Investigating Ion Transport in Nanochannels

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Abstract

Nanoscale ion transport in nanoconfinement has shown great promise in energy conversion, water purification applications and semiconductor industries as when nanoconfined, ion transport would exhibit uniquely different phenomena compared to macroscale/bulk ion transport. However, the full underlying mechanism behind nanoscale ion transport phenomena has yet to be fully explored and understood. Herein, we report the study of ion transport in nanoscale via ionic conductance measurement of silicon dioxide (SiO_2) nanochannels. Measuring the ionic conductance would eliminate the need for direct probing to study intrinsic properties inside nanochannels, where difficulty in direct analysis has limited the research in this field. We found that PEG (polythene glycol) additive has raised the ionic conductance for all the KCl solution concentrations we used, suggesting that the ionic transport inside the nanochannel has been affected and/or altered by the PEG additive. Our preliminary results also suggest that PEG as an additive has the potential to serve as a powerful tool in tuning the nanoconfinement effect.

Hypothesis

- The ionic conductance in SiO_2 nanochannels can be tuned by adding additive (e.g., polymers) into the electrolyte solution

Methods

1. SiO_2 Nanochannel Chip Layout

- Bottom SiO_2 nanochannel with a height of 8 nanometers is fabricated by bottom-up MEMS fabrication process
- Bottom SiO_2 nanochannel is then bonded to top glass chip via anodic bonding

