Investigating Ion Transport in Nanochannels

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Introduction

Electrochemical technologies like lithium-ion batteries are rate-limited by the speed at which ions can move through electrolyte. Nanochannels, which are channels confined at the nanoscale, have exhibited unique ion transport which differs from ion transport at bulk (non-nanoconfined) scale. In the future, nanochannels show great potential in aiding the development of faster-charging energy storage devices and more energy-efficient separation processes.

Goal: To investigate the ionic nanoconfinement effect with open-end, silicon dioxide (SiO_2) nanochannels and explore the effect of polymer additive on tuning the nanoconfinement effect.

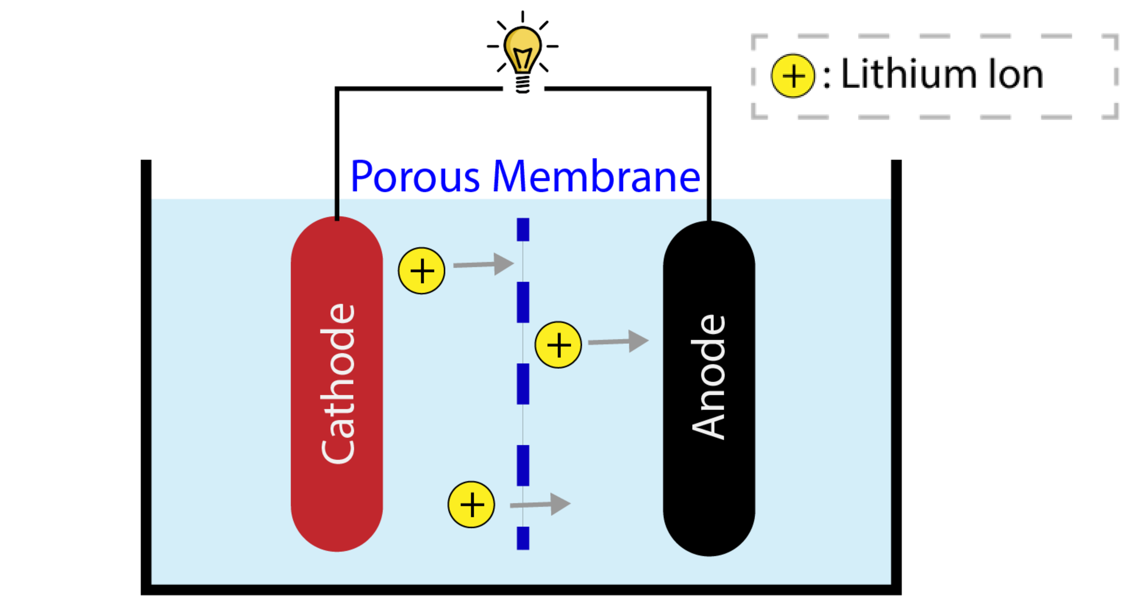


Fig 1: Ion transport in a lithium-ion battery. Charging speed is limited by how fast ions can travel through the porous membrane.

Methods

Fig 2A: Nanochannels were created with MEMs fabrication process and covered with glass.

