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Fabrication of antireflection nanostructures by hybrid nano-patterning lithography

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ABSTRACT

Antireflection (AR) nanostructures are fabricated on a glass substrate using hybrid nano-patterning lithography (H-NPL) consisting of nanosphere lithography (NSL) and UV-nanoimprint lithography (UV-NIL). The shape and diameter of the AR nanostructures were controlled by fabricating Si masters with different RIE conditions. The shapes of the AR nanostructures were a pillar-type and a corn-type. The diameters of the AR nanostructures were about 350 and 250 nm, respectively. AR nanostructures were successfully nanoimprinted on glass in accordance with Si master prepared by NSL. The pillar-type AR nanostructure with diameter of 350 nm exhibited the transmittance of over 98% in the wavelength range from 1100 to 2200 nm. From the results, the fabricated AR nanostructures demonstrate the possibility to improve the efficiency of optoelectronic devices such as a photo-detector and an IR-LED.

1. Introduction

A broadband antireflection (AR) property has been a primary interest for various applications to enhance the efficiency and sensitivity of optoelectronic devices such as photovoltaic cells, light emitting diodes and photo-detectors. Generally a thin film AR coating has been widely used to maximize the transmission of light through optical surface. Broadband AR multilayer coatings had been widely produced by several research groups [1]. Unfortunately, there exist some troubles in thin film AR coating techniques such as their production cost, duration, and reliability. Therefore, the AR nanostructures are recently studied as an alternative [2]. Especially, AR nanostructures are useful to improve the efficiency of the photo-detector and IR-LED in the near IR range. AR properties from nanostructures can be easily obtained using so-called "moth–eye structures". The basic idea is that the moth–eye nanostructures can reduce the reflection by gradually changing the effective refractive index between a dielectric medium and air. Therefore, the antireflection can be realized by making the nanostructures with the sub-wavelength pitch and protrusion height of the order of wavelength [3]. There are several techniques used for fabricating nanostructures such as photo-lithography [4], electron beam lithography [5], interference lithography [6], dip pen nanolithography [7] and micro contact printing [8]. However, these techniques are expensive and require sophisticated equipments. In order to avoid these problems, we tried hybrid nano-patterning lithography (H-NPL) consisting of nanosphere lithography (NSL) and UV-nanoimprint lithography (UV-NIL). NIL is one of the most potential nano-scale patterning techniques and has many advantages of rapidness, low-cost, and large-area production [9]. The NSL is now recognized as a powerful fabrication technique to inexpensively produce nano-patterned arrays with controlled shape, size and inter-pattern spacing [10]. In this study, we have fabricated a Si master with AR nanostructures by NSL using self-assembled nanospheres as an etching mask. The AR nanostructures are nanoimprinted on a glass substrate using the PDMS mold replicated from the Si master and the properties of AR nanostructures are analyzed.

2. Experimental

2.1. Fabrication of the nanostructures

The polystyrene (PS) nanosphere (Duke Scientific Co.) was prepared as 10 wt% in solution and diluted by mixing with an equal amount of ethanol. The mean size of PS nanospheres was about 500 nm. Prior to dispersing the nanospheres, the Si wafer (n-type ⟨1 0 0⟩) was cleaned with the standard RCA process, which was a treatment with 1:2:6 solutions of 25% NH_4OH, 30% H_2O_2, water at 80 °C for 15 min, and 10% dodecylsodiumsulfate solution for 24 h. This process was necessary to carry out surface treatments to make the surface hydrophilic. The solution containing PS nanospheres was dropped onto the surface of water in glass vessel. The PS nanospheres then formed an ordered monolayer on the water

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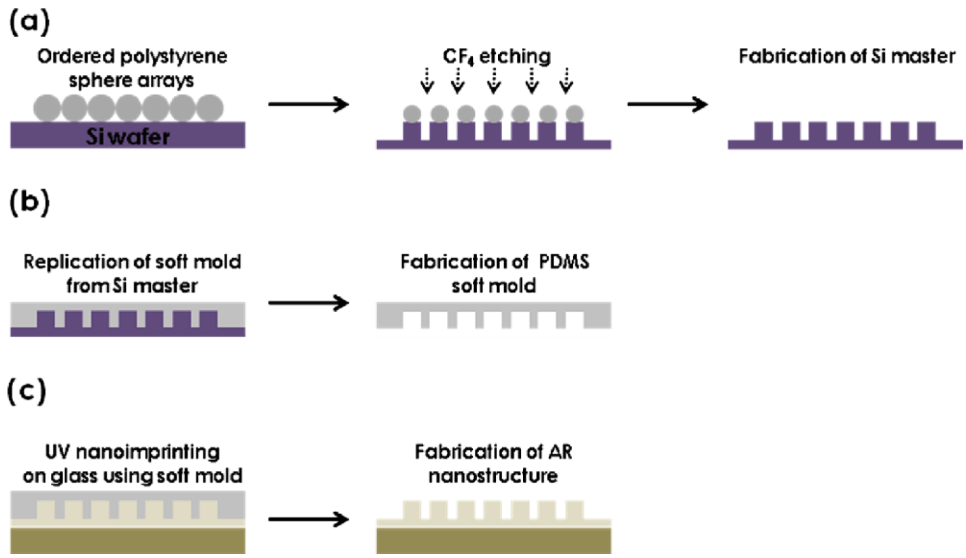

