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Fabrication and characterization of moth-eye mimicking nanostructured convex lens

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ABSTRACT

In this work, we demonstrate a simple fabrication method for the periodic nanopillar structures on both sides of convex lens and evaluation of their optical characteristics. The periodic nanopillar structures on convex lens are inspired from the moth-eye which can provide antireflective property. The fabrication is composed with the coating of colloidal nanoparticles on a convex lens and the plasma etching of it. Because the optical behavior depends on the surface morphology, the structural dimensions of nanopillars should be modulated by the various experimental conditions such as the processing times of two steps, which reduce the size of self-assembled particles and perform the pattern transfer into the lens material. Nanopillar structured convex lens exhibits the antireflective effect showing the increase in transmittance and the decrease in reflectance without any deformation of lens property such as chromatic and spherical aberration. Furthermore, the antireflective property of nanostructured convex lens can make the photography high quality without flare and ghost phenomena, even though the pictures are taken under the strong external light environment such as sunshine, sunset, and concentrated external light. The wettability of convex lens surface is also controlled to express the self-cleaning effect which is inspired from a lotus leaf by the low surface tension chemical coating on a nanostructured surface. This moth-eye mimicking nanostructured convex lens will be easily applicable to optical industry with easy and cost-effective fabrication for the advanced optical and wetting property.

1. Introduction

The bioinspired functional surface can be applied as a key component for the advanced functional devices or advanced materials due to the unique functionality such as self-cleaning of lotus leaf, structural color in morpho-butterfly, low friction surface from the snake skin, adhesive surface of gecko foot, and water harvesting from Namib beetle back [1–4]. Especially, the optically advanced functional structure exhibits the amazing properties based on their adaptive hierarchical structures from macrosize to nanosize. The hierarchical structures in nature can provide the various unique optical properties such as structural color, multi-view phenomenon, and antireflection in broadband based on the periodic nanostructures on surface [1,5–8]. Because these properties are based on the interaction between the incident light and the periodic structures in nanoscale, one of the central issues in such new area concerns how to construct uniform surface nanostructure with specific structural morphology such as height, size, shape, and periodicity for practical applications.

The tailored hierarchical structures have been made by taking either top-down methods such as a photolithography and e-beam lithography or bottom-up methods which include a soft lithography and self-assembly [9–12]. Among them, self-assembly method is promising due to the merits of an easy large area processing, low cost, high throughput, and high resolution [13]. For the construction of periodic nanostructures on surfaces using the self-assembled colloidal particles, there are several methods to make monolayered particles such as the convective method, floating method, template assisted method, and spin coating method [14–17]. Particularly, among them, the floating method has a great potential in generating self-assembled monolayer of particles on the flat surface as well as the curved surface owing to the flexibility in process. Generally, it is not easy to make nanostructures on curved surface because the non-flat shape hinders the formation of nanostructures on substrate uniformly. However, the curved surface with nanostructures is the critical component for the practical applications in advanced optical devices with the controllability of the light pathway such as focusing or defocusing the light [18,19]. The transparent curved substrate

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with nanostructures on the surface can provide not only the conventional lens effect but also the antireflective property which is inspired from moth-eye. These combinations of lens with nanostructures can help photo images to be clear by removing the ghost and flare phenomena which are caused by the internal reflection of incident light in lens [20]. Therefore, the construction of nanostructures on curved surface with a controlled height, size, shape, and periodicity is the essential and important issue for practical applications.

Here, we demonstrate the simple and promising method for constructing periodic nanopillar structures on both sides of convex lens. Self-assembled colloidal particles on convex lens which act as the mask layer are made by the floating method and then those convex lenses are etched to form the nanopatterns via the following plasma etching process. The fabrication conditions such as the size reduction of colloidal particles and etching process of lens are modulated for the constructing nanopillar structures that can induce the antireflective property. The nanostructured convex lens with low reflectance is applied to the optical camera lens that can remove the ghost and flare phenomena. The surface modification is also performed to get the superhydrophobicity on nanostructured lens surface.

