Determining the Sensing Mechanism of Hydrogel-Porous Silicon Structures to Detect Ion Concentrations in Sweat

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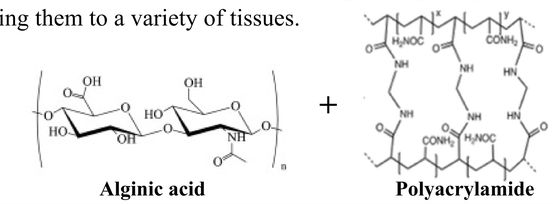
Abstract:

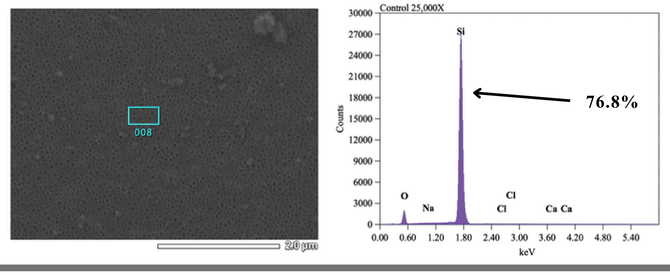
By combining the supportive structure of **alginate hydrogels**, the semiconductive nature of **porous silicon (pSi) membranes**, and the biodegradability of both of these materials, a unique, non-invasive biosensor can ideally be created for the chemical analysis of **health-relevant analytes**.

Porous silicon (pSi) is a highly porous form of the widely used elemental semiconductor and is used to conduct and measure electrical signals throughout the hydrogel matrix. When established in a diode form, these membranes exhibit measurable current values as a function of voltage, which can be used to detect bioelectrical stimuli such as the concentration of physiologically relevant ionic species such as Na^+, K^+, and Ca^{2+}.

Alginate polymer hydrogels are water-infused, biodegradable polymer networks that are easily able to interface with human skin and are particularly useful due to being derived from brown algae, making them environmentally abundant and inexpensive. The polymer is modified with **acrylamide** segments to add stability and shelf-life to the hydrogel material. Ultimately, these characteristics make hydrogels ideal for supporting the pSi membranes while assimilating them to a variety of tissues.



SEM Image of pSi at 25,000X shows the surface is mostly Si



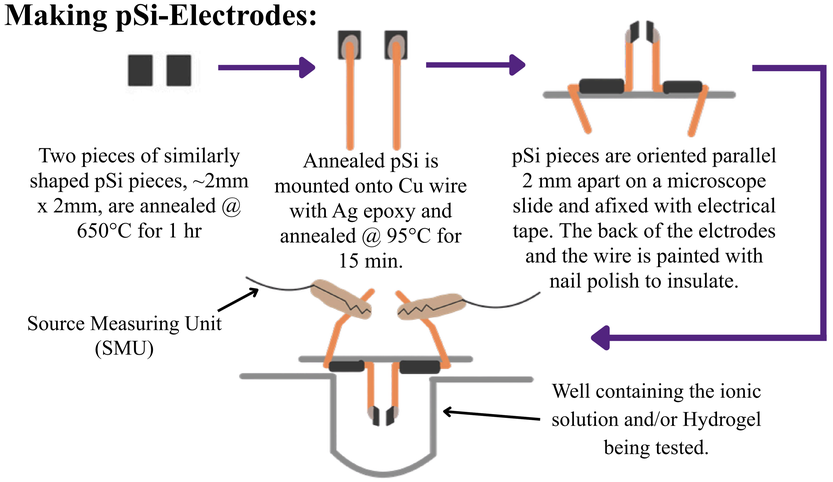
Electrolyte concentration in sweat can be associated with underlying health conditions:

Table 1. Key analytes in sweat and associated health conditions

Analyte	Health Condition
Na^+	Dehydration, hyponatremia, electrolyte embalence
Cl^-	Dehydration, cystic fibrosis
K^+	Hypokalemia, muscle cramps
Ca^{2+}	Myeloma, cirrhosis, renal failure, acid-base balance disorder

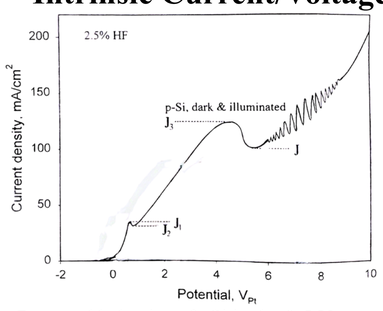
Methods:

Making pSi-Electrodes:

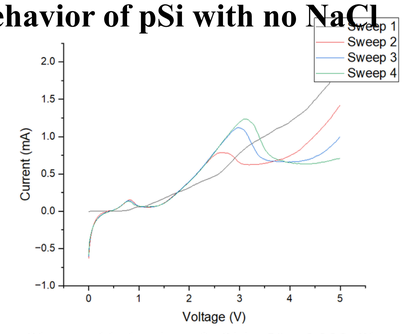


Data:

Intrinsic Current/Voltage Behavior of pSi with no NaCl

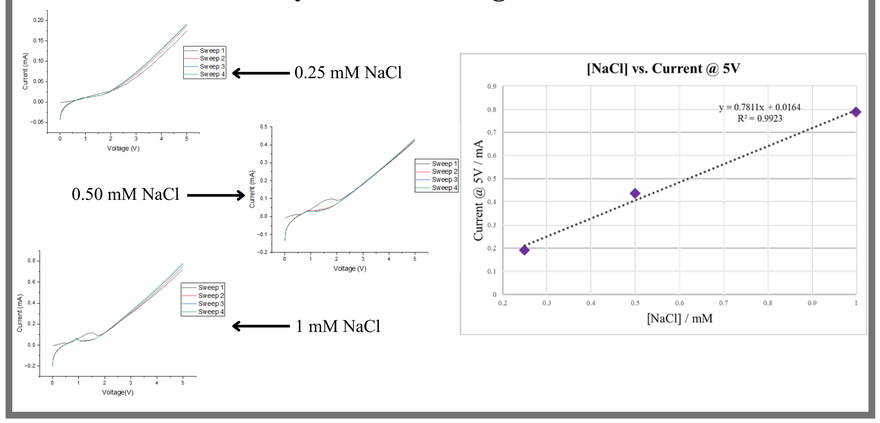


Reported behavior of pSi in the 0-5 V range

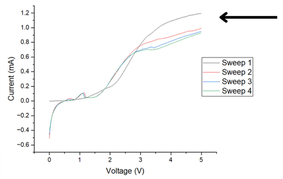


Observed behavior of pSi in 50 mM NaCl

In the NaCl concentration range of 0.25-1 mM, the current output increases linearly with increasing concentration of NaCl

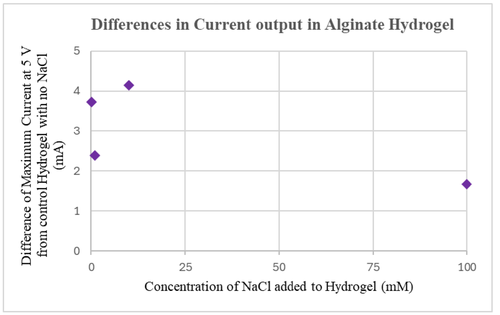


Detecting current output of pSi sensors in the Alginate Hydrogel exhibits less consistent results.



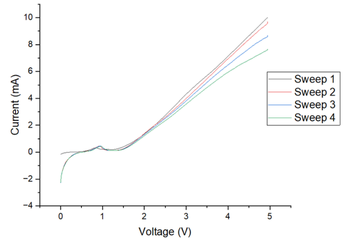
pSi Electrode in Alginate Hydrogel with no added ionic solution.
Current output at 5 V- 0.93159 mA

In Alginate Hydrogel, the pSi electrodes do not consistently demonstrate increasing current output with increasing concentration of NaCl.



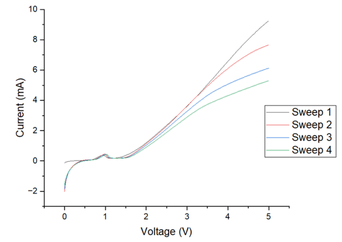
There are also inconsistent results between different electrodes with the same concentrations of NaCl

Electrode 13 in Hydrogel with 2 µL of 0.2 mM NaCl



Current output at 5 V- 7.67 mA

Electrode 14 in Hydrogel with 2 µL of 0.2 mM NaCl



Current output at 5 V- 5.30 mA

Discussion:

- pSi electrodes can be used to measure current output in both ionic solution and Alginate Hydrogels.
- The presence of a J-3 curve of the current vs. voltage graph could indicate corrosion of the pSi in solution
- In NaCl solution, the current output increases with the concentration of the solution and is predictable due to the linearity shown in low concentrations.
- Future plans will involve attempting to replicate these findings within the Alginate Hydrogel and find ways to improve sensing at higher ion concentration.

References:

Alginic Acid structure (Abstract)- Mahmud, Rois Uddin , and Md Zillur Rahman. “Synthesis and characterization of nanocomposites for tissue engineering.” Comprehensive Materials Processing. Second ed., vol. 13, Elsevier, 10 June 2024, pp. 241–269.

Polyacrylamide structure (Abstract)- Chowdhury, Nusrat. Structural Property Relation in Improving Chemically and Physically Crosslinked Hydrogel Surface Properties. 18 Dec. 2023, p. 20

Table 1 (Background)- Gao, Fupeng, et al. “Wearable and Flexible Electrochemical Sensors for Sweat Analysis: A Review.” Microsystems & Nanoengineering, vol. 9, no. 1, 1 Jan. 2023, pp. 1–21

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