Design an Electrohydrodynamics Micropump for Microelectronics Cooling

Andrew R.H. Rigit*, M.C. Chiong

Faculty of Engineering, University Malaysia Sarawak, 94300 Kota Samarahan,
Sarawak, Malaysia
*arigit@feng.unimas.my

Abstract−**This paper presents the results of initial simulation work for an electrohydrodynamic (EHD) ion-drag micropump. A 2D numerical simulation was performed, and the flow pattern was found similar with the results of previous workers. The results validate the current design presented in this paper.**

I. INTRODUCTION

An increased in microelectronics power dissipation and reduction of the device size have resulted in increasing of heat fluxes. Heat flux is expected even higher in future electronics device. The electronics device's temperature must be controlled to retain their performance. New heat removal technique is needed to replace current technique, which is using forced air-cooling. Electrohydrodynamics micropump is a new liquid cooling technique under development. It is popular because of its small size, no wearable mechanical part, cause no vibration, easily controllable, and consume less power. The theories of electrohydrodynamics (EHD) developed in 1960's. The first EHD micropump was developed by in 1998 [1]. Darabi [2] developed the ion drag micropump with saw tooth emitter, which greatly improves the ion generation, thus enhancing the electric field. Benetis [3] investigated the microchannel design geometry on the performance of ion-drag micropump. Shoostari [4] developed the numerical model for the interaction between electric field and dielectric fluid. Parisa [5] designed the micropump that uses liquid nitrogen as working liquid; she studied the charge generation in liquid nitrogen for her design.

The emitter and collector are traditionally planted at the bottom of microchannel; the shortcoming of this design is creating non-uniform electric field, which serves as the only propulsion force in EHD micropump. In this case, dragging force would be weaker at the top of microchannel. Darabi and Rhodes [6] simulated the design with emitter and collector planted at the top of microchannel. However, this design made the fabrication process much complicated. Kazemi et.al [7] came out with micropump pump that come with 3D micropillars inside the microchannel. The micropillars idea creates a more uniform electric field; their micropump generated maximum pressure of 2240 Pa at voltage of 900V. This is believed to be the most successful EHD Ion Drag micropump; however the generated pressure is still too low for practical cooling applications that require 5 – 10kPa [7]. This project will further investigate on Kazemi et.al. work and seek for improvement.

II. THEORY

In EHD ion drag pumping, neutral liquid molecules are dragged by friction force, which established by the moving ions.
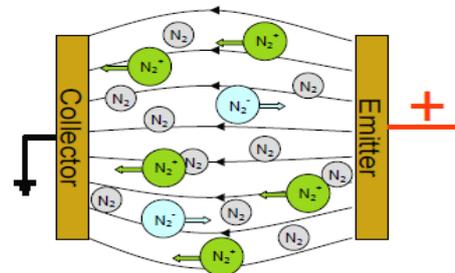

Figure 1: Schematic Diagram of Ion Drag Pumping Mechanism

As High DC Voltage is applied across the electrodes, molecules-molecules near to the electrodes are ionized. At emitter, liquids molecules loss their electron and become positively charged; on the other hand, liquids molecules close to the collector loss their proton, and thus become negatively charged. For ion drag pumping to occur, abundance of ions with only one polarity is preferred. This can be achieved by proper selection of working liquid and electrode design. The flows of dominant ions will then drag the neutral molecules to move forward, thus creating liquid flow.

