Ion Concentration and Electromechanical Actuation Simulations of Ionic Polymer-Metal Composites

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Introduction: Ionic polymer-metal composite (IPMC) materials are ideal candidates for soft robotics and artificial muscle applications due to their high deformability and low operating power. The primary actuation mechanism in such devices is ion migration in a polymer membrane, localized swelling, and a corresponding overall material deformation.

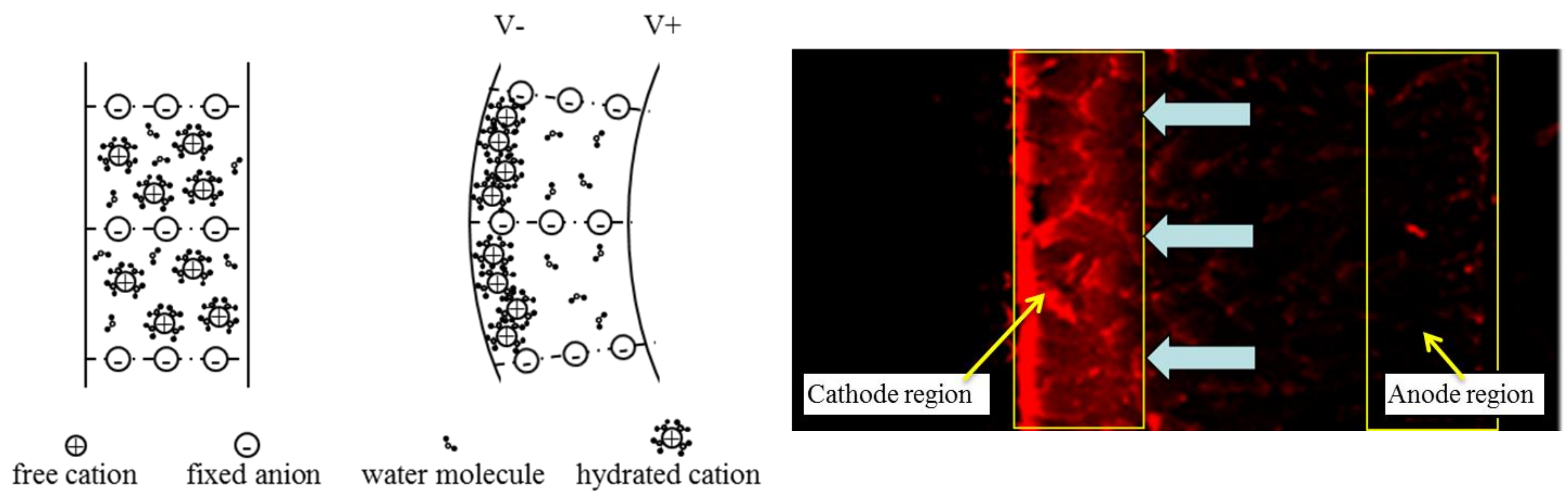

Figure 1. *Left*: Schematic of the working mechanisms of an IPMC actuator. *Right*: A florescence image of a 1mm wide IPMC during electromechanical transduction. [ref 1]

Computational Methods: The physics involved include transport of diluted species with migration in an electric field, Poisson's equation, solid mechanics, and electric currents physics modules. The primary governing equations are the Nernst-Planck and Poisson's equations coupled with solid mechanics physics.

Nernst – Planck: $$\frac{\partial C}{\partial t} + \nabla\cdot(-D\nabla C - z\mu F C\nabla\varphi) = 0$$

Poisson: $$-\nabla\cdot\nabla\varphi = \frac{\rho_c F(C - C_a)}{\varepsilon}$$

Newton's 2nd Law: $$\rho\frac{\partial^2 u}{\partial t^2} - \nabla\cdot\sigma = F$$