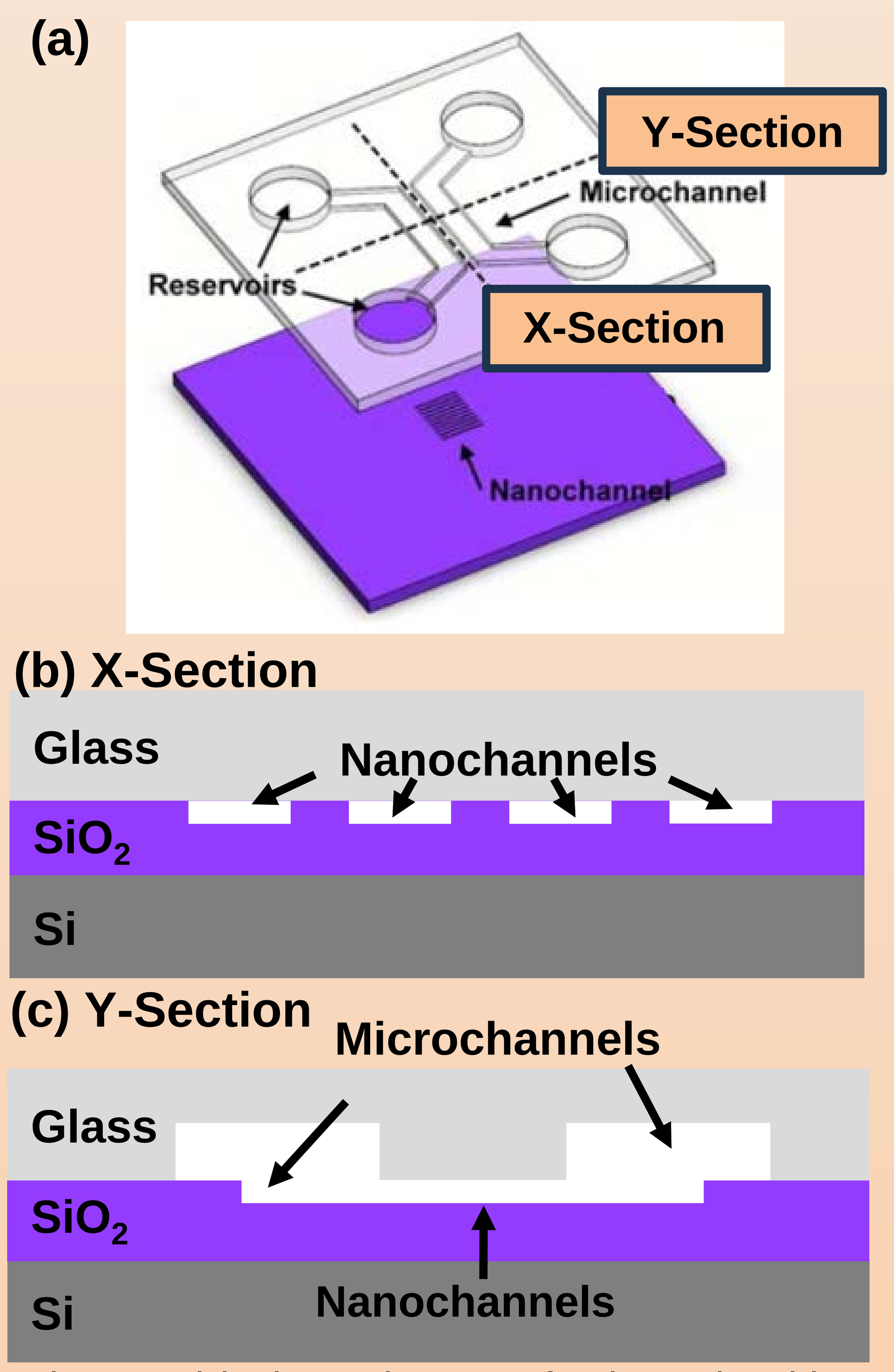

Figure 1. (a) Shows the setup for the entire chip. (b) Shows the cross section of the chip if cut along the X axis. (c) Shows the cross section of the chip if cut along the Y axis.

2. Ionic Conductance Measurement Setup

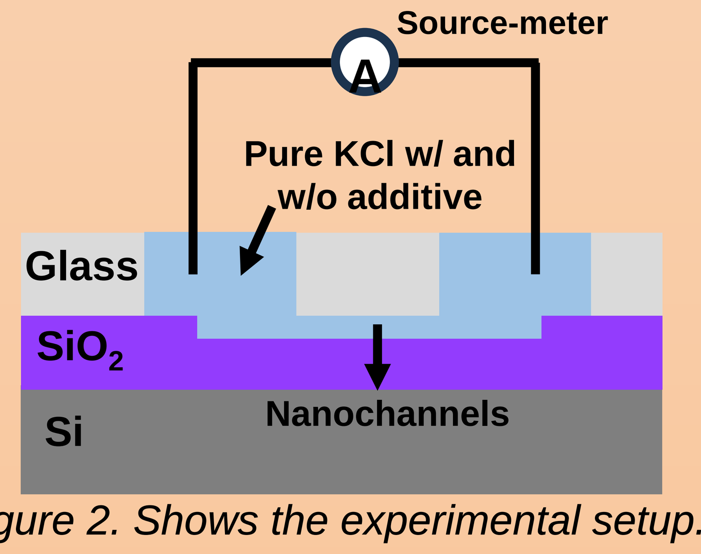

Figure 2. Shows the experimental setup.

- Using Keithley 6430 Sub-femtoamp remote SourceMeter as a power supply and data acquisition system, we tested 9 voltages (V) ranging from -40 mV to 40 mV
- The SourceMeter measured the current (I)
- Using a custom MATLAB code, conductance (G) at each measured voltage was calculated with the formula $G = I/V$
- Plots were generated through Origin Pro 2016

Results

1. Ionic conductance measurements

- **The ionic conductance is measured by the setup as described in the *Methods* section**

