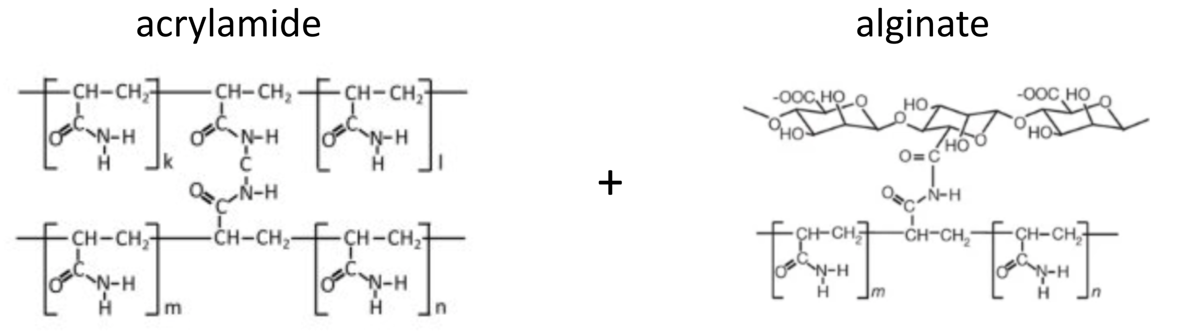


Figure 1. structure of alginate/acrylamide hydrogels with crosslinking through N,N-methylenebisacrylamide[1]

Porous silicon is an anodized form of silicon with tunable porosities. It is used to measure and conduct electrical signals throughout the hydrogel. pSi 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. Neonatal infants and pro-athletes are sensitive to changes in ion concentrations, so by continuously monitoring these parameters salt, overall health can be tracked.

II. Experimental

Porous Silicon Etching Process

Porous Silicon membranes ~110 μm thick and 79% porosity are fabricated from the anodization of low resistivity (100) Si in methanolic HF at an applied bias of 100 mA/cm^2 for 30 minutes[2] .

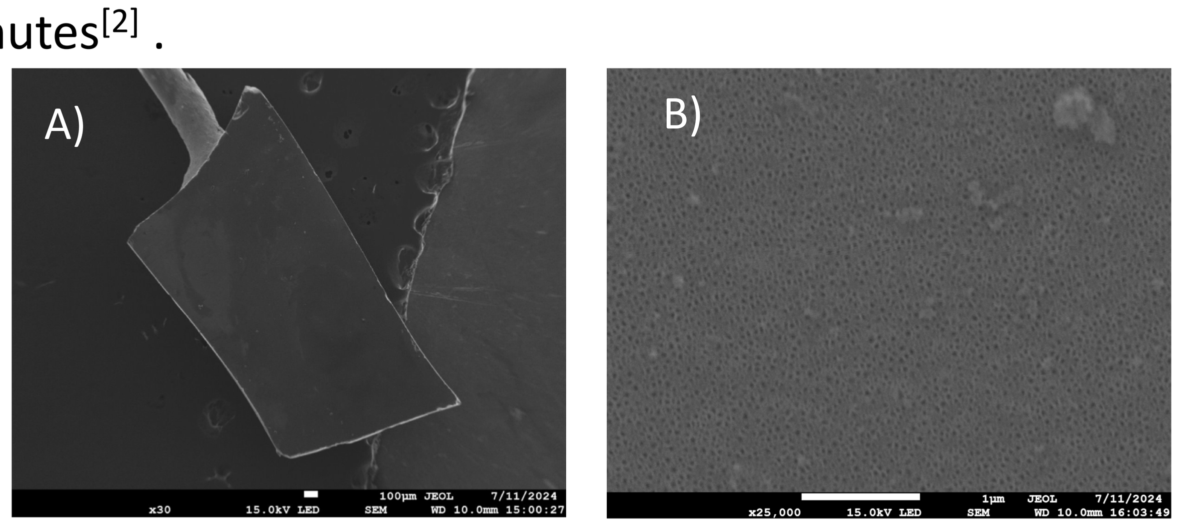


Figure 2. Scanning Electron Microscope (SEM) image of a Mesoporous Silicon membrane
(A, scale bar 100 μm)
(B, scale bar 1 μm)

