Research Areas

Electrochemical Materials & Devices
Energy
Materials Processing
Polymer Science & Engineering

Research Interests

Through the close interplay of scalable chemical synthesis and physical materials characterization, our research group seeks to manipulate the self-assembly of organic molecules into materials with well-defined nanoscale morphologies that manifest unusual and useful bulk properties. Each project area emphasizes the “bottom up” molecular construction of materials with the ultimate goal of uncovering new guiding principles for their design. Specific research project focus on the development of new economical and sustainable materials for energy storage and use, membranes for efficient chemical separations, and materials for applications ranging from advanced nanolithography to enhanced oil recovery.

Polydispersity Effects in Block Copolymer Self-assembly: Modern polymerization techniques enable syntheses of functional block copolymers with unusual thermal, electronic, and ionic conductivities. However, these new macromolecular syntheses often introduce significant molecular weight polydispersity (a chain length heterogeneity) into one or more of the copolymer blocks. Conventional wisdom stipulates that chain length uniformity (“monodispersity”) is a prerequisite for periodic nanoscale self-assembly of block copolymers. Few studies have questioned the validity and stringency of this preconceived notion. We are studying the melt-phase behavior of ABA-type triblock copolymers comprising either polydisperse A or B blocks. Contrary to conventional wisdom, polydisperse ABA BCPs also assemble into a rich array of periodic nanoscale structures with unexpectedly enhanced thermodynamic stabilities as compared to their monodisperse analogs. Based on these insights, we are now studying: (1) a series of new Li-ion conducting block copolymers for advanced batteries, and (2) new thermoplastic elastomers with unusual mechanical properties.
Lyotropic Liquid Crystal Self-Assembly: Towards Next-Generation Ion Exchange Membranes. Polymer electrolyte membranes (PEMs) that shuttle H+ or OH- are essential components of fuel cells and solar fuel production schemes. While various limitations of known PEMs have spurred the development of new materials, reliable molecular design criteria that guide syntheses of superior ion transporting media remain obscure. To address this fundamental yet technologically important challenge, we have developed a new small molecule surfactant platform that exhibits an unusual tendency to self-assemble in water into bicontinuous liquid crystalline phases comprised of interpenetrating aqueous and hydrophobic domains, which percolate over macroscopic lengthscales with tunable nanopore diameters (~0.6-6 nm) and well-defined pore functionalities. Using these self-assembling systems, we have produced a model set of nanoporous membrane materials that we are studying for fuel cell, water desalination, and selective chemical separations applications. We are also using these materials as an experimental platform to probe fundamental mechanisms of H+ and OH- transport in water-filled nanoporous media and to elucidate the structure of water in soft, ionic nanoconfinement using neutron scattering techniques.

Polymers for Advanced Li-ion Batteries: Advanced Li-ion batteries for transportation applications suffer from several important drawbacks, some of which stem from the poor oxidative and reductive stabilities of typical battery electrolytes. To address this important issue, we have recently developed a new class of polymeric lithium-single ion conducting electrolytes that exhibit unusual electrochemical stabilities. We are probing structure property relationships within this new class of materials in order to assess their viability as next generation electrolytes for high power Li-ion batteries.

Awards

- Kavli Foundation Fellow, 2015
- John H. Dillon Medal, American Physical Society 2013
- Emil Steiger Distinguished Teaching Award, 2010
- James W. Taylor Teaching Award, 2009
- NSF CAREER Award, 2007
- Fannie & John Hertz Foundation Graduate Fellow, 1997-2002

Selected Publications