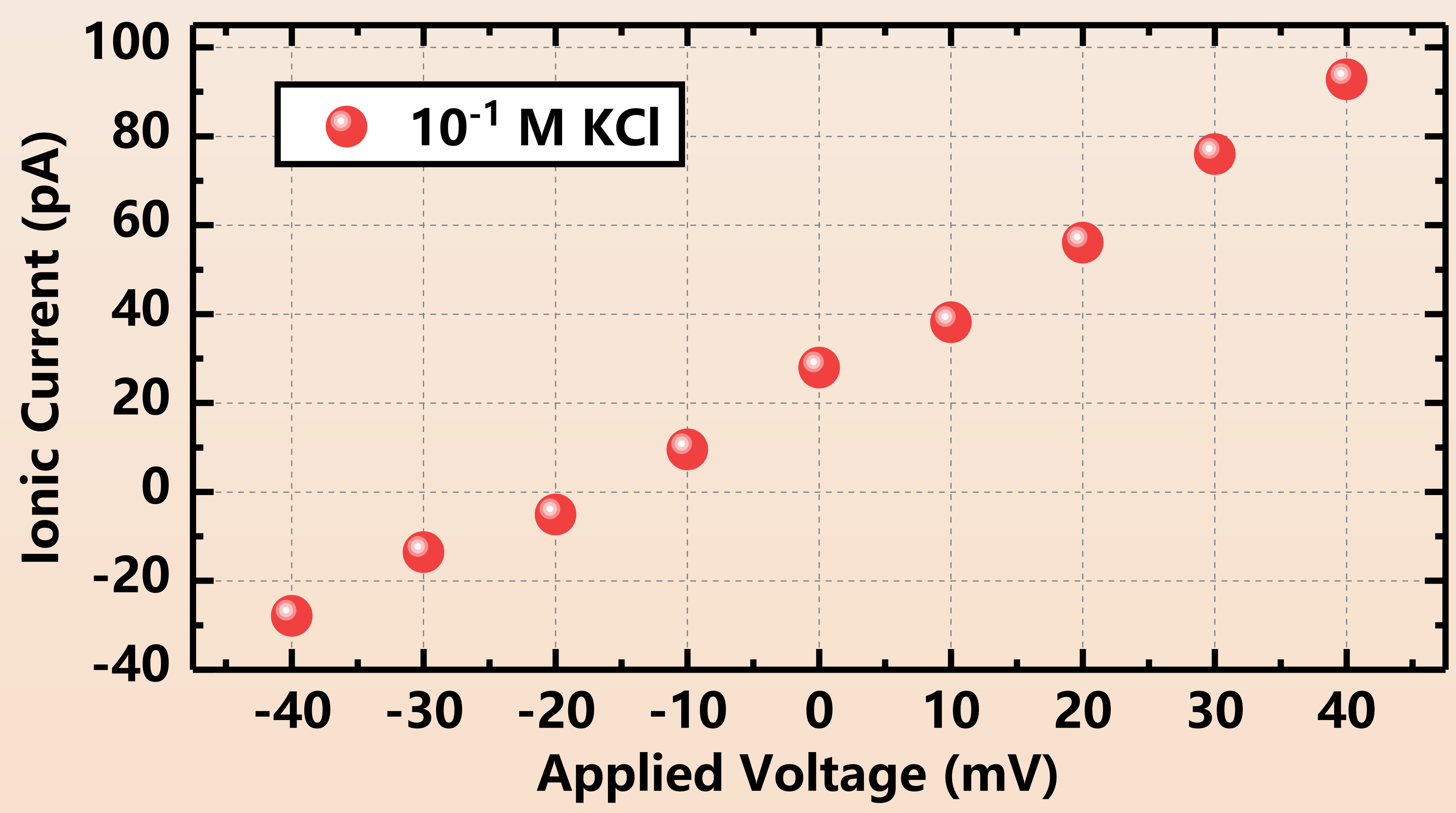

Figure 3. Example ionic conductance measurement result of 10^{-1} M KCl in an 8 nm high nanochannel

- **The ionic conductance is then extracted from the slope of the linear I-V curve**

