Computer Simulation of Electrochemical Impedance Spectroscopy for Detection of Single-bacterial Cell using Microelectrodes on CMOS LSI Chips

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1 Introduction

Living cell monitoring has widely been used in medical and pharmaceutical research, and one of the promising methods is based on electrochemical impedance spectroscopy (EIS) [1]. Single cell monitoring using EIS has also been demonstrated [2], and a large-scale integrated (LSI) circuit chip is an ideal platform because of its massive integration of microscale sensor electrodes and low-noise measurement using complementary metal-oxide-semiconductor (CMOS) circuits. The reported size of microelectrodes on LSI can be as small as 1.2µm×2.05µm, which is comparable to single-bacterial cell [3].

In this study, feasibility of single-bacterial cell detection by EIS using microelectrodes on CMOS LSI chip is explored by means of computer simulation.

2 Simulation Method

Fig. 1 illustrates the simulated model structure involving a set of elliptical microelectrodes of width \( W \) and length \( L \) at the bottom of wells with depth \( D \) in the separation \( S \), where the values and shapes were estimated from a previous report [3]. Maxwell’s equation is then solved by a finite-element method simulator COMSOL Multiphysics® to calculate the electrochemical impedance between two electrodes from the alternating current under sinusoidal voltage stimulation. A bacterial cell was modeled as a sphere with 1.0µm diameter.

3 Results and Discussion

Fig. 2 shows simulated EIS with/without a sphere representing a single bacterial cell. The EIS without cell distinctly shows electric double layer capacitance (\( f < 10^5 \)Hz), solution resistance (\( 10^5 \)Hz < \( f < 10^8 \)Hz), and solution capacitance between two microelectrodes (\( f > 10^8 \)Hz). The existence of a cell increases the solution resistance from 1.64MΩ to 1.87MΩ at 1.0MHz. Such increase may be read-out by on-chip CMOS circuit.

4 Conclusion

EIS with/without single bacterial cell as small as 1.0µm has been numerically simulated to show feasibility of single bacterial cell detection using CMOS LSI chip.

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References


Fig. 1: Model of microelectrodes and bacterial cell.

Fig. 2: Simulated electrochemical impedance spectroscopy.