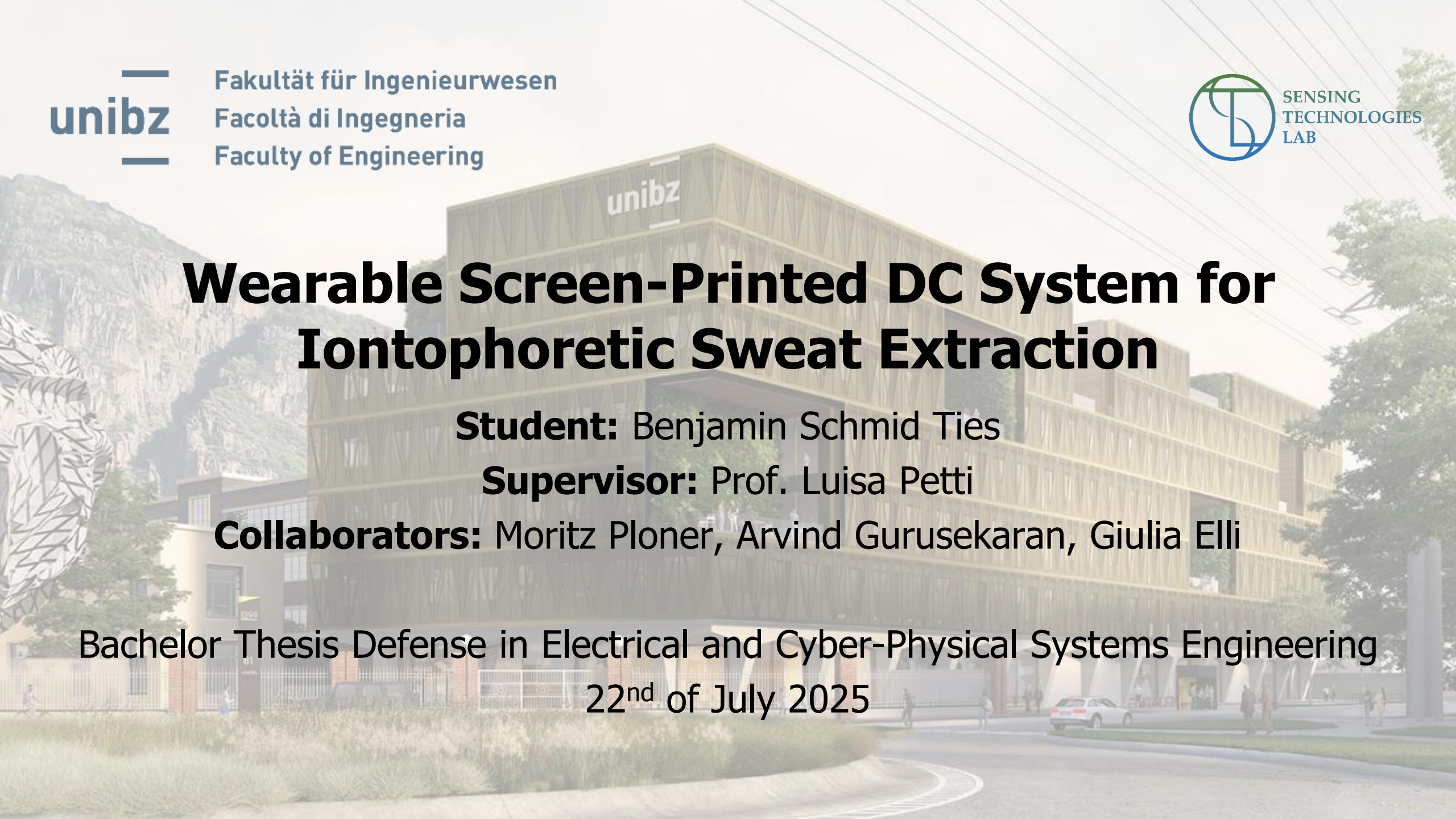

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SENSING TECHNOLOGIES LAB

Wearable Screen-Printed DC System for Iontophoretic Sweat Extraction

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Bachelor Thesis Defense in Electrical and Cyber-Physical Systems Engineering

22nd of July 2025

Introduction

Why sweat sensing:

- Sweat as alternative to blood
- Continuous monitoring of biomarkers
- Detect diseases before symptoms
- Sweat rich in analytes, correlated to blood

Challenges:

- On-demand/continuous sweat extraction
- Sweat unavailable when
  - Stationary
  - Climate controlled environment

[1]

Commercial sweat sensing unit:
Palmsense Sensit Wearable®

[1] https://www.palmsens.com/product/sensit-wearable/

Iontophoresis

- Method to extract sweat on demand
- Mild current flowing through skin
- Ion transfer through membrane
- Trigger sweating in sweat glands

