From Nature to Engineering
Current Research in the Kisailus Lab

Over the course of billions of years, Nature has evolved the capacity to utilize simple building blocks acquired from the environment to synthesize a wide range of complex structures. For example, many biomineralizing species can produce remarkably sophisticated three-dimensional organic-inorganic composite materials that in many aspects rival the structural, optical, and mechanical properties afforded by modern materials engineering strategies.

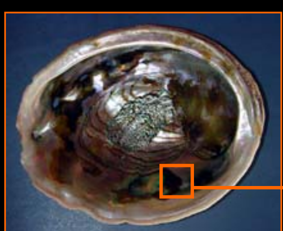
One such group, the radiolarians (seen at left) are an ancient assemblage of planktonic protozoans (single-celled organisms) that consists of more than 300 species and are predominantly found in the upper 200 m of the ocean. Despite their small size (frequently measuring no larger than the diameter of a human hair), they can synthesize intricate mineralized skeletal frameworks of amorphous hydrated silica (glass!). The beauty and precision of these structures are admirable, and possess unique properties that we, as scientists and engineers, can only hope to someday emulate.

One major area of research in the Kisailus group at UC Riverside involves studying the processes of biomineralization in order to understand the mechanisms controlling the synthesis and organization (through self-assembly) of the resulting structures. The ultimate goals of our research are to develop novel “bio-inspired” synthetic processes toward novel, technologically relevant materials. To achieve this, we investigate the interactions between the organic and inorganic phases present in these biominerals and understand how they regulate nucleation and growth of the resulting material. We then use biologically derived macromolecules (from the organism itself) or synthetic analogs of these molecules, based on lessons learned from analysis of the biological system, to direct the growth of crystalline and amorphous materials in a controlled manner. By modifying the size, shape, phase and orientation of these nanostructures, we can specifically control the resulting properties that are displayed. Descriptions of some of the lab’s recent projects are described below.

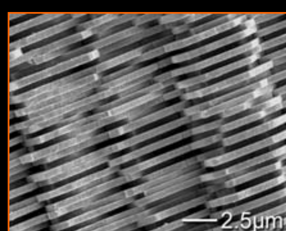
Biomimetic Nanocomposites

Nacre, the inner mother-of-pearl layer of many mollusc shells, is an elegant example of how biological systems build complex structures from simple components. Although the shell is made from $CaCO_3$, a brittle, inexpensive material (chalk), its fracture toughness, is ca. 3000x greater than its geologically formed counterpart and superior in many aspects to the best synthetic engineering materials.

The shell of the California Red Abalone, *Haliotis rufescens*

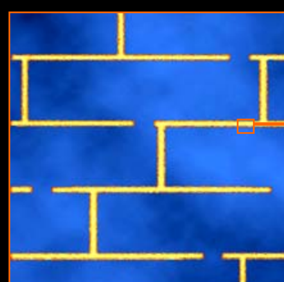


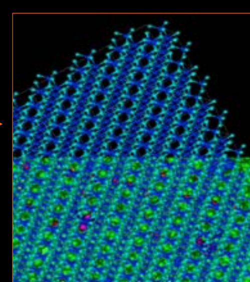
Nacre for toughness



Cross-section of fractured nacre

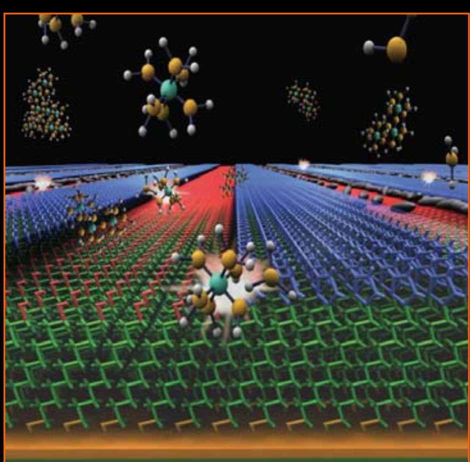
We are interested in understanding the nano and microstructural features that give these composites their enhanced properties as well as the interfacial phenomena that control the nucleation and growth of these materials. By understanding the nature of these organic-inorganic interactions, we will develop tools to build novel biologically inspired nanomaterials for structural applications.



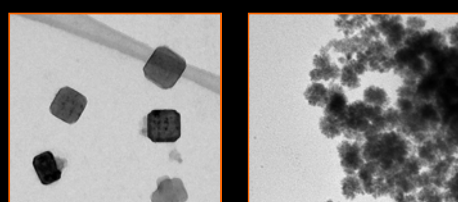


Schematic of of the mineral-templating organic matrix

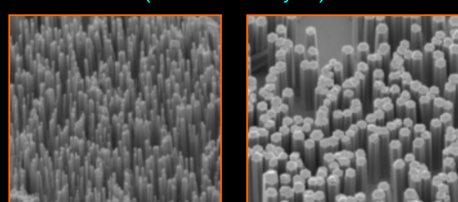
Harnessing the Molecular Mechanisms of Biomineralization for the Synthesis of Advanced Materials for Energy and Structural Applications



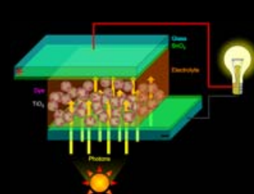
Catalytic Biomimetic Substrates



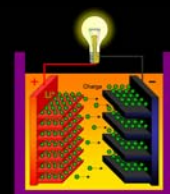
Morphological Control: Pt Nano-Crystals
(Fuel Cell Catalysts)



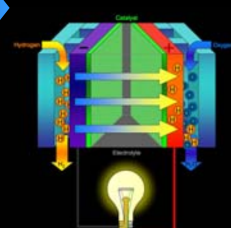
Orientational Control: ZnO Nano-Rods
(Piezoelectrics and Environmental Monitoring)



Photovoltaics



Batteries



Fuel Cells

Structural Materials