Patterned Self-assembly of Fine Particles and their Transfer/replication to Produce Complex Microstructures

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Abstract

This paper discusses methods for the application of self-assembled particles with specific pattern. By using two kinds of resin that has different affinity for the particles, the particles can be transferred or the profile can be replicated to the resin coated on another substrate. The effect of parameters such as imprint pressure was made clear using assembly of silica particles of 1 μm diameter. Typical characteristic is that the top height of the particles is precisely aligned in the assembly transfer. Thus application for grinding tool was discussed.

1 Introduction

Nanostructures can be fabricated by self-organizing processes with ease. Typical one is self-assembly of fine particles. The authors have applied this process using dip-coating [1] or dispenser system to produce assembly that have specific pattern [2]. However, particle fixation has not been discussed so far. This paper discusses both of a fixation process of the particle and a replication process of the profile to produce complex microstructures.

2 Principle and experiments

Figure 1 shows the process. Particles were self-assembled on “substrate 1” by dispensing suspension that contains particles. After the evaporation of solvent, the particles self-assembled to make up packed-structure of monolayer ideally. Ultraviolet (UV) curing resin was spin-coated on “substrate 2”, then they were pressed against each other and then the resin was cured. During release, particles are transferred to “substrate 2” if the affinity of resin for the particle is strong. Material transfer is effective when the particles have specific function such as abrasives for grinding tools or silver particles for disinfection. On the other hand, if the affinity is not strong, the profile of the particles is replicated to the resin. The increase in the surface area is effective for the improvement of sensor's sensitivity for example [3].

Table 1 shows the conditions for experiment. Silica particles of 1µm in diameter were dispersed in pure water. Silica is inorganic, thus, the assembly can be transferred to UV resin that has strong affinity for inorganic material (PAK01, Toyo Gosei Co., Ltd. Japan). On the other hand, the profile of the particle assembly can be replicated to the resin of which affinity is not strong (PAK02, Toyo Gosei Co., Ltd. Japan). The material of "substrate 2" was transparent polyethylene terephthalate (PET) for the irradiation of UV light. Photolithography equipment was used for irradiation of UV light and to apply imprint pressure utilizing the mechanism for contact printing.

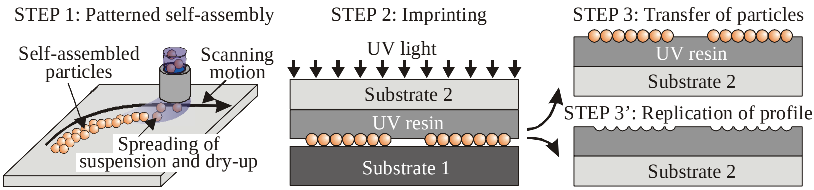

Figure 1: Concept of transfer/replication of the self-assembled particles

Table1: Experimental conditions

Suspen-sion	Particle	SiO_2 (ϕ1 µm), 1 vol%	UV Resin	PAK01: Affinity to inorganic
	Solvent	Pure water		PAK02: Affinity to organic

3 Results and discussion

Figure 2 shows the experimental results of transfer. Particles were assembled uniformly over 20 mm square on a silicon wafer and then transferred. With the increase in the imprinting pressure, penetration depth or transfer depth increased. It is found from the SEM photos that each particle is buried in resin. This means that the particles are well supported by the surrounding resin.

Figure 3 shows the result of profile replication. The "replication area" denotes the proportion of replicated area to the total imprint area. It is found that the profile is well replicated to the resin when the contract pressure is low. However, when the pressure is high, the particles were transferred to the resin unintentionally. Replication pressure should be determined carefully.

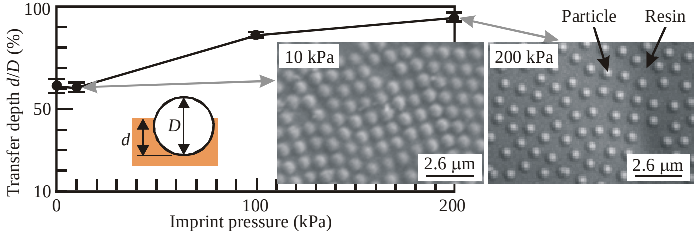

Figure 2: Effect of imprint pressure on the transfer process

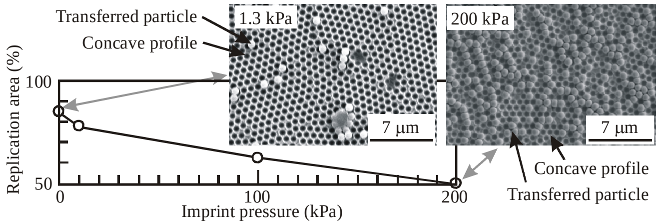

Figure 3: Effect of imprint pressure on the replication process

Figure 4 shows the height accuracy of the transferred structure. The SEM photos on the left side show the effect of the numbers of assembly layers. It is found that the top height keeps same level independent of the number of the layers over wide area, because the particles originally aligned on the mirror-polished substrate for assembly and thus the flatness of the top is copied from that of the substrate. The figure on the right side shows the result of white light interferometer observation. It is found that the particle top have constant height in nano-meter accuracy.

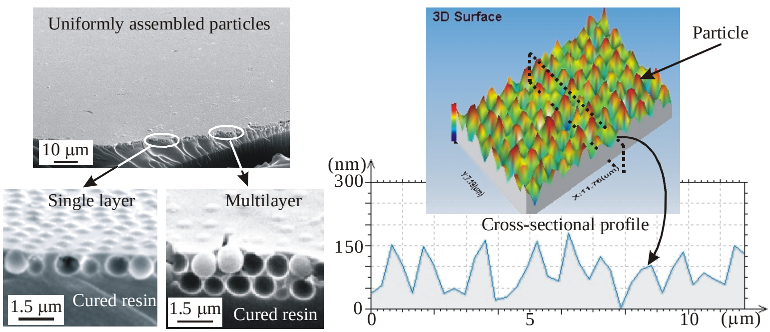

Figure 4: Macro-/micro-observation of the transferred particles

Accurate height of the structure can be advantageous to the application for grinding tools. Figure 5 shows an example. Spiral pattern was assembled on a silicon wafer by applying required motion between the wafer and dispenser nozzle. The spiral was intended to induce outward flow of the coolant according to its rotation during machining. It was found that the assembly was transferred precisely. Machining tests have not been completed. Diamond particles were also tried. However, the assembly was not uniform due to irregularity of the particle size.

The substrate for transfer or replication was limited to transparent material for the irradiation of UV light in this study. However, opaque substrate can be applied by changing the resin to thermo-set or thermoplastic resin instead of UV resin.

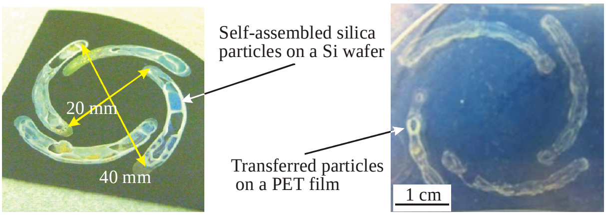

Figure 5: Spiral pattern assembly (left) and its transferred result (right)

4 Conclusions

Methods were proposed to produce complex micro-structures by combining mask-less self-assembly and imprint process. The results are summarized as follows:

(1) Self-assembled particles can be transferred to another substrate or its profile can be replicated by choosing affinity of the resin for the particle material.

(2) In the case of transfer, the top height of the structure was kept at same level independent of the number of assembly layers.

The authors express acknowledgement for the financial support of JSPS Grant-in-Aid for Scientific Research (B) 21360065.

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