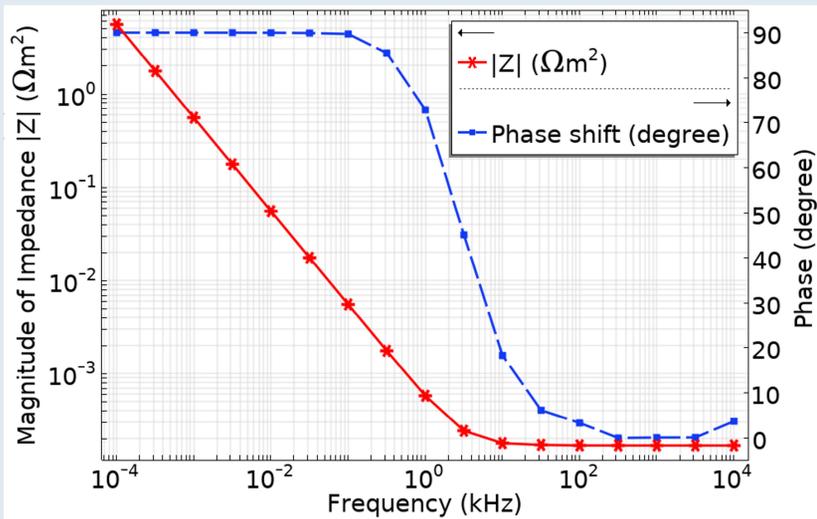


Electrochemical Impedance Spectroscopy in Carbonate Buffered Media for Biosensing Applications

1D simulation of a micro-electrode based Electrochemical Impedance Spectroscopy (EIS) sensor in carbonate buffered media intended for organ on a chip applications

Y. Abbas, A. R. M. Verschueren, J. F. M. Oudenhoven

imec at Holst Centre, Eindhoven, The Netherlands



Abstract

In biosensing applications, the Electrochemical Impedance Spectroscopy (EIS) technique can be used to **detect biomarkers** by monitoring the electrode-electrolyte interactions as well as the bulk electrolyte properties [1]. These biosensors can be used in the **inline monitoring** of analytes in **organ-on-a-chip** applications. Due to size restrictions in these applications, miniaturized sensors are desired, such as interdigitated micro-electrodes [2].

A **1D COMSOL® model** is developed to evaluate the measurement range of the EIS sensor for pre-validation of the sensor design before fabrication. This 1D model incorporates the effects of the electrolyte media and the sensor dimensions. The current response and the impedance response (**EIS Bode plot**), are plotted for a range of excitation frequencies. Finally, the effect of the **spacing between electrodes** on the EIS plot is plotted, showing a proportional change in impedance with spacing in a 1D geometry.

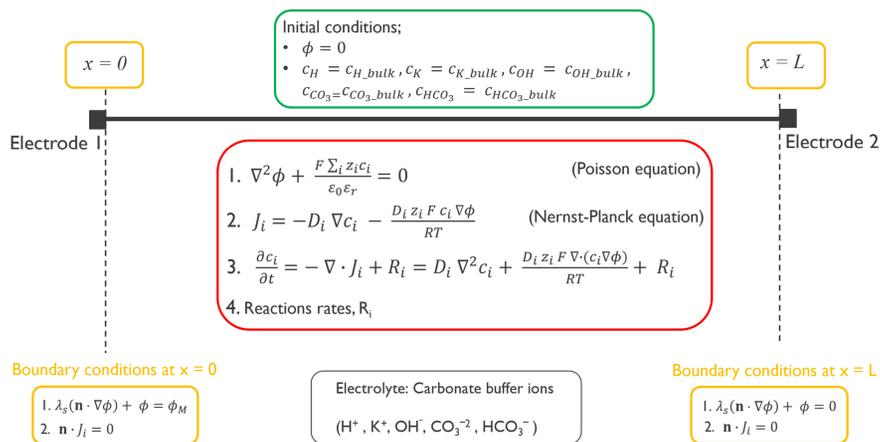


FIGURE 1. Details of the 1D EIS model showing the governing equations, initial conditions and boundary conditions

Methodology

The geometry is a 1D line (electrolyte) between two points corresponding to electrode 1 (the excitation electrode) and 2 (the ground electrode). A sinusoidal excitation signal, $E(t)$, is applied at electrode 1. The model **solves for the potential drop in the 1D domain** between the two electrodes and the concentration of the ionic species using the **Poisson and Nernst-Planck equations in a time-dependent study**. The details of the model, including the governing equations, ionic species, initial, and boundary conditions, are shown in Figure 1.

