Power Harvesting for Wearable Electronics Using Fabric Electrochemistry

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***Abstract*— We present a new method of power harvesting for wearable electronics that is based on epidermal electrochemical dressings dampened by a bodily exudate (sweat, wound exudate, etc.). Generation of DC power is achieved via an electrochemical process that enables transfer of electrons from silver- to zinc-printed dots using the bodily exudate as an electrolyte. Contrary to existing power harvesting methods (e.g.., RF or solar), the proposed method is fully-flexible and does not require bulky circuits or any sort of rigid components. Proof-of-concept results are presented, demonstrating: a) unobtrusive DC power generation in the µW range, and b) a batteryless epidermal sensor that identifies open wounds underneath its surface. Overall, this technology is expected to be of utmost significance for powering wearable electronics in military, healthcare, sports, and emergency applications, among others.**

Keywords—power harvesting; sensors; wearable; wireless; fabric electrochemistry.

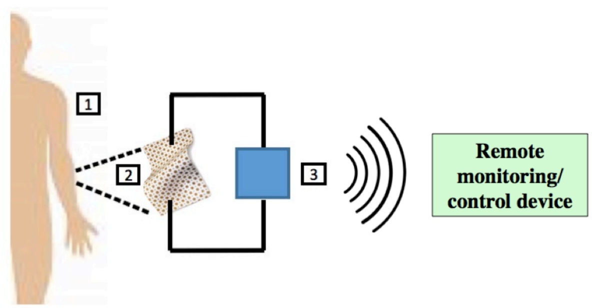

Fig. 1 Proposed concept of power harvesting from an epidermal electrochemical dressing (2) dampened by a bodily exudate (1). Generated DC power levels in the order of a few microwatts can be used to power on-body electronics (3).

I. Introduction

Wearable electronics are becoming increasingly popular for consumer, military, healthcare, emergency, space, and child monitoring applications [1-5]. Examples include sensors that monitor the heart rate, number of steps, motion, temperature, sweat levels, blood pressure, etc. In fact, the International Data Corporation (IDC) predicts shipment of over 237 million wearable devices (smart watches, bracelets, socks, shirts, etc.) in 2020 [6]. One of the biggest challenges associated with wearable electronics relates to the way of powering them [7]. Batteries are typically employed, but they are bulky and require frequent recharging and/or replacement. With these in mind, power harvesting technologies are recently being explored for powering wearable electronics. However, these methods are typically limited by the availability of harvestable energy and the use of bulky and rigid components [8].

In this work, we are taking a major leap forward and introduce a novel method of power harvesting using flexible electrochemical fabrics that feel and behave like regular clothing (see Fig. 1). The proposed fabrics generate DC power just by getting them moistened via a conductive liquid (sweat, wound fluid, etc.), and do not require any sort of rigid circuits or components. As such, a great variety of wearable and wirelessly sensors can be unobtrusively powered out of thin air. Along these lines, Section II describes the operating principle of the proposed power harvesting approach. Section III provides proof-of-concept measurement results, along with a demonstration of a batteryless epidermal sensor that identifies open wounds underneath its surface.

II. Operating Principle

The electrochemical fabric to be employed for DC power harvesting applications comprises alternating circular regions of silver and zinc dots. The "silver dots" contain oxides of silver, while the "zinc dots" contain oxides of zinc. When the electrochemical fabric is in contact with an aqueous solution, the silver acts as the positive electrode (cathode) which is reduced, while zinc acts as the negative electrode (anode) and is oxidized. When these electrodes contact a conducting fluid, such as sweat, wound fluid, saline solution, or even pure water, a set of reactions occurs. Beginning with the silver oxide electrode, OH^- ions are generated from [$Ag_2O + H_2O + 2e^- \rightarrow 2Ag + 2OH^-$]. The OH^- ions then migrate to the zinc dots and are consumed as [$Zn + 2OH^- \rightarrow ZnO + H_2O + 2e^-$]. In this way, DC voltage and DC micro-currents are generated just by getting the dressing moistened, without the need for any additional circuits or components.

III. Measurement Results

Proof-of-concept measurements were carried out using a commercially available electrochemical fabric that contained alternating dots of silver and zinc (Procellera® [9]). Though intended for expediting wound healing, and not optimized in any way for power generating applications, the Procellera® still served the purposes of our proof-of-principle demonstrations. Specifically, a 1”×1” Procellera® pad was employed in this study that was moistened in salt water (100mL water and 5mL salt). It is noted that electrochemical fabrics, such as the Procellera®, have recently appeared in the market for wound healing purposes. In brief, when skin is wounded, a change in electric potential occurs. This stimulus is the earliest guidance signal to initiate cell migration and re-epithelialization, as needed for wound healing [10]. Herewith, it is the first time that electrochemical fabrics are explored for power generating applications and used to power wearable electronics out of thin air, without requiring rigid circuits of any sort.

