Current Status of Nanonex Nanoimprint Solutions

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ABSTRACT

Nanoimprint lithography (NIL) has the advantage of high-throughput, sub-10 nm resolution and low cost [1]. It has been included into 2003 ITRS as the Next Generation Lithography (NGL) for 45 nm node [2]. This paper summarized current status of Nanonex imprint technologies. Nanonex imprint process includes thermal nanoimprint (T-NIL) and photo-curable nanoimprint (P-NIL). Both T-NIL and P-NIL utilized a proprietary air cushion press (ACP), which has the advantage of ultra-uniformity, low lateral stress, less damage to the mold and substrate, and higher alignment accuracy. Nanonex Corporation delivers user-friendly nanoimprint lithography tools and solutions for both experts and non-experts of micro and nanofabrication. Nanoimprint machines, resists, molds and processes have been developed and are available today.

Keywords: Lithography, NGL, NIL, T-NIL, P-NIL, air cushion press, Nanonex, nanofabrication

1. INTRODUCTION

Based on a new working principle, nanoimprint lithography has demonstrated high throughput, sub-10 nm resolution and low cost – a feat currently impossible for other existing lithography methods. During imprint, the pattern of the mask is duplicated into the resist, either thermally or by UV light. The resist pattern is then transferred to the substrate underneath. The imprint tools don't require expensive lens, or complex exposure sources, resulting in greatly reduced cost.

Nanonex imprint processes include both thermal nanoimprint (T-NIL) and photo-curable nanoimprint (P-NIL) (Fig 1). In a T-NIL process, the temperature of the resist is heated above its glass transition temperature T_g, the mold is pressed to deform the resist, and a replica of the mold is left in the resist. In a P-NIL process, the mold is pressed into the top layer UV resist under room temperature, UV light is then used to crosslink the resist, and the replica of mold left in the resist is transferred to the underlying resist and substrate. In both processes, the mold surface is coated with a passivation layer to prevent resists from sticking to the mold during separation.

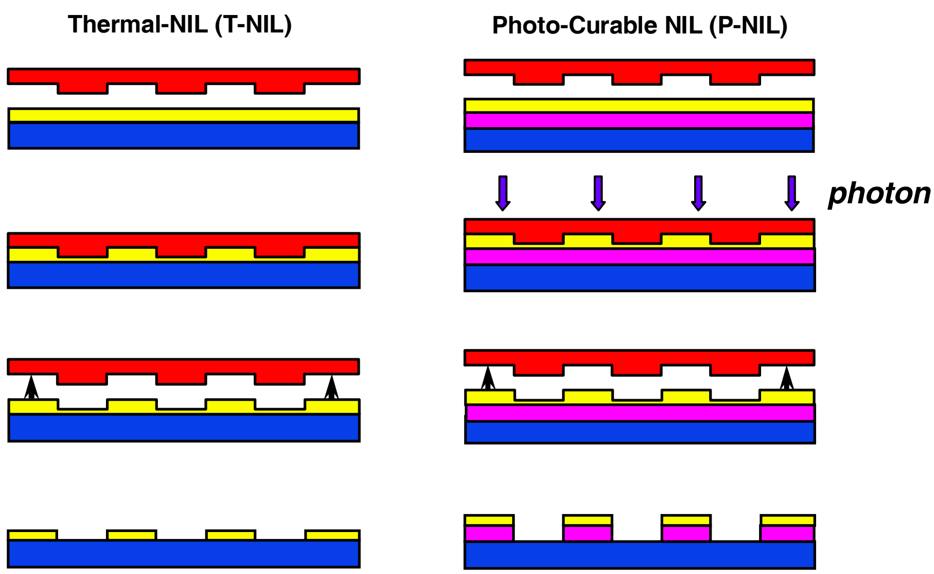


Figure 1. Nanonex thermal nanoimprint (T-NIL) and photo-curable nanoimprint (P-NIL)

Nanonex' technologies are built on over-seven years of multimillion dollar research by Professor Stephen Chou's pioneering nanostructure group at Princeton University. The technologies have been greatly enhanced by Nanonex's own development. Nanonex' technologies are "battlefield tested", since they have been used daily by research laboratories and a commercial manufacturer for the fabrication of nanodevices and nanomaterials.