- Uniform mesopores are observed throughout the surface of the membrane

Alginate/acrylamide hydrogel synthesis(3)

The following reagents are added to a beaker and heated at 60°C with constant stirring:

- 25 mL deionized H_2O
- 0.5 g alginic acid sodium salt powder
- 3.75 g acrylamide monomer
- 2.5 mg methylenebis(acrylamide) crosslinker in 2.5 mL H_2O
- 25 mg ammonium peroxodisulfate in 2.5 mL H_2O
- 0.05 mL accelerator N,N,N',N'-tetramethyl ethylenediamine (TEMED)

This mixture is poured into a microplate well, pSi diode is placed inside the well, and allowed to sit for four hours until solidification of the gel occurs.

Porous Silicon Diode Fabrication

- The pSi membranes are heated at 650°C for 1 hour
- A piece of Cu wire is attached to the diode using silver epoxy
- The structure is annealed at 95°C for 15 minutes
- Two membranes are positioned parallel to each other 2 mm apart on a microscope slide using black electrical tape
- The back of the membranes and the Cu wire are painted with clear nail polish
- The membranes are submerged in the hydrogel prior to gel solidification.

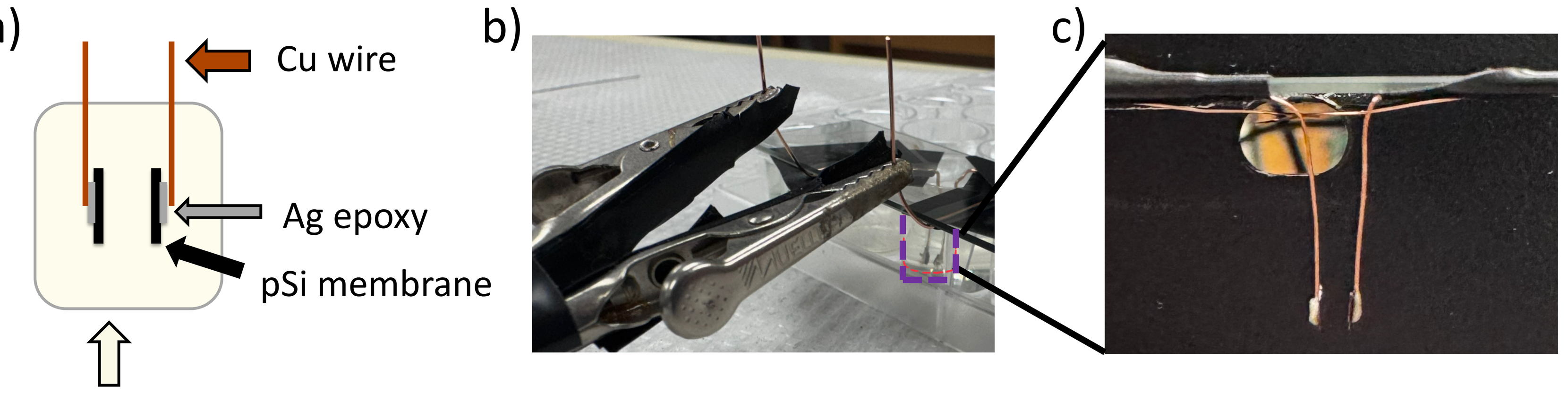
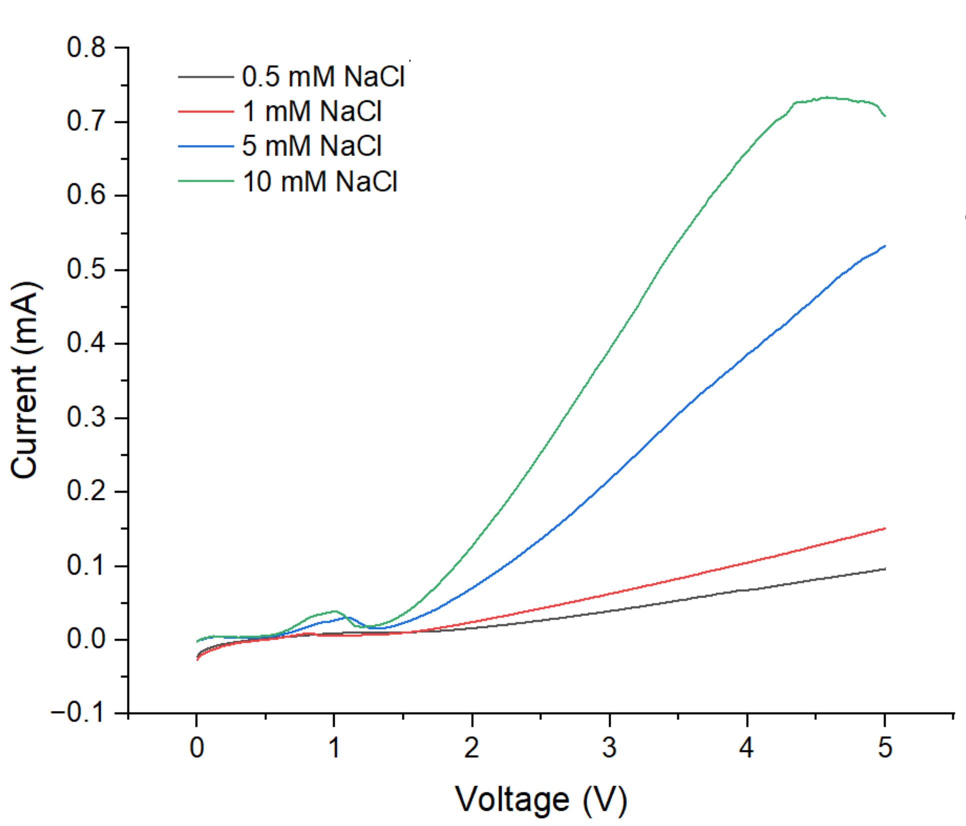


