

EDITORIAL

Unlocking the potential of molecular self-assembly: From nanotechnology to sustainable materials

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Scientists have used the powerful phenomenon of molecular self-assembly, drawing inspiration from nature to create innovative supramolecular architectures. Within the realm of supramolecular chemistry, molecular self-assembly assumes a pivotal role, enabling the creation of a wide range of nanostructures with suitable properties^[1,2]. This process relies on the orchestration of non-covalent interactions, encompassing hydrogen bonding, metal coordination, hydrophobic forces, van der Waals forces, π -stacking interactions, and electrostatic interactions^[3]. By harnessing these forces, scientists have unlocked the ability to engineer sophisticated and diverse supramolecular assemblies. The field of molecular self-assembly is experiencing rapid growth, captivating researchers from various molecular disciplines. Its potential knows no bounds, as it encompasses the exploration of a vast array of molecules. The expanding scope of molecular self-assembly has sparked immense interest and holds promise for groundbreaking advancements in the field^[2,3].

The concept of molecular self-assembly allows for the creation of a diverse range of supramolecular structures, including colloids, biomolecular condensates, crystals, gels, micelles, vesicles, liquid crystal phases, and Langmuir monolayers^[1]. These structures are frequently formed through the involvement of surfactant molecules, which drive the assembly process. Scientists globally are actively involved in captivating endeavors, seeking to exploit the intricate possibilities offered by biomolecules like proteins, nucleic acids, and peptides. Their objective is to engineer innovative synthetic materials through the process of molecular self-assembly. By harnessing the complexity inherent in these biomolecules, researchers are striving to unlock new frontiers in material design and fabrication. Cellular processes demonstrate remarkable instances of molecular self-assembly, such as the formation of amyloid fibrils, recognition between antigens and antibodies, assembly of chromatin, and self-assembly of phospholipid membranes. These examples highlight the fundamental role of molecular self-assembly in the intricate workings of cells. Molecular self-assembly has emerged as a powerful tool in supramolecular chemistry, facilitating the precise formation of complex structures. Its versatility extends to a wide range of fields, encompassing materials science, nanotechnology, and beyond, where it holds immense potential for practical applications^[4].

Moreover, molecular self-assembly also plays a crucial role in the bottom-up approach to nanotechnology. It allows for the precise programming of the desired structure by leveraging the shape and functional groups of the molecules involved. In contrast to top-down techniques like lithography, which involve carving structures from larger blocks of matter, self-assembly is considered a bottom-up manufacturing technique. In

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the realm of molecular nanotechnology, there is a speculative vision of constructing future microchips using molecular self-assembly^[2,5]. One advantage of utilizing self-assembly in the construction of nanostructures for biological materials is their ability to degrade back into individual molecules, which can then be broken down by the body. This offers promising opportunities for biocompatible materials with controlled degradation properties.

The spontaneous organization of molecules into a single layer at interfaces is commonly known as two-dimensional self-assembly. Langmuir-Blodgett monolayers and multilayers of surfactants are prominent examples of such assemblies. Over time, two strategies have gained popularity for the self-assembly of two-dimensional architectures: self-assembly through ultra-high-vacuum deposition and annealing, and self-assembly at the solid-liquid interface. Today, the design of molecules and the optimization of conditions to achieve highly crystalline architectures are considered forms of 2D crystal engineering at the nanoscale. These approaches offer precise control over the formation of two-dimensional structures with tailored properties and functionalities^[5,6].

Supramolecular gel is a fascinating result of self-assembly, where the main constituents are gelators and solvent molecules. In the formation of supramolecular gel, the gelator molecules immobilize the solvent molecules within three-dimensional soft gel scaffolds. This immobilization leads to the creation of a gel with unique properties, such as its soft and gel-like consistency. Supramolecular gels have attracted significant interest due to their potential applications in various fields, including materials science, drug delivery, and tissue engineering^[7].

The field of self-assembly is advancing in exciting directions, and its future holds great promise. One particularly noteworthy direction is the development of self-assembly systems that contribute to the creation of green and sustainable materials. By incorporating proper design principles, self-assembly systems can exhibit a high degree of responsiveness to their environment while remaining environmentally compatible. This environmentally conscious approach opens up new possibilities for the development of materials that are not only functional and efficient, but also align with the principles of sustainability. As researchers continue to explore and refine self-assembly techniques, we can anticipate significant advancements in the development of eco-friendly materials with enhanced responsiveness and performance^[1,2].

Conflict of interest

The author declares no conflict of interest.

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