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

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Abstract

Ionic polymer-metal composite materials are ideal candidates for soft robotics and artificial muscle applications due to their high deformability and low operating power. However, these devices have seen limited industrial application due to high fabrication costs and complicated dynamics and controls. Researchers and developers have provided insight and theorized the underlying physical mechanisms through experimental studies. These have provided groundwork to mathematically model this system to verify theory and develop a stronger understanding of the physical interactions. Together with experimental studies, modeling has helped further development of these materials. The devices are made of an ionomer membrane, which allows free migration of cations, with two or more noble metal electrodes plated on the membrane. For rectangular shapes, these are typically made in a layered arrangement, with electrodes plated on both sides of the polymer. The primary actuation mechanism in such devices is ion migration in a polymer membrane, localized swelling, and a corresponding overall material deformation. Inherently, solving for a deformed state given an input voltage is a temporal, highly-coupled, multiple-physics problem. Simulations of ion concentration and electromechanical transduction in a rectangular ionic polymer-metal composite are presented. A highly detailed approach to modeling these devices is presented and discussed.

The physics involved include transport of diluted species with migration in an electric field, Poisson's equation, solid mechanics, and electric currents physics. In this study, the meshing of geometry, model coupling, and solving of the multiple physics is performed using the COMSOL Multiphysics® software. Specifically, this requires defining and calling several functions based on built-in variables to properly associate the multiple physics. The transport of diluted species physics module is used for solving ion concentration in the polymer membrane. The electric currents physics module is used for charge through the electrodes. Poisson's equation is represented using the general form PDE physics module. Lastly, a solid mechanics physics module is used for solving for deformation, displacements, and stresses. Dirichlet boundary conditions are utilized at the composite interfaces, with a fixed end boundary condition for the solid mechanics model that is similar to the clamping mechanism in experiments. Modeling can be performed in 3D or 2D for simplification if given a regular shaped geometry device.

Using the developed models, one can solve for several variables of interest, such as displacements (Figure 1) and stresses of an actuator or the charge density throughout the

polymer membrane, as examples. Furthermore, one is able to simulate and visualize certain important governing variables that are difficult or impossible to monitor in experimental practice, such as cation concentration in the actuating polymer in-time (Figure 2). This has provided researchers and developers keen insight to the working mechanisms of ionic polymer-metal composite devices to better understand the underlying physics and refine fabrication to improve device performance.

Figures used in the abstract

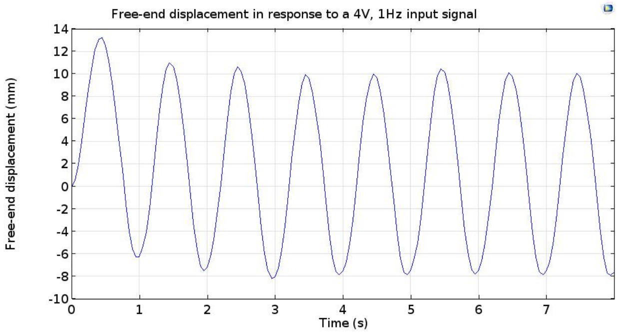

Figure 1: Simulated free-end displacement of a rectangular ionic polymer-metal composite actuated by a 4V, 1Hz sinusoidal signal

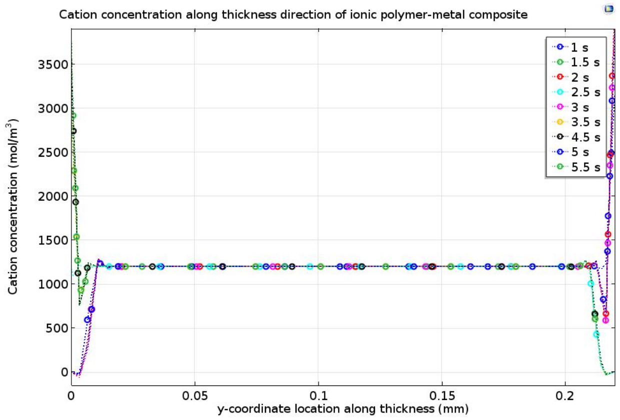

Figure 2: Simulated cation concentration at peak displacements across the thickness direction of a rectangular ionic polymer-metal composite actuated by a 4V, 1Hz sinusoidal signal