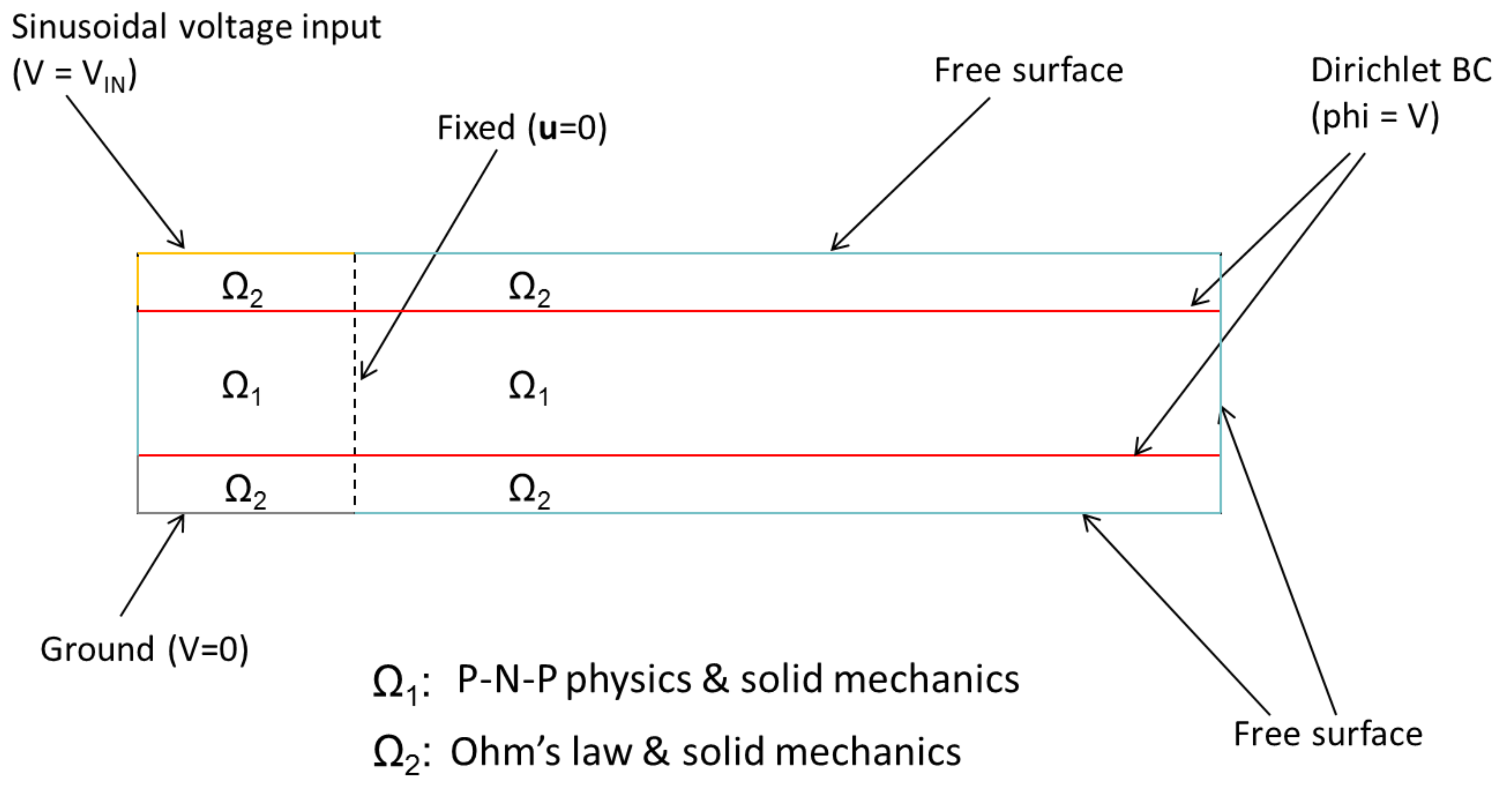

Figure 2. Ionic polymer-metal composite domain physics and boundary conditions.

Results: Simulations were performed for a rectangular IPMC actuator in response to a sinusoidal input voltage.

