Fabrication of Micro/nano-structures by Using Self-organizing Process

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Abstract

By using a self-organizing process, micro/nanostructures can be produced effectively at a lower cost as compared to traditional top-down processes. However, various trials conducted so far have shown that these processes have drawbacks such as randomness in the structures thus formed. This paper describes the process of self-assembly of fine particles, starting from an outline of the basic principle and moving on to its potential applications.

1 Introduction

The resolution and accuracy of top-down processes like cutting are limited by those of machine tools and tool on account of the copying rule. The throughput of these processes may be limited in the case of a single-point tool. On the other hand, self-organizing processes can potentially overcome these limitations in both resolution and throughput because they operate on a different principle. Self-organizing processes are governed by various principles such as phase separation in diblock copolymers and the electric field strength during the anodic oxidation of aluminum. This paper introduces the self-assembly of fine particles and the potential applications of the process of self-assembly.

2 Principle

Figure 1 shows the typical configuration of the self-assembly process. Particles are dispersed in a solvent to prepare a colloidal suspension. Typically, water is used as the solvent because of its high surface tension and ease of handling. When the hydrophilic substrate is drawn-up from the suspension, it spreads over the substrate, and the particles form a packed structure due to the meniscus between them along with the evaporation of solvent. In this process, the manipulation of each particle is not necessary, although some parameters such as draw-up speed and particle concentration should be determined by a trial-and-error method.

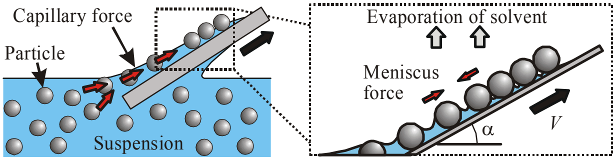
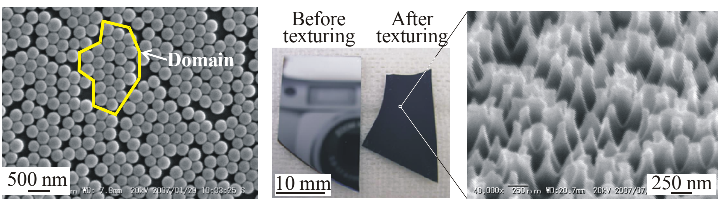


Figure 1: Principle of self-assembly of particles

3 Scalability

This process is scalable to large-sized substrates because it proceeds intrinsically not in serial but parallel. Figure 2 shows the antireflective surface of a ϕ100 mm silicon-wafer substrate. In this case, ϕ300-nm silica particles were assembled uniformly over the substrate; the resulting structure was used as etching mask. Nanopillars fabricated on the substrate decreased the reflectivity to 3% of the original substrate. The assembly did not exhibit perfect regularity but showed randomness due to the formation of domains. This randomness is advantageous because regularity causes the unnecessary interference of light. The size of the substrate can be increased to compensate for the low draw-up speed.



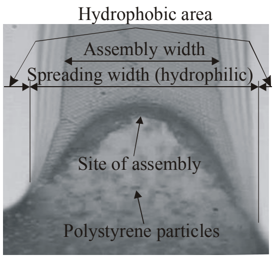
(a) Assembled particles (b) Appearance of substrate (c) Closeup image

Figure 2: Assembly as mask for production of antireflective surface [1]

4 Site-selective assembly

Site-selective assemblies are essential for applications such as sensor devices. Figure 3 shows an assembly that utilizes the wettability pattern. When the substrate is patterned with hydrophilic or hydrophobic material, the aqueous suspension spreads only over the hydrophilic part [2]. The left-hand-side image of Fig.3 shows the *in-situ* observation of the assembly. Suspensions that contain 1 μm polystyrene particles spread over the hydrophilic part, which has a width of approximately 50 μm and is sandwiched between hydrophobic parts. The assembly was placed near the centre of the region over which the particles had spread. It is found that the width of the assembly is narrower than that of the spreading. The right-hand-side image of Fig.3 shows the obtained assembly in another case. Defects in the assembly can be found within a width of 20 μm. It was found that the minimum assembly width was limited to several tens of micrometres.

