Geometric Optimization of Micromixers

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Abstract

Micromixing is a key step in realizing fast analysis time in many bio-chemical, biological and detection applications of Lab-on-a-chip (LOC) devices [1]. The conventional T-mixer design requires longer channel lengths and times to achieve complete mixing owing to its dependence on transverse diffusion. The performance of a homogeneous T-mixer can be enhanced significantly by the stimulation of secondary/ transverse flows in the microchannel [2-3]. Various mixing mechanisms are reported for enhancing micromixing performance such as grooves at the channel bottom, heterogeneous charge patterns, conducting & non-conducting obstacles, sequential injection etc. Most of these micromixers are studied with respect to planar geometric parameters such as groove width, groove spacing, channel height etc. The effect of geometric shape (on grooves structure or obstacle) or charge patterns (for electrokinetic mixing) is not systematically studied. In this work, we will summarize various case studies, for both electrokinetic and pressure driven flow, where geometric optimization is found to improve the mixing performance. This numerical optimization study would discuss the following micromixer case studies: (a) Heterogeneous charge pattern optimization for electrokinetic mixers [4] and (b) Groove shape optimization for pressure driven and electrokinetic micromixers [5]. COMSOL Multiphysics 3.5a with MATLAB® and COMSOL Multiphysics 4.2 are used for this computational study. The generic approach for optimization procedure is outlined in figure 1. The incompressible Navier-Stokes equations, Convection-Diffusion equations and Laplace equation from the MEMS Module (COMSOL Multiphysics 3.5a) are used to model the flow, species transport and electric potential distribution respectively. The shape optimization is carried out by representing the groove boundary by NURBS (Non-Uniform Rational B-Splines) or Bézier curves. The control points of these parametric curves are chosen as optimization parameters. For heterogeneous charge pattern optimization, a binary integer optimization approach is used to arrive at the optimal pattern shape. The channel bottom surface is discretized as shown in figure 2.The unit pattern block (shown in Figure 2a consists of 16 triangles) is repeated 10 times along the channel length (Figure 2b). The surface charge on each triangular surface is treated as a binary variable where a value of zero means homogeneous fixed charge surface and unity means heterogeneously charged surface. Various design patterns can be generated using this discretization scheme (2c-e). Figure 3 shows the mixing performance index η ($\eta = 0$ means perfectly unmixed and $\eta = 1$ means perfectly mixed) comparison for different heterogeneous charge patterns used for electrokinetic mixing. Using binary optimization approach, the diagonal pattern was found to be the optimal pattern for various electric fields. The detailed analysis (velocity, concentration plots) and parametric studies for heterogeneous charge pattern and groove optimization would be presented in the final paper (to be submitted later). The optimal design generates the most favorable transverse flow structure to provide optimal mixing

performance. Various parametric studies are carried out to compare the optimal designs with the existing designs. The developed design optimization approach could be implemented in any microfluidic device design procedures for performance enhancement.

Reference

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Figures used in the abstract

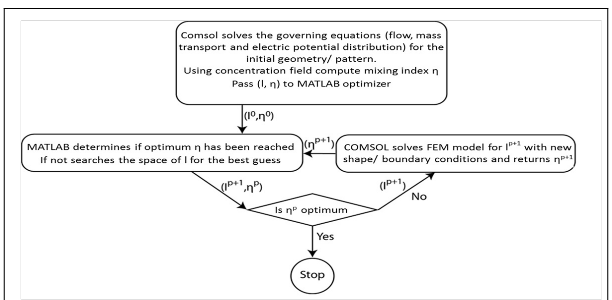

Figure 1: The flow chart showing the implementation of modeling-optimization procedure using Comsol and Matlab.

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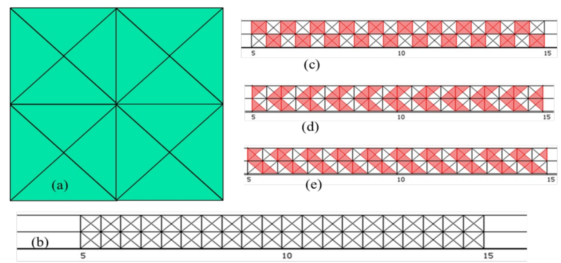

Figure 2: The channel base discretization is shown (a) Unit block with 16 triangles; (b) Channel base with 10 unit blocks; (c) Staggered (d) Herringbone (e) Asymmetric Herringbone charge patterns using triangular discretization.

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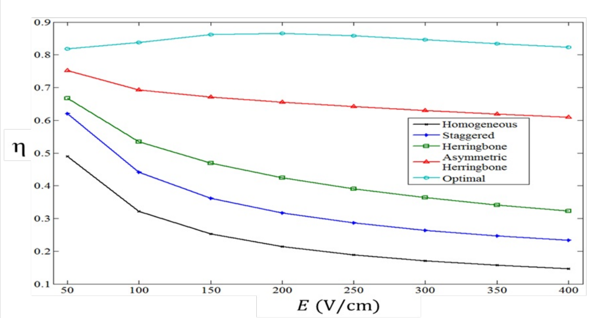

Figure 3: Mixing performance of different patterns for varying electric field.

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