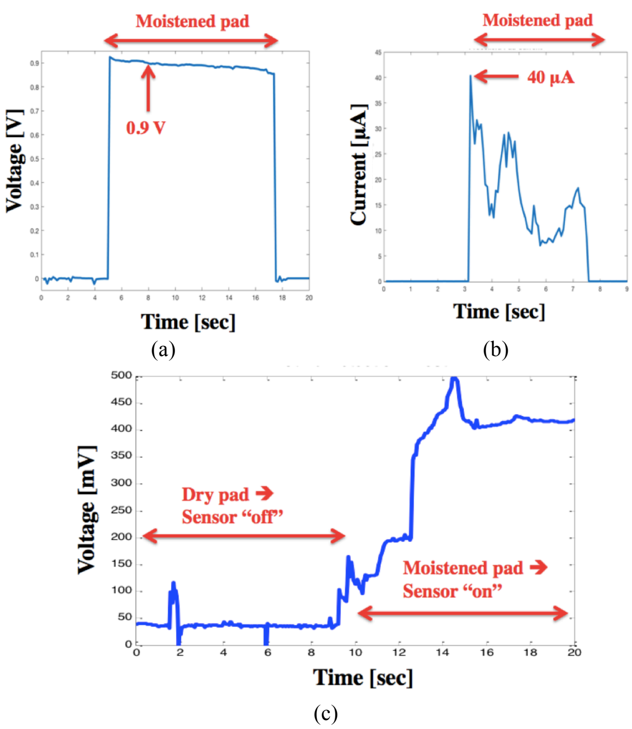

Fig. 2 Measured performance of a1”x1” electrochemical dressing dampened by a saline solution: (a) Generated open DC voltage across one pair of zinc and silver electrodes. (b) Generated current across one pair of zinc and silver electrodes. (c) Demonstration of powering a sensor that detects open wounds underneath its surface.

A. Power Generation Capabilities

Voltage measurements recorded when the positive (silver) and negative (zinc) dots of the moistened pad were connected to a voltmeter are shown in Fig. 2(a). The observed DC voltage measured from the Procellera® electrochemical dressing was approximately 0.9V. A peak current of ~40 µA, as shown in Fig. 2(b), was observed when the moistened pad was connected in series to a current meter. Remarkably, even these voltage/current levels measured from a proof-of-concept pad are high enough to produce several microwatts of power, enough to power a wide range of low-power electronic sensors.

B. Proof-of-Concept Demonstration of Epidermal ‘Wound Sensor’ Powered via Fabric Electrochemistry

A batteryless ‘wound sensor’ was subsequently demonstrated that was powered via fabric electrochemistry to detect the presence of an underlying open wound. As shown in Fig. 1, for this particular ‘wound sensor’, the electrochemical dressing (2) was used to actively ‘monitor’ the skin surface (1). In case an underlying wound opens, the resulting exudate acts as an electrolyte for the electrochemical fabric, causing it to generate static voltage. In turn, this voltage is used to activate an indicator/alarm unit (3), and/or wirelessly transmit this information to a remote monitoring/control device. For this proof-of-concept experiment, a diode was used in place of the alarm unit, and a saline solution (100 ml water and 5 ml salt) was use to emulate the wound exudate. When the electrochemical dressing came in contact with the saline solution, a static voltage was detected across the diode terminals; therefore, this ‘high’ voltage represented the ‘open wound state’ (see Fig. 2(c)).

IV. Conclusion

In this work, we demonstrated a novel method of powering wearable and other wireless sensors using fabric electrochemistry. Contrary to conventional powering techniques (batteries, RF power harvesting, etc.), the proposed method generates power using exudates that are readily available on-body (sweat, wound fluid, etc.), and is fully-flexible, feeling and behaving like regular clothing. A number of applications are envisioned for unobtrusively powering electronics in military, healthcare, sports, and emergency applications, among others. At the conference, we will provide in-house electrochemical fabric designs used to achieve scalable power generation capabilities.

References

[1] H. Elayan, R.M. Shubair, and A. Kiourti, “Wireless sensors for medical applications: Current status and future challenges,” in Proc. Europ. Conf. Antennas Propag., Mar. 2017.

[2] https://www.idc.com/getdoc.jsp?containerId=prUS41100116

[3] He, B., Baird, R., Datta, A., George, S., Hecht, B., et al.: ‘Grand challenges in interfacing engineering with life sciences and medicine’, *IEEE Trans. Biomed. Eng.*, vol. 60, no. 3, pp. 589-598, 2013.

[4] M.A. Hannan, S. Mutashar, S.A. Samad, and A. Hussain, “Energy harvesting for the implantable biomedical devices: issues and challenges,” Biomed. Eng. Online, vol. 13, 2014.

[5] Vomaris: ‘Procellera: Wound care with advanced microcurrent technology’, http://procellera.com/, accessed November 2016.

[6] Banerjee, J., Das Ghatak, P., Roy, W., Khanna, S., Sequin, E.K., et al.: ‘Improvement of human keratinocyte migration by a redox active bioelectric dressing’, *PLOS One*, vol. 9, no. 3, pp. 1-14, 2014.