Instead of the wettability pattern, shallow grooves can also be used to pattern the assembly because capillary forces attract the suspension, and geometrical constraints improve the accuracy of the assembly. Figure 4 shows the accurate assembly using grooves. The image on the left-hand side shows a 10-μm-wide groove. There is a drastic decrease in the number of defects. The right-hand-side image shows a single-line assembly. Polystyrene particles with a diameter 1 μm are aligned in a line along the groove. The width of the groove was the same as the diameter of the particles and the depth was only 0.12 μm; thus, the assembly is not straight but forms a zigzag pattern. Thus, these assemblies are suitable for narrow patterns because such patterns utilize the capillary force.



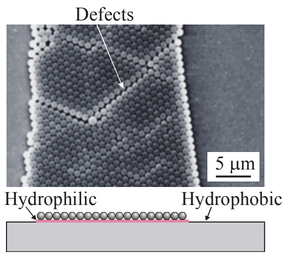
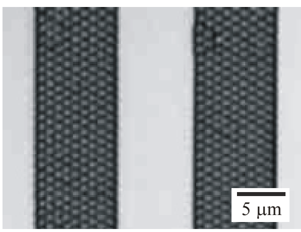


Figure 3: Site-selective self-assembly using hydrophilic/hydrophobic pattern



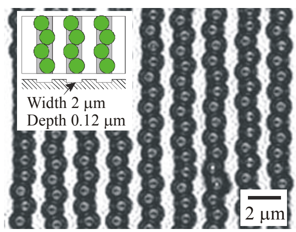


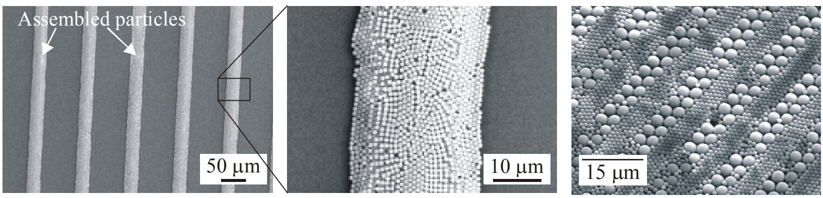
Figure 4: Accurate assembly using grooves

5 Potential applications

Biochemical analyses utilize various types of reactions such as antigen–antibody reactions in immunoassays. Figure 5(a) shows the assembly of silica particles modified by specific proteins for one such reaction. The particles were successfully assembled along the wettability pattern. Fluorescence observation confirmed that the proteins only occupy the appropriate portions on the substrate. The sensitivity increases with a decrease in particle size because for the same volume, there is an increase in the total surface area. In addition, the time required for analysis decreases with a decrease in size. Thus, miniaturisation is preferable. A highly sensitive gas sensor was developed using a nanocomposite of SnO_2 and ZnO particles [3].

Figure 5(b) shows a complex assembly made of different-sized particles. This structure was assembled by repeating the dip-coating process using various suspensions. During the coating process, particle fixation and modification of the substrate surface from a hydrophobic surface to a hydrophilic one were necessary. This kind of complex assembly suggests an integration of functional elements such as sensors and catalysts.

Summarizing, self-assembled structures can be used in various applications from chemical sensors to physical devices such as photonic crystals, which have not been mentioned here. Precisely aligned abrasive tools may be one of the other applications of self-assembly processes.



(a) Particles modified by protein (fluorescence observation) (b) Complex assembly

Figure 5: Various assemblies

4 Conclusions

The self-assembly of fine particles was introduced as an example of self-organizing processes. After the principle was introduced, the difficulties involved in and the various approaches proposed for the self-assembly process were discussed, and potential applications of the process were described.

References:

[1] N. Moronuki et al., Large-scale antireflective surface produced by the combination of self-assembled mask and etching, Proc. euspen, 2008, pp.469-472.

[2] A. Kaneko et al., An application of dip-coating technique to fabrication of self-assembled microstructure on hydrophilic/hydrophobic patterned substrate, Proc. euspen, 2006, pp.288-291.

[3] W-H Zhang and W-D Zhang, Fabrication of SnO2-ZnO nanocomposite sensor for selective sensing of trimethylamine and the freshness of fishes, Sensors and Actuators B 134, 2008, pp.403-408.