Large Area Nano Pattern Fabrication Using Improved Step and Repeat UV Nanoimprint

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Continuous nano structures whose sizes 100 nm line and space were successfully fabricated using two step nanoimprint including oxygen (O\(_2\)) plasma irradiation on a silicon substrate in 8 × 56 mm\(^2\) area. Silicon substrate surface condition is important property because fine and continuous pattern forming depend on photo curable resin uniform coating. O\(_2\) plasma irradiation is realized to change into hydrophilic without damage for silicon substrate. The water contact angle was decreased to smaller than 40° after O\(_2\) plasma irradiation. Therefore O\(_2\) plasma irradiation has an advantage of treatment process for continuous nanostructure forming. Our activities on UV nanoimprint lithography are expected to be progress for large area continuous nano structures fabrication.

\textbf{Keyword:} UV Nanoimprint Lithography (UV-NIL), large area, nano pattern stitching, O\(_2\) plasma irradiation

1. Introduction

Large size nano structures has been widely required in many field, including in nano structures for next generation Light Emitting Diode [1-2], Anti-Reflection Structures (ARS) for high functional solar cell [3], Wire Grid Polarizes (WGP) for Flat Panel Display [4], sub-32 nm nano structures for next generation semiconductor fabrication [5], and so on. Therefore nanoimprint lithography (NIL) is one of the promising technologies for nano devices production method [6]. High resolution and low cost mass productive nano structure replication can be realized by nanoimprint lithography without expensive fabrication tool such as an Electron Beam lithography system or an optical lithography system with extreme short wavelength.

However, nanoimprint lithography has several technical issues, for example large size devices fabrication requests expensive large scale molds [7].

Step and repeat nanoimprint is typical method to fabricate large size nano structures. In our previous work [8], we found a difficulty in fabricating continuous nano structures using only step and repeat nanoimprint, because ridge shape residual structures were formed around the mold shown in Figure 1 (a). Therefore, uniform nano structures were not formed due to this non-uniform structure, as shown in Figure 1 (b).

As a solution of this problem, we developed “Double UV nanoimprint lithography”, and successfully fabricated
continuous nano structures on a quartz substrate [9]. However, this process could not be applied for nano patterning on the silicon substrate.

In this paper, we described improved step and repeat UV nanoimprint including O₂ plasma surface treatment. This process enables large area nano patterning on the silicon substrate.

![Image](image_url)

Figure 1. Ridge shape residual structure, (a) Cross sectional SEM image, (b) Schematic ridge shape residual structure problem

**2. Experimental**

Figure 2 shows schematic of step and repeat nanoimprinting test structure.

![Image](image_url)

Figure 2. Schematic of step and repeat nanoimprinting test structure

Continuous nano structures were fabricated by two step nanoimprint in 8×56 mm² area. At first, 3 dies were fabricated on silicon substrate by first nanoimprint lithography (red). Next, 4 dies were fabricated on silicon substrate by second nanoimprint lithography (blue).

Figure 3 shows a proposed two step nanoimprint. The details are described below.

**First step nanoimprint**

![Image](image_url)

**Second step nanoimprint**

![Image](image_url)

Figure 3 (a)-(e) shows first step nanoimprint.

At first, a photo curable resin (Toyo Gosei Co., Ltd, PAK-01) of 120 nm thickness was spun on a silicon substrate. Next, nano structures whose sizes 100 nm line and space with 100 nm in depth were replicated on the photo curable resin layer by the UV nanoimprint system (Toshiba-machine Co., Ltd, ST05-PS) using quartz mold. The conditions of the nanoimprint were as follows: pressure of 5 MPa, UV irradiation...
energy of 500 mJ/cm². Ridge shape residual structure was formed at the area around nanoimprinting in this process. Then, photo curable resin was cured in all area by UV irradiation system (JV-C1500, JATEC Co., Ltd.). Then, nanostructures were transferred to the silicon substrate by the Deep Reactive-Ion Etching system (MUC-21, Sumitomo precision products Co., Ltd.). The conditions of the etching were as follows: process gasses of C₄F₈ and SF₆, RF power of 500 W, and process time of 96 s. After that photo curable resin layer which include ridge shape residual structure was removed by SPM cleaning.

Figure 3 (f) shows surface treatment process. The silicon substrate was treated by oxygen (O₂) plasma irradiation for improvement of wettability.

Figure 3 (g)-(k) shows second step nanoimprint. A photo curable resin of 150 nm thickness was spun on a silicon substrate having nanostructures of first step nanoimprint. The nanostructures were replicated at appropriate areas by nanoimprint again. Then, nanostructures were transferred to the silicon substrate by Deep Reactive-Ion Etching. The condition of the etching was process time of 156 s. At last, two steps Nanoimprint lithography was finished after removal resin by SPM cleaning.

3. Results and Discussion

Two steps nanoimprint lithography without surface treatment was demonstrated. Figure 4 shows SEM image of nanostructure at the overlap area.

![Figure 4: SEM image of nanostructure at the overlap area by two step nanoimprint without treatment](image)

Fine and continuous pattern was not formed. As a solution of this problem, we focused on substrate surface condition before photo curable resin coating.

Figure 5 (a) shows water contact angle droplet in the case of condition without surface treatment. Water contact angle was over 80°. In this case, the surface is hydrophobic. Photo curable resin was not uniformly coated in second step nanoimprint.

Water contact angle was decreased by O₂ plasma irradiation. Figure 5 (b) shows water contact angle droplet in the case of condition with surface treatment by O₂ plasma irradiation system (PR500, YAMATO Scientific Co., Ltd.). The condition of the O₂ plasma irradiation was pressure of 20 Pa, gas flow rate of 50 ml/min, RF power of 300 W, process times of 30 min. Water contact angle decreased to smaller than 40° after O₂ plasma irradiation.

![Figure 5: Water contact angle droplet, (a) without surface treatment, (b) with surface treatment](image)

Figure 6 shows surface roughness in the case of condition with O₂ plasma irradiated. The average of surface roughness (Ra) was 0.16 nm.

![Figure 6: Surface roughness after O₂ plasma irradiation](image)

As a result of Figure 5 and Figure 6, O₂ plasma irradiation was advantage process for two step nanoimprint because silicon substrate surface condition was changed into hydrophilic without damage.
structure were still remained at overlap area. We are going to solve this problem by optimizing the process conditions.

4. Conclusion
Continuous nano structures were formed on a silicon substrate by improved step and repeat nanoimprint including O_2 plasma irradiation in comparison with that shown in Figure 4. This result indicates that two step nanoimprint can be realized large size nano devices even on the silicon substrate.

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References

Figure 7. Result of two step nanoimprint including O_2 plasma irradiation, (a) All area, (b) SEM image of first step nanoimprint area, (c) SEM image of second step nanoimprint area, (d) Overlay area

Figure 7 shows result of two step nanoimprint with proposed surface treatment. Continuous nano structure was successfully fabricated, while unexpected residual