

Computational modeling and simulation of electrohydrodynamic (EHD) ion-drag micropump with planar emitter and micropillar collector electrodes

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Abstract: Computational models can be used to simulate a prototype of electrohydrodynamic (EHD) ion-drag micropump with planar emitter and micropillar collector electrodes. In this study, a simple and inexpensive design of an ion-drag micropump was modeled and numerically simulated. A three-dimensional segment of the microchannel was simulated by using periodic boundary conditions at the inlet and outlet. The pressure and velocity distribution at the outlet and in the entire domain of the micropump was obtained numerically. The effect of the gap between the emitter and the collector electrode, width and the height of micropillar and flow channel height was analyzed for optimum pressure and output flow rate. The enhanced performance of micropump was compared with existing designs. It was found that the performance of micropump could be improved by decreasing the height of micropillar and the gap between both electrodes. The numerical results also show that a maximum pressure head of about 2350 Pa and maximum mass flow rate 0.4 g min^{-1} at an applied voltage 1000 V is achievable with the proposed design of micropump. These values of pressure and flow rate can meet the cryogenic cooling requirements for some specific electronic devices.

1. Introduction

The prominent features of micropumps inspired their use in a wide variety of applications ranging from biotechnology and chemical analysis to space exploration and cooling of micro electro mechanical systems (MEMS) such as sensors and detectors [1-2]. EHD ion-drag micropump is a non-mechanical type of micropump that uses the electric forces (mainly the Coulomb force) in the liquid bulk. The fluid flow is produced due to the friction between moving ions and the working fluids drag [3-4]. Ion-drag micropumps are preferred for pumping single phase incompressible flows because of their attractive features. These pumps are extensively utilized for the applications of fuel injection loops and cryogenic cooling of microdevices [5]. In the last decade, different designs of ion-drag micropumps have been proposed and developed to enhance the output flow rate and pressure. Unfortunately, with the shrinking size of many electronic products still the high pressure output is required in certain applications. On the other hand, the development of new compatible designs of micropumps becomes more challenging because of microfabrication complexity and instruments cost. In such circumstances, the numerical simulation of micropumps plays important role not only to

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understand the different working principles but also enables to model the designs with better performance.

Numerical models for ion-drag pumping have been developed extensively to simulate and predict the fluid behavior. A number of numerical analyses and simulation of the EHD ion-drag mechanism inside liquids have been reported in literatures. Many [3, 6-11] were used to investigate the performance of different designs of ion-drag micropumps. To understand the effect of the electrode geometry on the electric field and fluid pumping effect, Chaudhary et al. [12] performed numerical simulations using FemLab 2D software. Darabi and Ekula [13] performed a three dimensional electric field analysis using ANSYS/Multiphysics to determine electric field distributions. Benetis et al. [14] did numerical modeling using fluent software to create a hydrodynamic model for the micropump. They found relation between internal pressure drop of micropump and mass flow rate, and investigated the relation between pump pressure head and delivered mass flow rate. Darabi and Rhodes [15] performed a two-dimensional numerical model using commercial CFD software FIDAP to model EHD ion-drag pumping between an array of emitter and collector electrodes. The focus of their simulations was to study the effects of electrode gap, stage gap, channel height, and applied voltage. Lee et al. [16] presented parametric numerical studies on the 3D micropillar electrodes that were performed using commercial Finite Element package COMSOL Multiphysics to model the EHD pumping between one emitter and collector stage. A numerical study using COMSOL Multiphysics was conducted by Kazemi et al. [17-18] and demonstrated for the first time, that an asymmetry in the electrode geometry (both 2D and 3D) will result in significantly higher pressure generation with lower power consumption than conventional symmetric electrode designs. A numerical model was developed by Hasnain et al. [19] for an EHD ion-drag micropump that takes into account the effect of the electric field on the charge distribution at the electrodes. The simulations of model were performed on COMSOL and validated using the experimental data of [18]. Rigit et al. [20] used COMSOL Multiphysics and obtained initial 2D simulation for the planar ion-drag micropump.

Most of the numerical models used to simulate and investigate the ion-drag pumping are two-dimensional which restrict to the designs of micropump with 3D geometric features. A 3D modeling and simulation of ion-drag micropump with three different designs of collector electrodes was presented by the same authors of this paper [21]. The simulation was carried out on COMSOL Multiphysics 4.2 and they concluded that a design with planar emitter and 3D micropillar collector may produce better output pressure and flow rate. This paper further analyses and optimizes the works of [21, 17] for enhanced performance and also validates the simulation results by comparing with the recent experimental data of [17].

The paper is arranged by first presenting the motivation of this research and its overview. In the next section, the three dimensional computational model with its boundary conditions is clearly discussed and the values for simulation are also presented. Finally, the numerical results are deliberated where the overall aim is to investigate the effect of various geometric parameters on the performance of a prototype design of ion-drag micropump. Particularly, the dimensions of micropillar collector electrode and the flow channel height were investigated for optimum output pressure and flow rate.

2. Computational Modeling and Simulation

The EHD phenomenon is a complicated process, since various electrostatics and hydrodynamics factors are involved. These factors include geometrical parameters, working fluid and actuator electrodes material properties, electro-chemical reaction factors, electric and fluid dynamics variables and many others. Therefore, the modeling of the EHD phenomenon is quite difficult unless several reasonable assumptions and simplifications are made. The mathematical models that govern the EHD phenomenon are derived from the Maxwell's general quasi-static electromagnetism equations and fluid flow conservative equations [7,10] and then simplified by using certain realistic assumptions [21]. The complete set of governing equations for incompressible steady state flow in 3D geometry is listed as follows: