Facile Fabrication of Concentric Gradient Nanostructures Using Interference Lithography and UV-cured Stamp Transfer

Siyi Min[1,2], Shijie Li[1], Zhouyang Zhu[1], Chuwei Liang[1], Xing Cheng[2], Wen-Di Li[1],
[1]*Department of Mechanical Engineering, Univ. of Hong Kong, Hong Kong*
[2]*Department of Materials Science and Engineering, Southern Univ. of Science and Technology*
liwd@hku.hk

Gradient structures have attracted increasing interests in recent years. Different from uniform nanostructures, gradient structures have spatially varying physical and chemical properties [1] such as gradient surface energy, gradient resonance wavelength, etc. However, deterministic fabrication of gradient nanostructures over large area is a challenging problem. In this work, we use interference lithography to fabricate concentric gradient nanostructures and then adopt nanoimprint lithography (NIL) to replicate the structures for device applications. We also developed a facile fabrication of the NIL template by directly transferring the photoresist pattern into UV-cured high-strength replication molding material, eliminating costly physical vapor deposition and reactive ion etching processing in common NIL template fabrication. Some replication materials now are commercially available, such as Ormostamp which is a UV curable organic hybrid material [2]. The NIL template fabricated by Ormostamp is rigid and transparent, so it is suitable for both thermal NIL and UV-NIL. By using the gradient interference lithography, NIL, and facile template replication, our process exhibits desirable advantages of high throughput, high resolution and low cost [3].

In this work, the concentric gradient structure is formed on photoresist and is gradually changing from pillars to holes from center to edge due to the Gaussian distribution light intensity of laser source (Figure 1g) in interference lithography process. After development of photoresist, Ormostamp molding material was applied and replicated the photoresist structure by UV-NIL to form a NIL template, as shown in Figure 1a-d. Finally, we use thermal NIL to transfer the concentric gradient structures from the Ormostamp template to cyclic olefin copolymer (COC) film (Figure 1e, f). To investigate the structural fidelity in the whole transfer process, the morphology and height of photoresist-patterned silicon wafer and replicated COC film were analyzed in corresponding area by scanning electron microscope (SEM) and atomic force microscope (AFM). The diameters of photoresist pattern, Ormostamp pattern, and COC pattern are also measured.

Some initial results are shown in Figure 2 and Figure 3. The Figure 2 exhibits concentric gradient structures in photoresist on silicon and on COC film imprinted by Ormostamp template. From these SEM images, the COC copy carries almost the same morphology as the original resist. Figure 3 shows quantitative measurement of the feature sizes of photoresist nanostructures, Ormostamp template, and imprinted COC film in different corresponding positions. Consistency in the structural dimensions on the original photoresist pattern, Ormostamp template, and final COC structures at different positions along the radial direction of the gradient structures can be confirmed. The differences of feature sizes at different stage of replication is about 10-20nm. Further device applications based on the gradient structurues can be developed in the future..

1. Dorri N, Shahbazi P, Kiani A. Self-movement of water droplet at the gradient nanostructure of Cu fabricated using bipolar electrochemistry[J]. Langmuir, 2014, 30(5): 1376-1382.
2. Noma, Hayato, et al. "Fabrication of Second Generation Replica Mold by Hybrid Polymer Material Ormostamp TM." Journal of Photopolymer Science and Technology 27.1 (2014): 95-98.
3. Chou, Stephen Y., Peter R. Krauss, and Preston J. Renstrom. "Imprint of sub-25 nm vias and trenches in polymers." Applied physics letters 67.21 (1995): 3114-3116.