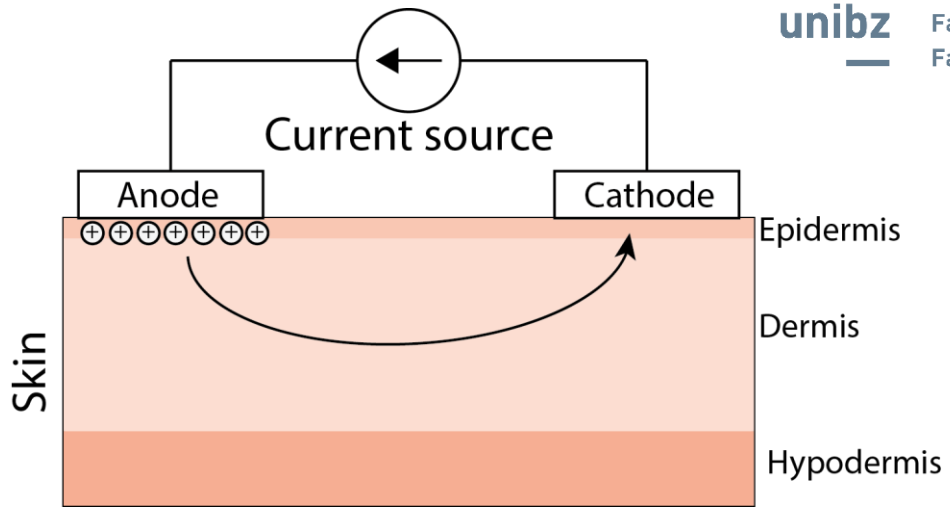
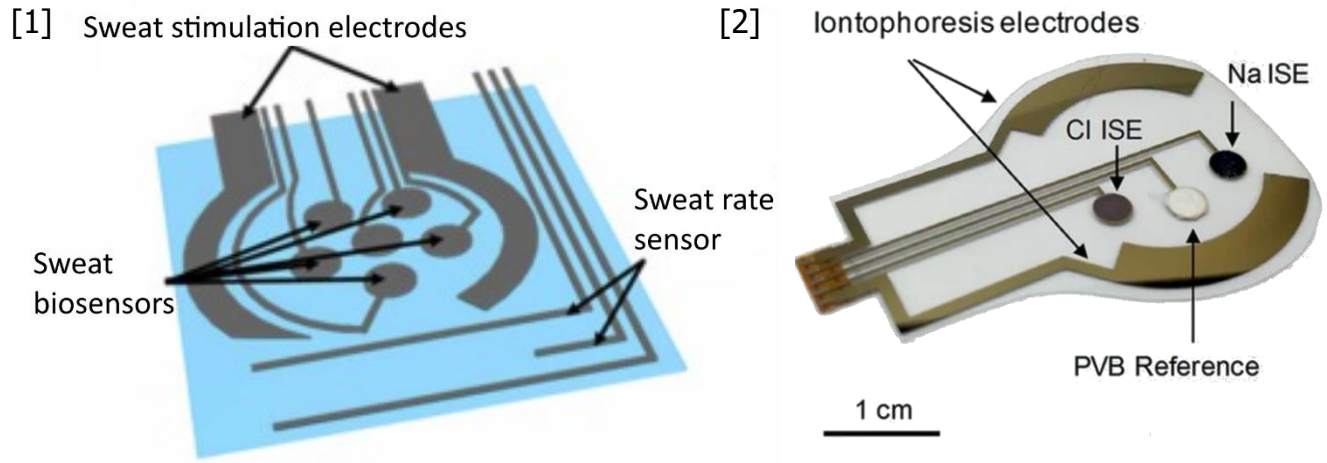


Illustration of iontophoresis for sweat extraction

State-of-the-art

- Two elliptical iontophoresis electrodes
- Large contact interface with skin
- Biosensors between electrodes
- Flexible substrate



State-of-the-Art iontophoretic platforms for sweat stimulation

[1] Kiran Peringeth et al., Selfpowered microfluidic-based sensor for noninvasive sweat analysis, Sensors and Actuators B: Chemical 423, 2025.

[2] Sam Emaminejad et al., Autonomous sweat extraction and analysis applied to cystic fibrosis and glucose monitoring using a fully integrated wearable platform, Proceedings of the National Academy of Sciences 114.18, 2017.

Research gaps and objectives

Research gaps:

- Limited studies on effect of iontophoresis current intensity on ion transport
- Unclear impact of stimulation duration on ionic permeability
- No standardized in vitro models for iontophoretic testing

Objectives:

- Develop a flexible, skin-compliant iontophoretic system
- Quantify ion transport across synthetic membranes
- Explore current intensity and duration for ion-permeability in lab-scale setting

Long-term goal:

- Enable on-demand, active sweat diagnostics via integrated wearable platforms

Methodology

- Screen printed Silver/Silver Chloride (Ag/AgCl) electrodes for iontophoresis
- Thermoplastic polyurethane (TPU) substrate
- Characterization:
  - Four-point probe
  - Optical profilometer
- Strat-M membrane as substitute for skin in experiments
- Artificial sweat
- Cyclic voltammetry for monitoring ion permeation

Fabrication of electrodes

- Thermoplastic polyurethane (TPU) substrate
- Silver/Silver Chloride (Ag/AgCl) ink (90%Ag 10%AgCl)
- Screen: 80 threads/cm
- Curing in oven (100 °C, 15 minutes)