Post-processing: The magnitude of impedance is determined by using Ohm's law and the phase shift by determining the shift between the peaks of the applied voltage and the current response.

$$|Z| = E_0 / I_0$$

Results

All the result plots are presented in Figure 2. A voltage step is applied at $t = 5$ ms, and the voltage drop in the electrolyte is plotted. The voltage drop in the electrolyte is zero before the step. During the rise time of the step, it drops linearly over the length of the electrolyte. After redistribution of the electrolyte ions, the applied voltage is fully taken up by the **Stern and Debye layers**, formed at the electrode-electrolyte interfaces (see insert of Figure 2c).

The sinusoidal response for 1 kHz and 1 MHz is shown in Figure 2d and e. The **phase shift** is higher at 1 kHz, whereas at 1 MHz, the responses are in-phase. The **EIS plot** (Figure 2f) illustrates the impedance response for 20 and 200 μm of electrode spacings. The **impedance changes proportionally** with the change in electrode spacing.

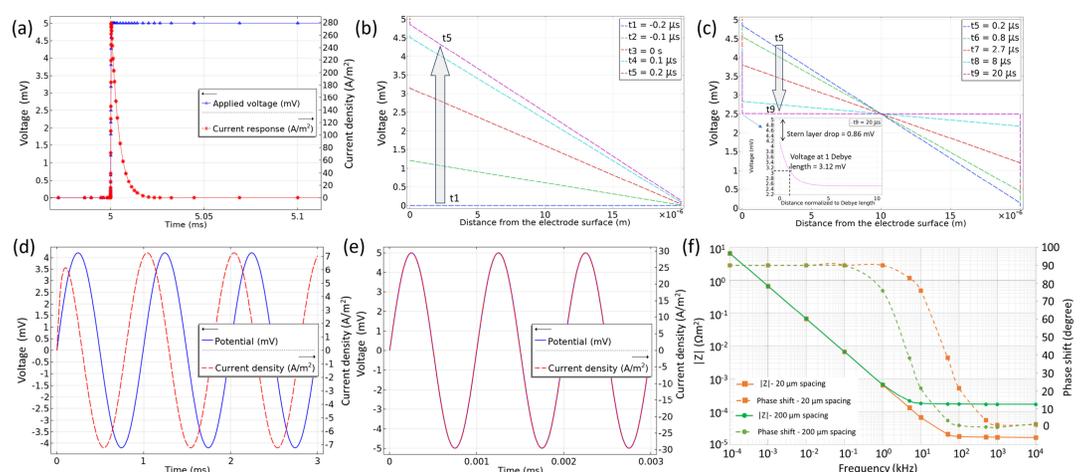


FIGURE 2. (a) Step voltage and current response (b & c) Voltage drop in the electrolyte (d & e) Sinusoidal excitation voltage and current response for 1 kHz and 1 MHz, respectively at 20 μm electrode spacing (f) EIS bode plot for 20 and 200 μm of electrode spacings.

REFERENCES

- [1] M. Saghafi, S. Chinnathambi and S. G. Lemay, "High-frequency phenomena and electrochemical impedance spectroscopy at nanoelectrodes," *Current Opinion in Colloid & Interface Science*, Vol. 63, p. 101654, 2023.
- [2] Tugba Kilic et al. "Organs-on-chip monitoring: Sensors and other strategies." *Microphysiological systems*, Vol. 2, p. 5, 2018.

