CHANNEL DEFORMATION IN ELECTROKINETIC MICRO/NANOFLUIDIC SYSTEMS

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ABSTRACT

We present results from a robust numerical model that predicts the deformation in electrokinetically operated micro- and nanofluidic channels with a step change in conductivity. This model accounts for the coupling between pressure and the change in hydraulic resistance from deformation. Using this model we unearth a relationship between the final deformation and the initial pressure and use it to predict deformation in typical micro- and nanofluidic systems and reveal that significant deformation orCha even channel collapse can occur under ordinary operating conditions.

KEYWORDS: Deformation, Electrokinetics, Microfluidics, Nanofluidics

INTRODUCTION

Large pressures can induce detrimental deformation in micro- and nanofluidic channels. Although channel deformation has been extensively studied for systems driven by pressure and capillary forces [1,2] deflection in electrokinetic systems due to internal pressure gradients caused by nonuniform electric fields has not been widely explored. Standard electrokinetic techniques such as isotachophoresis and field amplified sample stacking [3], as well the phenomenon of electrocavitation [4] have been shown to induce large pressures within channels, which can lead to channel deformation. To design devices and experimental procedures that avoid detrimental issues resulting from such deformation, we developed a model to predict deformation in typical micro- and nanofluidic systems.

METHODS

Using COMSOL we model ion distribution and fluid flow in micro- and nanofluidic channels with a step change in conductivity and examine resulting pressure distributions (Figure 1a). We then couple this model with a structural model to solve for deformation. In typical micro- and nanofluidic systems, the channel height is much smaller than the channel width ($h_0 << w$), therefore a 2D model is sufficient

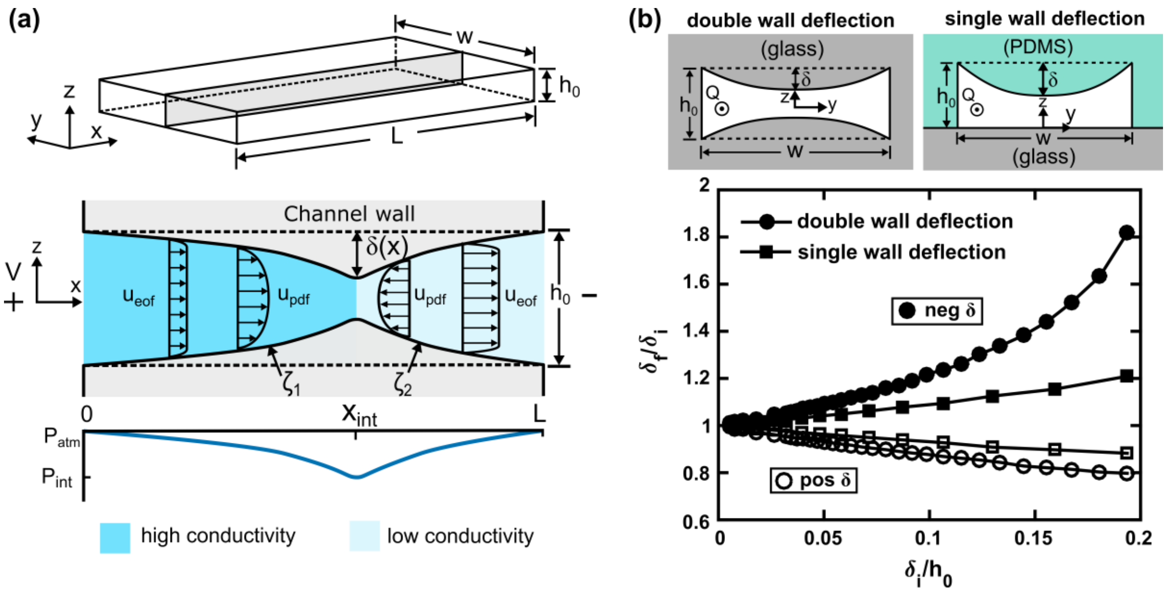

Figure 1: (a) Schematic of channel with step change in conductivity at some interface position X_{int}. Resulting pressure, p, and channel wall deflection, δ, due to the applied voltage, V, are depicted. (b) Comparison of maximum relative final deflection (δ_f/δ_i) and maximum relative initial deflection (δ_i/h_0) for both double wall deflection (e.g. channel completely in glass) and single wall deflection (e.g. PDMS on glass). In either case negative deflection (channel collapse) is self-amplifying while positive deflection (channel expansion) is self-dampening.

