Finite Element Modeling a Redox-Enzyme-Based Electrochemical Biosensor

Yue Huang and Andrew J. Mason
Electrical and Computer Engineering, Michigan State University
2120 Engineering Building, Michigan State University, MI 48824, USA

Introduction

This paper describes the modeling of an electrochemical biosensor embedded in a microfluidic channel to determine the concentration of a target biomolecule. The total amount of analyte in the sample can be calculated by integrating the analyte concentration over the duration of the peak current. The biosensor is constructed by immobilizing redox-enzyme on an interdigitated array (IDA) electrode using molecular self-assembly. By setting one working electrode of the IDA at the enzyme's reduction potential and the other at its oxidation potential, the target biomolecules can be recycled to generate higher faradic current, thus increasing sensitivity. Figure 1 illustrates the redox recycling on a simple IDA that is embedded in a microfluidic channel. The reference electrode and counter electrode are downstream in the electrochemical flow cell.

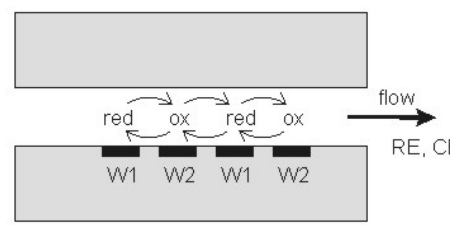

Figure 1: Cross-section of a capillary with an IDA detector utilizing redox recycling effect. The flow cell involves two working electrodes (W1 and W2), a reference electrode (RE) and a counter electrode (CE).

An alcohol sensor using secondary alcohol dehydrogenase (SADH), a redox enzyme, was chosen for this study. Due to the specificity of the enzyme, a SADH biosensor can be applied to capillary liquid chromatography (LC) as a detector for screening alcohols. Exchanging the redox enzyme within the system permits detection of a wide range of biomolecules and enzyme activity, for example in blood analysis.

Use of COMSOL Multiphysics

Modeling the redox recycling biosensor involves solving electrical field, fluidic dynamic, and electrochemistry problems. Several important parameters, such as the standard potential and effective electron transfer rate, were determined experimentally before modeling. Other parameters were assigned typical values. A 2D geometry of the fluidic phase domain was created to describe the microfluidic channel and sensor-fluidic interface. Laminar flow conditions were assumed for solving the incompressible Navier-Stokes equation of the fluid model. The conductive media model solves the electric field. The fluid model and conductive media model coupled to the electrochemical model by the solved variables, electric field and velocity vectors. The Nernst-Planck electrochemical model was solved under Butler-Volmer boundary conditions on both electrodes. In post-processing, the geometry of the IDA will be manipulated by its width, gap and number of fingers, and sensor sensitivity can be optimized by evaluating the steady-state current magnitude at various geometries. The peak current of the IDA can also be plotted as a function of flow-rate.

Reference

1. Niwa, et al, Improved detection limit for catecholamines using liquid chromatography-electrochemistry with a carbon interdigitated array microelectrode, Journal of Chromatography B: Biomedical Sciences and Applications, Volume 670, Pages 21-28, 1995.