PURDUE UNIVERSITY
School of Materials Engineering

Purdue Materials Engineering

"Design and Fabrication of Flexible Sensors for Single-Use Applications"

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ABSTRACT

The development of reliable, robust and low-cost sensor devices is a growing and important ongoing challenge. From environmental monitoring and household safety to food and biopharmaceutical industries, the necessity for specific analyte detection is crucial. Over the years researchers have come up with myriad materials that can be used for efficient sensing devices. The materials employed are governed by application and performance criteria as well as the sensing mechanism, which might be based on physical or chemical principles. In this thesis, two different types of electrochemical sensor technologies were examined with special attention paid to the application of the devices, the materials used, and their feasibility for scalable manufacturing.

In the first study, binary mixtures of conducting and semiconducting nanomaterials were explored as promising candidates for the manufacturing of low-cost ethylene sensor on flexible substrates. Ethylene (C2H4) is a small plant hormone which has been shown to affect the growth and senescence of flowers, leaves and fruits. Currently available devices have demonstrated high ethylene sensitivities with great potential for technology size reduction; however, some are not practical for use outside of the laboratory, lack portability, or require more research to demonstrate their reproducibility and stability in different environments, as well as selectivity to C2H4 in large-scale applications. Conductometric gas sensors based on a combination of carbon nanotubes (CNTs) and exfoliated molybdenum disulfide (MoS2) coated with molecular receptors is demonstrated for the selective detection of ethylene, including details on materials preparation, manufacturing, and characterization. Mixtures of CNTs and exfoliated MoS2 were deposited onto screen-printed interdigitated electrodes on plastic substrates, with optimization for scalable and continuous manufacturing by roll-to-roll methods. C2H4 detection levels of 0.1 ppm were readily achieved with responses on the second timescale.

The second sensor technology shows how thin-film potentiometric electrodes based on ion-selective membranes can be designed to tolerate sterilizing radiation while providing excellent performance and signal stability. This sensor's development was motivated by the expanding need for single-use bioreactor systems in the biopharmaceutical industry, which require strict control over cell culture conditions for several weeks or more. Until recently, critical analysis has been conducted mostly by offline or "at-line" sampling of aliquots withdrawn from the sterile bioreactor. The latter is inefficient and can increase the risk of contamination. Inspired by the challenges related to cost, integration and performance following irradiation a potentiometric pH-electrode was developed, intended for single-use applications. It was shown to be radiation-tolerant while providing reliable data comparable to a commercial pH meter over a period of three months. The electrodes exhibited quasi-linear signal drifts of +0.28 mV/day or 0.005 pH units/day. Thin-film γ-irradiated electrodes could provide accurate pH readings in sterilized culture media using a single-point calibration, within 0.07 pH units of a commercial meter with glass electrode and daily calibration. Furthermore, to advance the development of market-ready sensors past the conceptual stage, a few automated processes for scalable membrane deposition were investigated.

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