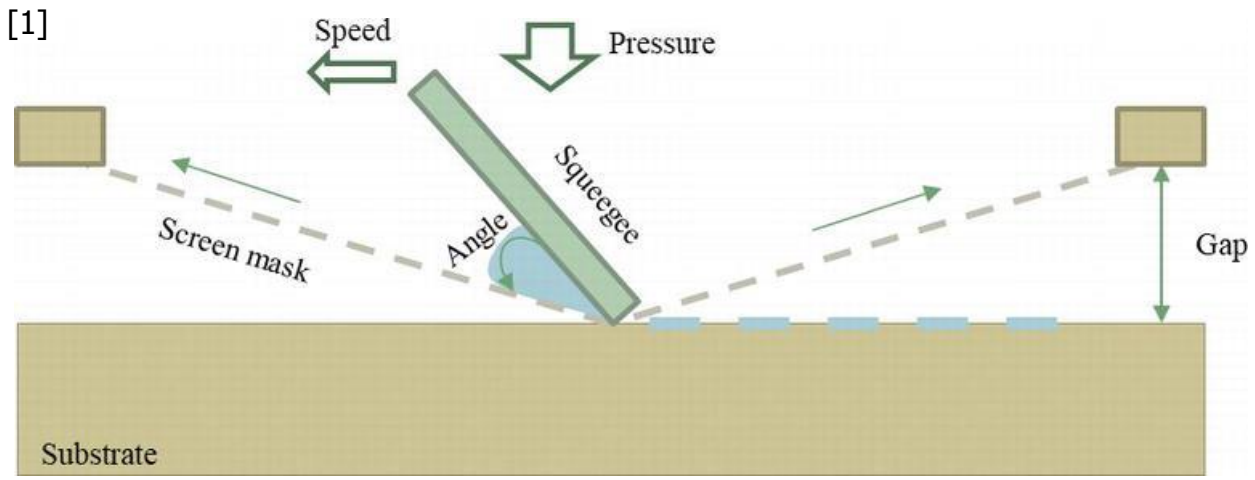
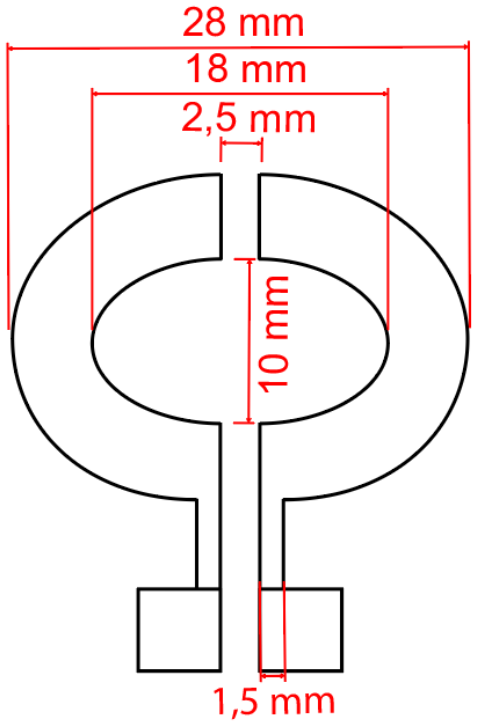


Illustration of screen-printing process



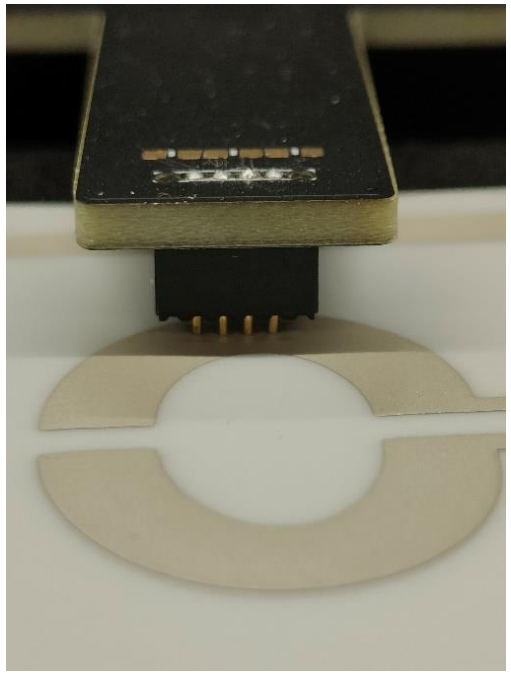
Design and printed electrodes

Fabricated electrodes

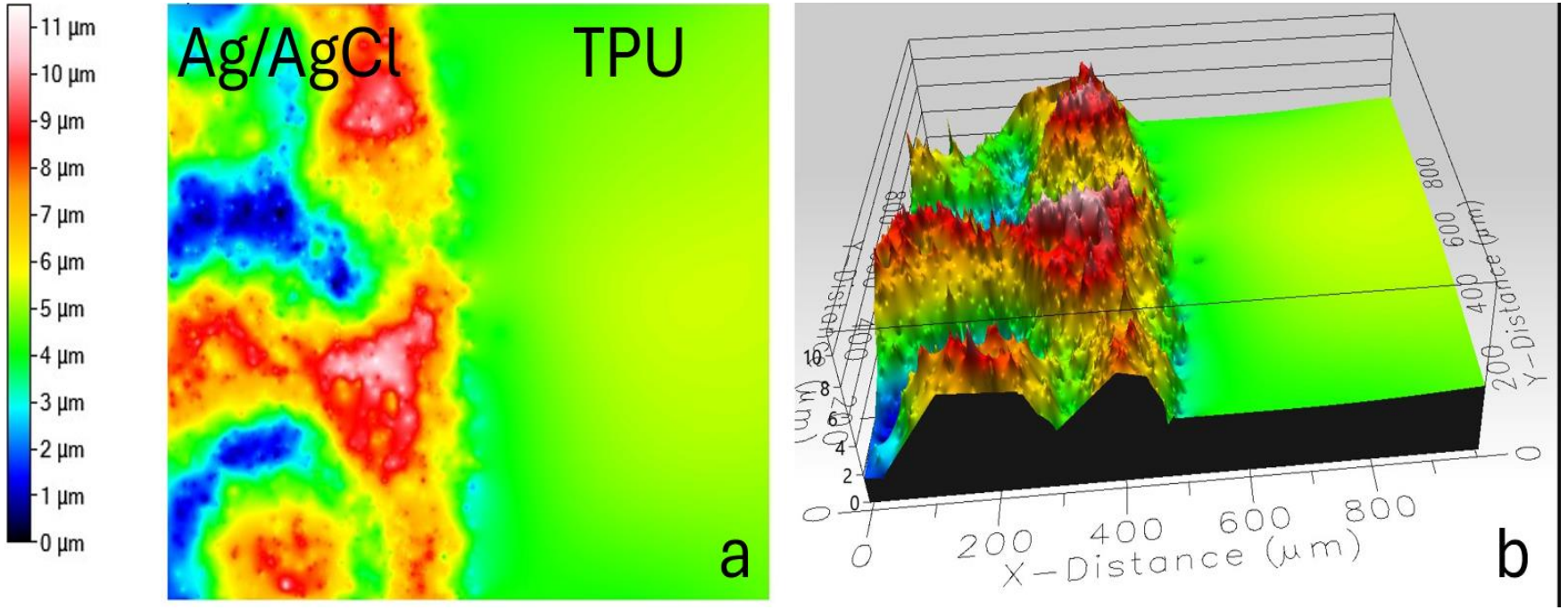
[1] Almudena Rivadeneyra et al., Technological Integration in Printed Electronics, Flexible Electronics, 2018.