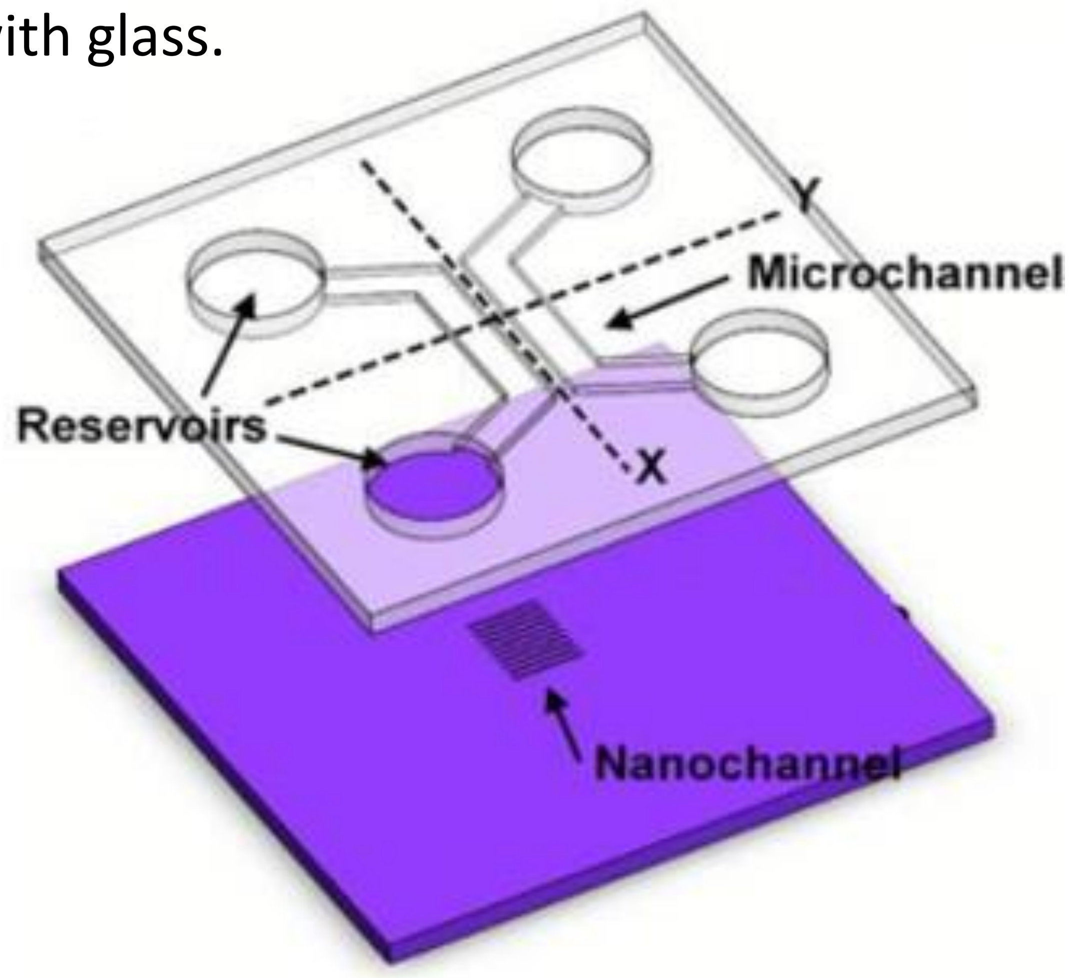


Fig 2B: Conductance was measured by applying voltage across nanochannels.

