



# Recent Advances in Biomimetic Material Synthesis

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**Abstract:** Recent development in the bioinspired materials and biomimetic material synthesis gained more interest and attention. Biomimetic material synthesis can be achieved either by mimicking the organisms that employ biological processes to produce materials or substances. Biomimetic synthesis requires complete understanding of interactions behind the inorganics and organics. In this review, I describe the current progress in biomimetic synthesis in both experimental and simulations mode and classify this information in following perspectives: biomimetic system with template; progress in molecular simulations; materials development based on simulation; intelligent biomimetic system; and bioinspired systems. In addition, synthesis, simulations, principles and relationships are discussed, and the challenges and directions for further development are considered.

**KeyWords:** Bioinspired Materials, Molecular Simulations, Biomimetic Materials, and Nanomaterials

## I. INTRODUCTION

The concept of learning from nature traced back a few thousand years ago until the term biomimetics was suggested by Schmitt in 1960 [1–4]. The term was used to investigate the formation of biologically produced substances and materials (such as enzymes or silk) and processes (photosynthesis and protein synthesis), specifically for synthesizing similar products by synthetic mechanisms that mimic natural ones. In recent years, biomimetics or bioinspired materials gained more attention and taking lessons from nature and extend research in many fields, such as robotics [5], bioelectronics [6], medicine, catalysis [7], self cleaning [8], material science, and energy. With an increase in miniaturization of the objects of nano sized plays a big role in nanofabricated structures and microfluidic technologies. It requires in depth understanding of tools from nanotechnology.

Nanotechnology is a study of manipulation of nano sized materials in space and time with substantial amount of detail. Increasing demand of quantitative details in the biological experiments, biologists resort to knowledge offered by physics, chemistry, and nanotechnology. Biomimetic synthesis of nanomaterials is the fastest and interesting area in the branch of biomimetics. It can be classified into areas: functional biomimetic synthesis and process biomimetic synthesis. Functional biomimetic synthesis aims to mimic nature materials/structures/systems to create artificial systems such as bones and artificial organs. In case of process biomimetic synthesis is a kind of synthesis method, that attempts to prepare artificial materials/substances by mimicking synthesis process. For example, by mimicking protein synthesis process, many nanostructures like dendrimer, cubes, 2D arrays, 3D AuNP tubes, pyramids have been assembled in vitro.

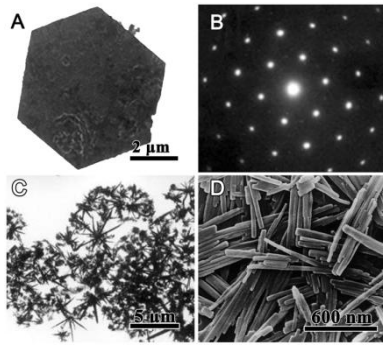
Organism contain a lot of information about biological processes, such as molecular assembly,

recognition, and template regulation. With advanced recognition biomineralization involves elementary biological processes. Synthesis of nanomaterials can be conducted by mimicking biological processes in vitro. Biomimetic synthesis uses animal structures such as butterfly wings [9], sea-urchin skeletons, beetles, silk-fibrin filaments, spider silk, and eggshell membranes [10]. Butterfly wings has several colors and patterns due to their periodic pattern and are widely exploited for biomimetic synthesis. Notably, Zhang's group prepared ZnO [11] and ZrO<sub>2</sub> photonic crystals and Fe<sub>3</sub>O<sub>4</sub> magnetophotonic crystals with a 3D network using butterfly wings.

Cells can also be used for the biomimetic synthesis of nanomaterials. Red blood cells (RBCs) show biological responses to chemical agents, and four distinct morphologies, stomatocytes, echinocytes, spherocytes, discocytes, can be obtained. These asymmetric RBC shapes can be used as anisotropic composites and inorganic particles using a process of silica bioreplication. As a result, due to the adjustable shapes of RBCs, the internal structure/porosity of the obtained mesoporous material can be tuned.