2. Experiment

2.1. Fabrication process

Fig. 1 shows the fabrication process of nanopillar structures on convex lens. We used a solution of commercial polystyrene colloidal nanoparticles (NPs, Polyscience Inc.) to prepare the monolayer of hexagonally packed NPs as the mask layer for etching process. The size of NPs determines the periodicity of nanopillars on surface. The average size of used NPs is about 200 nm in diameter and the size distribution is ± 10 nm. First, the hexagonally packed NPs monolayer on water surface was formed using the self-assembly property of colloidal particles, as shown in Fig. 1(a) and (b). After the assembling of NPs on water surface, some area of the well packed NPs assembly on water was lifted up with convex lens (PCX 25 mm Dia, Edmund optics), which was already treated with UV-Ozone for 15 min, by the simple floating method, as shown in Fig. 1(c). The drying of residual water between the NPs was followed in air at room temperature and the convex lens was etched with NPs as a mask. The plasma etching process has two steps: size reduction process of the NPs with O_2 plasma treatment; and etching process with CF_4 and H_2 plasma treatment for the regulating of shape and height of nanopillar, as shown in Fig. 1(d)–(f). The size

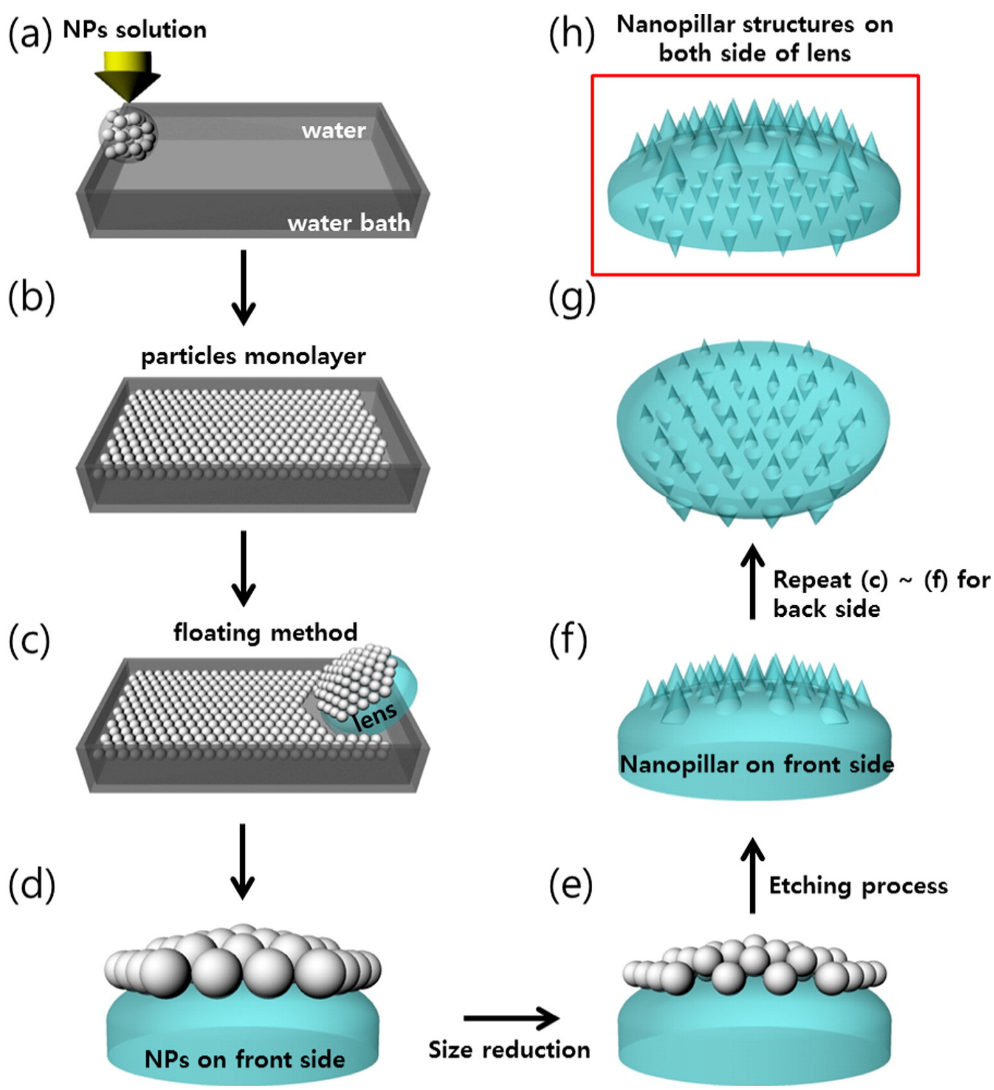

Fig. 1. Schematic diagram of the fabricating process for the nanopillar structure on convex lens; (a) filling the water in water bath and dropping the NPs solution on air–water interface, (b) self-assembling the NPs on water surface spontaneously, (c) lifting up the convex lens with self-assembled NPs layer, (d) monolayer of NPs on convex lens, (e) size reduced NPs on convex lens after size reduction process, (f) nanopillar structures on convex lens after etching process, (g) both sides nanostructured convex lens after repeating the same process, and (h) nanopillar structured on both sides of convex lens after whole fabrication.