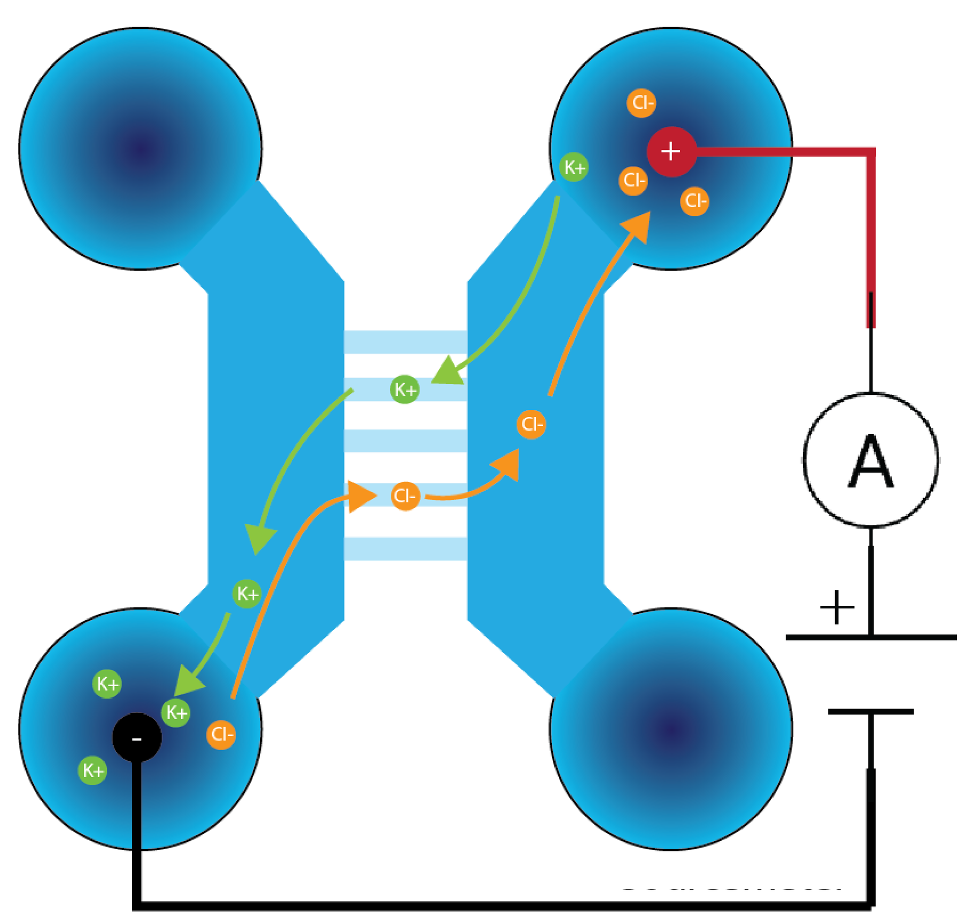
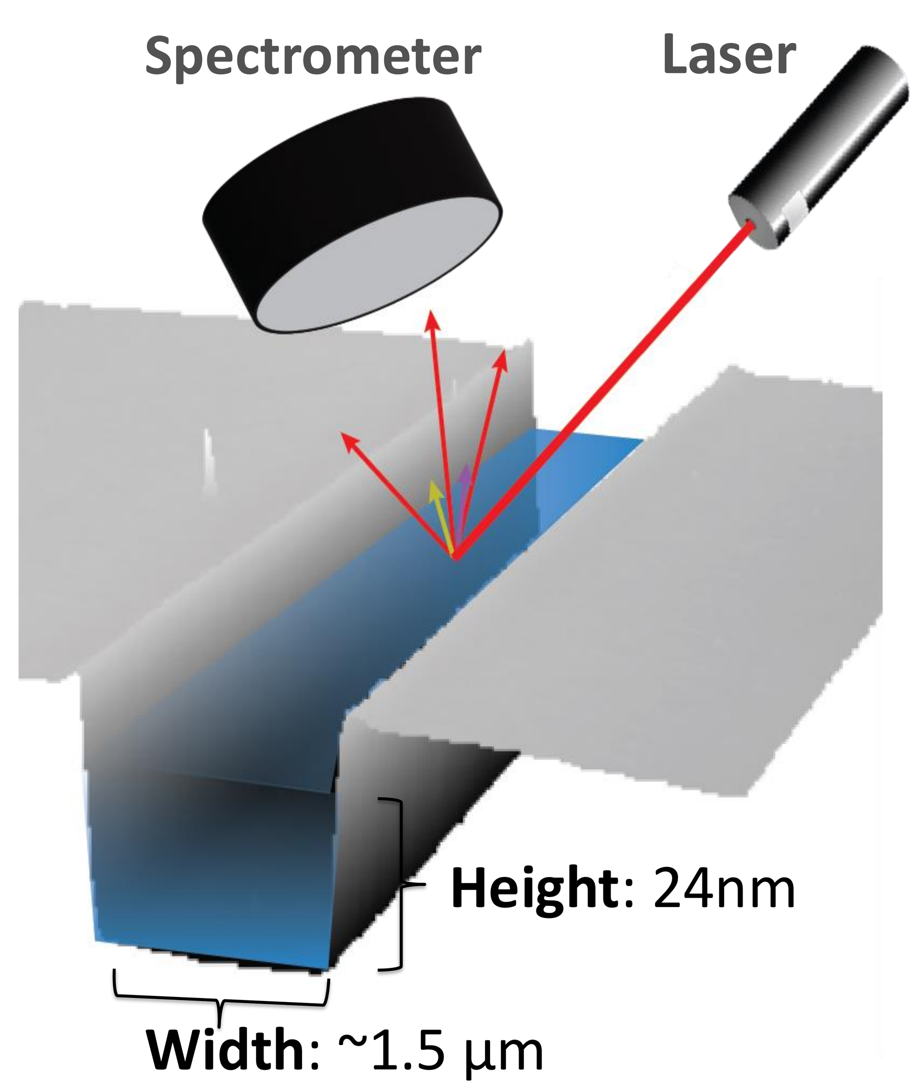
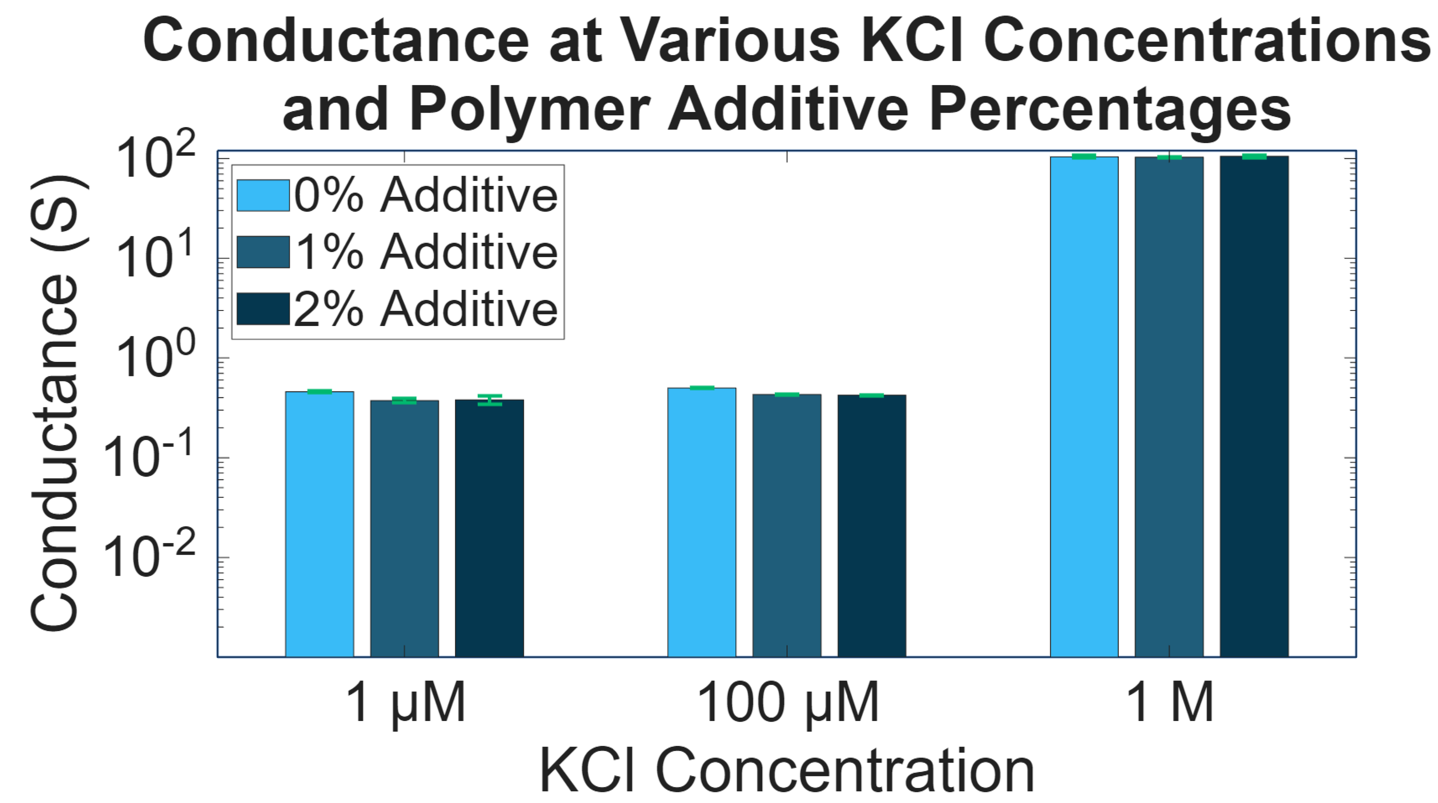


