A FLEXIBLE PLATFORM WITH INKJET-PRINTED ORGANIC ELECTROCHEMICAL TRANSISTORS INTEGRATED IN MICROFLUIDICS FOR SELECTIVE ION DETECTION

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ABSTRACT

This paper reports on flexible Organic Electrochemical Transistors (OECTs) with Ion Selective Membranes (ISMs) integrated in a soft microfluidic channel. The transistors are fully fabricated via inkjet printing on polymeric foil and the fluidic channel is made by laser-cutting and laminating a stretchable and biocompatible thermoplastic, to create a wearable sensing platform. In addition to the proposed fabrication and assembly procedures, this communication includes results on the sensitive and selective detection of potassium (K^+).

KEYWORDS: Flexible sensor, Ion sensing, Organic electrochemical transistor, Printing, Microfluidics

INTRODUCTION

Ion selective sensors are of critical importance for monitoring biologically relevant ion for diagnosis purposes. In particular, this is of significant interest for measurements performed in complex biofluids such as sweat, where multiple ions are present. Considering sweat, concentrations of K^+ and Na^+ range from 1-18.5 mM and 10-100 mM respectively and their individual variation can reveal insights on dehydration of individuals [1].

OECTs are gaining strong interest for ion sensing, due to their very high sensitivity and simple manufacturability [2-3]. Compared to standard potentiometric sensors fabricated by screen printing, OECTs can exhibit better sensing performances. Furthermore, the use of inkjet printing (IJP) to pattern thin functional films allows the integration of hermetic microfluidics using a simple lamination process. In this study, we focus on OECTs for ion sensing using fully IJP devices in combination with ISMs for the selective detection of K^+. The integration of the OECTs in a microfluidic channel is also reported, potentially allowing continuous ion measurements for sweat analysis and for simple point-of-care testing of biofluids.

EXPERIMENTAL

A schematic showing the fabrication process of the integrated platform is presented in Figure 1(a). The main fabrication steps include: (1) the use of a thin polyimide foil (125 µm-thick) as substrate; (2) inkjet printing of two layers of silver nanoparticles ink (PvNanoCell) and their sintering at 150 °C for 1 hour; (3) inkjet printing of four layers of PEDOT:PSS (0.8% in H_20, Sigma Aldrich) and its post-treatment with dimethyl sulfoxide (DMSO); and (4) lamination of the microfluidic channel. The printing steps were performed with a Dimatix DMP printer. The OECTs integrated in a microfluidic channel are shown in Figure 1(b). The OECT design consists of a 1x5 mm^2 PEDOT:PSS active layer and a 1 mm wide Ag gate. The microfluidics was made of the thermoplastic Flexdym™ (Eden Microfluidics) patterned using CO_2 laser. The microfluidic system is made of two Flexdym layers (800 µm-thick). The bottom layer contains a ~500 µm wide channel and 3x3 mm^2 reservoirs, and the top layer has inlet and outlet of 2 mm in diameter. An ISM for K^+ was drop casted (~10 µL solution) on the PEDOT:PSS active layer prior the microfluidics integration. The ISM was prepared using potassium ionophore, sodium tetraphenylboron in cyclohexanone, bis(2-ethylhexyl) sebacate and polyvinyl chloride. The OECTs characteristics were acquired with a semiconductor parameter analyzer (Agilent 4155A).

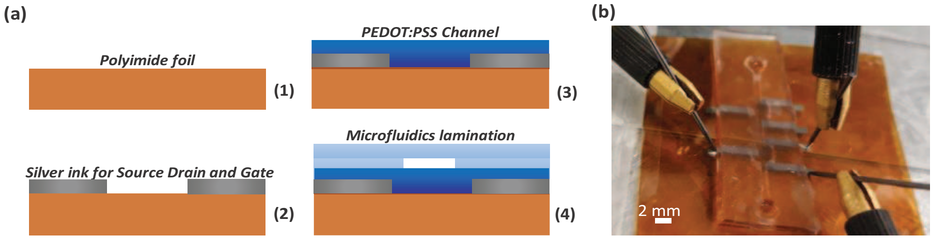

Figure 1: (a) Sketch showing the devices' cross section and process flow. (b) Platform during testing.