## II. BIOMIMETIC SYNTHESIS Via LIQUID MEMBRANES

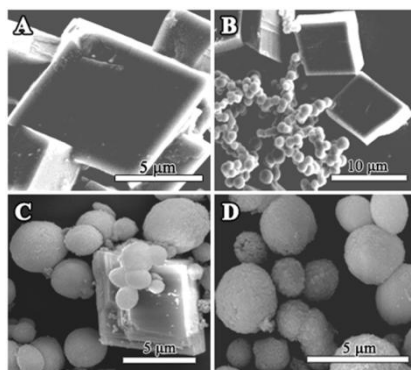
Recent employment of liquid membranes such as emulsion liquid membranes (ELMs) and supported liquid membranes (SLMs). Emulsion liquid membranes successfully employed to create biomimetic system. Surfactant is a crucial factor for synthesis of nanomaterials/nanostructures that influences crystal nucleation and growth. Wu coworkers demonstrated the ELM system to synthesize range of quantum dots, such as CdS, HgSe, and ZnSe, which shows quantum confinement that is different from bulk materials.



**Fig-1:** A) TEM image of one ortho-hexagonal ZnSe slice. B) SAD of ortho-hexagonal ZnSe slice C) TEM images of a BaCrO<sub>4</sub> superstructure. D) SEM image of a composite Co-Fe oxalate. Reproduced with permission [12].

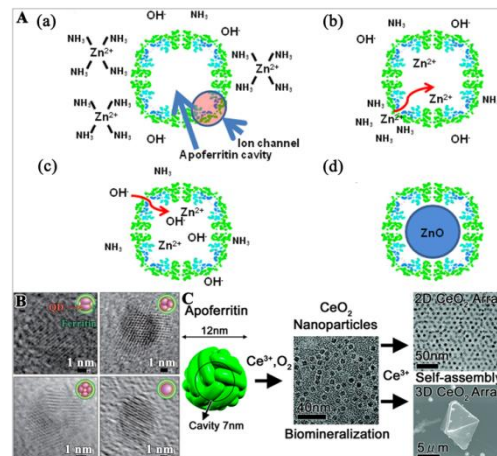
An assembly of ZnSe quantum dots into 2D ortho-hexagonal ZnSe single-crystal slices (Fig 1A, B) was observed in an ELM biomimetic system. Using ELM system flower like BaCrO<sub>4</sub> superstructures can be obtained in ELM system (Fig 1C). Rare earth oxide composite phosphors can be obtained in an ELM system and facilitate the route for designing composite structures and components via control of the transport rate and charge ratios. Composite structure CoFe<sub>2</sub>O<sub>4</sub> was prepared using ELM system (Fig 1D).

Wu coworkers successfully applied SLMs, a type of monodisperse liquid membrane, for the synthesis of nanostructures/nanostructures. ZnS chain-like nanospheres, CdS hollow/solid nanospheres, bunched PbMoO<sub>4</sub> nanobelts, and Cd(OH)<sub>2</sub> nanowires were synthesized using SLM biomimetic system. SLM can be employed to mimic the transmembrane transport process of biomembrane via mobile carriers in a liquid membrane and offers an inorganic-organic interface for crystal nucleation and growth. SLM biomimetic synthesis may provide a new route for metastable crystal synthesis. It was reported that abnormal structure conversion of CaCO<sub>3</sub> from calcite to vaterite using an SLM system. Initial calcite is formed by biomimetic system (Fig 2A), but it is gradually transformed into vaterite (Fig 2B, C, D).



**Fig-2:** SEM images of abnormal polymorph conversion of CaCO<sub>3</sub> in SLM system for 5 min (A), 30 min (B), 4 h (C), 60 h (D). Reproduced with permission [13].

