

Supporting information for

Surface Conduction and Electroosmotic Flow around Charged Dielectric Pillar Arrays in Microchannels

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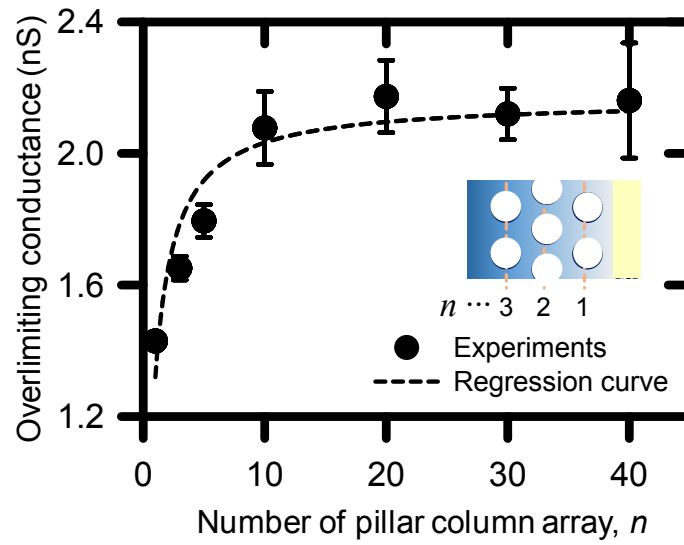
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Effect of the number of dielectric pillar array



SI Figure 1. Experimentally measured overlmiting conductance depending on the number of pillar column array.

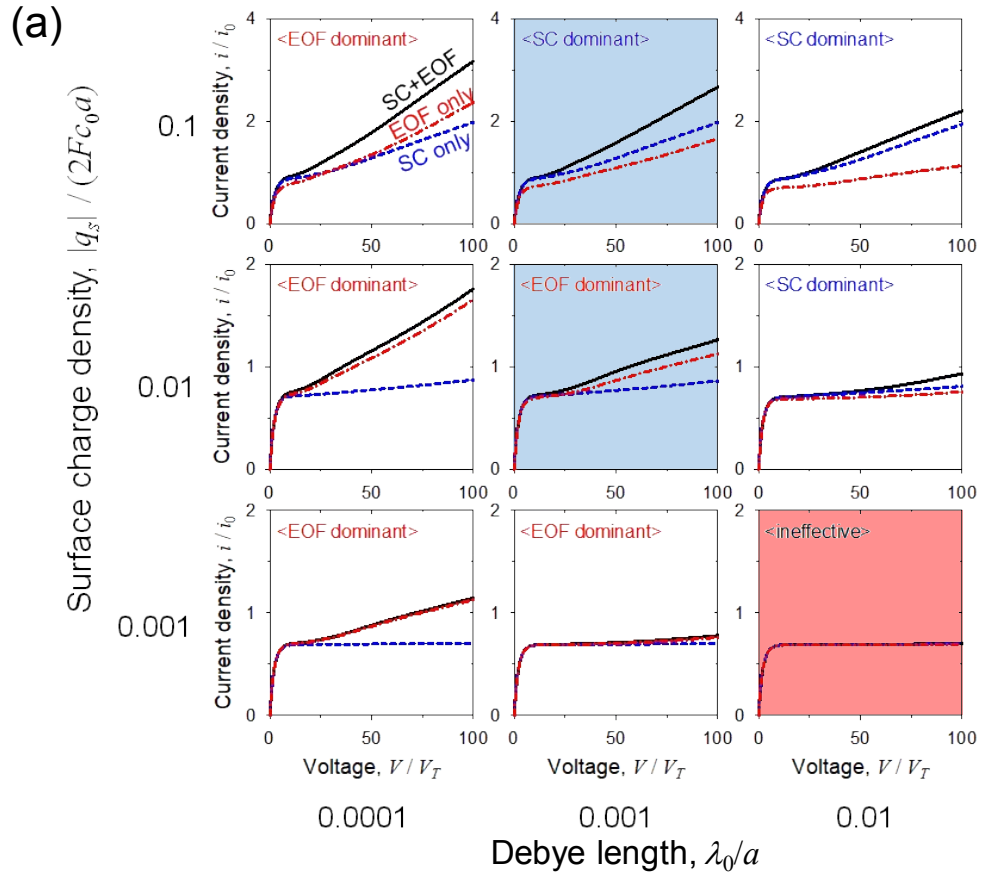
Current-voltage characteristics depending on surface charge density and Debye length.