2. NANONEX NANONIMPRINT SOLUTIONS

2.1 Imprint Tools

Different from traditional projection photolithography, nanoimprint involves mechanical contact of a mold to a substrate. The residual layer thickness after imprint should be uniform to achieve good CD control; the lateral stress during imprint should be reduced; the relative movement during mechanical contact has to be overcome to improve the overlay accuracy; to have high yield NIL for manufacturing, the damage to the masks, substrates and tools should be kept at a minimum; a conformal contact of the mold and substrate is also very important since they are not absolutely flat in reality. The pressure uniformity is the key to meet all these requirements. Solid parallel plate press used in traditional imprint tools has the inherent problem of relative shift between the mold and substrate and non uniform pressure distribution due to the surface roughness and parallelness of the plates (Fig 2). Nanonex developed a novel pressing method called Air Cushion Press (ACP), which applied air pressure for conformal contact and imprint, therefore achieved ultra-uniformity over the whole imprint field (Fig 3). Pressure indicating papers were used to compare the pressure uniformity during solid plate press and ACP. The result demonstrated that ACP can give ultra uniform imprint while the parallel plate press has a variation of 4 times in pressure magnitude over 4" wafer (Fig 4) [3].

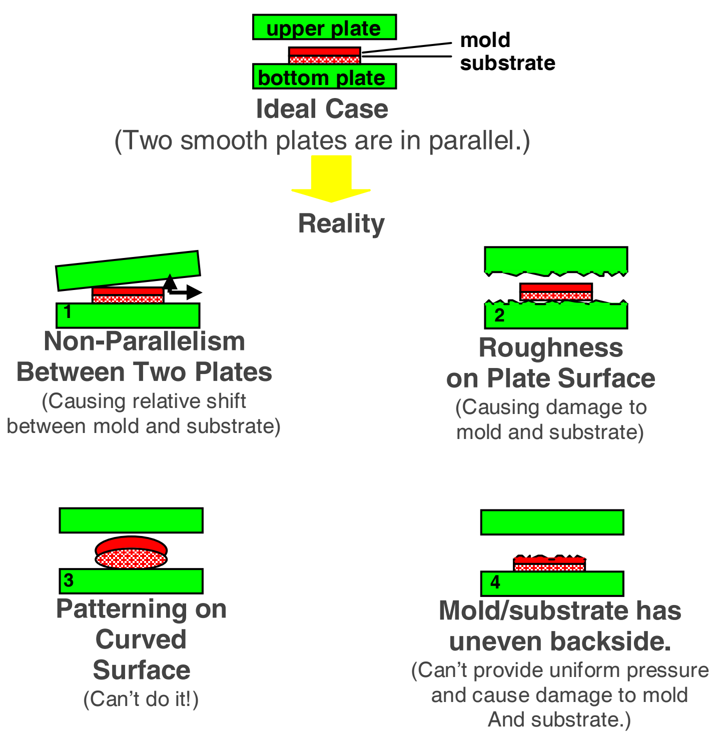


Figure 2. Various problems inherent to solid parallel plate press.

