Biomimetic Strategies in Crafting Bionanomaterial-Based Systems

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The challenge of designing new materials with well-defined structures and desirable functions is prominent in materials science, especially when dealing with nanometer-scale dimensions. In contrast, nature achieves complex functional nanostructures through the self-assembly of basic building blocks, both physically and chemically simple. Under specific conditions, nanofibers can reach momentarily favored states far from equilibrium, stabilizing nano/micro-scale self-assembled structures that amalgamate into macroscopically organized hierarchical structures. Recently, the mimicking of self-assembly processes in nature has led to the development of various functional nanomaterials through the self-assembly of genetically and chemically engineered viral particles. From another perspective, biomimicry can be broadly applied, and notably, the use of substances derived from the human body can be considered a biomimetic approach in a comprehensive context. The design is meticulously crafted in this manner when applying various nanomaterials with excellent properties to the field of bio-applications, necessitating the essential design of interfaces through such an approach.

Firstly, I present the helical nanofiber shape of the M13 bacteriophage (phage) and its self-assembled liquid crystalline structures for designing diverse structures based on helical nanofibers. As an illustrative example, we developed a novel, sensitive, and selective color sensor utilizing cross-reactive M13 phage structural array matrices and an accompanying smartphone-based sensing system. Additionally, I demonstrate vertically aligned and polarized piezoelectric nanostructures derived from biological piezoelectric nanofibers, specifically M13 phage. This achievement involves control over orientation, polarization direction, microstructure morphology, and density through genetic engineering and a template-assisted self-assembly process. The resulting vertically ordered structures exhibit strong unidirectional polarization and can serve as a piezoelectric energy harvester (PEH). Finally, I introduce an ultrasensitive and rapid molecular diagnostic platform that combines nanoparticles and genetic materials.