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PCB-Based Electrochemical Electrodes with Self-temperature Regulation Functionality for Electrochemical Studies at Target Temperatures

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Summary:

Electrochemical electrodes with self-temperature regulation functionality developed by PCB technology are reported. A two-layer PCB on which electrochemical electrodes in a three-electrode configuration on the top layer and a heater on the bottom layer are designed. The heater warms up the electrochemical electrodes and the sample on them, and a controller switching circuit is designed to turn on/off the heater sequentially in order to keep the sample temperature constant at the target value. Cyclic voltammetry represents the stable performance of PCB-based electrochemical electrodes with both electroplated gold and ENIG surface finishes at different temperatures. The presented platform has a great potential for developing temperature-sensitive chemical/biochemical sensors.

Keywords: PCB technology, temperature regulation, electrochemical electrodes, sensors

Background, Motivation an Objective

Printed Circuit Board (PCB) technology has recently been a popular approach for developing electrochemical sensors [1]. Specifically, PCB technology is exploited for fabricating electrodes of electrochemical sensors. However, beyond fabricating electrochemical electrodes, PCB technology has still significant potential for developing more advanced electrochemical sensors.

Temperature plays a key role in the performance of biochemical and chemical sensors. Temperature variation can influence the chemical and biochemical reaction rates, especially for biochemical sensors that usually contain enzymes or antibodies, whose activity is highly sensitive to temperature variations [2]. However, this important factor is usually neglected in sensor developments, and the sensor functionality is merely investigated at room temperature.

In this work, we present electrochemical electrodes and an integrated heater on a single board made by PCB technology for electrochemical analysis at target temperatures. The heater warms up the electrodes and the sample to a chosen temperature, and the reached temperature is kept constant by a designed controller circuit. The developed PCB-based platform offers a promising solution for temperature-sensitive chemical and biochemical sensors, due to its ability to maintain stable electrochemical functionality across varying temperatures and ensures precise temperature control.

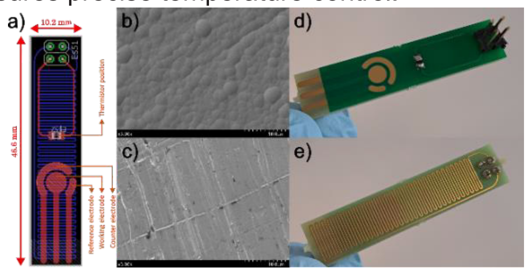

Fig. 1. a) Layout of the designed PCB. b, c) SEM image of ENIG and electroplated PCBs, respectively. d, e) Pictures from the top and bottom layer of the fabricated PCB, respectively.

Description of the New Method or System

The designed PCB layout (Fig. 1a) was produced by a commercial PCB company (https://www.multi-circuit-boards.eu/) on FR-4 boards with two different surface finishes, electroplated gold and Electroless Nickel Immersion Gold (ENIG). While both offer gold surfaces, the electroplated surface offers thicker gold layer and a flatter surface. Scanning Electron Microscopy (SEM) images of ENIG and electroplated gold electrodes are shown in Fig. 1b and 1c, respectively. The top layer of the PCBs contains electrochemical electrodes in a three-electrode configuration and a position on which an SMD NTC thermistor (Vishay, NTCS0805E3472FMT, 4.7K) is soldered (Fig. 1d), while a heater is designed on the bottom layer (Fig. 1e). The heater was biased by a DC power supply with I = 1.2 A. A switching circuit powered by an Arduino Uno was designed to turn on/off the heater at a target temperature in order to keep the temperature constant over the sample on top of the electrodes (Fig. 2). Different temperatures can be achieved by modifying V_t in the Arduino code. Cyclic voltammetry (CV) was used to study the electrochemical properties of electrodes at different temperatures with a well-known reversible electrochemical reaction $[K_4[Fe(CN)_6]/K_3[Fe(CN)_6]$ (5mM in KCl 0.1M).

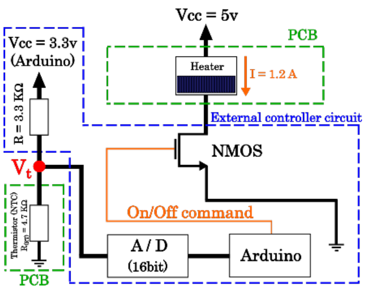

Fig. 2. Schematic diagram of the controller switching circuit.

Results

The sample is dropped over the electrochemical electrodes on the PCB top layer, and the heater on the PCB bottom layer is turned on subsequently. Based on the designed controller circuit, the PCB reaches higher temperatures by setting V_t at lower values, and the generated heat is transferred to the sample over the electrochemical electrodes. A commercial needle tip digital thermometer was used to precisely measure the sample temperature independently. Fig. 3 shows the temperature evolution of both the thermistor on the PCB and the sample at different V_t values. After a short transient state, both the thermistor and sample temperatures reach a stabilized value, which is kept constant using the controller circuit. The transient state duration and the stabilized temperature value depend on the chosen V_t value.

It should be noted that the thermistor temperature reflects only the temperature of the location on the PCB at which the thermistor is positioned, while the sample is located at a different location on the PCB. However, since the thermistor temperature uniformly follows the sample temperature in the designed PCB (Fig. 4a), V_t can be used as a parameter to set the sample temperature (Fig. 4b).

After reaching the stabilized temperature, CV was performed to conduct the electrochemical reaction $[K_4[Fe(CN)_6]/K_3[Fe(CN)_6]$. CV plots show the stable electrochemical performance of

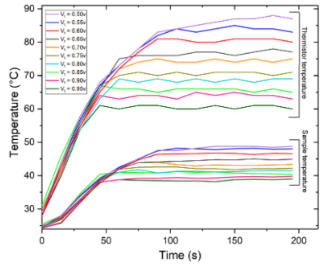

Fig. 3. Temperature evolution of the thermistor and the sample at different V_t values.

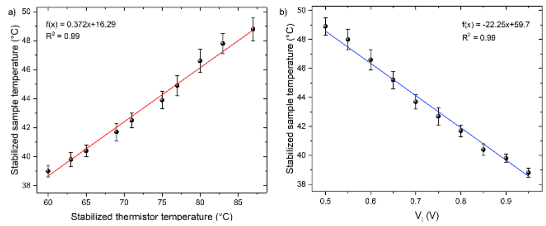

Fig. 4. a) Stabilized thermistor temperature vs, stabilized sample temperature. b) V_t can be used as a variable to set the sample temperature.

PCB-based electrodes at different temperatures for both ENIG and electroplated surface finishes (Fig. 5). The observed shifts in the peak voltages are likely caused by using a pseudo reference electrode. Also, a slight difference in the peak currents observed at different temperatures is probably due to a change in the reaction rate and diffusion coefficient at different temperatures.

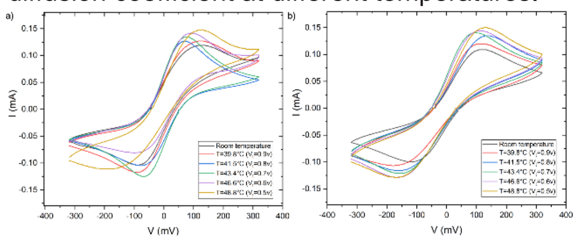

Fig. 5. CV plots at different temperatures for a) ENIG and b) electroplated electrodes.

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