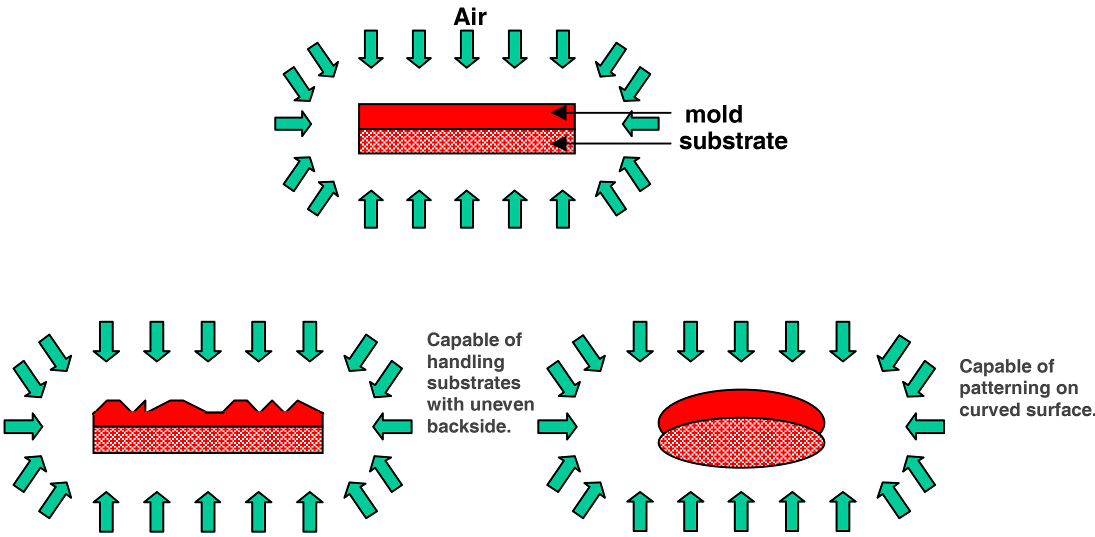
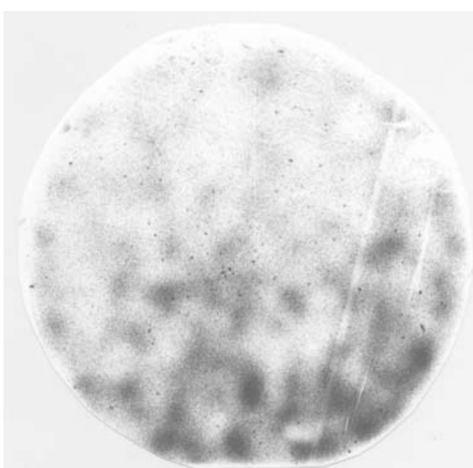
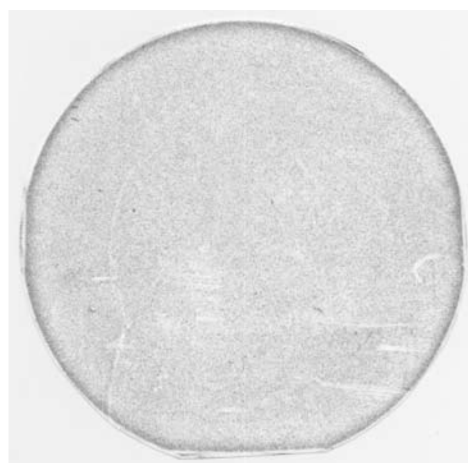


Figure 3. Air Cushion Press (ACP) offers ultra uniform pressure during imprint. It has advantages over traditional parallel plate press: capable of handling substrate with uneven back and pattering on curved surface.



(a) parallel plate press



(b) air cushion press

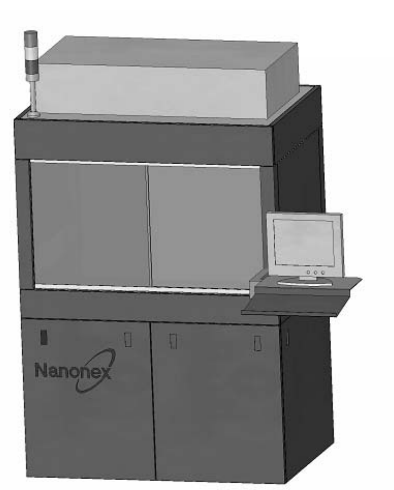
Figure 4. Comparison of pressure uniformity for conventional parallel plate press and Nanonex air cushion press: (a) parallel plate press (b) air cushion press. The pressure paper is sandwiched between mold and substrate. The current intensity demonstrates the magnitude of the pressure during imprint. From the reading, the real pressure has a magnitude variation of 4 times over a 4” wafer for parallel press while the pressure is uniform for air cushion press. [3]

Presently, Nanonex provides three series of nanoimprint tools (NX-1000, NX-2000, and NX-3000) for T-NIL and P-NIL, with and without alignment. All of them use the ACP to achieve excellent pattern uniformity. They all have sub-60 sec/wafer imprint cycle and are capable of handling up to 8” wafers as well as small piece parts. In-situ demolding is possible. All the tools are computer controlled with user friendly graphic interface (GUI), while the loading and unloading of samples are manual.

NX-1000 series (Fig 5a) are T-NIL tools without alignment. Upgrade options are also available to add in P-NIL and alignment functions. Figure 6 shows the captured temperature and pressure readings during one typical run. The process is less than one minute and the temperature and pressure during imprint can be controlled to within 1%. Figure 7 is the cross sectional SEM image of the imprinted resist grating of 200 nm pitch and 100 nm linewidth. It is uniformly patterned over entire 4” wafer. Figure 8 shows the imprinted resist zone plate with 125 nm minimum linewidth. There is no observable distortion of the ring patterns.

(a) NX-1000: thermal NIL tools without alignment

(b) NX-2000: thermal NIL and photo-curable NIL without alignment



(c) NX-3000: thermal NIL and photo-curable NIL with alignment

Figure 5. Nanonex imprint tools: (a) NX-1000 (b) NX-2000 and (c) NX-3000. All of them use Nanonex ACP, have sub-60 sec/wafer throughput, and are capable of handling up to 8” wafers as well as small piece parts.

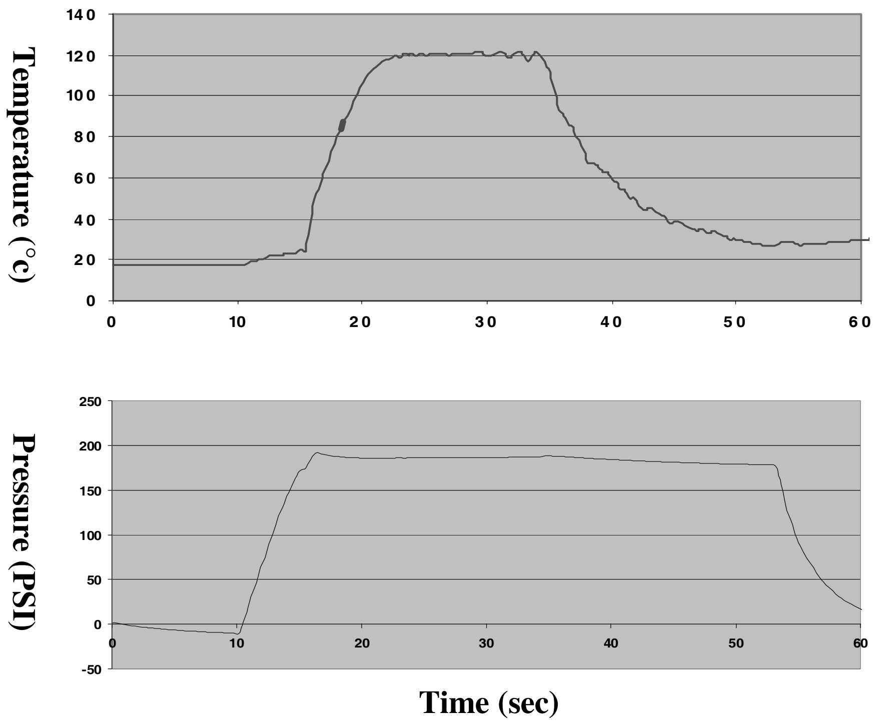


Figure 6. Temperature and Pressure captured during one typical cycle of NX-1000. The process can be finished within one minute. Temperature and pressure in the process can be controlled within 1%.

