MEASUREMENT OF ELECTRIC CONDUCTIVITY OF WATER IN EXTENDED NANOSPACE USING STREAMING POTENTIAL/CURRENT

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ABSTRACT

Understanding ion transport phenomena in extended nanospace (10-1,000 nm) is important for the evolution of nanofluidic devices. We developed non-probe measurement system of electric conductivity of water for elucidating proton transport in the extended nanospaces. The results showed that conductivity in extended nanospace was approximately 500 times higher than that in bulk. The measured conductivity was consistent with the calculated one, which was determined using electric double layer (EDL) model and specific macroscopic parameters previously measured in extended nanospaces. It will be important information for nanofluidics.

KEYWORDS: Nanofluidics, Electric double layer, Streaming potential, Extended nanospace

INTRODUCTION

Recently, integrated fluidic devices are downsizing from microspace to extended nanospace. To construct innovative nanofluidic devices, understanding of liquid properties in extended nanospaces is required. Liquid properties are expected to be changed by the nano-confinement, because the extended nanospace represents a transitional regime from single molecules to the bulk condensed phase. We reported that liquids confined in extended nanospace had higher viscosity, lower dielectric constant, and higher proton mobility [1]. From these results, we suggested that the confined water molecules formed loosely-ordering structures of within 50 nm from surface and that the unique liquid properties were derived from the weighted-average of three phases consisting adsorbed water, loosely-ordering water, and bulk water. Unique ion transport phenomena were also found and discussed with EDL model, while the knowledge of water and proton transport still was not clarified. In this study, electric conductivity of water confined in extended nanospaces were measured using streaming potential/current system without any probe for understanding proton transport phenomena. Measured conductivity was compared with calculated conductivity due to EDL model.

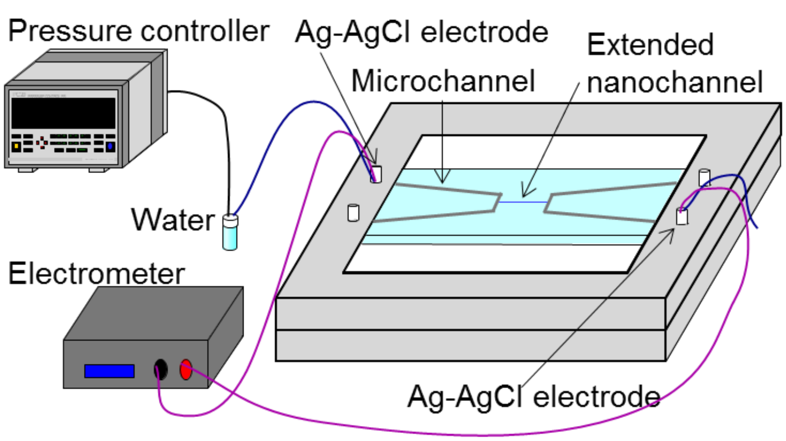

Figure 1. Schematic illustrations of experimental setup for conductivity measurements using a streaming potential/current method.

EXPERIMENTAL

Conductivity was measured using streaming potential/current system [2] as shown in Figure 1. An extended nanochannel was fabricated on the glass plate by electron beam lithography and plasma etching. Water was filled in the channel and controlled by a pressure controller. Potential and current generated by pressure-driven flow were measured using Ag-AgCl electrodes (see Figure 2). In addition, a numerical simulation based on EDL model with Gouy-Chapman-Stern model was performed as shown in Figure 3. Poisson-Boltzmann equation and site-dissociation model of silanol group were used for the determination of charge distribution of protons and of surface charge density, respectively [3]. In the simulation, specific macroscopic parameters characterized in extended nanospaces, 3 times lower dielectric constant [4] and 8 times higher molar conductivity [5] compared to the bulk, were used.

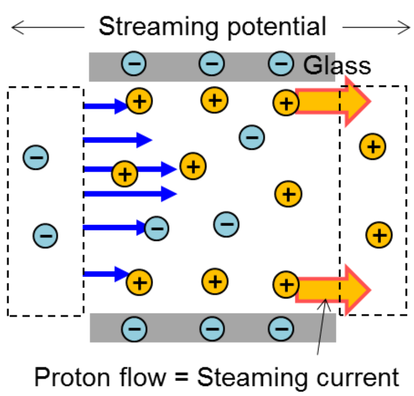

Figure 2. Principle of streaming potential/current by pressure-driven flow.

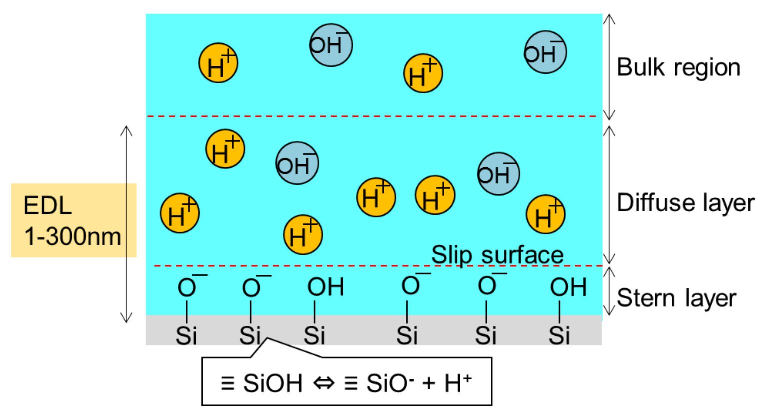

Figure 3. Gouy-Chapman-Stern model. Ion distribution and surface equilibrium were considered for calculation.

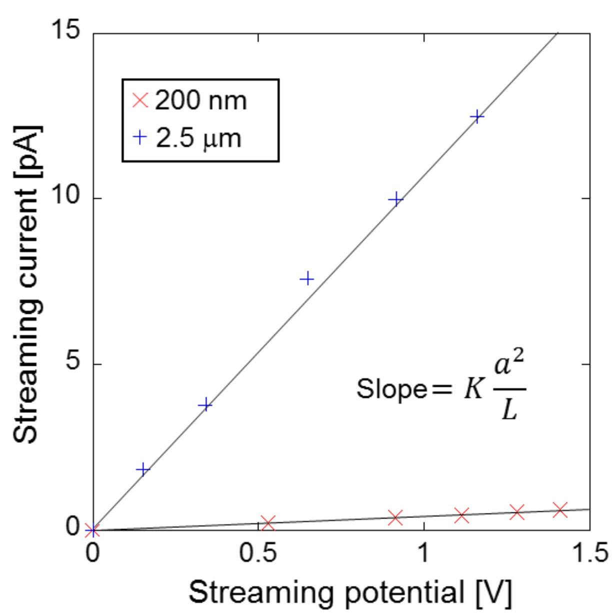

Figure 4. Relationship between streaming potential and current in different channel diameter a. Its slope is a function of conductivity K, a, channel length L.

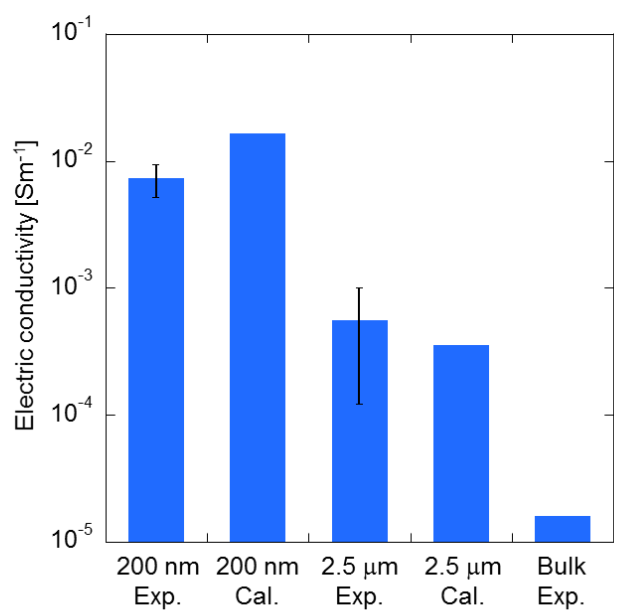

Figure 5. Electric conductivity of water in extended nanospaces and microspaces and bulk. Experimental results were compared to calculated results.

RESULTS AND DISCUSSION

Experimentally obtained streaming potential and current values were plotted in Figure 4. We found that they had a good linear relationship. Conductivity could be determined by its slope with normalization of channel sizes. Size dependency of measured conductivity and calculated conductivity was shown in Figure 5. We found that the measured and calculated data were well accorded with each other, and that the conductivity in 200 nm was approximately 500 times higher than bulk conductivity. Such 500 times higher conductivity can be explained by EDL model and specific macroscopic parameters in extended nanospaces experimentally obtained in previous studies. These results suggest that novel molecular description, which is composed by three-phase model and EDL model, are needed to construct as shown in Figure 6.

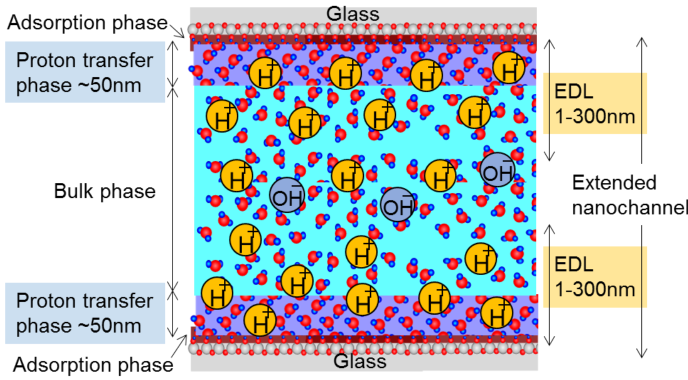

Figure 6. Three-phase model and EDL model in extended nanospaces discussed in this study.

CONCLUSION

We developed non-probe measurement system of electric conductivity of water using streaming potential/current for elucidating proton transport in the extended nanospaces. The obtained streaming potential and current had good liner relationship, and conductivity of water confined in each size was successfully obtained. The results showed that conductivity in extended nanospace was approximately 500 times higher than that in bulk. The measured conductivity was consistent with the calculated one, which was determined using electric double layer (EDL) model and specific macroscopic parameters previously measured in extended nanospaces. These results suggest that novel molecular description, which is composed by three-phase model and EDL model, are needed to construct. It will be important information for nanofluidics.

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REFERENCES

[1] T. Tsukahara, K. Mawatari, T. Kitamori, *Chem. Soc. Rev.*, **39**, 1000-1013 (2010).

[2] K. Morikawa, K. Mawatari, M. Kato, T. Tsukahara, T. Kitamori, *Lab Chip*, **10**, 871-875 (2010)

[3] C. C. Chang, Y. Kazoe, K. Morikawa, K. Mawatari, R. J. Yang, T. Kitamori, *Anal. Chem.*, **85**, 4468-4474 (2013)

[4] K. Morikawa, Y. Kazoe, K. Mawatari, T.Tsukahara,T. Kitamori, *Anal. Chem.*, **87**, 1475-1479 (2015).

[5] H. Chinen, K. Mawatari, Y. Pihosh, K. Morikawa, Y. Kazoe, T. Tsukahara, T. Kitamori, *Angew. Chem. Int. Ed.*, **51**, 3573-3577 (2012)

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