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Fabrication of PECVD-grown fluorinated hydrocarbon nanoparticles and circular nanoring arrays using nanosphere lithography

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Abstract

Nanosphere lithography (NSL) masks were created by spin-coating of polystyrene particles onto silicon surfaces. Fluorinated hydrocarbon films were coated on the nanosphere lithography masks using plasma-enhanced chemical vapor deposition (PECVD) to obtain ordered arrays of fluorinated hydrocarbon. Atomic force microscope images show hexagonally ordered nanodots of dimension 225 ± 11 nm with a height of 23 ± 4 nm. Every hexagon encloses a circular ring of diameter 540 ± 24 nm having a height and width of 13.5 ± 0.6 nm and 203 ± 16 nm, respectively. FTIR analysis shows two distinct zones of atomic bonding of CH_x and CF_x in the plasma coated ordered fluorinated hydrocarbon films.

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Keywords: Nanosphere lithography; Plasma-enhanced chemical vapor deposition; Nanodots; Nanorings

1. Introduction

Nanometer size dielectric, semiconductor, and metallic structures have received a great deal of attention lately due to their interesting physical properties and vast range of potential applications [1–5]. For example, nanometric coatings can be used as optical devices [1], electronic devices to create large flat screen display [2], the dielectric coatings can be used as gate oxide for CMOS devices [4] and metal nanoparticles incorporated dielectric films can be used in electrical switching devices [5]. Recently, Sarkar et al. have intensively investigated structural, chemical, optical, electrical as well as surface morphological properties of several nanostructured thin films [4–7].

Photolithography and electron beam lithography techniques are routinely used to prepare ordered micro/nanostructures [8]. The alternative to these techniques are the relatively inexpensive nanoimprint [9] and nanosphere lithography (NSL) [10–12]. Nanosphere lithography has been used recently for its simplicity in creating well-ordered metallic nanodots by electron beam evaporation [10], ordered semiconductor patterns by reactive ion etching [11], and ordered metal oxides by drop coating process [12]. Nevertheless, the plasma-enhanced chemical vapor deposition (PECVD) technique has not been used yet to prepare ordered nanopatterns utilizing the NSL mask, having the potential to be used in different technological applications [13–15].

In this paper, we report the design of fluorinated hydrocarbon, as a representative of plasma coating, nanoparticle arrays using nanosphere lithography. The masks of nanosphere lithography patterns were created by spin-coating 1-μm polystyrene spheres followed by fluorinated hydrocarbon coating using PECVD and by the removal of polystyrene microspheres. The creation of hexagonally-ordered nanodots of size 225 ± 11 nm with a height of 23 ± 4 nm and circular ring of diameter 540 ± 24 nm has been achieved in this work.

2. Experimental

The subsequent steps involved in creating nanopatterned fluorinated hydrocarbon were (i) spin-coating of micrometer-

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sized spherical polystyrene particles, (ii) PECVD coating of fluorinated hydrocarbon, and (iii) chemical etching of polystyrene microspheres. Silicon surfaces were spin coated (spin coater, Laurell Technologies corporation) using a polystyrene bead solution prepared by mixing 350 μl of polystyrene microsphere beads of diameter 1 μm (Cat#07310-15, Polysciences Inc.) in 50 μl of Triton X-100 (Sigma–Aldrich) diluted with methanol by 1:400 in volume ratio [11]. The spin-coating process of the polystyrene bead solution consists of three consequent steps: (i) 400 rpm for 10 s to spread the bead solution evenly; (ii) 800 rpm for 2 min to spin away the excess bead solution; (iii) 1400 rpm for 10 s to spin off the excess materials from the edges. Fluorinated hydrocarbon coatings were carried out using inductively coupled PECVD by applying a power of 100 W in the RF-source in presence of three gases (Ar, CH_4, C_2F_6) with a flow ratio of 40:14:7 (in sccm) maintaining a total pressure of 20 mTorr in a high-vacuum chamber (base pressure $\sim 2 \times 10^{-6}$ Torr). A bias voltage of −50 V was applied to the substrate holder while coating. The fluorinated hydrocarbon-coated nanosphere lithography mask was immersed in cyclohexane and placed in an ultrasound bath for 20 min to remove polystyrene microparticles. The microstructure of these films was investigated using field emission scanning electron microscopy (FESEM, LEO 1525) and an atomic force microscope (AFM) (Digital Nanoscope IIIa by Digital Instruments). Atomic bonding of the fluorinated hydrocarbon was characterized using Fourier transform infrared spectroscopy (FTIR) (Perkin-Elmer Spectrum One).