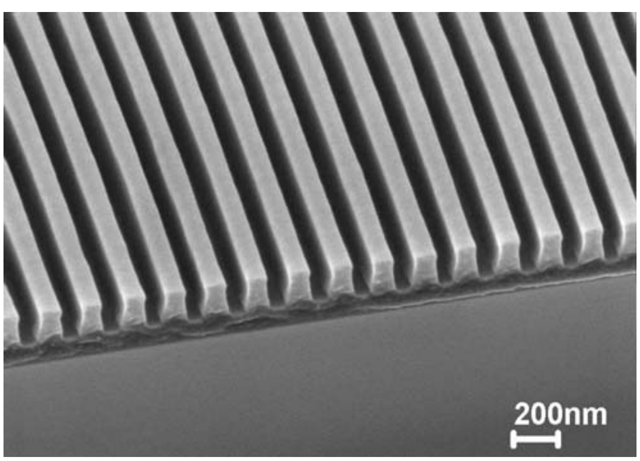


Figure 7. Resist gratings of 200 nm pitch and 100 nm linewidth. They are uniformly patterned by NX-1000 over 4” wafer.

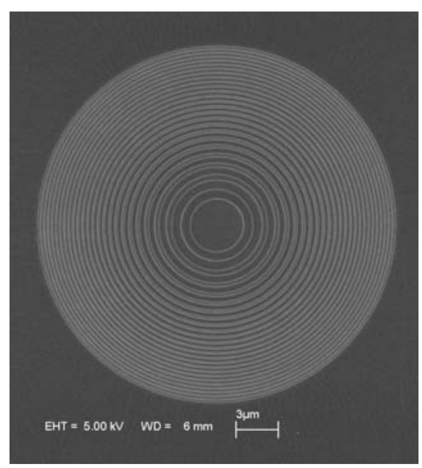


Figure 8. Resist zone plate with 125 nm minimum linewidth pattern by NX-1000.

NX-2000 series (Fig 5b) are the most versatile imprint tools capable of T-NIL, P-NIL and embossing. Upgrade options are available to add in alignment functions. P-NIL has sub-10 nm resolution [4]. Figure 9 shows the cross-sectional and top view of 200 nm pitch double layer resist grating. It is uniformly patterned over 4” wafer by P-NIL.

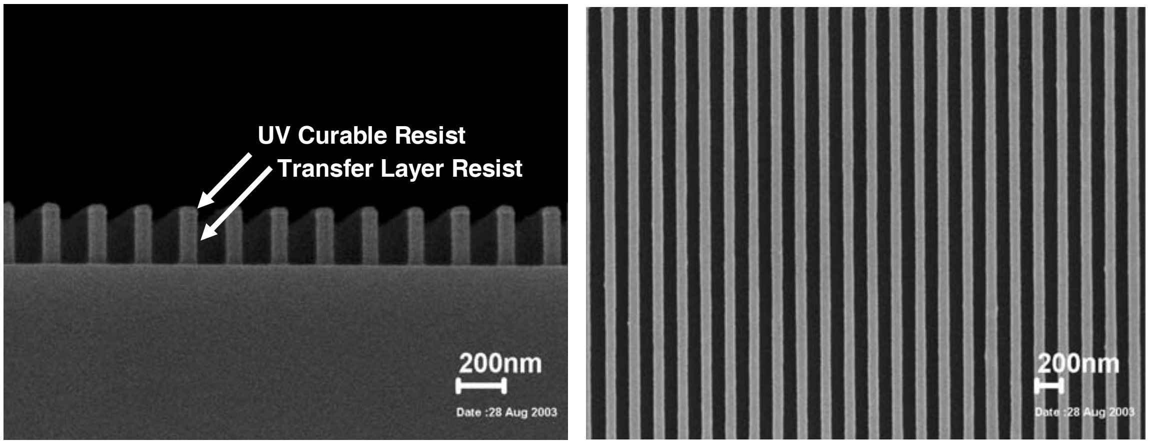


Figure 9. Cross-sectional and top view of double layer photo-curable resists show vertical sidewalls and smooth grating lines. The resists are uniformly patterned over 4” wafer by P-NIL process using NX-2000.