Characterization of electrodes

- Average sheet resistance 44.47 ± 10.57 $\frac{m\Omega}{sq}$
- Ag/AgCl: low sheet resistance and biocompatible
- Surface roughness, (1-10µm at edge of print)



Four-point-probe

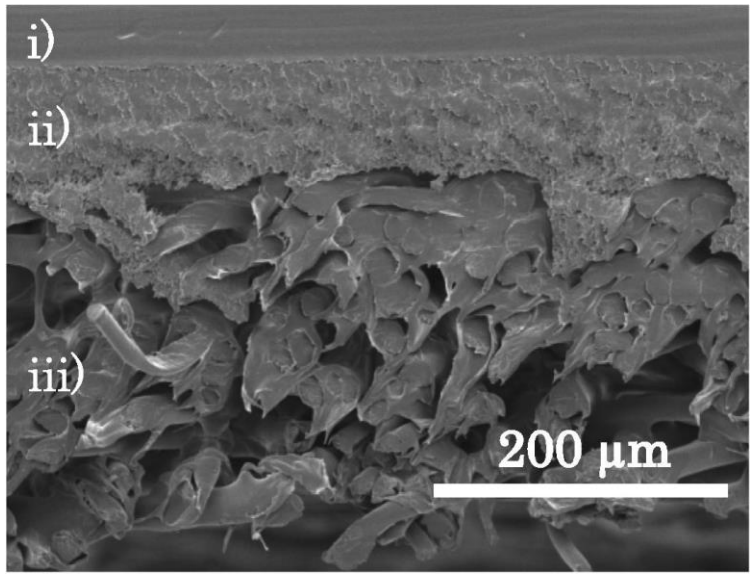


Optical profilometry scan

Strat-M membrane as skin alternative

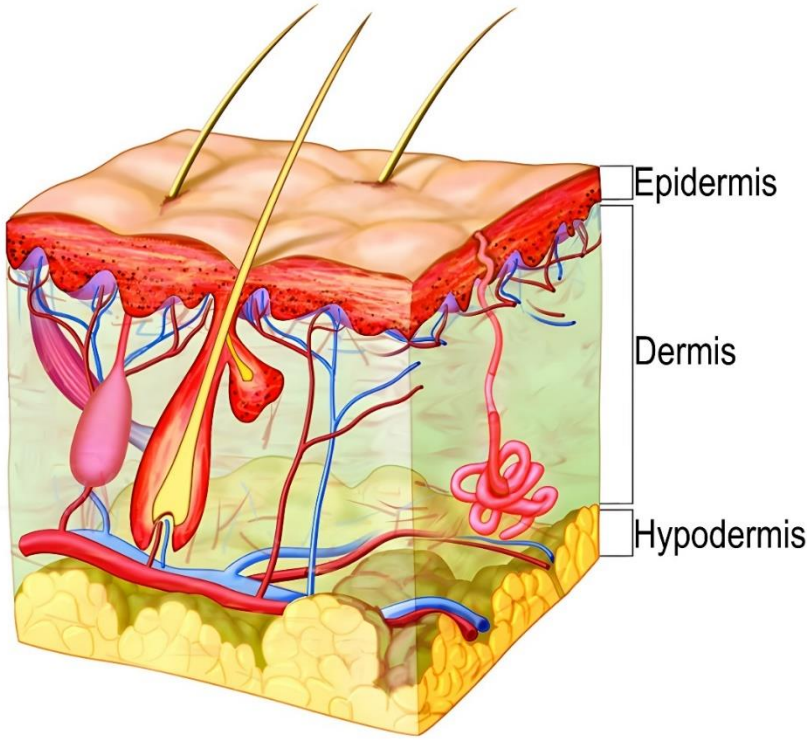
- Synthetic membrane
- Model for ion permeation through skin
- 3 polymer layers modelling epidermis, dermis and hypodermis
- Used for testing skin permeation of drugs

[1]



Scanning electron microscope image of Strat-M

[2]



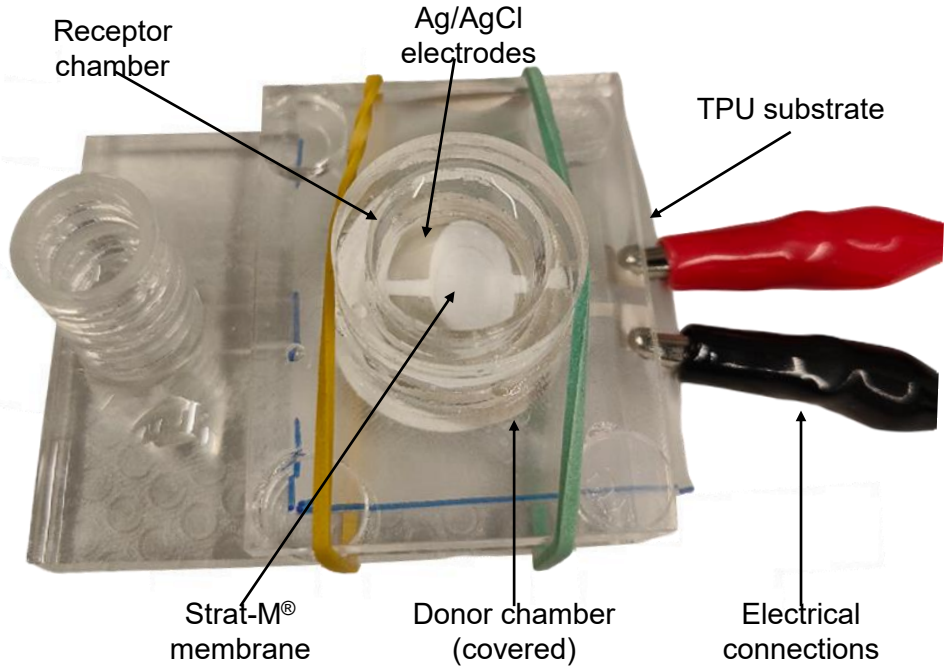
Corresponding layers in human skin

[1] Takashi Uchida et al., "Prediction of skin permeation by chemical compounds using the artificial membrane, Strat-M™", European Journal of Pharmaceutical Sciences 67, 2015.

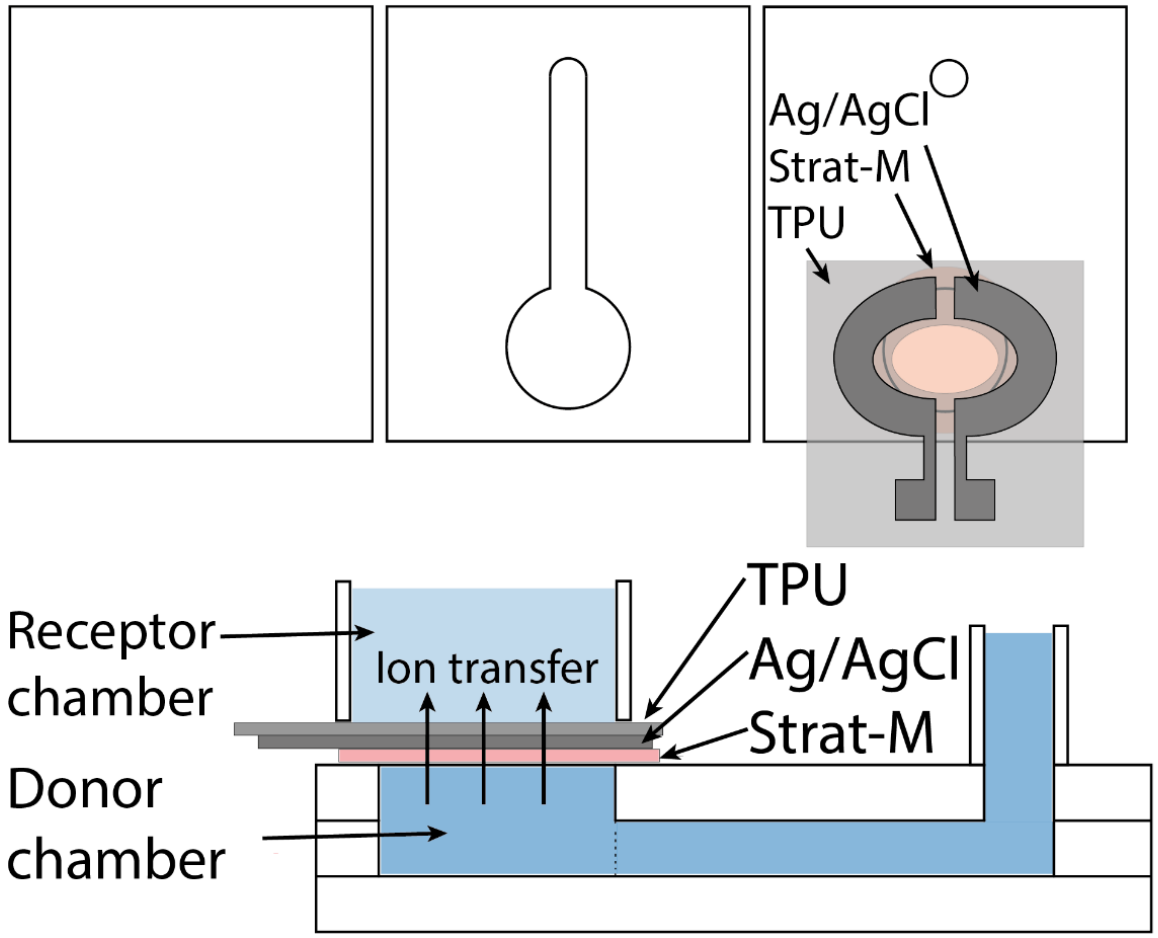
[2] https://pressbooks.ccconline.org/bio106/chapter/integumentary-structures-and-functions/

