Model of an Interdigitated Electrodes System for Cell Counting Based on Impedance Spectroscopy

Elena Bianchi[1], Francesco Bellati[2], Enrica Rollo[3], Gabriele Dubini[2], Carlotta Guiducci[4]

[1]Swiss Federal Institute of Technology (EPFL),Laboratory of Life Sciences Electronics - Swiss Up Chair, Lausanne, Switzerland AND Politecnico di Milano, LaBS, Laboratory of Biological Structure Mechanics, Milano, Italy

[2]Politecnico di Milano, LaBS, Laboratory of Biological Structure Mechanics, Milano, Italy

[3]Swiss Federal Institute of Technology (EPFL), Laboratory of Life Sciences Electronics - Swiss Up Chair, Lausanne, Switzerland

[4]Swiss Federal Institute of Technology (EPFL),Laboratory of Life Sciences Electronics - Swiss Up Chair, Lausanne, Switzerland

Abstract

Introduction: A cell counter sensor based on impedance spectroscopy has been modeled by means of COMSOL Multyphisics 4.2a. The cell counter consists in a system of vertical interdigitated electrodes, built on a silicon wafer by means of microfabrication technologies (Figure 1). With the aim to overcome the critical limiting factor of the low throughput characterizing the existing cell counters, this device aims to enable parallel measurements to detect cells flowing through in parallel-plate flow-chambers with large width-height ratio. Impedance spectroscopy (IS) is a powerful method for characterizing many of the electrical properties of materials and their interfaces [1]: it allows real-time detection, non-invasive sensing, label-free analyses and easiness of integration in a high-throughput screening. Use of COMSOL Multiphysics: Impedance spectroscopy (IS) is an electrical measurement: the approach is to apply a known AC voltage stimulus to the electrodes and observe the resulting response in current, assuming that the properties of the electrodes and of the system do not change with time [2]. Sweeping over a wide frequency range f =1e-5 - 1e9 Hz with a small-amplitude (50 mV) single-frequency voltage, the phase shift and the amplitude, or the real and the imaginary part of the resulting signal are measured. The model has been solved by the electric current module: electrodes' boundaries where the voltage is applied are defined as Terminals and the resulting value of impedance Z [Ω] is calculated as the inverse of the admittance (ec.Y11) and expressed as the combination of a real and a complex term. The electric properties of the materials (silicon, platinum, buffer fluid, cell/bead core) have been assigned in terms of conductivity σ [S/m] and permittivity ε [-]. We introduced critical thin structures/layers or contact impedances, defined by conductivity σ [S/m], permittivity ε [-] and thickness d [m]. This approach has shown to be crucial in order to reduce of the number of elements of the grid. Our system has been characterized by employing polystyrene beads that show similar insulating behavior as cells in the frequency range of interest. The detection of a bead between the electrodes has been verified as a variation of Z value, observable only in a restricted range of electrical frequency (Figure 2). Results: The sensitive portion of the electrode system has been modeled. Dependence of the impedance spectrum Z(f)

from the dimensions, number and configuration of the electrodes has been studied and compared to IS experimental measurements. Influence of buffer fluid conductivity on the efficiency of bead detection has been investigated, in order to guide the experimental characterization of the electrodes system (Figure 2). Conclusion: The results of the impedance simulation of the electrodes system models have given results consistent with the electrical equivalent model and with the experimental characterization of the device. A come out limitation of the simulations is the representation of the device limited to the sensitive area: parasitic effects related to the presence of connection wires cannot be appreciated by means these models.

Reference

1. Cheung, K., S. Gawad, and P. Renaud, Impedance spectroscopy flow cytometry: On-chip label-free cell differentiation. Cytometry Part A, 2005. 65A(2): p. 124-132.
2. Morgan, H., et al., Single cell dielectric spectroscopy. Journal of Physics D: Applied Physics, 2007. 40(1): p. 61-70.

Figures used in the abstract

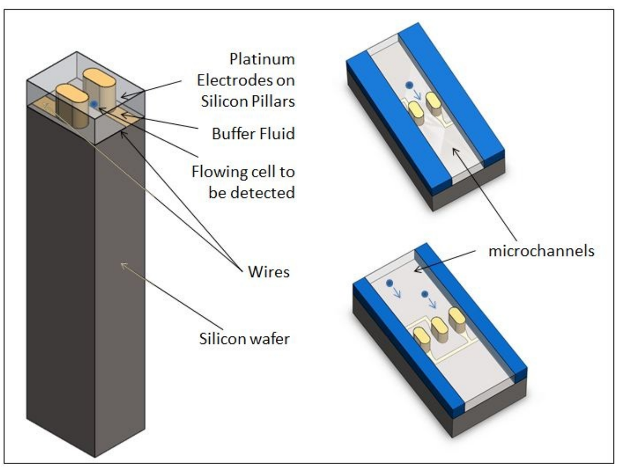

Figure 1: Sketch of the model (left), Sketch of different device configurations (right).

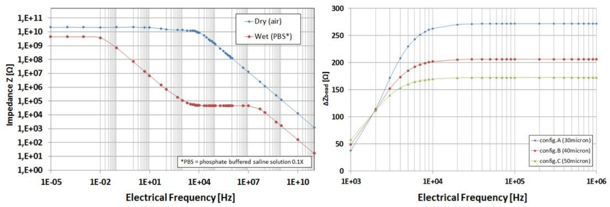

Figure 2: Modulus of the impedance of the microdevices consisting of the two electrodes (left), change in impedance due to the presence of a polystyrene bead (substitute for cell) between the electrodes (right).