NX-3000 series (Fig 5c) is capable of sub-µm alignment over 4” wafer for both T-NIL and P-NIL. Machine vision system and motorized stages together enables the automatic alignment, while veriner gratings patterned respectively on the mask and substrate are used for the alignment. Figure 10 shows the optical microscope image of alignment marks after P-NIL. Figure 11 is the alignment map over 4” wafer. To demonstrate the application of NIL to semiconductor devices, a standard four mask processes have been chosen to fabricate the MOSFETs with all four levels (the active, gate, via and metal layers) defined by nanoimprint lithography. 60 nm channel length MOSFETs over the entire 4” wafer by nanoimprint are demonstrated (Fig 12) [5]. Sub-micron alignment accuracy is achieved during nanoimprint for the alignment of gate, via and metal layer over previous layers. Imprint can be carried out on previous defined non-flat surfaces.

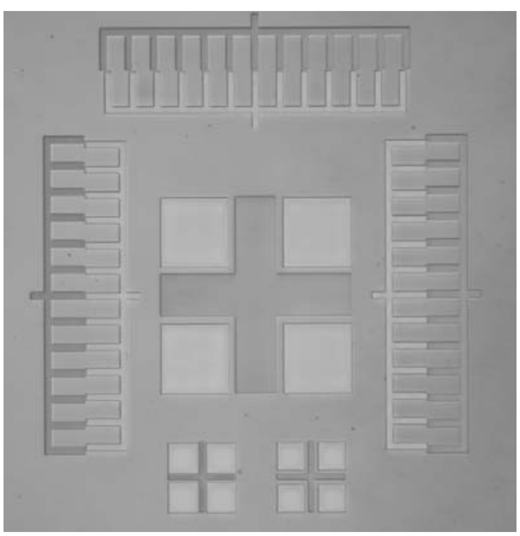


Figure 10. Optical microscope image after alignment and imprint using NX-3000

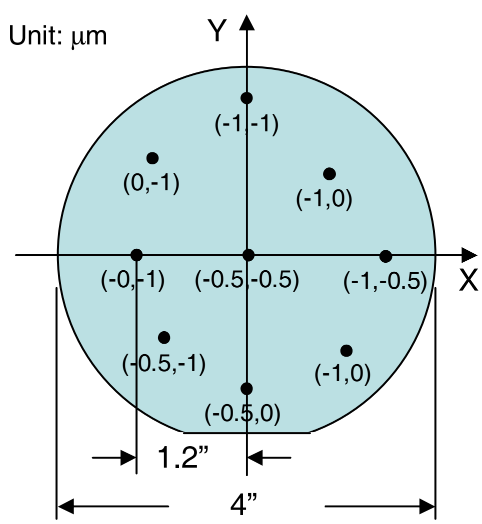


Figure 11. Alignment map over 4” wafer shows alignment accuracy within one micron

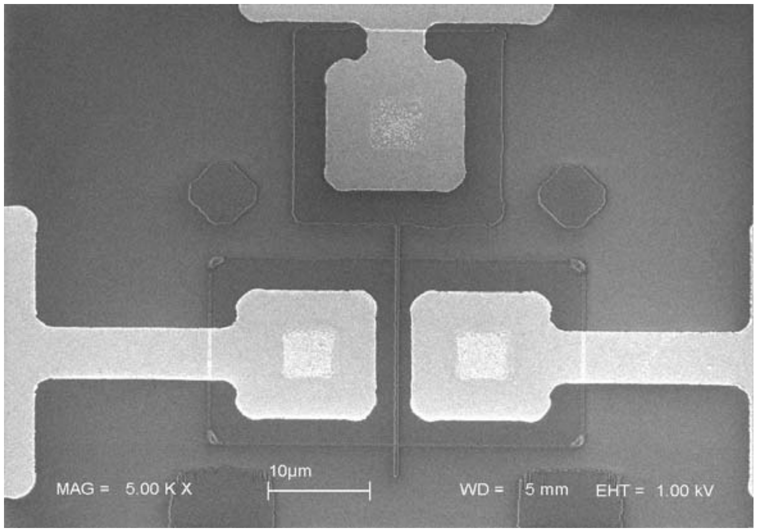


Figure 12. SEM image of the fabricated 60 nm channel length MOSFETs with all four lithography levels defined by NIL. [5]

