Four-inch photo-curable nanoimprint lithography using NX-2000 nanoimprintor

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ABSTRACT

Photo-curable nanoimprint lithography (P-NIL), a low pressure and room temperature process, is developed on Nanonex NX-2000 nanoimprintor. The process is capable of achieving uniform imprinting over large area in less than 60 seconds, which is mainly attributed to the Nanonex patented air cushion press (ACP) technology. Nanostructures such as 200nm pitch grating have been successfully demonstrated on 4-inch wafer level using P-NIL on NX-2000 nanoimprintor.

Keywords: photo-curable nanoimprint lithography, P-NIL, nanoimprintor, Nanonex, air cushion press, ACP

1. INTRODUCTION

Nanoimprint lithography (NIL)[1] is a low-cost, high-throughput and sub-10nm patterning technology. It is considered as one potential solution to future nanomanufacturing. Nanoimprint solutions, offered by Nanonex, have two alternatives, i.e., thermal nanoimprint lithography (T-NIL) and photo-curable nanoimprint lithography (P-NIL).

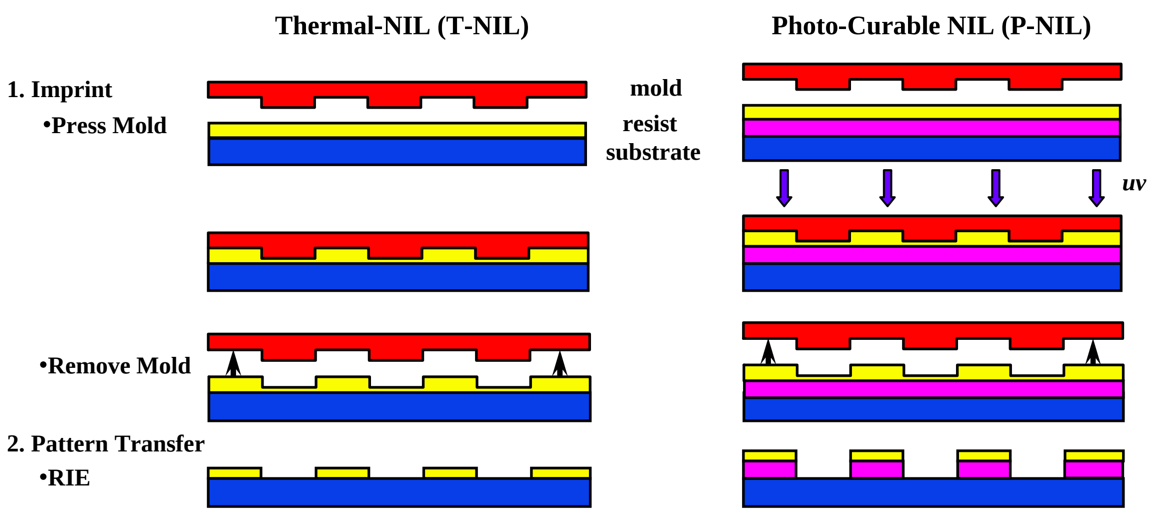

Figure 1. Nanoimprint lithography (NIL) has two alternatives, thermal NIL (T-NIL) and photo-curable NIL (P-NIL).

As shown schematically in figure 1, T-NIL is typically a single-layer resist process, in which temperature is elevated above the glass transition temperature (T_g) of the resist, and pressure is applied to deform the highly viscous resist film. Patterns on the mold surface are transferred to the resist after temperature goes down below T_g and pressure is released. A single step oxygen reactive ion etching (RIE) is needed to remove residual resist at trench bottom. P-NIL is typically a bi-layer resist process performed at room temperature, in which lower pressure is applied to deform top liquid resist layer (resist monomers) and ultra violet light is used to crosslink the monomers. Patterns on the mold surface are left in the top photo-curable resist layer after pressure is removed. A two-step RIE (fluorine-based RIE followed by oxygen RIE) is used to remove residual photo-curable resist and transfer patterns further to underlayer resist. The resist template created by either T-NIL or P-NIL can be used for the following additive/subtractive process.