As electric field is established, electric body force is generated, and it is transmitted to neutral molecules by viscosity, which results in bulk flow. The electric force is described as:

$$F_e = \left(\rho_e E\right) - \left(\frac{1}{2}E^2 \nabla \varepsilon\right) + \frac{1}{2}\left[\nabla E^2 \left(\frac{\partial \varepsilon}{\partial \rho}\right)_T \rho\right]$$

The three terms on right hand side are known as Coulomb force, Dielectrophoresis force, and Electrostrictive force. Dielectrophoresis force is generated as a result of permittivity gradient at the liquid-vapour interface in the two-phase flow or due to a temperature gradient in the non-isothermal fluids. Electrostrictive force acts upon the dipoles in dielectric liquid; this force requires the presence of an inhomogeneous electric field or fluid compressibility. Since Ion-drag pumping uses a single-phase, incompressible fluid

placed in a homogeneous electric field. Thus, the electric body force can be simplified to:

$$F_e = (\rho_e E)$$

Poisson equation, conservation of charge, and Electric Field are given as:

$$\nabla^2 \phi = \frac{-\rho_e}{\varepsilon}$$

$$\frac{\partial \rho_e}{\partial t} + \nabla \cdot J = 0$$

$$\vec{E} = -\nabla \phi$$

For unipolar charge injection, the transportation of ions is defined as:

$$J = (\rho_e u) + (\sigma E) + (\mu_e \rho_e E)$$

Where: ρ = Unipolar charge density, σ = Conductivity of liquid, μ = Mobility of liquid

The current flux can also be modelled using Nernst-Plank equation, which describes the ions transport mechanism:

$$\frac{\partial c}{\partial t} + \nabla \cdot (-D \cdot \nabla c - z\mu Fc\nabla V) = R - c\boldsymbol{u}$$

Where: D = Diffusion Coefficient, c = charge concentration, z = charge number, μ = charge mobility, V = Applied Voltage, F = Faraday Constant, R = Reaction Rate, u = Liquid Velocity.

First term inside bracket represent the Diffusion mechanism, second term inside bracket represent Migration mechanism, and on the right hand side reaction rate and convection mechanism.

Poisson equation is solved to obtain Electric Field strength and Nernst-Plank equation is solved to obtain charge distribution. Both of these results are combined to obtain the electric Coulomb force, F=ρE. Coulomb force is then incorporated into the Navier–Stokes equations as an additional body force to couple the effect of electric field and charge distribution on the fluid flow as:

$$\nabla \cdot u = 0$$

$$\rho \left[\frac{\partial u}{\partial t} + (u \cdot \nabla)u \right] = -\nabla p + \rho \cdot g - \nabla \cdot \tau + F_e$$

III. COMPUTATIONAL APPROACH

A 2D numerical model was performed using commercial computational software Comsol Multiphysics. There are few assumptions being made for simplifications:
1) Only one kind of charge exists (Unipolar).
2) Only Electric Coulomb force is present.
3) Charge injection take place only at the emitter.
4) Diffusion and Convection of ions are neglected.

5) All coefficients are constant, and do not depend on the electric field/influenced by high voltage.
6) The liquid flow is steady-state and incompressible.

The boundary conditions for electrostatics are straight forward. The emitter surface is set as applied voltage, collector is grounded, and the rest of the walls are insulated. The ions concentration at emitter surface is not well known, most of the processors obtained this value by measuring the electric current, however it is set as 0.01 mol/m^3 for simulation purpose, collector surface is set to concentration of 0, and the rest are set as insulator. For the liquid flow, both inlet and outlet are set to atmospheric pressure, while the rest are configured as no-slip wall.
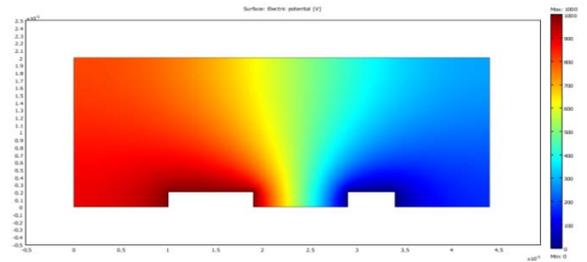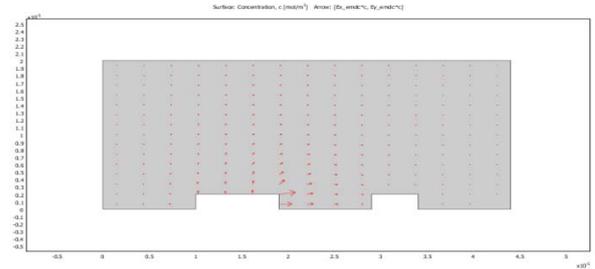