3. Results and discussions

Fig. 1(a) and (b) shows AFM and SEM images, respectively, of the nanosphere lithography mask of polystyrene microsphere on silicon surfaces. These images show that the polystyrene microspheres are hexagonally packed in two dimensions producing a nearly triangular aperture formation between any three spheres. The area of this triangular aperture is related to the radius of the sphere by the following equation:

$$A_\Delta = \left(\sqrt{3} - \frac{\pi}{2}\right) R^2 \quad (1)$$

where A_Δ is the area of the triangular aperture and R is the radius of the sphere. If an equilateral triangle would be formed using this area given by Eq. (1), the side of the triangle would be found by the following equation:

$$a_\Delta = \left(4 - \frac{2}{\sqrt{3}}\pi\right)^{1/2} R = 0.61R \quad (2)$$

where a_Δ is the side of the triangle.

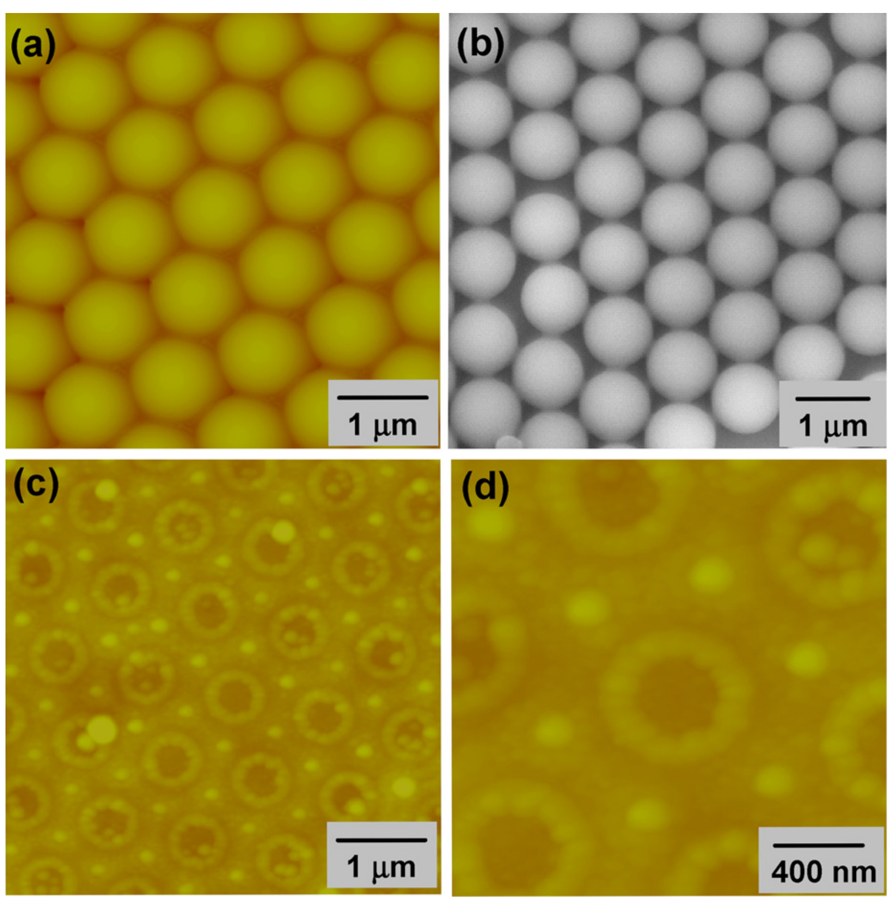

Fig. 1. (a) AFM image of nanosphere lithography (SPL) mask, (b) SEM image of nanosphere lithography (NPL) mask, (c) AFM image of hexagonally pattern nanodots and microrings of fluorinated hydrocarbon, (d) zoomed view of (c).