

Juan Wang and Xuehai Yan*

National Key Laboratory of Biochemical Engineering, Institute of Process Engineering, Chinese Academy of Sciences, Beijing 100190, China

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*Corresponding author: Xuehai Yan, National Key Laboratory of Biochemical Engineering, Institute of Process Engineering, Chinese Academy of Sciences, Beijing 100190, China, E-mail: yanxh@ipe.ac.cn

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Opinion

Self-Assembly as a Technique for Peptide-Based Materials

culturing [16-18] and energy materials [19-21]. The mechanical properties of organogels are the key technique problems that needed to improve for applications.

Amphiphilic peptides

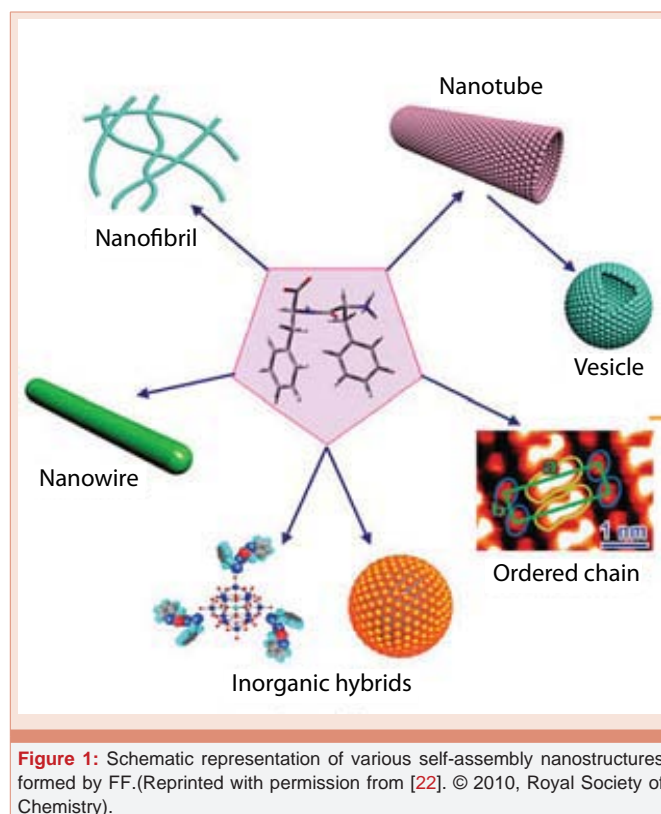
Amphiphilic peptide (AP), which behaves in some respects like amphiphilic surfactants, is a class of molecule that consists of a hydrophilic peptide segment and a hydrophobic domain. In water, these molecules generally self-assemble into rods with a hydrophobic core. The peptide segments outside the hydrophobic core always prefer a β -sheet conformation. As introduced in the latest reviews [23,24], the self-assembly of AP are mainly controlled by the balance between hydrophilic and hydrophobic segments, and influenced by parameters such as temperature, pH, lights, and so on. Therefore, many pH-responsive [25], temperature-responsive [26], UV light-responsive and enzymes-responsive [27] materials have been developed and applied, and some of these are already in commercial use, e.g. in skincare products [28].

Introduction

Molecular self-assembly is a key function in biology and has been developed as an elegant technique for fabrication of various complex structures and functional materials. Key importance for structural formation in terms of self-assembly is molecular recognition pertaining to intermolecular weak interactions such as hydrophobic interactions, hydrogen bonds, π - π stacking, electrostatic forces and dipole-dipole interactions etc. A combination of several kinds of such weak interactions can govern molecular organization and thus ordered supramolecular architectures. Among molecular building blocks are the bioinspired and bioderived molecules including peptides and proteins. Peptides consisting of several amino acids are most popular over decades for development of molecular biomaterials owing to ease of availability, programmable molecular motif, biocompatibility and biodegradation, flexible functionality and low cost-effectiveness. The nanostructures and materials assembled using peptides as building blocks have presented an important potential for green-life new technology and biomedical applications. In this opinion, self-assembly and application of several kinds of peptides including aromatic dipeptides, polypeptides, amphiphilic peptides, lipopeptides, and inorganic-hybridized peptide will be stated briefly.