Fig 2C: Raman spectroscopy was performed on bulk and nanoconfined water.

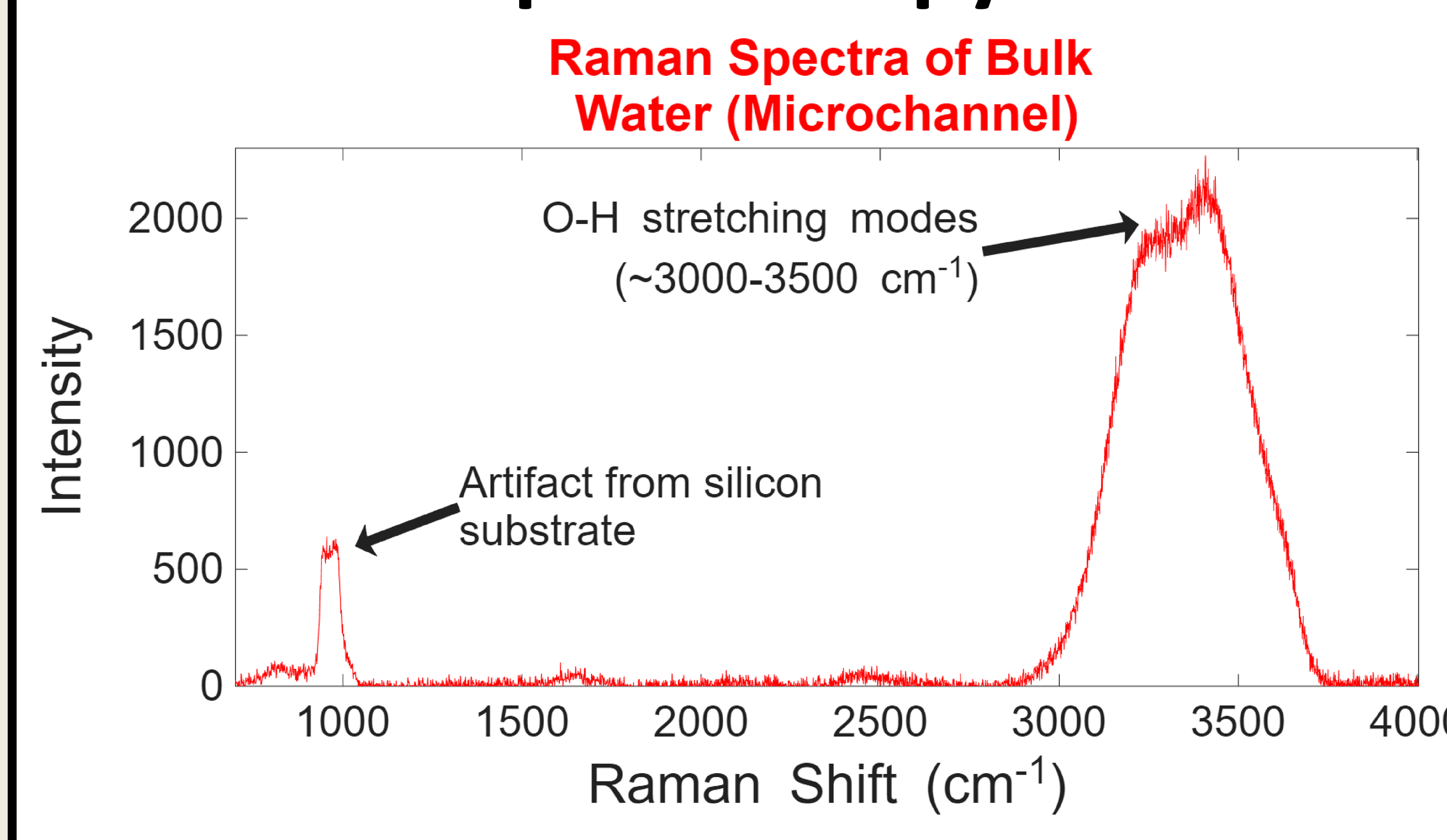


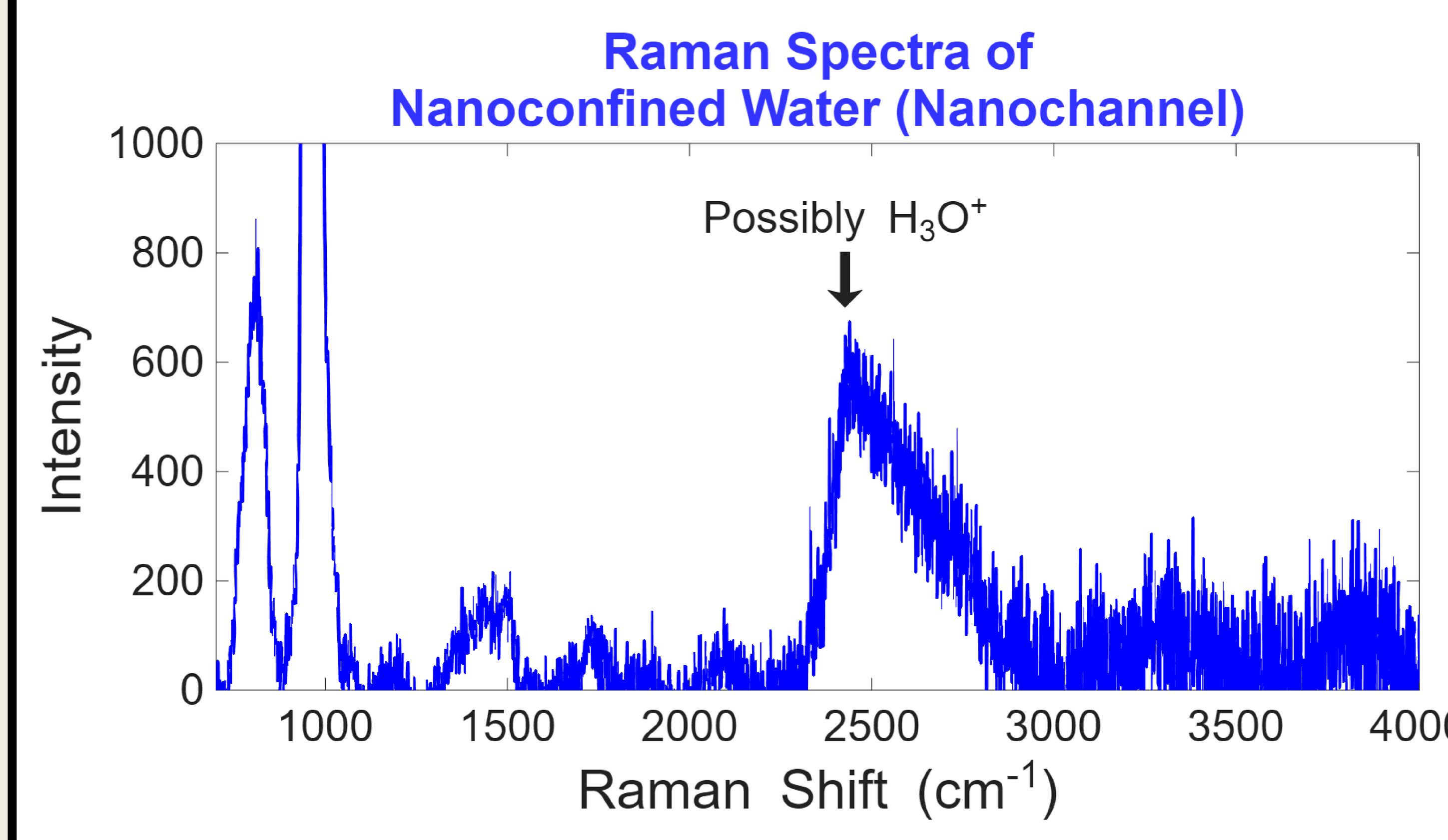
Conductance Results



- Ionic conductance with polymer additive showed significant change compared to bare KCl ionic conductance.

Raman Spectroscopy Results





- Raman spectra of bulk water (Microchannel) matches Raman spectra of previous studies.
- Raman spectra of nanoconfined water (Nanochannel) has a higher relative intensity of low-frequency bands (2400-2500 cm^{-1}) and a lower relative intensity of high-frequency bands (2800-3750 cm^{-1}).
- Nanoconfined spectra differs from bulk spectra, potentially suggesting a unique structuring of nanoconfined water.

Discussion & Conclusion

1. Conductance behavior:

a. Polymer additive could be adsorbed onto the negatively-charged SiO_2 channel wall surfaces, leading to a decrease in surface charge density and a lower conductance across nanochannels.

b. Or, the polymer additive could change the water structuring (e.g. hydrogen bonding network) inside the nanochannel, effectively leading to change in ion transport behavior within the channel.

2. Raman Spectrum:

a. Low-frequency Raman bands in water are typically associated with stronger hydrogen bonding networks. Hence, results may indicate that nanoconfined water forms more organized water-to-water hydrogen bonding networks.

b. The packed hydrogen bonding network is likely due to the hydration layer adjacent to the hydrophilic silica nanochannel walls, where water molecules share stronger attraction forces.

References

1. Duan, C., Majumdar, A. Anomalous ion transport in 2-nm hydrophilic nanochannels. *Nature Nanotech* **5**, 848–852 (2010). https://doi.org/10.1038/nnano.2010.233

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