Liquid Microlenses with Adjustable Focusing and Beam Steering for Single Cell Optogenetics

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Abstract

In optogenetics research it is highly desirable to have a method that can deliver light and excite individual neurons in the brain in a controllable and single cell manner. Working toward this goal, we are developing liquid microlenses with active electronics that enable both focusing and beam steering in a single optical element that will eventually be attached to an implantable optical probe. In this design, the liquid microlens is formed by the interface between immiscible liquids which are contained in a conically tapered lens cavity etched into a fused silica substrate. Interdigitated metal electrodes were patterned along the taper sidewalls to electrically control the liquid interface formed between two immiscible liquids. This taper design allows for both simultaneous focusing and beam steering, depending on the voltages applied to each electrode and how the radius of curvature of the liquid interface changes and/or tilts within the taper cavity. In order to understand how the liquid interface would move and tilt within the cavity, and to determine what taper angle and taper depth would provide the best dynamic range, numerical simulations were performed to guide the liquid microlens design. The liquid interface behavior as a function of voltage was modeled using the laminar two-phase flow level-set method, found in the CFD module in COMSOL Multiphysics®. In this method the liquid interface boundary formed between two immiscible liquids is determined solving the Navier Stokes momentum equation with surface tension acting as the source term. One of the boundary conditions is defining the contact angle that is formed by the three-phase contact line at a wall boundary. In this modeling work, a mathematical expression was used as a boundary condition applied to the sidewalls of the taper geometry to define the contact angle change as a function of voltage. This expression was derived from the Lippman-Young's equation which relates contact angle to surface tension and voltage. A voltage range was implemented through a solver parameter sweep. Simulations were conducted for different taper angles as well as for different sets of voltages applied to the sidewalls. From the simulations it was found that conical taper with a 45° angle, 15 μm deep would allow for a wide dynamic range of liquid interface movement for focusing and beam steering.