Experimental setup for iontophoresis

- Similar to a Franz-Diffusion cell
- Electrodes attached to Strat-M membrane
- Application of DC current
- Measure ion permeation through Strat-M
- From donor to receptor chamber



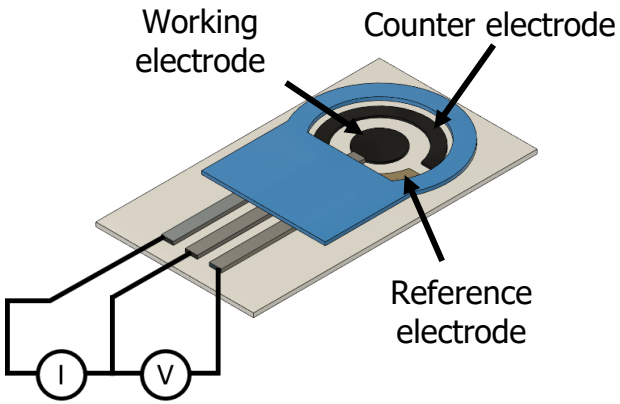
Assembled test setup



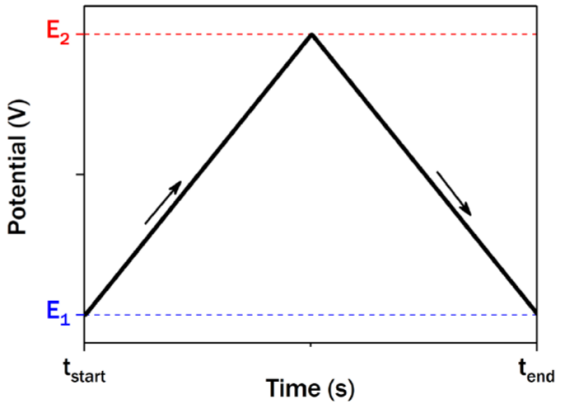
Layer by layer and side profile of testing device

Validation of ionic permeation

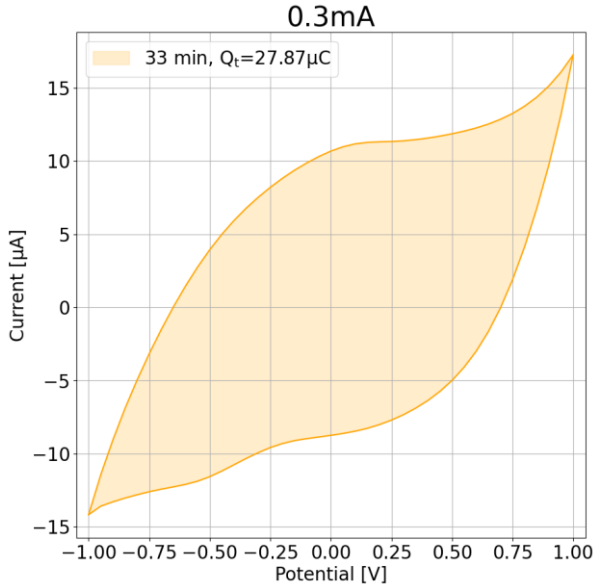
- Periodic sample retrieval from receptor chamber (60 µL samples every 5 minutes)
- Analysis of ionic composition of receptor solution via cyclic voltammetry
- Cyclic voltammetry performed on a three-electrode platform (DropSense®)
  - Working electrode (WE) and counter electrode (CE): Carbon
  - Reference electrode: Ag/AgCl



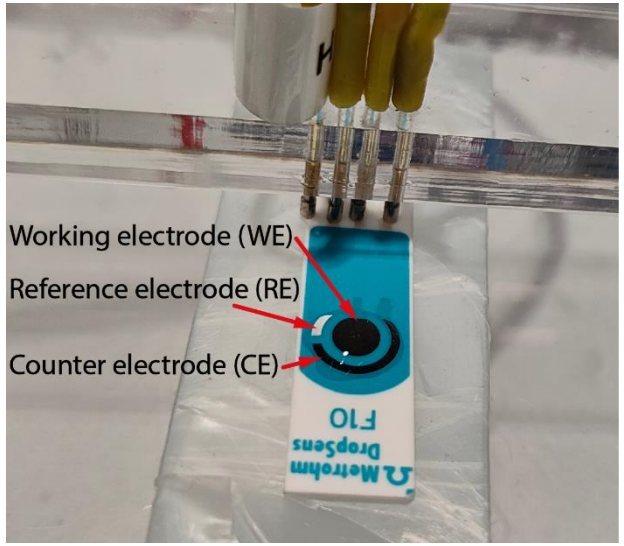
Cyclic voltammetry on a three-electrode platform