2.2 Resists

Nanonex has developed resists for both thermal NIL and photo-curable NIL. Currently, three series of imprint resists (NXR-1000, NXR-2000 and NXR-3000) are available. NXR-1000 series are thermal resists with fast respond time and excellent uniformity. They have low imprint temperature and pressure with excellent flow ability. Figure 6 shows the cross-sectional view of imprinted thermal resist grating with 200 nm pitch. The grating is patterned uniformly over 4" wafer. NXR-2000 and NXR-3000 are used for photo-curable NIL. NXR-2000 series are top layer UV curable resists with low viscosity. They are spin on resists with excellent uniformity; have excellent flow ability with only 20 psi imprint pressure required; have fast response time with sub-60 sec/wafer throughput. NXR-3000 series are under layer resists for photo-curable NIL. Varieties of formulations can be selected to facilitate the following pattern transfer process: it can have either excellent etching resistance or excellent lift-off property.

2.3 Masks

Nanonex offers a variety of NIL masks. Periodic 1D or 2D patterns with 200 nm and 300 nm pitch over the entire wafer are fabricated by interference lithography (Figure 13). Nanonex is currently working with different mask vendors for 1x masks used in NIL. Customized masks are also available through Nanonex.

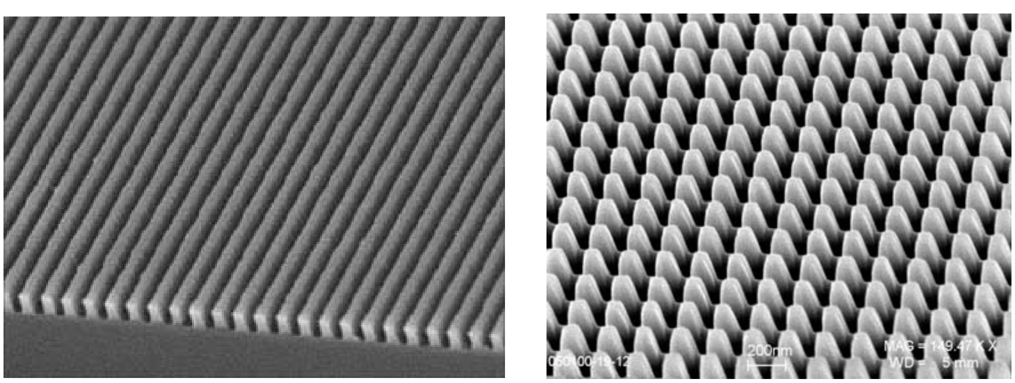


Figure 13. Periodic 1D and 2D masks fabricated at Nanonex using interference lithography. The pattern period can be as small as 200 nm while the pattern area can be 4".

2.4 Processes

As a lithography tool, the application of NIL is not limited to silicon process. Promising fields include optical devices, magnetic storage, MEMS, bio-technology etc. Nanonex has demonstrated 3D patterning for microwave devices (Figure 14) [6], micro-fluid channels used in bio-technology (Figure 15), ring structures for VRAM (Figure 16), passive optical components, etc. Nanonex will provide NIL recipes and technical guidance to assist the fabrication in these fields.