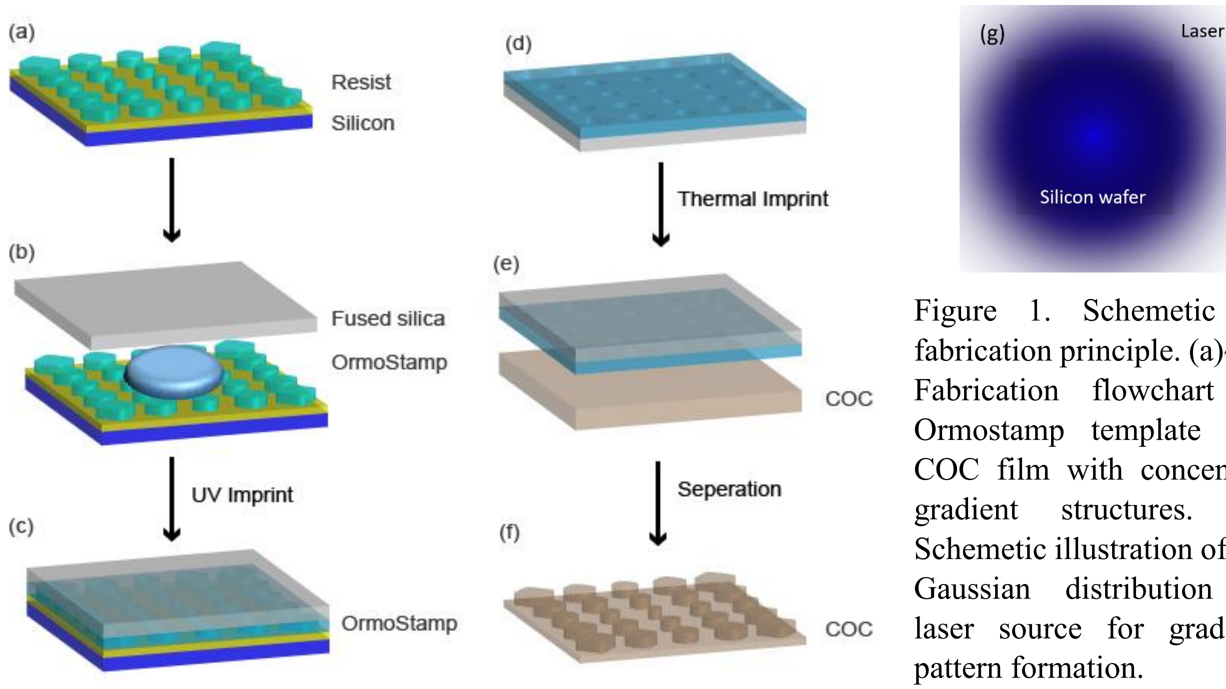

Figure 1. Schemetic of fabrication principle. (a)~(f) Fabrication flowchart of Ormostamp template and COC film with concentric gradient structures. (g) Schemetic illustration of the Gaussian distribution of laser source for gradient pattern formation.

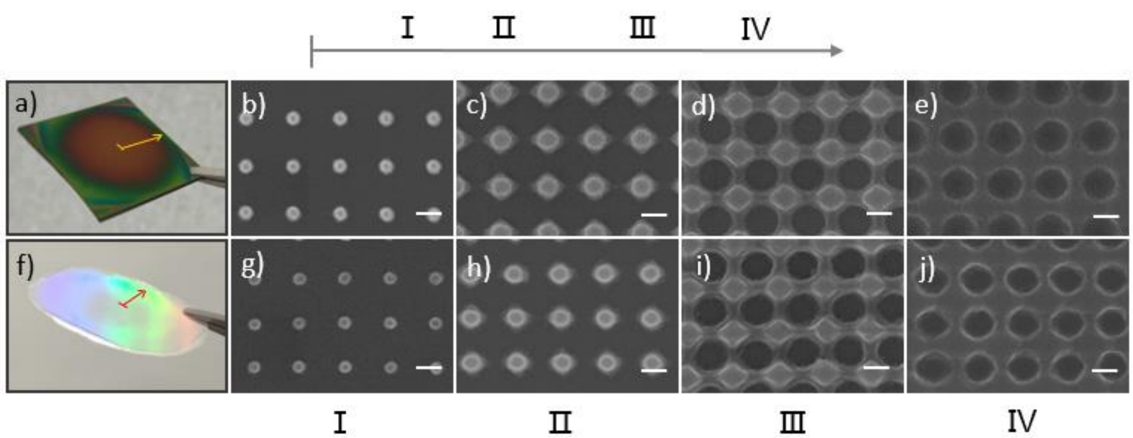

Figure 2. (a) Photoresist pattern with concentric gradient structure. (b)~(e) SEM images of (a) in different positions as shown in the arrow and position label. (f) COC film imprinted by Ormostamp template. (g)~(j) SEM images on (f), at positions corresponding to (b)~(e). The scale bar is 200nm.

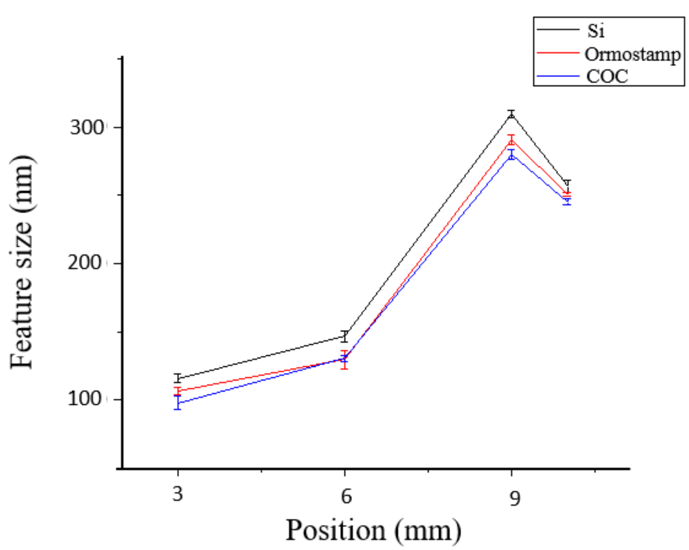

Figure 3. The feature sizes of patterned structures on photoresist, Ormostamp template, and imprinted COC film in different corresponding positions of samples.