Novel mesoscopic photo-responses achieved by combining photochemical reactions and radiation pressure

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Abstract

Utilizing the advantageous characteristics of laser light, such as monochromaticity, high coherence, high output intensity, and ultrashort pulse duration (fs - ps), we have been exploring new mesoscopic photoresponse of materials by combining photochemical reaction and radiation pressure. For instance, we have 1) demonstrated the spatio-temporal control of photopolymerization in nanospace by radiation pressure (optical trapping) and applied it to successful fabrication of polymeric 3D microstructures and, 2) developed micro-optomechanical systems based on radiation pressure controlled by photoisomerization (photochromic) reaction. Furthermore, we have achieved selective transportation and spatial patterning of plasmonic nanoparticles by strong radiation pressure due to optical resonance.

Background & Results

Optical micromanipulation can be attained by using radiation pressure acting on small objects as a result of the momentum change of photons. Conventionally, the main application of the radiation pressure was the manipulation of the micrometer-sized particles. We have extended it to nanomaterial manipulation and achieved the control of photopolymerization reaction by the trapping of the reaction intermediates.

In the liquid phase at room temperature, the lowest limit of particle size for optical trapping is generally 10-20 nm and the application of optical trapping to the control of chemical reactions has been regarded as a difficult task. However, we pointed out that the radiation pressure can efficiently act on polymer chains under propagation even in solution at room temperature and, we demonstrated the trapping of reaction intermediates (growing chains) under photopolymerization, leading to significant improvement in the spatial selectivity of the polymerization reaction (Fig. 1). This is of great significance not only for its application to 3D microfabrication, but also as a pioneering study on the control of chemical reaction by radiation pressure in terms of fundamental science. In addition, by utilizing the dependencies of radiation pressure on the particle shape and size, we have succeeded in selective sorting and spatial patterning of uniform silver nanorods from silver nanocolloids containing a mixture of spherical and rod-like particles (Supplementary Figure).

Optical manipulation can also be applied to the controlled motion of micro-mechanical systems that do not require electrical wiring. From such viewpoint, we have developed a novel micro-photo-mechanical systems by combining photochromic reaction and radiation pressure. By modulating the radiation pressure (mainly the absorption force) by the photochromic reactions, we realized micro-reciprocating motions of particles synchronizing with the photoreaction (Fig. 2).

Significance of the research and Future perspective

Materials science including chemistry is an academic field that aims to develop new functional substances useful to human beings and to elucidate their mechanisms. In recent years, advances in so-called AI have been making it possible to predict the molecular and crystal structures of materials with desired physicochemical properties based on a wide range of correlations between the desired properties (=functions) and various characteristics, which seems to break out the paradigm in the material science soon. Therefore, in the future, the exploring of new physicochemical properties that cannot be predicted from existing knowledge due to the little information on the correlations should be more important in material science. Along this line, we will explore further novel mesoscopic photo-responses with a view to developing nano-processing and micro-optomechanical devices.

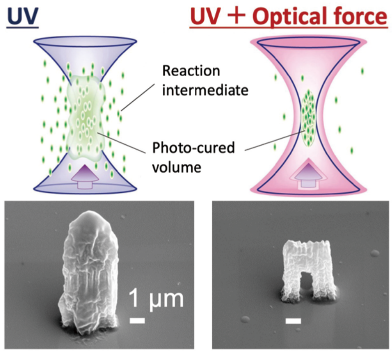


Fig. 1

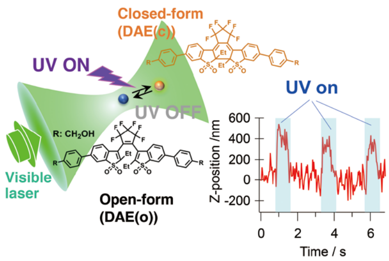
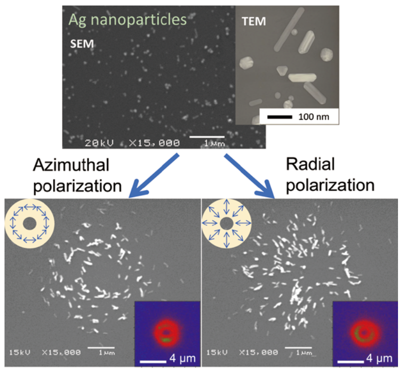


Fig. 2



Suppl. Fig.

Patent

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