FULLY INTEGRATED OXYGEN SENSOR WITH FOUR LAYER PRINTED CIRCUIT ELECTRONICS ON PAPER

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ABSTRACT

Paper-based devices are receiving significant attention for low-cost disposable medical diagnostics in resource-poor settings. However one still needs to interface paper based diagnostic devices with external readout units that are sometimes bulky and expensive, which makes them less suitable for wearable and disposable applications. In this paper we report a novel miniaturized and low cost integrated sensor platform on paper substrates for monitoring wound oxygenation, one of the critical parameters in wound healing. The device also contains a 4-layer multi-purpose printed circuit board (PCB) integrated along with sensor on the same paper substrate.

KEYWORDS: Paper-based Diagnostics, Wound Healing, Smart Bandage, Oxygen Sensor

INTRODUCTION

Continues monitoring of the key biomarkers in the wound microenvironment is important in effective treatment of wound since it can facilitate real-time closed-loop monitoring and intervention. This has the potential to improve wound healing, lower further tests and complications from non-healing wounds and reduces overall cost of healthcare significantly. Oxygen is one of the critical factors regulating wound healing process and it's monitoring along with pH and temperature provides the most useful information about the wound. Electrochemical approach including amperometric and galvanic methods are two common approaches which have been used for the implementation of oxygen sensors. However, integration of sensors on wound dressing should be conformal and easily integrated with read-out electronics. Another considerable aspect is using cost effective materials and approaches. The wound healing process imposes more than $20 billion of health care costs in USA [1]. Therefore, development of low-cost, reliable, self-contained devices using common earth-abundant materials is needed. Of many possible alternatives, common paper has been suggested as a suitable and conformal substrate material for such devices. Recently a lot of paper-based devices have been demonstrated such as paper-based supercapacitors, glucose sensors [2, 3].

Fabrication of sensors on paper substrates are receiving significant attention but interface of those sensors with read-out electronics components are still challenging and make the entire platform bulky and expensive. Recently, integration of sensors with portable read-out electronics for low cost diagnostic is investigated, but utilizing such bulky tools and integration will not be practical for wound dressing application [4].

In this study, we propose a smart paper-based platform with four layers of custom-designed printed circuit board in which oxygen sensor is implemented on the bottom layer and electronics read-out is assembled on top layers of the paper substrate. Sensors and electronics are connected easily with vias that can be easily punched through paper. Furthermore, simple microfluidic platform for injection and blood filtration could be added in future to complete the monitoring platform for wound healing. The proposed integrated paper-based platform could be used for other point-of-care diagnostics due to its low-cost and simplicity.

EXPERIMENTAL AND FBRICATION PROCESS

The device three dimensional rendering is shown in Figure 1. Two pieces of paper were used for implementation of the four layers of a PCB. Interconnects and foot-print of surface mount components were patterned on the top and backside of the first piece of the paper. Sensor is implemented on the back side of the second piece of paper. Power and ground lines are patterned on the inside surfaces. Double-sided tape is used to attach the papers to one another and can be extended to multiple layers.

The fabrication process starts by making interconnects and large circles for vias which were patterned on a tape using laser cutter (Versa VLS2.40) (power 40%, speed 20%), then the patterned tape was attached to the paper; a small through hole was created on the circles for vias using any sharp needle or laser source. Silver ink was spin coated and cured (5 hours, 60℃). Interconnects and electrodes were defined by peeling off the patterned tape. Off-the-shelf operational amplifiers (LMP91000) were surface mounted using conductive epoxy (NCA 130, Norland, USA).

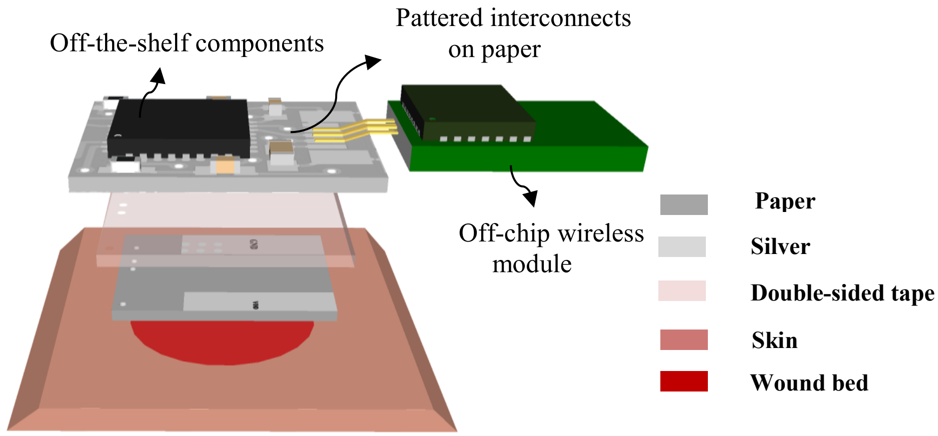

Figure 1: Schematic of 4 layers paper-based PCB integrated with oxygen sensor.

RESULTS AND DISCUSSION

Galvanic oxygen sensors of the kind shown in Figure 2a are implemented on other side of the paper device. Silver and electroplated zinc electrodes serve as cathode and anode respectively. In addition 0.1 M potassium hydroxide saturated on filter paper is used as the electrolyte and a thin layer of PDMS serves as the oxygen-selective membrane. This galvanic cell produces current proportional to the reduced oxygen at the cathode (zinc is oxidized at the anode). Parylene is also employed as an impermeable membrane to guard the sensing area from other parts. To fabricate the oxygen sensor, two silver electrodes were patterned by screen printing method mentioned above and then zinc was electroplated on one of the electrodes.

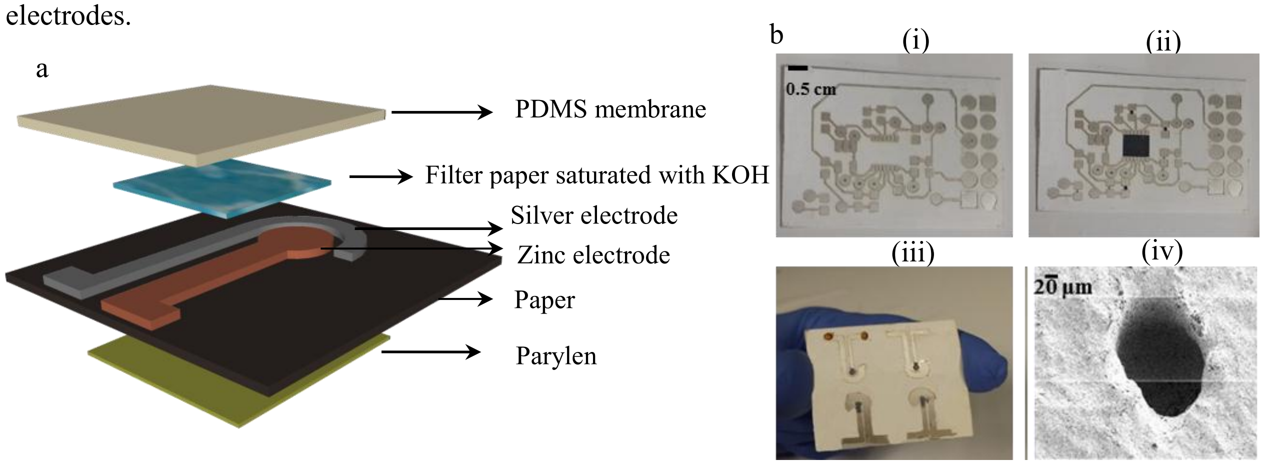

Figure 2: (a) Structure of oxygen sensor on bottom layer (b) Microfabricated fully integrated device (i) Top layer without electronics components (ii) Top printed circuit layer with electronic components (iii) bottom layer for sensors (without membrane) (iv) SEM image of via.

To fabricate the free standing PDMS membrane, a layer of PDMS with thickness of 12 µm (2500 rpm, 60S) was spin coated on silicon wafer which was covered with SPR photoresist as a sacrificial layer, then it was bonded using oxygen plasma to a PDMS ring which was prepared before; dissolving the photoresist using acetone allowed the creation of a thin layer of free standing PDMS membrane. Figure 2b shows different layers of fabricated four layers PCB.

Output of oxygen sensor is shown in Figure 3. Gain of the front-end amplifier is 2.75 KΩ, 7K KΩ, and 35 KΩ (see Figure 3c). The oxygen sensor is relatively linear with sensitivity 1.5µA/%oxygen concentration with response time of 20s. The entire platform is fully self-contained except for a battery.

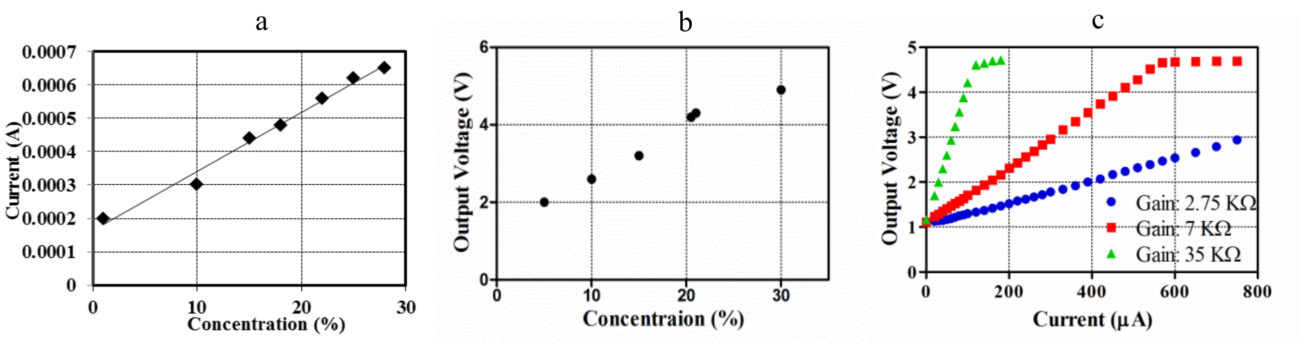

Figure 3: (a) Calibration curve of oxygen sensor (b) Calibration curve of oxygen sensor using front-end amplifier (c) Output characteristic of front-end amplifier.

CONCLUSION

In this sturdy, we propose the integrated platform including sensors and electronics all on paper. Relatively linear oxygen sensor was implemented on bottom layer of four layers PCB and programmable gain front-end amplifier assembled on first and second layers. While the proposed structure targeted for wound monitoring application, is also suitable for other low-cost wearable and disposable biomedical diagnostic applications.

ACKNOWLEDGEMENTS

Project was funded by the National Science EFRI-1240443.

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