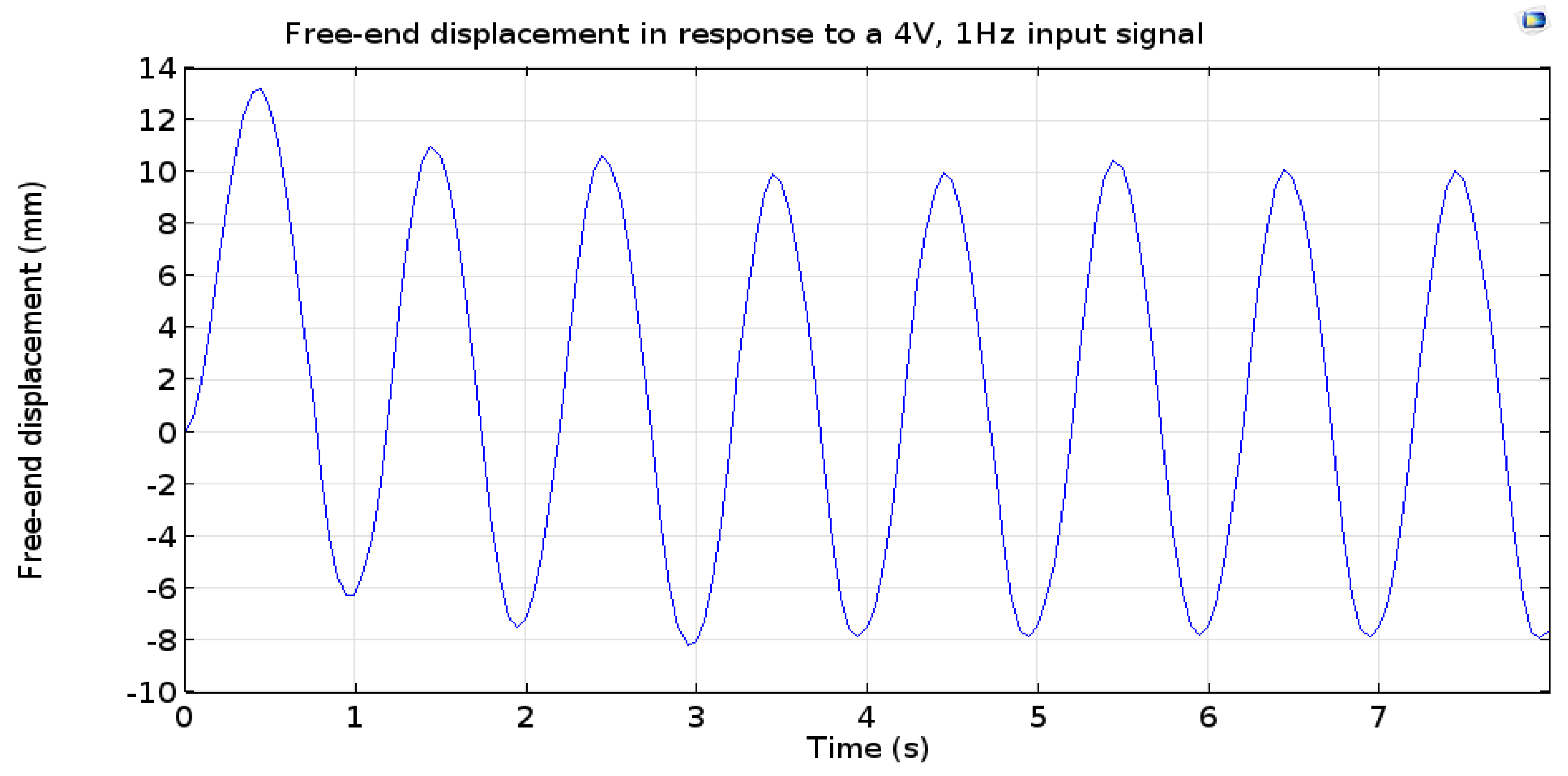

Figure 3. Simulated free-end displacement of a rectangular ionic polymer-metal composite actuated by a 4V, 1 Hz signal.