Applied potential between working and reference electrode



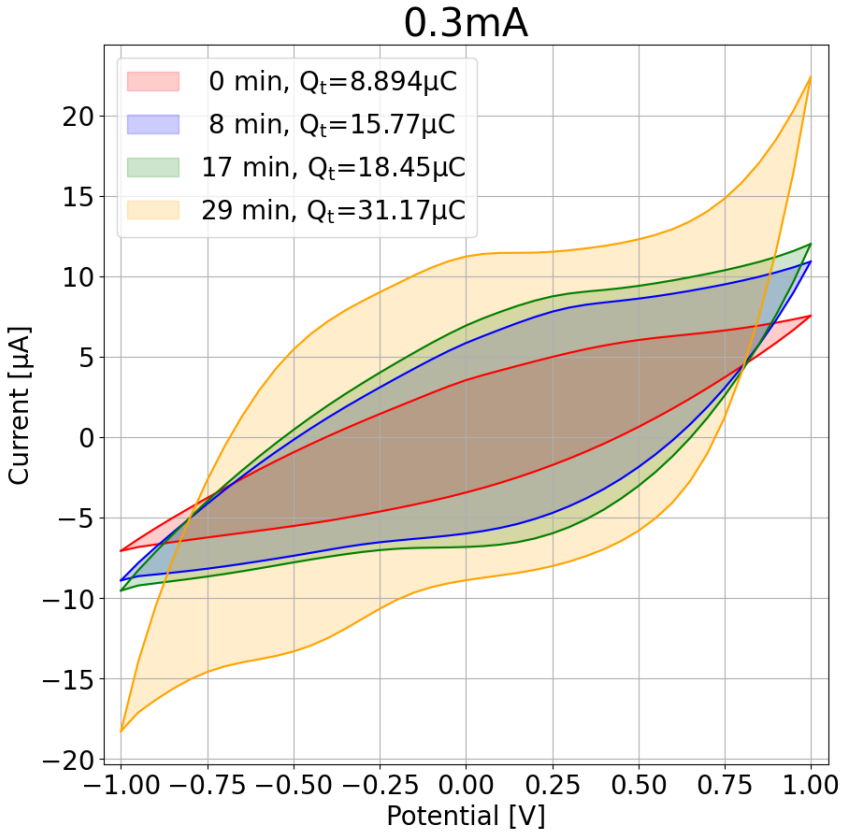
Cyclic voltammogram

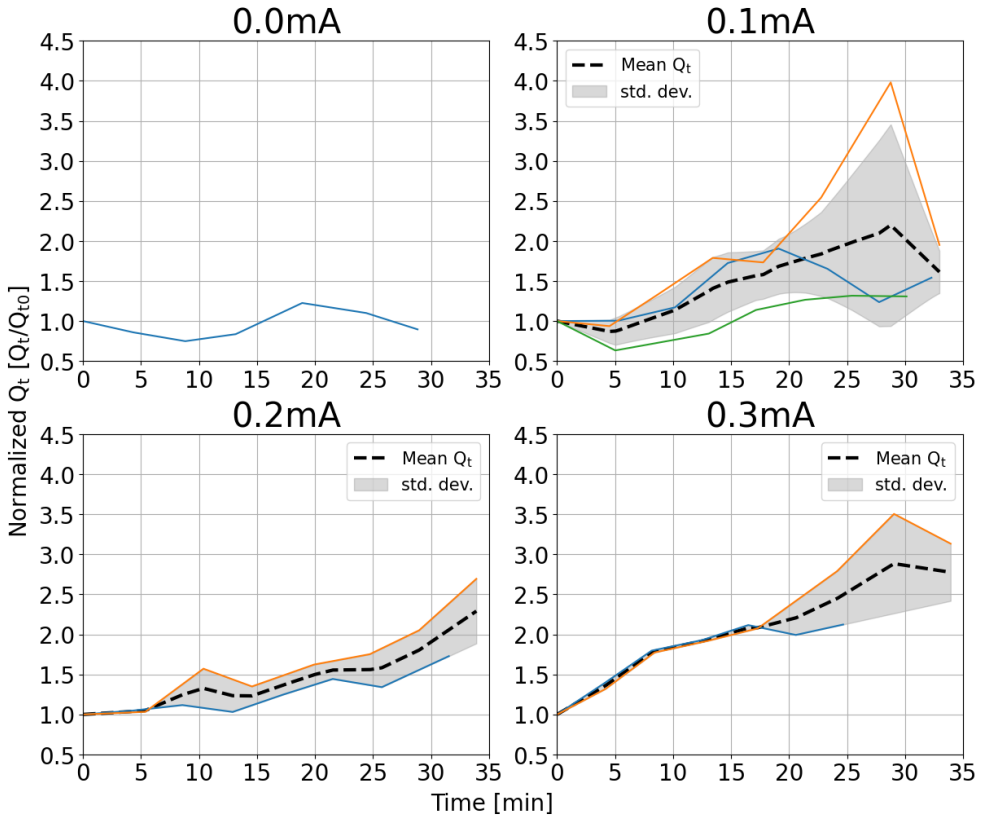


Experimental setup for ionic composition measurements

Results I

- Analyze change in area enclosed by cyclic voltammograms → Proportional to conductivity of solution
- Area increases with time ions pass through membrane



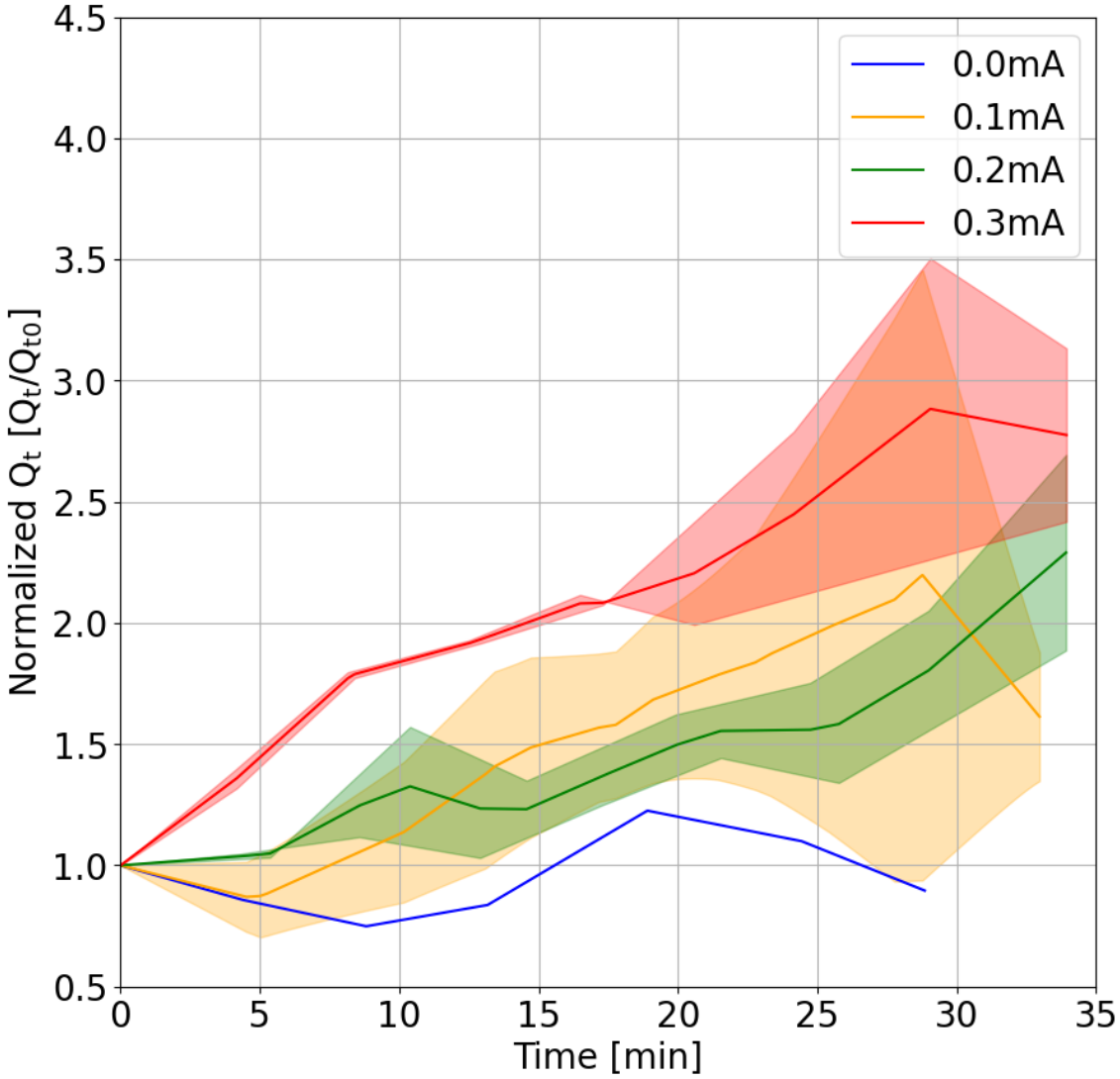


Cyclic voltammograms over time

Relative change in Qt over time for different current intensities

Results

- Relative change in ions transferred proportional to current
- When no current is applied, no significant ion transfer across membrane
- Maximum ion transfer at 0.3mA
- 0.3mA still far below pain treshold
- Ion transfer does not saturate over time

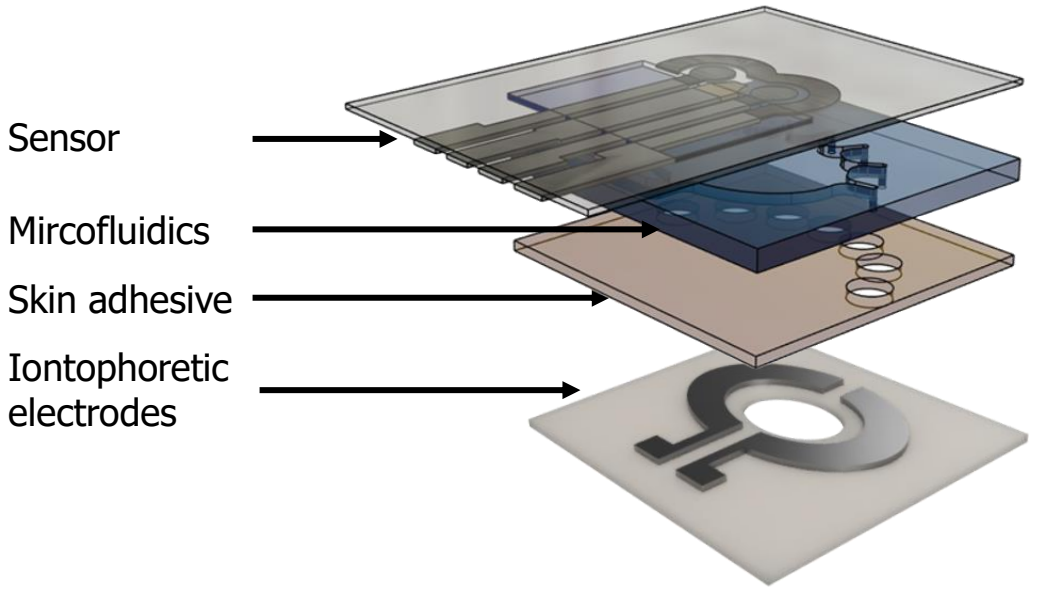


Ion transfer accross membrane increases with current intensity and duration

Conclusions and outlook

Outlook:

- Establishes foundation for future wearable, continuous, on-demand sweat sampling
- Enables development of fully integrated wearable biosensors combining sweat stimulation and analysis



Iontophoretic-equipped and microfluidics-integrated sensor for sweat analysis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Thank you for your attention
Questions?
Thank you to:
Prof. Luisa Petti, Moritz Ploner, Arvind Gurusekaran, Giulia Elli
22nd of July 2025