Fig. 1. Schematic illustration of (a) fabrication of Si master by nanosphere lithography, (b) replication of PDMS soft mold, and (c) fabrication of AR nanostructures on glass by UV-nanoimprint lithography.

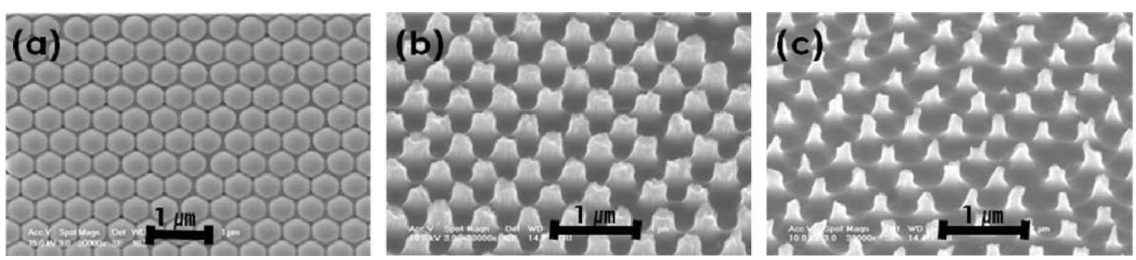

Fig. 2. SEM images of the fabricated Si masters; (a) close-packed single layer of 500 nm diameter polystyrene nanospheres coated on the Si substrate, (b and c) 45° tilted view images of the fabricated Si masters with different RIE time.

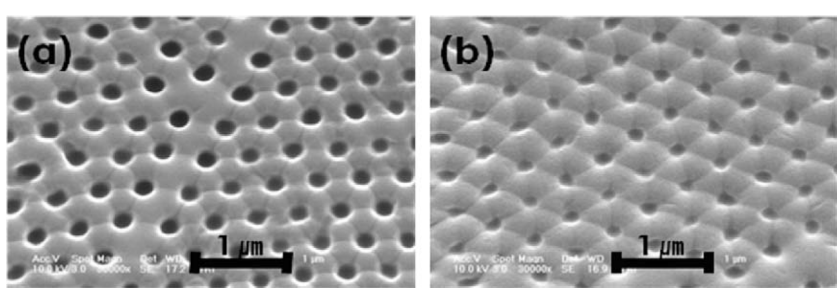

Fig. 3. SEM images of the PDMS soft molds replicated from the (a) pillar-type and (b) cone-type Si masters.

surface slowly. Such monolayer was then slowly lifted off from the water surface using the Si wafer. The Si masters were then obtained by this simple etching process. The prepared Si wafer was etched by reactive ion etching (RIE) process with PS nanospheres as an etching mask. The RIE process was performed with CF_4 of 20 sccm and Ar of 5 sccm under RF power of 10 W for 40 and 50 min, respectively. The size of the prepared Si pillars was diameter of around 350–250 nm and height of 350 nm. The yield size of the Si masters is 2 × 2 cm.

2.2. Replication of the nanostructures

The PDMS molds were fabricated by cast molding from the prepared Si masters. The PDMS mold was prepared from 'Sylgard 184' (Dow Corning) by mixing with a ratio of ten parts of the 'base' and one part of the 'curing agent'. After removing bubbles using a vacuum desiccator for 30 min, it was poured into a Si wafer with nanostructures. Then, it was baked on the oven at 60 °C for 12 h.

2.3. Nanopatterning on the glass

The UV-NIL process was performed on a glass using the PDMS soft mold replicated from the Si maters. Before the UV-NIL process, the adhesion promoter (AZ5124) was spin-coated on the glass with 3000 rpm for 30 s and the glass was baked at 120 °C for 90 s. UV curable acrylate-based resin (home-made) was then spin-coated with 3000 rpm for 30 s. Its refractive index is 1.535 and the viscosity is 400 cps. UV-NIL was executed on the glass with Nano-Imprinter (Obducat) using the PDMS mold under the pressure of 1 bar and for 10 min. Surface morphologies of the Si masters and