“TEXTILE-BASED ELECTROCHEMICAL SENSORS AND BATTERIES FOR WEARABLE BIOSENSING”

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Wearable biosensors have gained tremendous attention in the past decade due to their capacity for ex vivo physical and biochemical measurements of important physiological parameters including heart rate, oxygenation of the blood, respiration rate, skin temperature, bodily motion, brain activity, blood pressure, and sweat composition. This has been achieved, in part, through recent developments in flexible sensors and miniature electronics, which can offer high sensing performance on a compact, lightweight platform. While much progress has been made in this field, existing wearable chemical sensors are prone to damage due to mechanical deformation and/or require bulky, rigid electronic components. In this work, we explored the development of robust, textile-based electrochemical sensors and batteries for wearable sensing applications. In particular, a novel method for fabricating flexible electrochemical sensors was introduced by utilizing embroidery. Using this technique, conductive thread-based electrodes were fabricated onto various types of textile and fabrics, which could be made with customized geometries and configurations to accommodate commercial or custom electrochemical instrumentation. For proof of concept, embroidered biosensors were used for measurements of glucose and lactate in buffer and whole blood samples, which offered excellent analytical performance, good resiliency against mechanical stress and superior repeatability. We also adapted this technology for generating embroidered sensors onto gauze for rapid measurements of uric acid, a biomarker of wound healing. We demonstrated that this embroidered gauze sensor maintained high accuracy up to 7 hours for continuous wound monitoring.

We also explored the development of liquid-activated textile batteries as a lightweight, flexible power source for textile biosensors. Two generations of batteries, the first utilizing thin film metal electrodes and the second utilizing screen printed electrodes, were designed, fabricated and tested. These batteries are designed to turn on upon exposure to small amounts of liquid (~30 µL per cell) and turn off after being completely dried, thus facilitating autonomous operation. Additionally, this battery can be reactivated simply by adding more liquid to the cell(s). Through optimizing various battery parameters, a steady output voltage of 1.3 V was achieved from a single cell, which exhibited discharging times of 100 min and 50 min for loading currents of 1 µA and 50 µA, respectively. Batteries with higher voltages and currents were obtained by connecting multiple cells in series or parallel.

Towards a fully integrated, wearable “smart diaper” sensing platform, we developed a textile biosensing system consisting of a screen-printed, liquid-activated battery and electrochemical
sensor integrated with a miniature detection circuit. This device was used for quantitative measurements of xanthine oxidase (XOx), a biomarker correlated with urinary tract infections, in spiked buffer samples, which exhibited good linearity and accuracy. We also analyzed urine samples from patients with positive urine cultures using this device, which could detect XOx at concentrations between 0 U/L to 16,000 U/L, demonstrating the clinical usefulness of this platform. In conclusion, the results and technological advancements presented in this dissertation will provide researchers with new insights into the design and fabrication of textile-based chemical sensors and batteries, as well as their integration with miniature electronics, towards the realization of fully integrated, robust, wearable biosensing platforms.