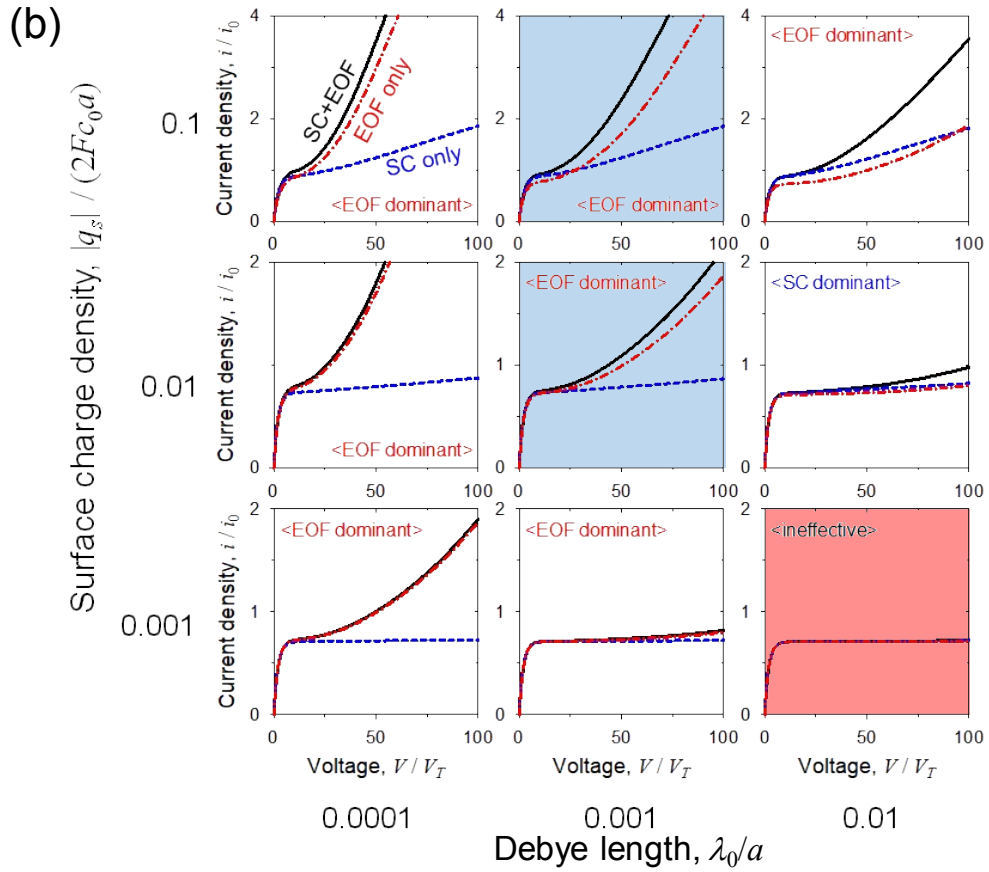
The tiles of I-V plots were generated as a function of surface charge density for column and Debye length for row as shown in SI Figure 2. Note that bottom most plot of the third column is the case of ineffective condition (i.e. no effect of SC and EOF due to near-zero surface charge and extremely thick electrical double layer, respectively). In this condition, the current density stays at its steady value. Among the plots, the practical experimental conditions in this work are closed to the second column (blue backgrounded plots) demonstrating the nearly equal contribution of SC and EOF. Lowering surface charge density and decreasing Debye length would enhance the EOF contribution (i.e. toward the bottom plot of the first column) and *vice versa* for the SC contribution.

Note that the slope of the I – V in the limiting current region should scale with λ_0 / a^{1-4} . However, a dependency in the equation on λ_0 / a is not visible in these plots. These previous works considered the formation of space charge layer (SCL) beyond the electrical double layer (EDL). To rigorously describe the SCL, fully-coupled Poisson equation and the Nernst-Planck equations for cation and anion should be solved without the assumption of zero EDL. In such modeling, the finite thickness of EDL results in the formation of SCL in the limiting current region, leading to the non-zero slope of the I-V curve as you mentioned in this comment. In fact, the slope is proportional to the dimensionless Debye length in those references.

