

High-Performance Miniaturized Reference Electrodes for Electrochemical Sensors

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Summary:

Screen-printed electrochemical sensors are increasingly adopted for low-cost, disposable sensing platforms in medical diagnostics and patient monitoring. While substantial progress has been achieved in the development of printed working electrodes, the reference electrode remains a critical and often underestimated limitation. Conventional printed Ag/AgCl pseudo-reference electrodes are compact and easy to manufacture; however, their potential is intrinsically dependent on chloride activity and sample matrix composition. This dependence results in signal drift, calibration bias, and compromised reliability when measurements are performed in complex biological fluids, limiting their suitability for clinical and point-of-care applications

Keywords: reference electrode, pulstrode, biofluids, screen-printing, ionic liquid

Background, Motivation and Objective

Screen-printed electrochemical sensors are increasingly adopted for low-cost, disposable analysis in healthcare and life-science applications. Despite major progress in printed working electrodes, the reference electrode remains a critical and often overlooked bottleneck. Conventional printed Ag/AgCl pseudo-reference electrodes are compact and easy to manufacture, but their potential directly depends on chloride activity and matrix composition, leading to drift, calibration errors, and unreliable readout in real biofluids.

The objective of this work is to develop and validate a fully solid-state, chloride-independent reference electrode compatible with scalable screen-printing technologies and capable of reliable operation in complex biofluids [1].

Description of the New Method or System

Here we present a fully solid-state, self-referencing pulstrode integrated on screen-printed electrodes, designed to fundamentally overcome chloride-related instability. The concept relies on an Ag/AgI element operated by a pulsed protocol, where a defined quantity of iodide is locally released by a short cathodic current pulse, the reference potential is measured at zero current, and the interface is subsequently regenerated by iodide recapture.

This self-contained mechanism decouples the reference potential from the bulk chloride concentration and enables a stable, reproducible reference without liquid junctions or internal electrolytes.

Results

The pulstrode was fabricated using printing-compatible and scalable processes and evaluated under conditions relevant for disposable sensing. In non-stirred environments and climate-chamber testing at 20 °C and 80 % relative humidity, the pulstrode reference potential remained stable within 2-3 mV over 48 h (see Fig. 1), whereas conventional printed Ag/AgCl pseudo-reference electrodes typically exhibit potential shifts of several tens of millivolts due to their chloride-dependent ($\approx 59 \text{ mV dec}^{-1}$) response [2].

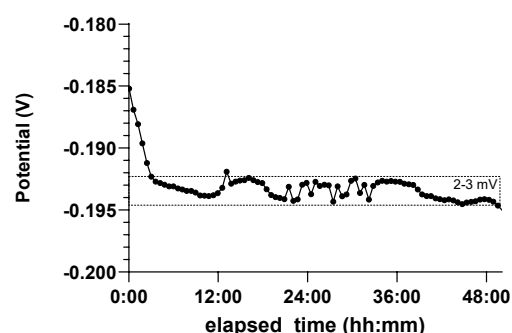


Fig. 1. Continuous pulsing stability test of the pulstrode over 48 h in a climate chamber at 20 °C and 80 % relative humidity.

When applied to a potassium ion-selective electrode in highly viscous artificial saliva, pulstrode-referenced measurements showed excellent agreement with a commercial Horiba reference (see Fig. 2), with a mean percent difference of ~1 % (n = 5) (Tab. 1).

Tab. 1: Quantitative deviation of potassium concentration measured using the Pulstrode reference electrode in artificial saliva compared to a commercial Horiba analyser

Sensor	Estimated concentration in saliva (mM)	Variation with Horiba (%)
Horiba	43.7	0.0
Pulstrode 1	45.1	3.1
Pulstrode 2	44.1	0.9
Pulstrode 3	45.1	3.2
Pulstrode 4	43.2	-1.0
Pulstrode 5	43.1	-1.4

These results demonstrate robust and accurate operation under chloride variations representative of real biofluids.

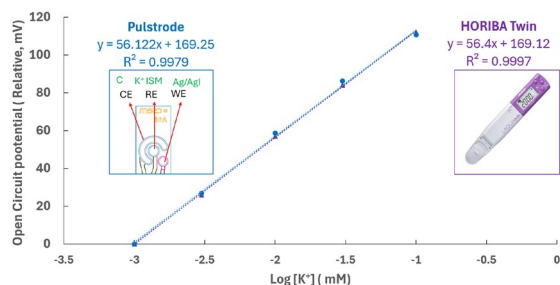


Fig. 2. Potassium ion-selective electrode response in artificial saliva, using the Pulstrode electrode as reference and benchmarked against measurements obtained with a commercial Horiba analyser.

Since chloride sensitivity represents the main limitation of printed reference electrodes, alternative chloride-independent strategies were also explored. Ionic-liquid salt-bridge (ILSB) reference electrodes were investigated as a complementary approach. A moderately hydrophobic ionic liquid embedded in a polymer matrix provides a stable phase-boundary potential over a wide range of buffer solutions and biofluids and can operate with carbon screen-printed transducers, eliminating the need for silver. However, compared to the pulstrode, challenges remain in

terms of long-term robustness and full system integration.

Overall, the pulstrode concept introduces a fundamental shift in reference-electrode design, enabling chloride-independent, stable, and manufacturable reference electrodes fully compatible with screen-printed sensor platforms for reliable electrochemical sensing in complex biofluids

References

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