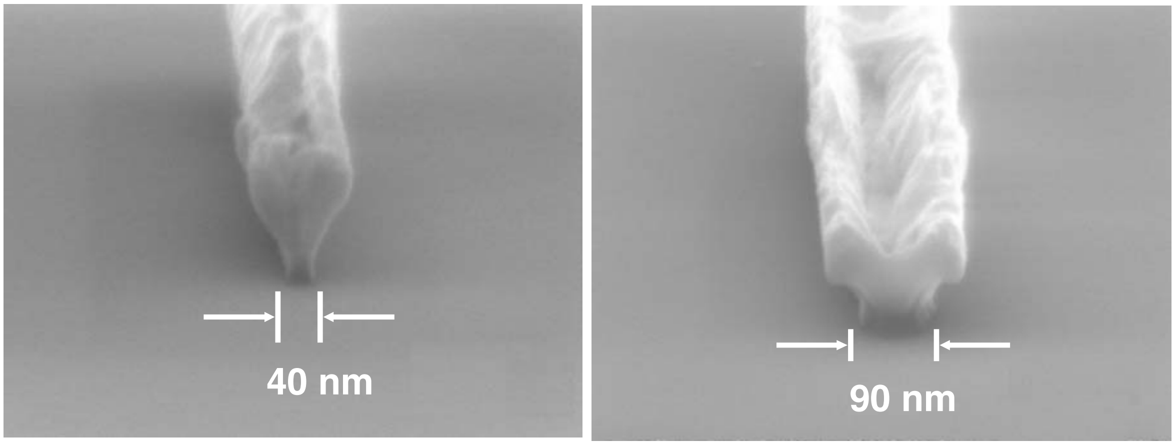


Figure 14. Sub-50 nm metal T-gate fabricated by NIL and lift-off. [6]

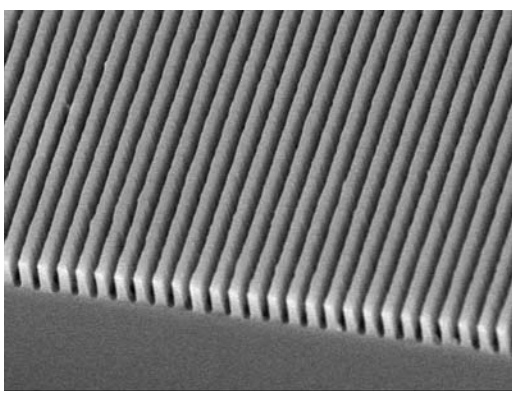


Figure 15. Micro-fluid channels fabricated by NIL.

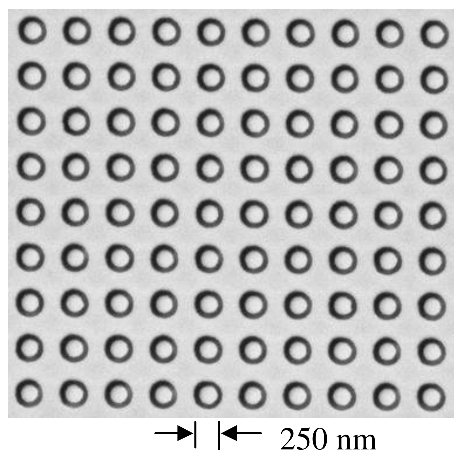


Figure 16. VRAM structure fabricated by NIL

3. CONCLUSIONS

Nanoimprint lithography has demonstrated sub-10 nm resolution, high throughput and low cost and proved to be a ubiquitous enabling nano-manufacturing technology. Application of nanoimprint relies on the imprint tools, imprint resists, masks, and imprint processes. With the help from Nanonex, which offers nanoimprint tools and complete solutions today, nanoimprint lithography will play a critical role in the commercialization of nanostructures.

REFERENCES

1. S.Y. Chou, P. R. Krauss, and P. J. Renstrom, Applied Physics Letters, **67**, 3144, 1995; and Science, **272**, 85, 1996
2. http://public.itrs.net/ 2003 ITRS
3. H. Gao, H. Tan, K. Morton, and S.Y.Chou, submitted to EIPBN 04
4. M. Li, H. Tan, L. Kong, L. Koecher, submitted to SPIE 04
5. W. Zhang, S.Y. Chou, Applied Physics Letters, **79**, 845, 2001
6. M. Li, L. Chen and S.Y. Chou, Applied Physics Letters, **78**, 3322, 2001