However, in this work, the Debye length is ~ 10 nm, because 1 mM KCl electrolyte is used. Furthermore, the distance from cation-selective surface to stationary bulk (characteristic length scale in this work) is larger than 1 mm. Thus, λ_0 is at most 10^{-5} (10 nm / 1 mm) in our microfluidic system. Note that λ_0 in those references was approximately 10^{-3} . Such small non-dimensional Debye length in this work implies that the formation of SCL hardly ever contributes to the limiting current regime so that the assumption of zero λ_0 would be reasonable

to describe our experimental system. In other words, the experimentally obtained slope of I-V beyond Ohmic regime was determined only by surface conduction and electroosmotic mixing rather than the formation of SCL. This situation and analysis correspond to the work of Dydek et al⁵.

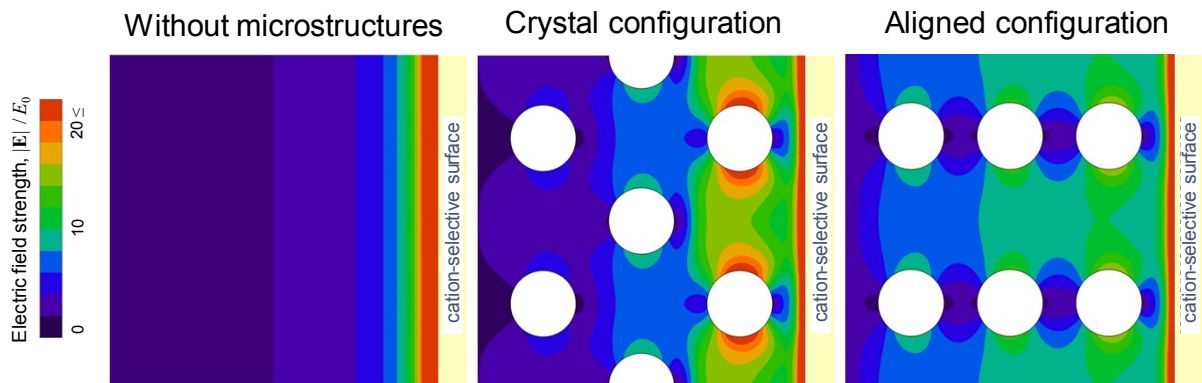




SI Figure 2. Current-voltage characteristics depending on surface charge density and Debye length of (a) the crystal configuration and (b) the aligned configuration. In these tile plots, q_s is the surface charge density of dielectric spacer, F is the Faraday constant, a is the radius of the dielectric spacer and λ_D is the Debye length. The denoted surface charge density and the Debye length are dimensionless. In each plot, current density and applied voltage are normalized by limiting current scale $i_0 = 2FDc_0 / L$ and thermal voltage scale, respectively.

Simulated electric field for each configuration.

The electric field became 20 times stronger only in the vicinity of the membrane so that all pillars in aligned configuration and the pillars from the second column in crystal configuration are absolutely in the non-polarizable environment⁶⁻⁸.



SI Figure 3. Electric field profile of the device on (a) No microstructures (b) Crystal configuration (c) Aligned configuration.

REFERENCES

1. I. Rubinstein and L. Shtilman, *Journal of Chemical Society Faraday Transactions II*, 1979, **75**, 231-246.
2. E. Yariv, *Phys. Rev. E*, 2009, **80**, 051201.
3. Y. Ben and H.-C. Chang, *J. Fluid Mech.*, 2002, **461**, 229-238.
4. C. P. Nielsen and H. Bruus, *Phys. Rev. E*, 2014, **89**, 042405.
5. E. V. Dydek, B. Zaltzman, I. Rubinstein, D. S. Deng, A. Mani and M. Z. Bazant, *Phys. Rev. Lett.*, 2011, **107**, 118301.
6. G. Yossifon, I. Frankel and T. Miloh, *Physics of Fluids*, 2006, **18**.
7. Y. Eckstein, G. Yossifon, A. Seifert and T. Miloh, *J. Colloid Interface Sci.*, 2009, **338**, 243-249.
8. S. K. Thamida and H.-C. Chang, *Physics of Fluids*, 2002, **14**, 4315-4328.