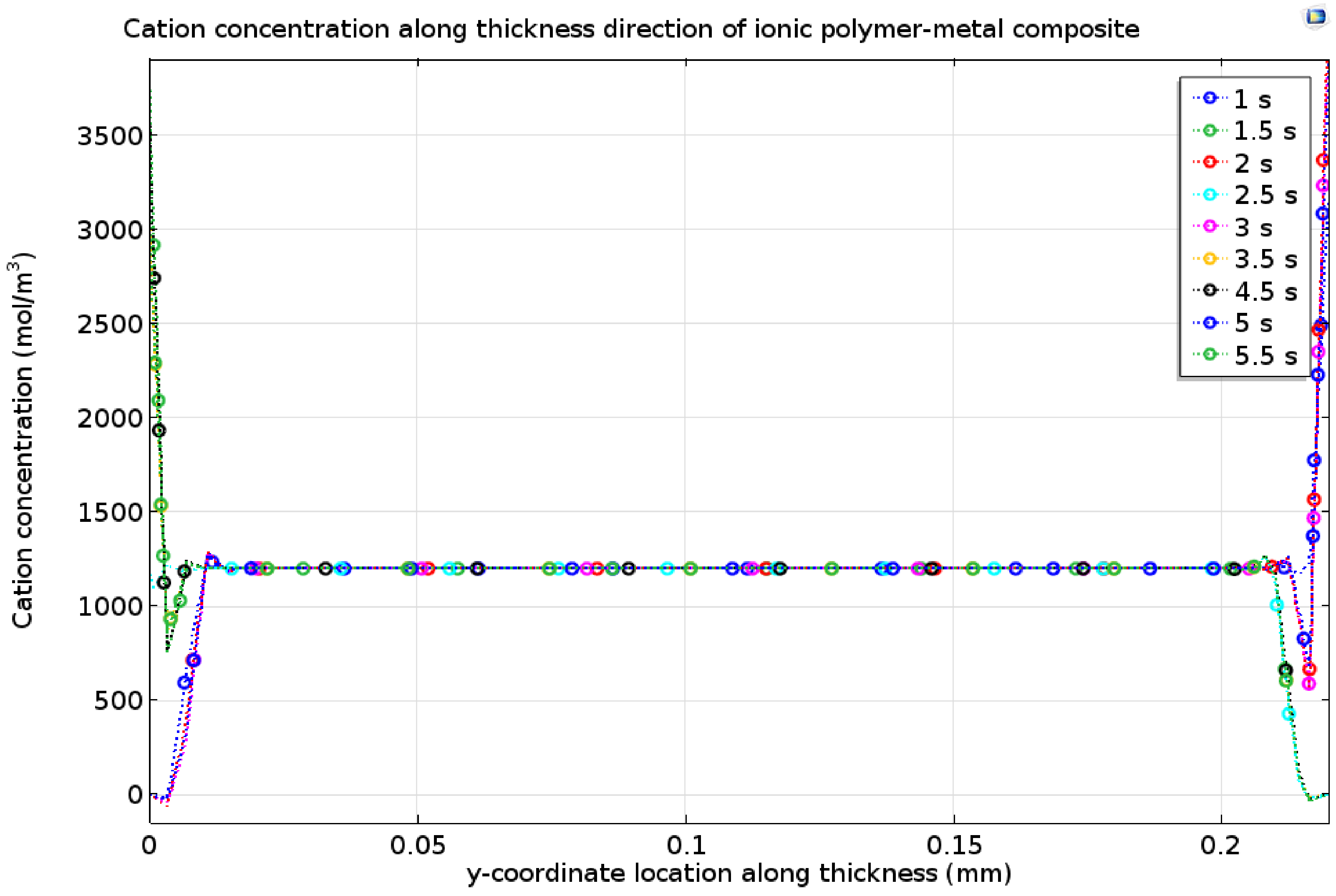

Figure 4. Simulated cation concentration at peak displacement across the thickness direction of a rectangular ionic polymer-metal composite actuated by a 4V, 1 Hz signal.

Conclusions: Physics-based modeling provides strong insight to the cation migration during IPMC actuation. The simulated cation migration shows a strong increase in a very small sub-surface layer near the electrodes, which agrees with the theory of underlying physics in IPMC actuators.

References:

[1] T. Stalbaum, D. Pugal, S. Nelson, V. Palmre, and K. J. Kim, "Physics based modeling of mechano-electric transduction of tube-shaped ionic polymer-metal composite," Journal of Applied Physics, 117.11, 114903, (2015).

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