Modeling Electric Fields in Slit Capillary Array Fluidic Actuators with Complex Electrode Geometries

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Abstract

Fully-automated sample-to-answer diagnostic devices can provide molecular diagnostics in highly resource-limited settings without laboratory infrastructure or trained laboratory personnel. For practical application in these settings, the processing must be fully enclosed in an extremely low-cost disposable cartridge, and the assay must be rapid so the test can be completed while the patient waits. Accelerating complex molecular diagnostic assays requires precise manipulation of small volumes. Traditionally pumps and syringes have been utilized as a means of flow control, but due to their large size and reliability challenges with a fluidic interface to a disposable cartridge, they are not practical in devices designed for resource-limited settings (Kricka 2007). Electroosmotic (EO) fluidic actuators that are fabricated in silicon (Laser 2006) can be manufactured in high volume at sufficiently low cost for several to be integrated in a disposable cartridge, providing active flow control without any fluidic interfaces between instrument and cartridge. However, optimizing the design of these devices requires expensive and labor-intensive fabrication iterations. COMSOL offers a way to optimize geometric parameters in a rapid and cost-effective manner. In this study the electrode design of the slit capillary array EO fluidic actuator was investigated using COMSOL electrostatics modeling. In general, the back pressure through which an EO fluidic actuator can propel fluid scales with the electric potential drop across the slits. A parametric investigation of the percentage of electric potential dropped across the slits was performed with parameters including the electrode size, geometry, and position relative to the slit capillary array and slit array geometry. COMSOL simulation results were evaluated against experimental results from physical devices (results not shown). An image of one model along with its physical counterpart is shown in Figure 2. Figure 3 shows a top view of a slit capillary array fluidic actuator design with fSCA and gSCA indicating the dimensions of the slit area that were varied in simulations. Simulations, summarized in Figure 3, indicated that the percentage of the electric field that is dropped across the slits rather than outside the slits can be maximized by clustering the slits as close as possible to the electrode, or by reducing the height of the electrode above the slits. as seen in Figure 3. Additional simulations (results not shown) have shown that with a ring-shaped electrode, the electric potential drop across the slits is maximized if the slits are arranged in concentric rings.

Reference

1. Edited on behalf of the National Institute of Biomedical Imaging and Bioengineering/National Heart, Lung, Christopher P. Price, and Larry J. Kricka. 2007. "Improving Healthcare Accessibility Through Point-of-Care Technologies." Clinical Chemistry 53 (9): 1665 –1675. doi:10.1373/clinchem.2006.084707.

2. Laser, D.J. 2006. "Temporal Modulation of Electroosmotic Micropumps." Proc. ASME IMECE, Fluids Engineering in Micro- and Nano-Systems VII: 13960.

Figures used in the abstract

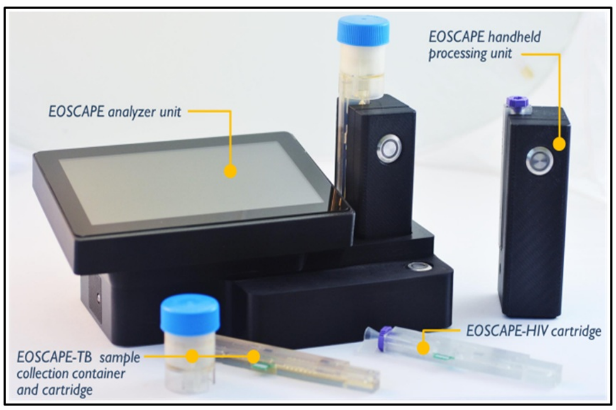

Figure 1: Wave 80 Bioscience's EOSCAPE line of molecular diagnostic devices. Each low-cost disposable cartridge includes four electroosmotic fluidic actuators and all reagents required for the assay.

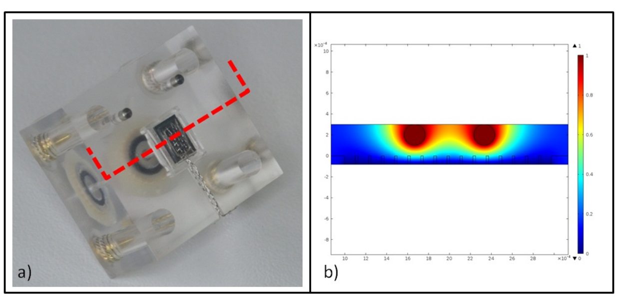

Figure 2: a) Image of an EO fluidic actuator in a fixture with a platinum mesh electrode. The red line indicates the cut line used in the COMSOL model. b) A 2D image of a COMSOL Electro statics model showing a parallel arrangement of long, narrow slits, referred to as a slit capillary array. Electric fields are applied across the slit capillary array by two electrode wires at a height, lE above the slits modeled across the red cutline shown in (b).

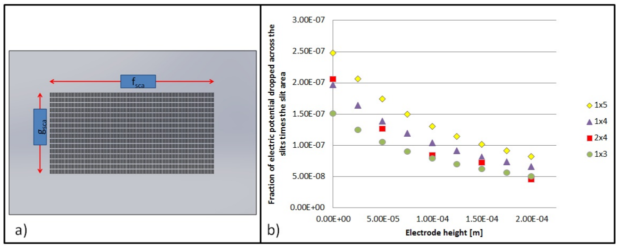

Figure 3: a) Top view of the EO fluidic actuator design with dimensions gsca and fsca indicating the slit area. b) These simulations used a single wire electrode aligned with the longer dimension, and centered across the shorter dimension. Four different slit areas were used; the dimensions, gsca x fsca, in mm are shown in the legend. For each design, the fraction of the total electric potential that is dropped across the slits (rather than outside the slits), multiplied by the slit area, is plotted versus lE, the electrode height above the slits. The simulations indicate that the importance of slit area parameters increases as lE decreases, and the electric potential dropped across the slits is maximized with a slit area that clusters the slits close to the electrode wire.