Aromatic dipeptides

Diphenylalanine (FF), which is extracted from Alzheimer's β -amyloid polypeptide, is one of the simplest and most common used recognition motifs for molecular self-assembly [1]. It is known that FF as well as its derivatives can assemble into various nanostructures including nanotubes [1,2], nanofibrils [3,4], ribbons, nanowires [5], spherical vesicles [6], and so on (Figure 1). These morphology of FF nanostructures can be controlled, interconverted [6] and affected by parameters, e.g. solvent conditions [3] and temperature [7]. Especially, because of their unique physical and chemical properties, the development and potential application of FF nanotubes have been rapid growth [8-11]. For example, nanotubes and nanospheres in solutions can be used as ink and patterned on ITO plastic surfaces [12]. Recently, various functional FF nanotubes with photoluminescent [13], fluorescent [14], and piezoelectric activity [15] are reported. The studies of FF fibrils and ribbons are essential since the formation of FF fibrils is ubiquitous and relevant to diseases such as Alzheimer's disease. In addition, FF organogels formed by FF fibrils are novel soft materials, having potential applications in drug delivery, cell



Lipopeptides

Lipopeptide can be treated as a special type of AP, and the hydrophobic tail of lipopeptide has a similar structure as the lipid. Therefore, when lipopeptide molecules are exposed to water, vesicle-like structures can be spontaneously formed by self-assembly. These vesicles have potential application in drugs and genes delivery [29-32]. For example, the vesicles formed by a multivalent cationic lipopeptide has a binding affinity with DNA and expected to be a new type of gene transfection reagents [30].

Polypeptides

Synthetic polypeptide (PP) is a kind of polymer that polymerized by amino acids molecules, and the self-assemble properties of PP are determined by its amino acid segments. PP molecule is a perfect combination of flexible polymer and amino acid. The polymerization techniques significantly develop the stimuli-responsive of amino acids (Figure 2) [33]. Moreover, comparing to the low weight FF-based organogels, the mechanical strength of PP-based organogels can be dramatically increased. On the other hand, by layer-by-layer assembly technique, a polypeptide multilayer film can be fabricated on solid substrate and applied in bionanotechnology such as cell and tissue culture [17,34], immunogenicity control [35], antimicrobial films [36], and so on. The vesicles and particles assembled by PP can load drug molecules and be used for drug delivery [37-40].

Peptide-inorganic hybrids

The interventions of inorganic functional materials, including polyoxometalates (POMs), nanocrystals, and nanoparticles, will provide unique electronic, catalytic, photonic properties to peptides. For example, the hybrids combined of a cationic dipeptide and a Keggin-type POM exhibit spherical nanostructures through strong electrostatic interactions and further multiple noncovalent interactions [41]. These hybrids, which showing unique pH and temperature responsive, can be applied in controlled release of drugs.

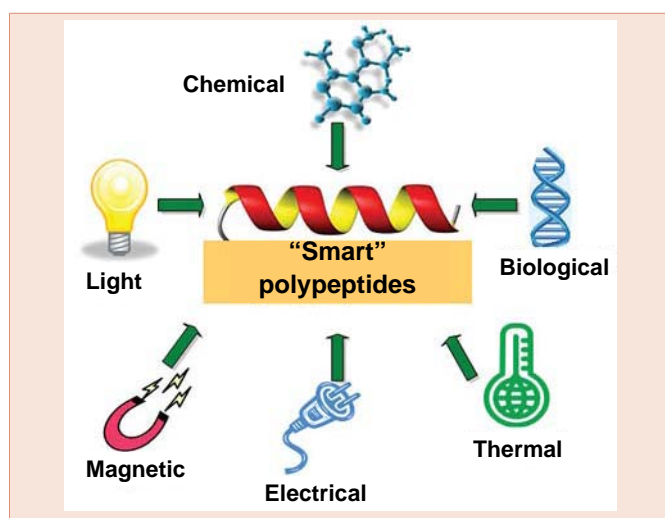


Figure 2: Various stimuli-responsive modes of polypeptides. (Reprinted with permission from [33]. © 2013, Royal Society of Chemistry).

By using FF-based organogels as candidate, quantum dots (QDs) can be entrapped [42]. Thus hybrid gels with various electronic, optical, and magnetic properties can be achieved.

Peptides assembled on the surfaces

The materials fabricated by ordered peptides assembled on various surfaces or substrates such as Si [43,44], Cu [45], gold [46-48], and polymer [49] are also attractive because of their potential applications in bionanotechnology and biosensing devices. The assembly of peptides on surfaces benefit the studies on single-molecule level [50], and development of two-dimensional materials.

Summary and Outlook

Molecular self-assembly is an interdisciplinary research field involving chemistry, materials science, life science and physics so on. Self-assembly, as a “bottom-up” technique starting from molecular units, provides a powerful tool to obtain various biologically-based materials with potential applications. It has been demonstrated that different architectures including nanofibers, nanotubes, spherical vesicles and ribbons can be formed through peptide self-assembly. They show a significant potential for biomedical applications such as drug delivery, biosensors and tissue engineering. However, the studies in this field are still in its infancy. The development of peptide-based materials is yet challenging but exciting. The systematic understanding on governing mechanisms for self-assembly and the translation into practical industrial uses are needed and appreciated. Breakthrough in these research topics will surely promote the development of peptide-based materials, in turn which will motivate the activity for developing molecular self-assembly as a technique for preparation of new types of green, ecologically friendly and smart materials.

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