2. Tuning of ionic conductance via PEG additive

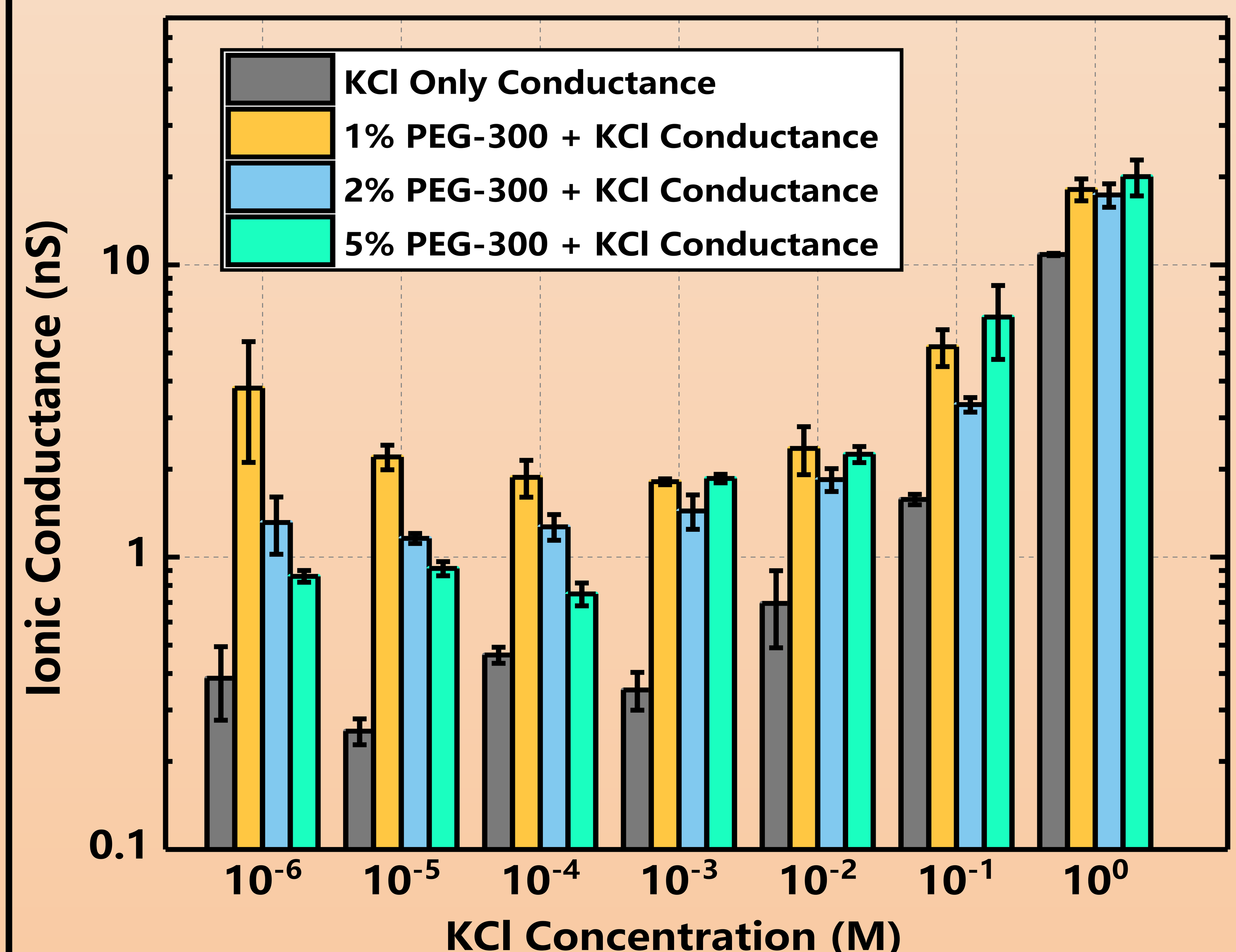

Figure 4. Shows ionic conductance as a function of KCl concentrations with and without PEG additives.

- **PEG(polyethylene glycol)-300 is added into KCl solution in concentrations of 1% / 3% / 5% (by weight) and conductance in 8 nm SiO_2 nanochannel is evaluated as outlined in the *Methods* section**
- **Resulting ionic conductance showed significant change compared to bare KCl ionic conductance**
- **The increase in ionic conductance is observed in all three PEG-300 concentrations used in our measurements**

Discussion & Conclusion

Regarding this significant increase in ionic conductance, we have two potential explanations:

1. The PEG molecule could potentially be ***adsorbed*** on to the nanochannel wall surface, thereby altering the inherent environment inside the nanochannel and ultimately, the ion transport.

2. Alternatively, the PEG molecule could ***change and/or participate in the water-structuring*** inside nanochannel. Water structuring is known to behave uniquely within nanoconfinements. Therefore, the nanoconfined water-structuring would then be potentially changed by the PEG additive and ion transport is then also changed.

Future Study

1. Study of PEG's effect on:
   - More nanochannel heights
   - More PEG concentrations and molecular weights
2. In-Situ measurement of the water structuring within nanoconfinement via optical method(e.g. Raman Spectroscopy)

References

1. Xie, Q.; Xin, F.; Park, H. G.; Duan, C. Ion transport in graphene nanofluidic channels. Nanoscale *2016*, 8, 47, 19527-19535.

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