Development of Functional Organic/Inorganic Hybrid Materials by Macromolecular Templates

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1. Introduction: Preparation of functional materials through self-organization processes

Biominerals such as bones, teeth, seashell nacre, scales of coccolithophores, and the exoskeletons of crustaceans are organic/inorganic hybrids with highly controlled hierarchical structures (Figure 1). Organisms exploit the mechanical, optical, and magnetic properties of these structures for a variety of purposes. In living organisms, these structures are formed under gentle conditions through self-organization processes that are controlled by macromolecular templates. The structures, properties, and formation processes of natural biominerals inspire new approaches to synthetically develop functional hybrid materials. In accordance with this idea, we previously reported the formation of thin films of inorganic crystals using a biomineralization approach. The resulting hybrid materials consisting of inorganic crystals and organic polymers exhibited a wide variety of morphologies (Figure 2). Here we discuss our recent strategies for the development of new inorganic/organic hybrid materials such as unidirectionally oriented thin films, macroscopically oriented crystals, and hybrid thin films.

2. Study of peptides isolated from crayfish exoskeletons

Functional peptides play important roles in the formation of biominerals. Our research targets focus on structural control and lightweight materials with both high flexibility and mechanical strength. We designed and synthesized new recombinant peptides based on the functional peptide CAP-1, which was isolated from the crayfish exoskeleton. We have examined the effects of these peptides on the formation of calcium carbonate and organic hybrid materials.
in aqueous solution. In the presence of these recombinant peptides containing chitin-binding moieties, plate-like tripodal calcite crystals were formed on the chitin matrix with a unidirectional crystallographic orientation (Figure 3). Two kinds of interactions between the acidic part of the peptides and calcium ions and specific binding interactions of the peptides to chitin are essential in the formation of these oriented crystals and the control over specific morphologies. The crystallite size is indirectly proportional to the number of acidic units in the mutated peptides. This bio-inspired design of peptides controlling the inorganic/organic interface may open gateways to potentially highly versatile hybrid structures.

3. Orientation control of inorganic/organic hybrid materials

Oriented calcite crystals can be obtained using simple acidic polymers with matrices that exhibit macroscopic liquid-crystalline order. In order to prepare functional biominal-inspired hybrid materials, control over the orientation and structure of both inorganic and organic components on the macroscopic scale is crucial. Our methodology using liquid-crystalline templates for crystallization can be applied to the synthesis of novel highly organized hybrid structures. We are able to tune the chemical and self-organized structures of the template polymer matrix for the crystallization of inorganic crystals in order to produce oriented hybrid materials with interesting optical, electrical, and magnetic properties.

4. Conclusion

We have prepared new organic/inorganic hybrid materials with hierarchical structure via self-organization processes under mild conditions using macromolecular templates. These approaches are inspired by biomineralization and can be applied to develop hybrid materials between a variety of inorganic crystals (including transition metal-based compounds) and organic functional macromolecules. The resulting materials show great potential in a wide range of applications such as energy devices, high strength eco-friendly materials, and biocompatible materials.

References: