Nanoimprint lithography

1. Introduction

The Nanoimprint lithography (NIL) is a novel method of fabricating micro/nanometer scale patterns with low cost, high throughput and high resolution (Chou et al., 1996). Unlike traditionally optical lithographic approaches, which create pattern through the use of photons or electrons to modify the chemical and physical properties of the resist, NIL relies on direct mechanical deformation of the resist and can therefore achieve resolutions beyond the limitations set by light diffraction or beam scattering that are encountered in conventional lithographic techniques (Guo, 2007).

The resolution of NIL mainly depends on the minimum template feature size that can be fabricated. Compare with optical lithography and next generation lithography (NGL), the difference in principles makes NIL capable of producing sub-10 nm features over a large area with a high throughput and low cost (Chou et al., 1997). Therefore, the charm of NIL largely comes from its capability for patterning with high resolution, high fidelity, high throughput, and low cost. In addition, nanometer sized patterns can easily be formed on various substrates, e.g., silicon wafers, glass plates, flexible polymer films, and even nonplanar substrates. The process has been added to the International Technology Roadmap for Semiconductors (ITRS) for the 32 and 22 nm nodes. Toshiba, moreover, has validated it for 22 nm and beyond. What is more significant is that NIL is the first sub-30 nm lithography to be validated by an industrial user (Yoneda et al.,1997).

Nanoimprint lithography was first invented by Chou and his students in 1995 as a low-cost and high throughput alternative to photolithography and e-beam lithography (EBL) for researchers who need high resolution patterning, motivated by the high expense and limited resolution of optical lithography. Due to historical reasons, the term NIL initially refers to a hot embossing lithography (HEL) process, and was also used as a synonym for thermal NIL (Chou et al., 1995). However, NIL has now an extended meaning which includes not only two fundamental types (Hot Embossing Lithography and UV-based Nanoimprint Lithography, UV-NIL) but also many different variations developed such as roll imprint process, laser-assisted direct imprint, reverse imprint lithography, substrate conformal imprint lithography, ultrasonic NIL, etc.

Furthermore, NIL has currently demonstrated great potential and commercial prospects in many application fields, such as Hard Disk Drive (HDD), LED, OLED, flexible display, optical and biological devices, etc.

NIL technology involves two fundamental aspects: the basic research and the application research. The basic research consists of the process, tool, template (mold), material (resist, functional material, etc) which aim to meet the different application requirements, namely the micro/nano structures or devices fabrication. NIL applications mainly cover nanoelectronics, nano-optoelectronics, nanophtonic, nano-biology, optical components, etc.

2. NIL process

2.1. Principle of NIL

NIL is based on the principle of mechanically modifying a thin polymer film (mechanical deformation of the resist) using a template (mold, stamp) containing the micro/nanopattern, in a ***thermo-mechanical or UV curing process***. It does not require expensive and complex optics and light sources for creating patterns.

Since NIL can be considered as such a process based on squeeze flow of a sandwiched visco elastic material between a mold and a substrate, the property of surface and interface between the two materials has to be considered throughout the entire process, both from topographical, chemical, and mechanical points of view.

Furthermore, the characteristics of the interface and surface have a great impact on the demolding capability and filling behavior which can strongly influenced pattern quality and throughput (Schift, 2008, Bhushan, 2007, Guo, 2004).

2.2 Two fundamental processes for NIL

Currently, there are a great variety of NIL process types, but two of them are most important and fundamental: Hot Embossing Lithography (HEL) or thermal nanoimprint lithography (TNIL), and UV-based Nanoimprint Lithography (UV-NIL), as shown in Fig. 2.10 (Steward & Willson, 2005). Both thermal and UV-NIL have demonstrated a sub-10 nm resolution. T-NIL is the earliest NIL developed by Stephen Chou's group.

Thermal Nanoimprint Lithography (T-NIL): In a standard **T-NIL** process, a thin layer of imprint resist (thermoplastic polymer) is spin-coated onto the substrate. Then the mold, which has predefined topological patterns, is brought into contact with the substrate and they are pressed together under certain pressure. When heated up above the glass transition temperature (T_g) of the polymer, the feature pattern on the mold is pressed into the melt polymer film. After being cooled down, the mold is separated from the substrate and the pattern resist is left on the substrate. A subsequent pattern transfer process (e.g. reactive ion etching) can be used to transfer the pattern in the resist to the underneath substrate.

UV Nanoimprint Lithography (UV-NIL): In **UV-NIL**, a UV-curable liquid photopolymer instead of thermoplastic as resist is applied to the substrate and the mold is normally made of transparent material like fused silica, quartz mold. After the mold and the substrate are pressed together and the cavities (trenches) are fully filled by resist, then the resist is cured in UV light and becomes solid. After demolding, a similar pattern transfer process can be used to transfer the pattern in resist onto the underneath material. The polymer residual layer is removed by reactive ion etching (oxygen plasma etching) process (Nanoimprint lithography, 2009).

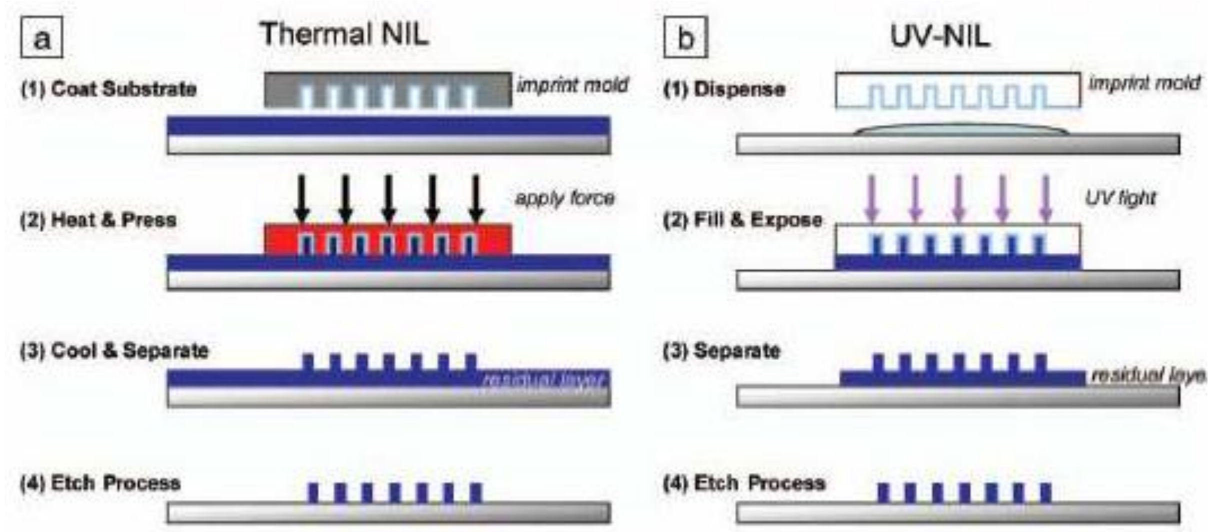

Fig. 2.10 Two fundamental process types for NIL (Steward & Willson, 2005)

2.3 Difference between UV-NIL and T-NIL:

Each process has of its own prominent advantages .The basic difference between both of them is that of resist:

In UV-NIL, it is liquid at room temperature and low pressure (force) is required to press mold into resist, which is then cross linked and hardened by exposure to UV light at room temperature.

In T-NIL thermoplastic polymer resist is spin coated on substrate and high pressure (force) is required to press mold into resist and then and heat (high tempratue) to melt the resist.

T-NIL is low-cost since non-transparent molds can be used (Less restrictions on mold).

UV-NIL is one of the most important NIL technologies for structuring of large wafer areas up to 300 mm in diameter as compared to T-NIL.

2.4 Types of UV-NIL

UV-NIL offers two approaches for patterning ssing either :

- Rigid quartz glass molds (Hard UV-NIL)
- Soft molds (Soft UV-NIL)

for structuring of UV sensitive resists resulting in an etching mask for the substrate to be patterned (Glinsner et al., 2007, Plachetka et al., 2004).

Drawbacks of hard mold or hard UV-NIL:

For UV-NIL using a rigid mold, the hard mold brings about following weaknesses:

- One is the sticking characteristic which can lead to the following shortcomings that a release agent or surfactant is necessary, and the demolding force is especially large.
- Another is the limitation in imprint area due to having the surface waviness onto the mold and the substrate surfaces. Furthermore, it is rather difficult to ensure uniform and parallel surface contact between a template and a wafer during imprinting process.
- Shorten the life-time of the master mold.

Advantatges of Soft mold of Soft UV-NIL

- Compared with the hard mold, using a soft or flexible mold can avoid the sticking or adhesion of resist with mold and relatively small demolding force is required.
- Enlarge the imprint area and reduce the parallelism error between the mold and the substrate because high flexibility of the mold enabled conformal contact between mold and substrate as well as imprinting at significantly reduced imprint pressure.
- Lengthen the life-time of the master mold.

Drawbacks of Soft mold or Soft UV-NIL

On one side, the elastomeric behavior of the soft mold offers numerous advantages, but one the other hand some drawbacks., will have to be considered and resolved.

Swelling is a commonplace issue with PDMS based molds since most organic liquids will swell PDMS deforming molds. These deformations limit the resolution of soft UV-NIL principally. Therefore, compared to T-NIL and UV-NIL used rigid molds, it is particularly important for the soft UV-NIL to understand and reduce as much as possible the mold deformation for the practical application of the technique.

The current capability for the process from AMO and Süss can ensure nanoscale resolution down to sub 50 nm and perfect pattern stability (SCIL, 2009). However, the deformations of the soft mold during imprinting process which can cause serious consequences have to be considered for the practical application of the process and further improving the pattern resolution (Lan et al., 2009).

3. NIL applications

Data storage devices (HDD's and Solid State Memories)

Since the first demonstration of NIL in the mid 1990s, patterned magnetic media for harddisk drives (HDDs) has been a key application, driving the development of NIL technology (Bhushan, 2007). NIL has emerged as a likely candidate for high-volume fabrication of patterned media disks, and electron beam lithography as the method required to produce nanoimprinting master stamps. Nanoimprint providers and their users are also focusing on the high-density memory, such as NAND flash.

However, many challenges in implementation of nanoimprinting technology into patterned media disk fabrication process still abound, such as choice of nanoimprinting resist, pattern transfer fidelity and uniformity, and lifetime of master stamp. System-level integration issues also create additional challenges in track-following, head-disk interface, and signal processing.

Photonic or Opto- electronic devices (LED's, Quantum dot based Solar Cells etc)

NIL can be used as a most effective patterning tool to fabricate high density photonic crystals for high efficiency and low cost LED devices. Rapid progress is being made to reach manufacturing quality and cost targets suitable for high volume LED manufacturing.

NIL is being used by a number of leading edge device manufacturers and universities to develop photonic crystal and other light extraction technologies for LEDs. Scientists at Glasgow University along with the Institute of Photonics at the University of Strathclyde devise brighter LEDs via NIL.

LEDs have not been introduced as the standard lighting in homes because the process of making the holes is very time consuming and expensive. Using NIL makes millions of microscopic holes on the surface of a LED bulb, which increase the amount of light the LEDs give off. They believe they have found a way of imprinting the holes into billions of LEDs at a far greater speed, but at a much lower cost (Glasgow, 2009).

4. Prospects and challenges in NIL

NIL has now been considered as an enabling, cost-effective, simple pattern transfer process for various micro/nano devices and structures fabrications. Two unique benefits of NIL is the ability to pattern 3-D and large-area micro/nano structures with low cost and high throughput. In addition, NIL is able to achieve aspect ratios greater than 10.

The progress However, NIL is still facing many serious challenges. The currently crucial challenges for NIL include overlay alignment, mold fabrication, mold lifetime issues, resist sticking with mold, defect control, high yield, and seeking especially suitable application fields. In particular, two key challenges remain for NIL before it can be adopted for semiconductor manufacturing: alignment (overlay) and template/mold fabrication.

For resists, there are still significant challenges to develop low viscosity resists and nanoimprint resist materials with high etching resistance. A crucial requirement for being able to further extend the success of the NIL technique is to improve resolution and throughput of conventional NIL schemes as well as to explore unconventional ways to utilize NIL processes for fabrication of novel nanodevices and nanomaterials. There is still a long way to go for NIL technology and various industrial applications. Further potentials of NIL need still to be explored and developed.

Bottom up approach

In this approach, different physical, chemical and and green methods are used to synthesize nano materials. Wet chemicals methods include chemical reduction, hydrothermal method etc.

Chemical reduction method for synthesis of nanoparticles

Main salt + Reducing agent ⟶ Nanoparticles + By products