RESULTS AND DISCUSSION

The integrated platform was tested for the detection of K^+ ions using potassium chloride (KCl) solutions. The I_d-V_d output characteristic showed modulation of the drain current sweeping the gate voltage from -1 V to 1 V (Figure 2(a)). The I_d-V_g transfer curves were then obtained for different KCl concentrations and at drain voltage V_d = -0.4 V (Figure 2(b)), including the relevant concentrations of potassium in sweat. A sensitivity of 2.8 µA/dec exhibiting a high linearity (R^2= 0.985) was determined (Figure 2(c)). The transconductance of the OECT ($g_m = dI_d/dV_g$) was of 0.4 mS before the ISM casting, and 0.01 mS afterwards. The OECT lower performances after ISM casting are possibly due to the limited ions penetration in the active layer. This could be improved through a reduction of the thickness of the membrane or by embedding a liquid electrolyte between the membrane and the PEDOT:PSS layer. Nevertheless, the drain current is effectively changing with the KCl concentration. A further prove of the effectiveness of the OECT K^+-ISM can be seen in Figure 2(d), where the dynamic drain current response of the device is shown (V_g= 0.8 V, V_d= -0.4 V) following consecutive KCl injections at different concentrations, while negligible drain current variation is measured adding the interferent sodium chloride (80 mM NaCl in 50 mM KCl).

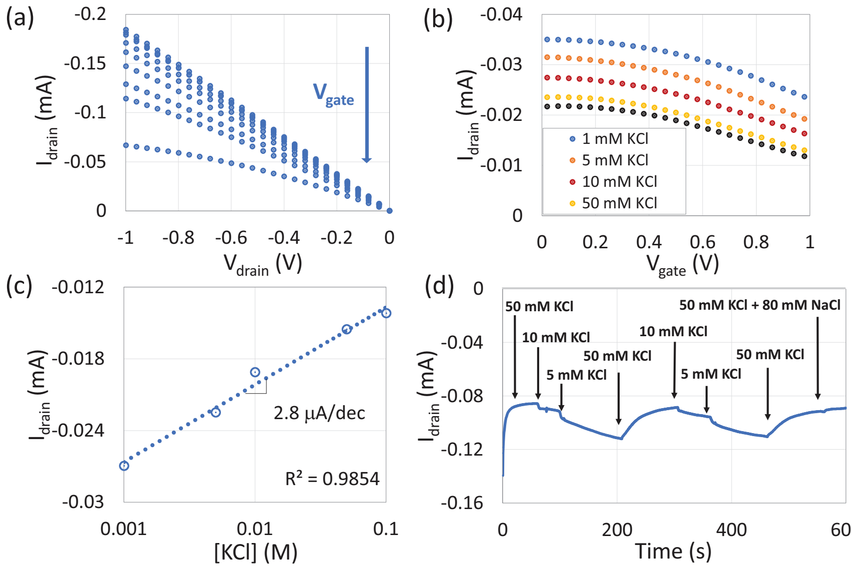

Figure 2: (a) I_d-V_d curve in 100 mM KCl solution (V_g from -1 to 1 V). (b) I_d-V_g curves with successive KCl solutions and at V_d= -0.4V. (c) Calibration curves at 0.8 V of V_g. (d) I_d-time measurement at different injections (V_g= 0.8 V, V_d= -0.4 V).

CONCLUSION

This platform made of IJP OECTs integrated in microfluidics has great potential for biochemical analysis. The facile fabrication process allows for easy integration of multiple sensors, enabling multi-parametric analysis for wearable and point-of-care testing applications. Further tests have to be performed for improving the transistor performances after ISM casting on the active layer, and for a further characterization of the detection and discrimination capability for different ions and at different pH levels, including variations relevant for sweat analysis.

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