Figure 2: Voltage Gradient
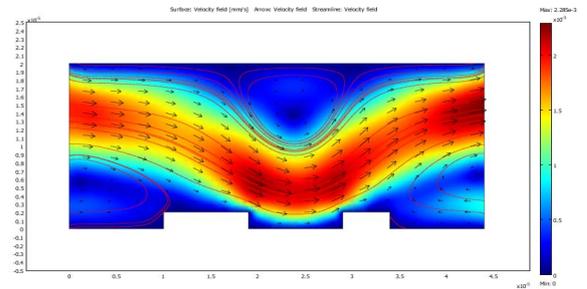

Figure 3: Electric Coulomb force
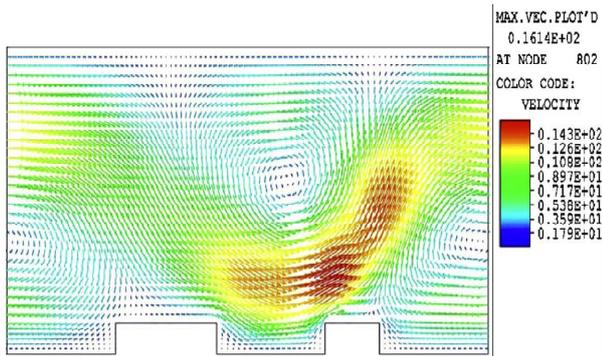

Figure 4: Liquid Flow Field

Figure 5: Liquid Flow Field by Darabi [6] using FIDAP

The liquid flow field is similar as compared with Darabi's work, but the velocity magnitude is different. The reason being initial charge concentration setting for Darabi's work might be different from ours, and there is no fixed value for it. By comparing both liquid flow plots, we believe that our methodology is correct.

IV. CONCLUSION AND FUTURE WORK

Using the same methodology, we will proceed on to simulate our own design, which will focus on improving Kazemi et.al design.

REFERENCES

[1] S.H. Ahn and Y.K. Kim (1998), "Fabrication and experiment of planar micro ion drag pump", Sensors and Actuators A, Physics, vol.70, pp1-5.

[2] Darabi, J., Rada, M., Ohadi, M. and Lawler, J. (2002). "Design, fabrication, and testing of an electrohydrodynamics ion drag micropump". J. Micromechanical Systems, Vol. 11, No. 6, pp. 684-690.

[3] Vytenis, B. (2005). "Experimental and computational investigation of planar ion drags micropump geometrical design parameters". PhD thesis, University of Maryland, USA.

[4] Shoostari, A. (2004). "Experimental and Computational Analysis of an Electrohydrodynamics Mesopump for Spot Cooling Applications". PhD thesis, University of Maryland, USA.

[5] Parisa. F. (2008). "Design and Characterization of an Electrohydrodynamics micropump for Cryogenic Spot Cooling Applications". PhD thesis, University of Maryland, USA.

[6] Darabi. J, and Rhodes C (2006). "CFD Modelling of an Ion-Drag Micropump", Sensors and Actuators A. Physics, vol 127, pp94-103.

[7] P.Z. Kazemi, P.R. Selvaganapathy, and Chan Y. Ching (2009). "Electrohydrodynamics Micropump with Asymmetric Electrode Geometries for Microscale Electronics Cooling". IEEE Transactions on Dielectric and Electrical Insulation, vol 16, pp 483 – 488.

[8] Darabi. J, and Rhodes C (2006). "CFD Modelling of an Ion-Drag Micropump", Sensors and Actuators A. Physics,vol 127, pg94-10