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WEARABLE POTENTIOMETRIC SENSORS BASED ON COMERCIAL CARBÓN FIBRES FOR MONITORING SODIUM IN SWEAT

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SPECIAL ISSUE

Wearable Potentiometric Sensors Based on Commercial Carbon Fibres for Monitoring Sodium in Sweat

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Abstract: The use of commercial carbon fibres (CCF) to build wearable potentiometric sensors for the real-time monitoring of sodium levels in sweat during exercise is presented. CCF are an attractive substrate for building wearable electrochemical sensors because of their good electrical conductivity, chemical inertness, flexibility and mechanical resilience. In the first part of this work, the analytical performance of these novel potentiometric ion-selective electrodes made with CCFs is presented. Then, through the incorporation of a solid-contact reference electrode, the development of a complete miniaturized potentiometric cell with a Nernstian response (59.2 ± 0.6 mV/log [Na^+], N=4) is obtained. Finally, the cell is integrated into a wearable patch and attached onto the skin of an athlete. The analytical characterization of the wearable patch shows a near-Nernstian response (55.9 ± 0.8 mV/log [Na^+], N=3) for sodium levels from 10^{-3} M to 10^{-1} M in artificial sweat, well within the physiological range of interest. The device shows low noise levels and very good stability (-0.4 ± 0.3 mV$\cdot$h^{-1}). To improve the usability of the sensor in real scenarios, a calibration-free approach is also explored. This platform opens new and attractive avenues for the generation of meaningful personalized physiological information that could be applied – among many other fields – in sports, nutrition and healthcare.

Keywords: carbon fibres • potentiometry • real time monitoring • sodium sweat patch • wearable sensor

1 Introduction

The development of wearable sensors embedded into garments for monitoring exercise and improve sports performance is an increasingly growing trend [1,2]. Indeed, the seamless integration of sensors into clothes presents many attractive features for the end-user, such as the easy access to real-time personalized data, portability and simplicity of operation [3,4]. The information generated by these sensors may yield significant benefits, such as the improvement of the performance in athletes [5] and the minimization of the risks of injuries [6]. Hence, the generation of personalized physiological data can provide valuable insights to enhance the experience and early detect and prevent health issues [7]. For this reason, different approaches to integrate smart microsensors (i.e. heart rate, electromyography, accelerometers, gyroscopes and magnetometers) into sport garments have been intensively pursued. Today, a growing range of commercial products and applications are available [8,9]. Research activities for the development of watches, wristbands, adhesive patches and even epidermal tattoos are also being applied to monitor a broad range of movements and biometric parameters [10], such as cardiac respiratory or skeletal muscle activity. "Wearability", i.e., the ability to withstand mechanical stress and embed these devices with minimal disruption for the user, is a key requirement. Thus, significant efforts in material science [11,12] are currently being devoted to the development of stretchable and bendable electronics [13] that can serve as flexible substrates and adapt to different routines [14]. Remarkably, despite of all this progress, there is a relative lack of wearable sensors that can produce reliable (bio)-chemical information. Indeed, while wearable sensors for physical parameters (temperature, heart rate, movement, etc.) have come a long way, the development of wearable sensors to produce relevant chemical and biochemical information has moved at a significantly lower pace.

The development of a wristband glucometer [15] more than a decade ago can be considered as one of the earliest wearable chemical sensors that reached the market. Although this device presented several practical issues and had to be recalled from the market, it stressed the advantages of electrochemical sensing in the field of wearable devices. Early contributions from Diamond *et al*. were also pioneers in this field, mostly by focusing on the improvement of the chemo-biosensing through body sensing networks (BSN) [16–18]. Although they were truly visionaries, these early works faced two major challenges. First, that at the time many of those early platforms were proposed, most of the technology nowadays widely available (flexible substrates, miniaturized low-power consumption electronics, etc.) was not yet mature. Therefore, these prototypes were not fully portable and adaptable for monitoring properties in real scenarios. Second, the difficulty for building consistent chemical

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