Simulation Of The Tunable MEMS Electrostatic Peristaltic Pump

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Abstract

This work introduces a method for single-cell trapping using a planar patch clamp integrated with an array of capacitive micropumps. The Patch-Clamp/MEA system is a revolutionary tool for single-cell studies, significantly advancing our understanding of neuronal activity and cellular communication. Its capability to simultaneously measure electrical signals from individual cells and network dynamics offers profound insights into the brain's complex workings [1]. This proposal outlines the development of an integrated platform for single-cell studies. By combining planar patch clamps and microelectrode arrays with active micropumps, the platform aims to automate both intra- and extracellular measurements with high throughput. However, precise control over the position and pressure of liquid exchange within a closed microchannel poses a significant challenge. Peristaltic micropumps (PMPs) have emerged as a promising solution to these obstacles. Typically consisting of three or more sequentially operating pumping chambers, PMPs utilize electrostatic forces generated by actuation electrodes to achieve high accuracy, repeatability, and reliability in fluid transport [2]. These pumps control flow without passive valves, reducing the risk of damaging particles and living cells within microchannels. In this project, the goal is to develop and fabricate a system capable of automating both intracellular and extracellular measurements of single-cell activities. Achieving this goal involves addressing several design parameters, including size, geometry, materials, and the number of stages required for the peristaltic pump. These critical challenges must be overcome to achieve sufficient flow rates and output pressure necessary for cell trapping. A deep simulation understanding of the system using COMSOL software is essential. This work investigates an electrostatic diaphragm micropump using COMSOL Multiphysics 6.2. A mechanically operated micropump consisting of three pump chambers connected with a microchannel actuated by electrostatic actuators is designed and simulated. Each pump measures 750 µm × 4 µm, with the thickness of the microchannel and the movable membrane being 3 µm and 2 µm, respectively. Then it was required to complete the 3D model by implementing suitable mesh size and boundary conditions for the inlet and outlet. Open boundary conditions are imposed for the inlet and outlet. Also, it was noted that in COMSOL, deforming mesh simulations encounter solving issues when the mesh deformation surpasses a certain threshold. Due to the device's complexity, which combines solid mechanics, electrostatics, and fluid dynamics, results are obtained stepwise. Preliminary analyses with simplified models are performed before introducing the different physics involved. Initially, electromechanical static simulations evaluate membrane displacement and pull-in phenomena. Then, a fluid-dynamic model assesses the fluid flow characteristics inside the microchannel. Finally, a simplified fully coupled electrostatic fluid-structure dynamic model is proposed, requiring a moving mesh for the deforming fluid domain. As the membrane is deformed by the electrostatic actuation, the fluid domain and its mesh must also adjust accordingly. This issue was addressed by implementing a moving mesh model featuring a hyperelastic mesh smoothing approach. With an applied step voltage of 20 V amplitude, the maximum deflection of the pump diaphragms is approximately 2.2 µm. Based on the evaluated switching time of applying voltage for each stage, the initial iteration time starts at 0 and ends at 1.2 ms with a time step of 5 microseconds. This model aims to capture the maximum displacement of the membrane, generated pressure, and the flow rate of fluid motion.

Reference

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[3]. M Ahamed, Sharmin Atique, and et al. The fluid-structure interaction of a peristaltic pump: basics and analysis. Am. J. Eng. Res, (2016).

Figures used in the abstract

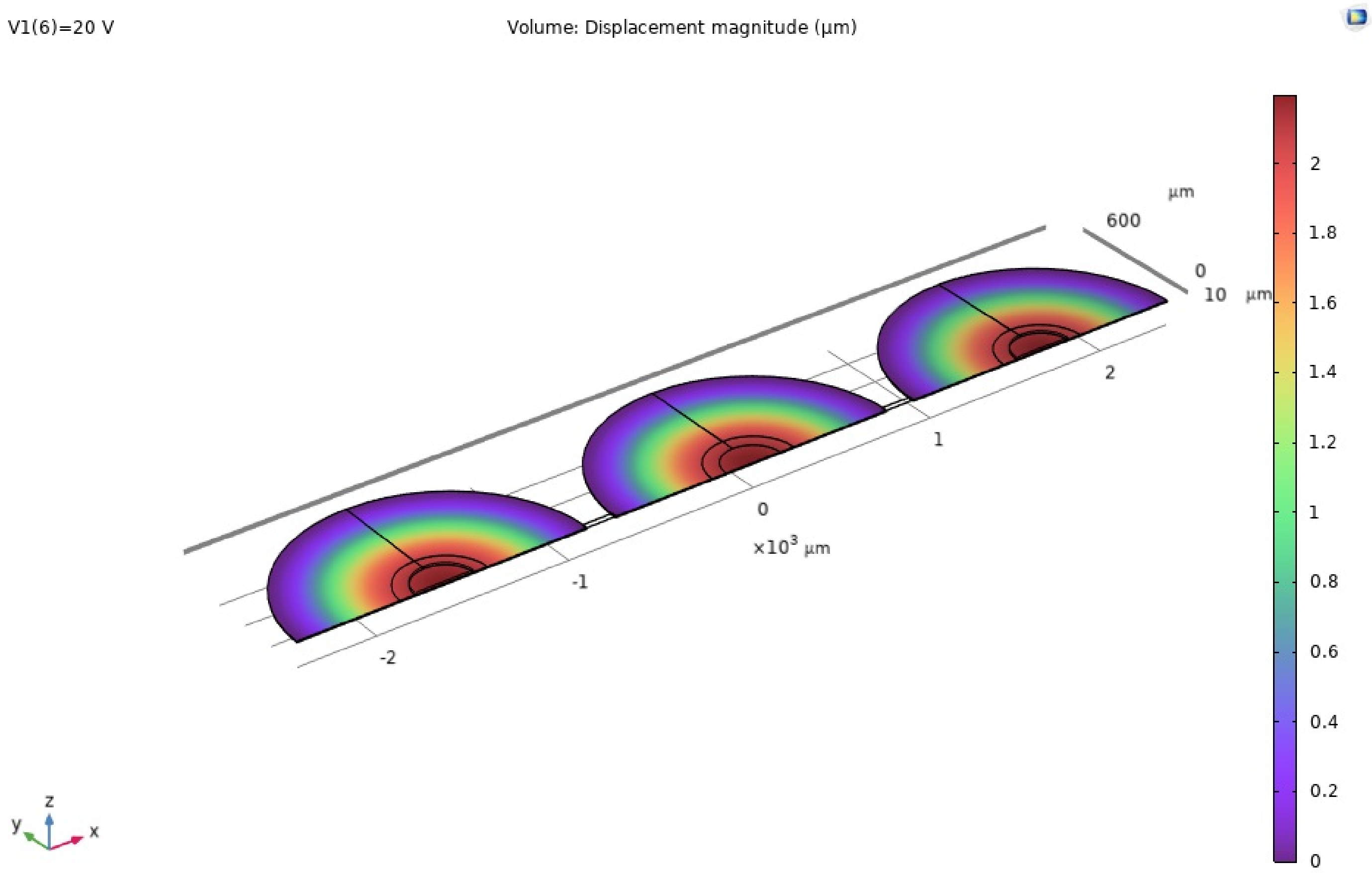

Figure 1 : FEM simulated the results of the micropump plate displacement in response to an applied voltage of 20V. Legend in µm. Max deflection approx. 2.2 µm.