to model the flow through the channel. Following [1], we assume that the deformation along the center of the channel (δ) can be modeled as a linear function of pressure (p); $\delta = cwp/E$, where c is a proportionality constant and E is the elastic modulus. The final deformation in a system is iteratively solved because of the intrinsic coupling between deformation and hydraulic resistance.

RESULTS AND DISCUSSION

We determined maximum relative deflection values for both single wall deflection (e.g. PDMS channel on glass) and double wall deflection (e.g. channel entirely in glass) for both negative and positive deflection (Figure 1b). In the case of negative deflection (channel collapse) the increase in hydraulic resistance causes an increase in induced pressure resulting in larger deformation relative to the initial prediction ($\delta_f > \delta_i$). For positive deflection (expansion) the opposite occurs and deformation is decreased ($\delta_f < \delta_i$). In both cases the iterative effects on predicted deformation are much less in the PDMS channel where only a single channel wall deflects.

Using the correlation between initial and final deformation (figure 1b) and the linear deflection approximation as given by [1] ($\delta = cwp/E$), the final deformation can be predicted for a given system using the initial pressure p_i. Applying this method we predict deformation for typical system parameters (Table 1) and reveal that considerable deformation can occur in electrokinetic systems under normal operating conditions, most noticeable for soft materials such as PDMS and for stiffer materials such as glass at the nanoscale.

Table 1. Example deflection calculation results for typical micro- and nanofluidic system parameters. For all calculations: ζ-potential = 25 mV, E_{glass} = 72 GPa, E_{PDMS} = 0.4 MPa, electric double layer thickness = 0.1h_0, conductivity ratio = 0.1, X_{int}/L = 0.76 (position of maximum pressure for given conductivity ratio). Full channel collapse is indicated by X.

Material	w	h_0	V	p_i (Bar)	δ_i/h_0	p_f (Bar)	δ_f/h_0
glass	1 µm	10 nm	1000	-8800	-1.2	X	X
glass	10 µm	50 nm	1000	-350	-0.094	-420	-0.11
PDMS/glass	100 µm	10 µm	100	-0.00088	-0.0017	-0.00088	-0.0017
PDMS/glass	100 µm	1 µm	100	-0.088	-1.7	X	X

CONCLUSION

We present a model that predicts the deformation in electrokinetic micro- and nanofluidic systems. Using this model we show that significant deformation can occur in typical systems under normal operating conditions, even leading to channel collapse in glass nanochannels. To date, there has been no other investigation of deformation in such systems, therefore our work has large implications in the design and development of such devices.

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REFERENCES

[1] T. Gervais, J. El-Ali, A. Gunther, and K.F. Jensen, “Flow Induced Deformation of Shallow Microfluidic Channels,” *Lab Chip*, 6, 500-507, 2006.

[2] J.W. van Honschoten, M. Escalante, N.R. Tas, H.V. Jansen, and M. Elwenspoek, “Elastocapillary Filling of Deformable Nanochannels,” *J. Appl. Phys.*, 101, 094310, 2007.

[3] R. Bharadwaj and J.G. Santiago, “Dynamics of Field-amplified Sample Stacking,” *Journal of Fluid Mechanics*, 543, 57, 2005.

[4] K.G.H. Janssen, J.C.T. Eijkel, N.R. Tas, L.J. de Vreede, T. Hankemeier, H.J. van der Linden, “Electrocavitation in Nanochannels,” *Proceedings of Micro Total Analysis Systems 2011*, 1755-1757, 2011.

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