2. PROCESS DETAILS IN PHOTO-CURABLE NIL

2.1 Glass Mold

The mold substrate, 0.5mm thick, 4-inch glass wafers (Pyrex 7740), has 100nm thick oxide deposited by plasma enhanced chemical vapor deposition (PECVD). The pattern on the mold surface is defined by high resolution lithography (such as electron beam lithography, nanoimprint lithography, interference lithography, etc.), and transferred to PECVD oxide by lift-off and fluorine-based RIE. The mold surface is passivated with one monolayer of perfluoroalkylchlorosilane as mold release agent. The protrusion height on the mold is about 60nm.

2.2 Imprint Substrate

The imprint substrate is 500µm thick, 4-inch silicon wafers. The substrate is first soaked in $NH_4OH:H_2O_2:H_2O$ (1:1:5) at 75^{o}C for 15 minutes and then rinsed by deionized water for 5 minutes. After blown to dry using filtered nitrogen, the substrate surface, heated to 200^{o}C, is cleaned by high pressure CO_2 jet using a snow gun.

2.3 Advantages of Using Spin-On Resist Coating

Both underlayer and photo-curable resist are applied to imprint substrates using standard spin-on coating method. Spin-on coating offers excellent uniformity in resist film thickness (better than 5% across a 4-inch wafer) and short process cycle time (high throughput).

The underlayer resist, Nanonex brand NXR-3010 resist, is first spin-coated onto a silicon wafer. After being baked at 90^{o}C for 25 minutes, the resist film is about 200nm thick. The photo-curable resist, Nanonex brand NXR-2010 resist, is then spin-coated onto the underlayer resist film. The photo-curable resist layer is about 70nm thick and stays at liquid state until crosslink occurs.

2.4 Imprint

The glass mold is pressed against the bi-layer resist film on the imprint substrate. The pressure applied over 4-inch substrates is typically 15-50psi. The NXR-3010 resist is crosslinked by ultraviolet light illuminated through the mold. The threshold for NXR-3010 resist to crosslink is 40mJ/cm^2, and the curing time on NX-2000 nanoimprintor is around 5 seconds. With removal of the mold, patterns on the mold surface are duplicated in the photo-curable resist.

2.5 RIE Process

A two-step RIE process is needed to finish transferring patterns through the resists. Fluorine-based RIE is first used to remove residual NXR-3010 resist at trench bottom. Oxygen RIE is then used to transfer patterns to NXR-2010 resist, using NXR-3010 resist as an etch mask. Due to the silicon content in NXR-2010 resist, a selectivity of 11 to NXR-3010 resist is achieved in oxygen RIE.

3. AIR CUSHION PRESS TECHNOLOGY AND NX-2000 NANOIMPRINTOR

3.1 Air Cushion Press (ACP) Technology

Air cushion press (ACP) technology, developed and patented by Nanonex, has been used in Nanonex brand nanoimprintors. ACP technology applies isotropic pressure to perform imprinting, thus resolving problems encountered by conventional parallel plate press (such as relative shift between mold and substrate, nonuniform pressure distribution across mold/substrate, etc.), extending the patterning capability of parallel plate press (such as imprinting on curved surface, imprinting fragile compound semiconductor substrates), and increasing mold lifetime. Contrary to low pressure parallel plate press, ACP technology does not require super-flat substrates, since ACP enables conformal contact between mold/imprint substrates.

3.2 NX-2000 Nanoimprintor

NX-2000 nanoimprintor, developed and manufactured by Nanonex, is a versatile imprinting tool for thermal NIL, photo-curable NIL and hot embossing. It offers sub-10nm patterning capability and can handle up to 8-inch wafers, with 4-inch as standard. The imprinting cycle time on the machine is less than 60 seconds.

4. DEMONSTRATION OF P-NIL USING NX-2000 NANIMPRINTOR

As shown in figure 2, 100nm pitch, 20nm holes are imprinted in NXR-2010 resist. The pattern on the 4-inch mold is generated by electron beam lithography, and the pattern area is limited by the size of the writing field on our e-beam writer. The feature size demonstrated here is limited by the availability of the imprint mold.

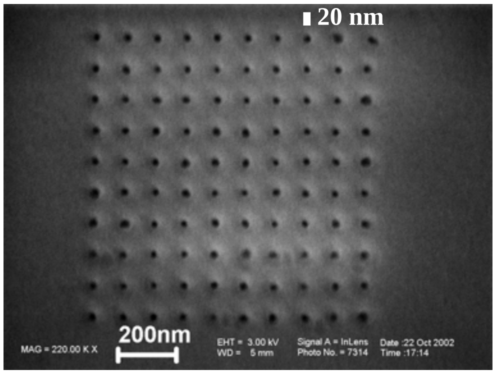

Figure 2. 100nm pitch, 20nm holes imprinted in NXR-3010 resist using P-NIL on NX-2000 nanoimprintor.

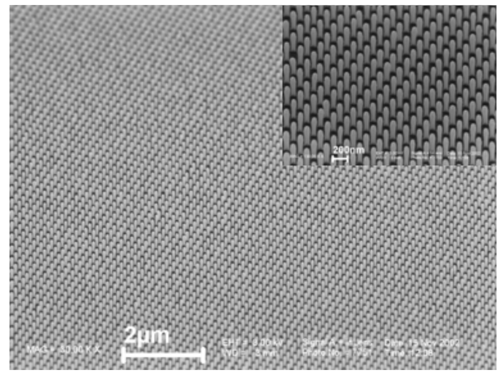

Figure 3. 200nm pitch, 65nm pillars imprinted in NXR-2010/NXR-3010 resist over 4-inch wafer using P-NIL on NX-2000 nanoimprintor.

Figure 3 shows 200nm pitch pillar array with 65nm pillar size imprinted in NXR-2010 resist and transferred to NXR-3010 resist. The aspect ratio of pillars is 6. Straight and smooth sidewalls are obtained in the P-NIL process.

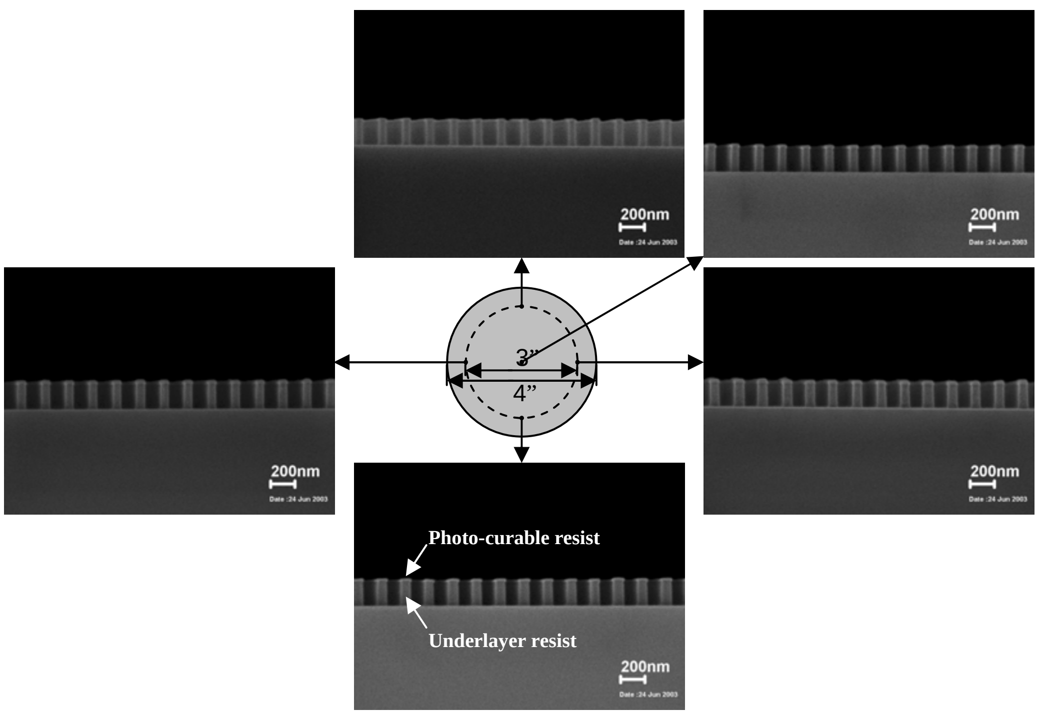

Figure 4. 200nm pitch grating imprinted in NXR-2010/NXR-3010 resist over 4-inch wafer using P-NIL on NX-2000 nanoimprintor.

Figure 4 shows 200nm pitch grating imprinted in NXR-2010 resist and transferred to NXR-3010 resist. Very smooth and straight sidewalls are obtained. The small variation of linewidth among different locations on the 4-inch wafer is attributed to light intensity nonuniformity in interference lithography used to generate the mold.

Besides imprinting grating patterns having uniform pattern density, we also imprinted the gate level of MESFET (metal-semiconductor field effect transistor) circuit. Figure 5 shows uniform imprinting is obtained across a 4-inch wafer, as qualitatively shown by the uniform color of resists. A detailed study on the distribution of residual layer thickness on 4-inch wafer level is underway.

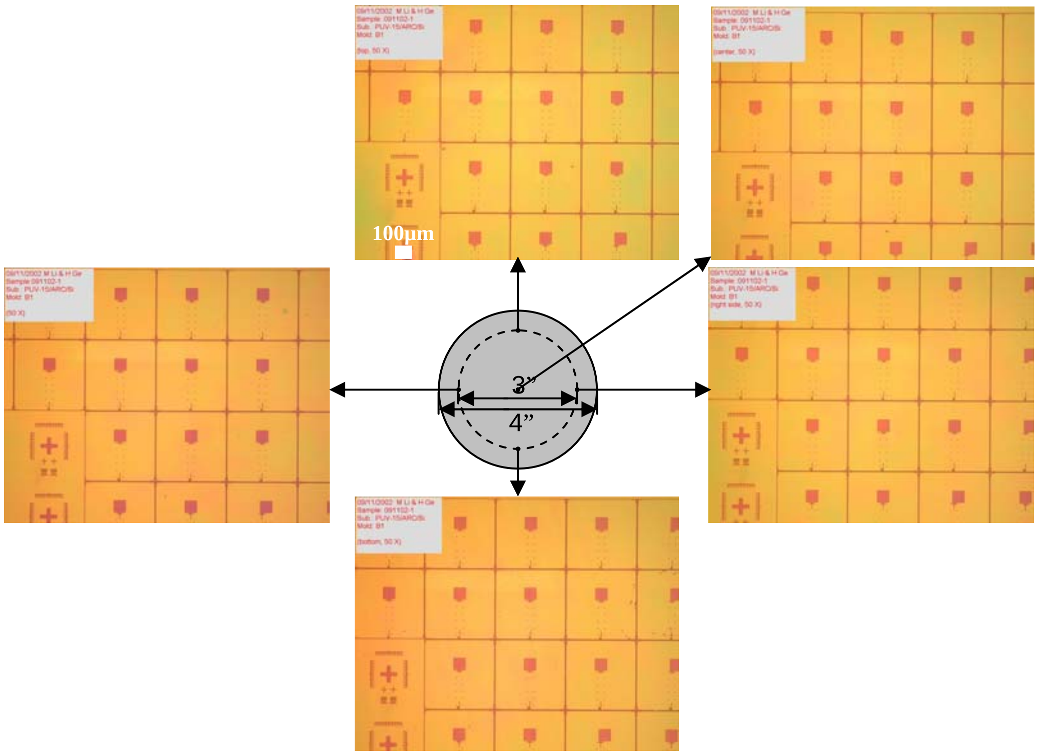

Figure 5. The gate level of MESFET circuit is imprinted in NXR-2010 over 4-inch wafer using P-NIL on NX-2000 nanoimprintor. The CD on the circuit is 1.5µm.

5. CONCLUSION

We have successfully demonstrated photo-curable nanoimprint lithography (P-NIL) on 4-inch wafer level using NX-2000 nanoimprintor, achieving excellent duplication over large area with feature size from nanometers to tens of microns. The P-NIL process utilizes Nanonex patented air cushion press (ACP) technology, providing uniform pressure distribution and conformal contact between mold and imprint substrate. NIL and NX-2000 nanoimprintor are expected to find great applications in data storage, optoelectronics, biotechnology, and so on.

6. ACKNOWLEDGEMENT

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7. REFERENCES

[1] S. Y. Chou, P. R. Krauss, and P. J. Renstrom, Appl. Phys. Lett., **67**, 3114, 1995; Science **272**, 85, 1996