Figure 3: a) Illustration of the diode in the hydrogel B) configuration of the diode in the hydrogel c) close up view of the diode configuration

III. Results

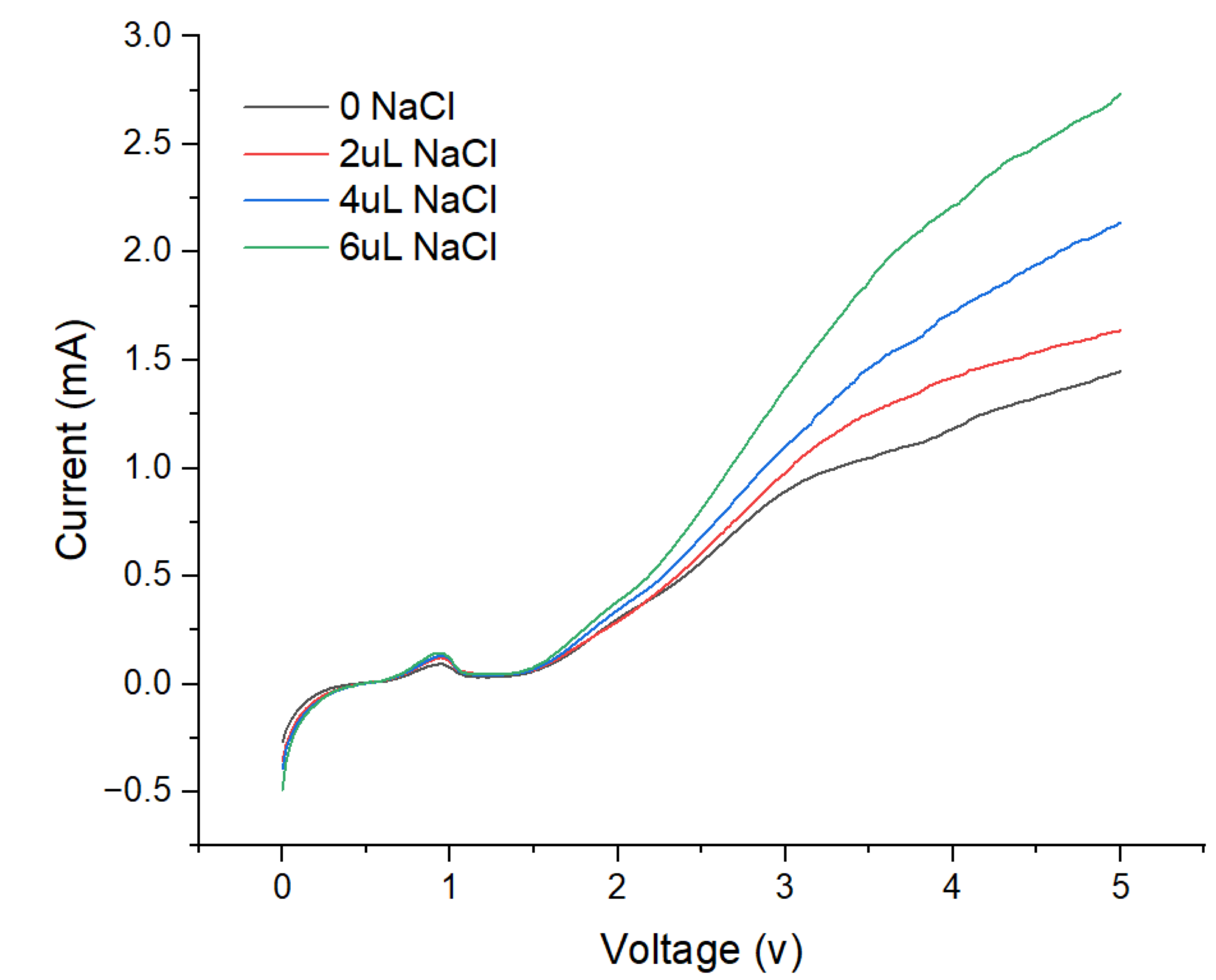
A. Current/Voltage Measurements of pSi membrane in NaCl solution of varying concentrations



- Magnitude of maximum current output increases at 5V as the amount of NaCl in the solution.

B. Current/Voltage Response to Immersion in Alginate Hydrogel

Injection of 2 μL of 1M NaCl solution between the pSi membranes:



- Current output increase at 5V is proportional to increasing NaCl concentration but different in magnitude to solution response

IV. Discussion

- Hydrogels allow for ion exchange between the diodes.
- Porous silicon diodes are sensitive to ion flux in hydrogel medium.
- Stability of the hydrogel may cause fluctuations in current output.
- Differences in response are likely due to viscosity of the medium.

V. Future Work

- Examining sensor response to miniaturized silicon surface area
- Pursue alternative device configurations / reduced electrode architecture
- Evaluate device biodegradability.

VI. References

1. Sun, J.-Y.; Zhao, X.; Illeperuma, W. R. K.; Chaudhuri, O.; Oh, K. H.; Mooney, D. J.; Vlassak, J. J.; Suo, Z. **Highly Stretchable and Tough Hydrogels.** *Nature* **2012,** *489* (7414), 133–136. https://doi.org/10.1038/nature11409.
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3. Polymer Scope. *Making Stretchable Hydrogel | Synthesis poly(Acrylamide)/Alginate wound dressing Hydrogel;* YouTube, 2021. https://www.youtube.com/watch?v=_sz0KkT603E (accessed April 2, 2025).

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