### III. PROTEIN BASED TEMPLATE BIOMIMETIC SYNTHESIS



**Fig-3:** Apoferritin is used as a template for biomimetic synthesis. Reproduced with permission [14–16].

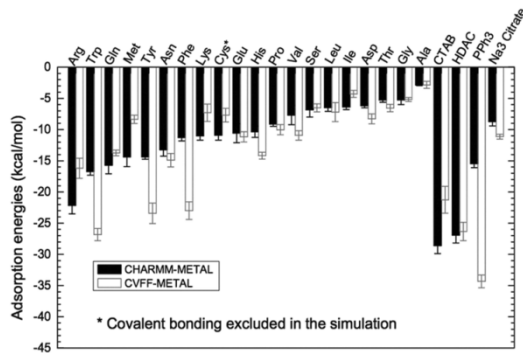
Proteins are the primary source of regulators in living organisms. Both soluble and insoluble proteins can influence the crystal morphology during biomineralization. Insoluble proteins act as template for crystal nucleation and growth, and soluble proteins can adsorb preferentially to specific facets and influence the oriented growth of crystals. In vitro, these effects can be mimicked to either probe the mechanism of biomineralization or to synthesize complex nanostructures and functional inorganic nanomaterials.

Apoferritin is a ubiquitous protein in living organisms and serves as an iron-storage protein that maintains iron homeostasis in cells. Apoferritin is a 24 polypeptide subunits, exhibiting a spherical structure with a diameter of 12 nm and an internal cavity of 7 nm. Studies have shown that the biomineralization reaction in apoferritin helps nucleation and crystal growth through a multistep process involving the uptake of Fe II, oxidation to Fe III (Fig 3). Studies also showed that heat shock proteins, and DNA-binding proteins, have a similar capacity as apoferritin, in that they can be used as nanoreactors for the biomimetic synthesis of nanomaterials.

### IV. SIMULATIONS ASSIST BIOMIMETIC SYNTHESIS

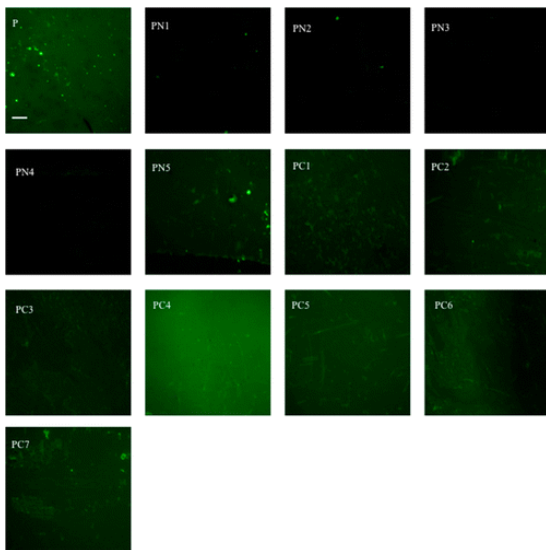
Current computational methods to examine structural, chemical, and physical properties underlying interactions between the inorganics and organic molecules. Quantum mechanical calculations enable the analysis of the geometry of molecules, conformers, and clusters of molecules with a focus on electron density, orbital geometry, chemical reactions, and transition states, whereas molecular dynamics and monte carlo simulations reveals structure, conformations,

binding energy. Several force fields were built to study the interface (Fig 4).



**Fig. 4** Computed adsorption energies of the natural amino acids on gold(111) surfaces in solution using CHARMM-INTERFACE and the CVFF-INTERFACE force field. Reproduced with permission from [17]

Specific binding of peptides selected by phage display has also been computationally studied on metals and semimetals such as Pt [18, 19] and silicon [20, 21]. On the  $n^+$  silicon (100) surface, three peptides identified by phage display were found to be attracted with binding energies of  $-12$ ,  $-15$ , and  $-7$  kcal mol $^{-1}$ . D, T, H, S, and R were found to increase absorption. With knowledge from simulations, authors designed novel peptide with enhanced properties that is used as template for greater adhesion (Fig 5) [22].



**Fig-5:Engineered peptides for greater adhesion to substrate. Reproduced with permission from [22]**

## V. CONCLUSIONS

In conclusion, only a few methods for used to develop biomimetic synthesis were reviewed. There is no doubt that biomimetic synthesis will lead to develop novel materials with predictive properties. Many researchers tend to use bioinspired and biomimetic approaches to address fundamental material synthesis. Nature mimicking materials have greater precision compared to

classical trial and methodologies. Simulations on the other hand can provide quantitative trends in interactions and help design binding molecules for each class of materials, allowing the formulation of materials-specific concepts with predictive character.

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