Towards Wearable Sensors for Wireless pH Monitoring in Sweat

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Disposable solid-contact ion-selective electrodes for environmental monitoring of lead with ppb limit-of-detection

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Sensors for the Digital World

- Analyte
- Chemo/Bio Sensing
- Wireless data transmission
Sensors for the Digital World

✓ Cost
✓ Reproducibility
✓ Compatible with Wearable & Environmental Applications

IS-Membrane
Conducting Polymer
Silver
Carbon
Resist
PET Substrate
pH ISE – An Initial Design

1st calibration after overnight conditioning

\[ y = -52.1x + 521.2 \]
\[ R^2 = 0.994 \]

\[ y = -53.8x + 524.8 \]
\[ R^2 = 0.996 \]

2nd calibration after 3 days in the conditioning solution

\[ y = -53.3x + 537.1 \]
\[ R^2 = 0.970 \]

\[ y = -54.9x + 544.1 \]
\[ R^2 = 0.972 \]

\[ y = -53.2x + 504.8 \]
\[ R^2 = 0.973 \]

Loss of linearity & offset change over time.

May we improve this limit working on SPE fabrication?
“Initial” vs “New” SPE
“Original” vs “New” SPE

Original SPE

\[ y = 21.5x + 1.53 \quad R^2 = 0.986 \]

\[ y = -52.4x - 0.21 \quad R^2 = 0.999 \]

New SPE

\[ y = 71.9x + 1.27 \quad R^2 = 0.997 \]

\[ y = -65.1x - 2.71 \quad R^2 = 0.996 \]

\[ \sigma \approx 1.6 \]
pH ISEs – Silverless-SPE and Membrane Thickness

Carbon prints were masked used PSA and PMMA. PET substrate were laminated with PSA and PMMA after that tracks carbon was screen printed: Integration of ISE within microfluidic system

175 \mu m PMMA + 50 \mu m PSA as masking layer

\begin{align*}
    y &= -48.55x + 529.1 \\
    R^2 &= 0.988 \\
    y &= -54.2x + 529.8 \\
    R^2 &= 0.996 \\
    y &= -53.6x + 522.2 \\
    R^2 &= 0.996 \\
    y &= -53.1x + 522.7 \\
    R^2 &= 0.995
\end{align*}

500 \mu m PMMA + 50 \mu m PSA as masking layer

\begin{align*}
    y &= -48.55x + 529.1 \\
    R^2 &= 0.988 \\
    y &= -52.6x + 530.8 \\
    R^2 &= 0.973 \\
    y &= -49.6x + 524.3 \\
    R^2 &= 0.989 \\
    y &= -57.0x + 572.3 \\
    R^2 &= 0.998
\end{align*}

550 \mu m well allows a better reproducibility!
pH ISEs – Performance over Time & Storage

Calibration repeated after 5 days storage in conditioning solution

- Day 0
- Day 5 (kept in conditioning solution)
- Day 19 (kept in dry conditions)

Printing protocols, e.g., presence of Ag,, have a significant impact in sensor reproducibility over time!

Dry storage may preserve sensor functionality!

\[ y = -55.2x + 563.5 \quad R^2 = 0.997 \]
\[ y = -54.3x + 552.4 \quad R^2 = 0.997 \]
\[ y = -57.9x + 579.0 \quad R^2 = 0.995 \]

\[ y = -53.5x + 524.3 \quad R^2 = 0.996 \]
\[ y = -55.8x + 565.0 \quad R^2 = 0.997 \]
\[ y = -55.8x + 544.6 \quad R^2 = 0.992 \]
Reference Electrodes based on Lipophilic Salts on SPE


- SC=PEDOT
- SC=POT

Cl⁻ \(\approx 20\) mV/decade

Need optimisation

Possibility for RE where [Cl⁻] is constant
Mote Interface and Wireless Communication

- Bias between motes and standard instrumentation < 0.3 mV
- Bias between motes < 0.1 mV
Dual SPE – Integration of pH & RE on same substrate

- The two carbon disks printed on the PET substrate will be modified to give a pH and a reference electrode.
- The substrate can also be laminated with PSA and PMMA for further integration within microfluidics.

Work currently under progress to optimize sensor response!!
Wearable pH Sensor – Concept

- Mote Casing
- Strap
- Patch
- Sensor + Microfluidic
Wearable pH Sensor – Layers

Mote

Mote Casing

Patch

pH ISE & RE

Microfluidics
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Thank You for Attention
pH ISEs – Role of SPE Design

A comparison between 1° calibration for (Ag+C) SPE & C (Batch II) SPE

\[ y = -51.9x + 519.6 \quad R^2 = 0.997 \]

\[ y = -53.4x + 523.9 \quad R^2 = 0.996 \]

• (Ag+C) SPE
• C SPE