【Grant-in-Aid for Transformative Research Areas（A）】

Materials Science of Meso-Hierarchy

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Research Area Information	Number of Research Area : 23A203　Project Period (FY) : 2023-2027 Keywords : Mesoscale, Supramolecule, Self-Assembly, Hierarchy

Purpose and Background of the Research

●Outline of the Research

Chemists have traditionally used organic synthesis to create molecules with diverse shapes. These molecules have a scale of a few nanometers (1 nanometer = 1/100,000 of the thickness of a hair), and they display a variety of functions based on their shapes. This can be considered one of the technologies within the realm of nanotechnology. On the other hand, within our bodies, various molecules, such as proteins and DNA, self-organize to create diverse shapes on a larger scale. For example, in photosynthetic organisms, ring structures play a role in harvesting light, and many of our body's movements are based on the interplays between like rings and cylinders. This scale, one or two orders of magnitude larger than the nanoscale, is referred to as the mesoscale and has been considered a particularly challenging area for chemists to create shapes. In this research area, the question we want to pose is: Can we create diverse shapes in the mesoscale region, a scale one or two orders of magnitude larger than conventional nanotechnology based on molecules, by assembling molecules like living organisms? Can we study these structures by directly observing them? Can we expect these mesoscale structures to exhibit certain functions even without assembling them on a macroscale? We aim to clarify the control of "shapes" and their correlation with functions in the mesoscale region and thereby develop mesoscience and mesotechnology.

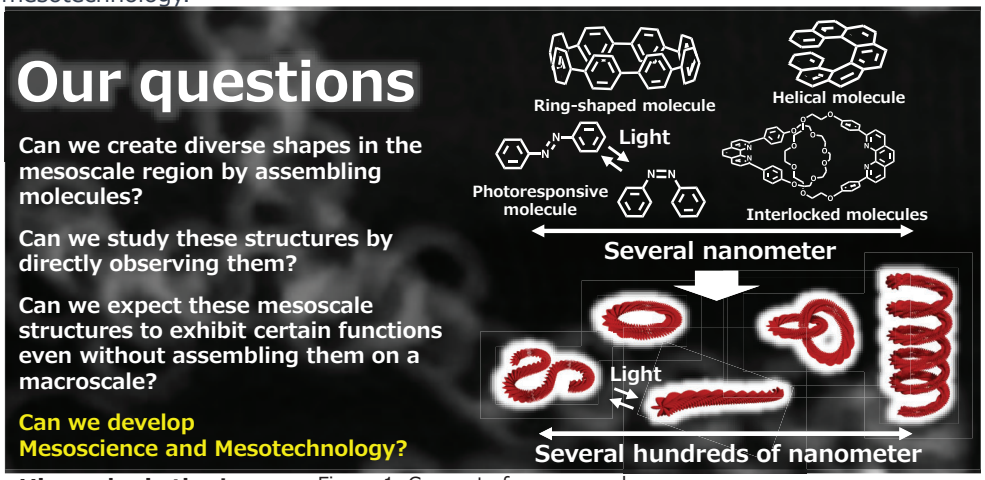

Figure 1. Concept of our research area

●Hierarchy is the key

Another important concept in this area is hierarchy. It is difficult to assemble small molecules all at once and create larger shapes in the mesoscale without diverging to the macroscale. Therefore, we utilize hierarchy, i.e., from molecules to shape A, and from A to a larger shape B, and then further assemble B to create a mesoscale shape C.

Expected Research Achievements

●Synthesizing, Observing, Measuring, Utilizing, and Theorizing Meso-Hierarchy Structures

The impetus for initiating this research field was the creation of the world's first "meso-hierarchy structure", interconnected nanosized self-assembled rings (Figure 2). In this instance, molecules first form supramolecules, which further assemble to nanostructures, and the nanostructures hierarchically organize into mesostructures. The methodology for making mesoscale structures in this hierarchical way is adaptable to a diverse range of materials. Moreover, other methodologies may already exist (as illustrated in Figure 3a) and are anticipated to be further developed.

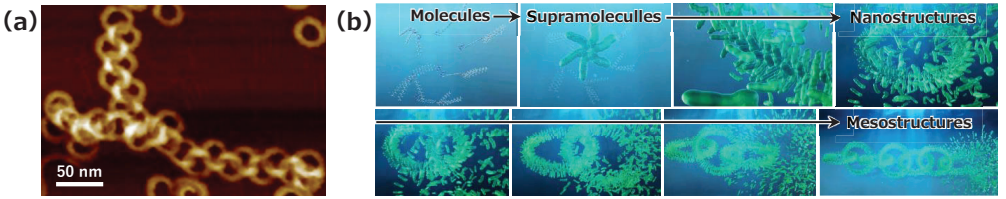

Figure 2. AFM image of meso-hierarchy structure (a) and animation of its formation process (b) (https://www.youtube.com/watch?v=glzqiT1cXYc)

In this research area, we not only create meso-hierarchical structures but also observe them using specialized microscopy techniques (Figure 3b), measure their encapsulated optical/electronic properties (Figure 3c), explore their photophysical (Figure 3d) and mechanical (Figure 3e) functionalities, and further predict their formations through simulations and elucidate the underlying principles (Figure 3f).

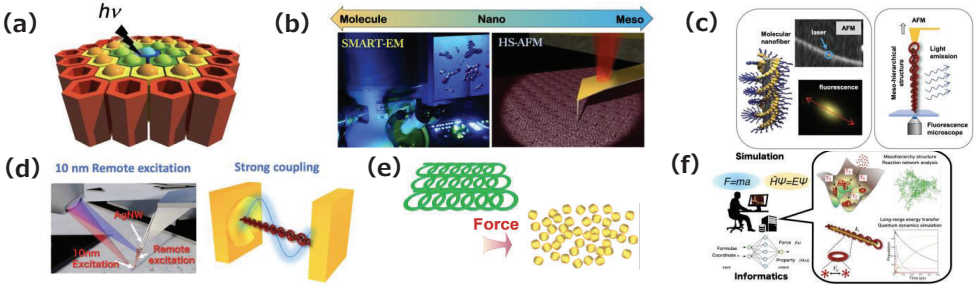

Figure 3. Various techniques to crease and study meso-hierarchy materials

●Impact

We will bring together above various technologies to create a wide range of meso-hierarchy materials that were previously impossible to achieve and explore their functions. Examples include mesoactuators capable of directly manipulating small objects like proteins, ultra-sensitive radiation light sensors, mesoscale mechanosensors capable of measuring forces on cells, and exciton circuits utilizing mesoscale optical energy transfer. We will also establish a systematic theory for creating meso-hierarchy structures and expand them to a variety of materials. In doing so, we aim to lead the international transition from traditional nanotechnology to mesotechnology.

●Cultivating Young Talent

We create a forum where young researchers can gather. We foster an environment where events not typically experienced in individual research labs can frequently occur to cultivate a desire to become a researcher, to expand interest in different fields. Additionally, we will actively offer opportunities for domestic researcher exchange programs and overseas studies.

MESO HIERARCHY

Meso-Hierarchy for Rising Generation

Figure 4. Logos of our area

Homepage Address, etc.	https:/mesohierarchy.jp/ (Homepage)　https://twitter.commesohierarchy/ (X)