Micro- And Nano- Patterning Using Imprinting Technique

HAIJING LU, X. C. SHAN*, YAOFENG SUN, SUM HUAN NG
and ALBERT C. W. LU

Singapore Institute of Manufacturing Technology, 71 Nanyang Drive, Singapore
638705

xcshan@simtech.a-star.edu.sg
http://www.simtech.a-star.edu.sg

Abstract. This research aims to develop capabilities in patterning micro-, nano- structures and devices using thermoplastics. Fundamental investigations are conducted using NEB-22 resist as the substrate material in the imprinting of micro- and nano- structures. Imprinting on 200 mm diameter wafers has been achieved with well acceptable uniformity. Features with linewidths down to 50 nm and uniformity with less than ±1% over an 8-inch wafer has been obtained. Micro gratings for optical sensing, nano-scaled channels and pillars for bio-related filtering have been manufactured.

Keywords: nanoimprinting, polymer, nano-grating, nano-pillar and uniformity

1. Introduction

Nanoimprinting technology [1], as one of the most promising fabrication technologies, has been demonstrated to be a powerful tool for large-area replication up to wafer-level, with features down to nanometer scale. Nanoimprint lithography is a cost-effective and high throughput fabrication technique for creating uniformly imprinted micro- and nano- scale devices and systems in a single patterning step. This fast and low cost method becomes an increasingly important solution for the fabrication of biochemical, microfluidic, micro-optical and telecommunication devices. Due to its advantages over conventional fabrication methods in terms of process flexibility, process simplicity, low cost and bio-compatibility, nanoimprinting will find wide applications in fluidic systems, biomedical systems as well as optical and sensing systems [2-3].

This paper reports on fundamental investigations of the nanoimprinting technique using NEB-22 as the imprint substrate material. The coated NEB-22 resist layer is 300 nm thick; the imprinting temperature and loading pressure are 130 °C and 1.3 MPa, respectively. With the optimizations of resist coating and imprinting process, imprinting on 200 mm diameter wafers has been achieved with well acceptable uniformity. Micro gratings for optical sensing, nano-scaled channels and pillars for bio-related filtering have also been manufactured. Future studies will include nanoimprinting on bulk solid substrates like PMMA and polycarbonate.

2. Process Description
An EVG520 system consisting of a nanoimprinter and wafer-bonder is used in this research. The system is configured with high-vacuum and high-contact force capabilities. The chamber can be heated up to 250 °C by its top and bottom heaters, which makes it suitable for imprinting a wide range of polymeric materials. It can accept substrates with diameters of 200 mm and 100 mm.

The mould can be made of either silicon or metal such as nickel; the polymeric materials could be either resist layers coated on silicon substrates or polymer films. In the nanoimprinting process, as illustrated in Fig. 1, polymeric materials are brought into soft contact with the mold. Upon heated up in the vacuum-chamber to the desired process temperature ($T_1$) that is above its glass transition temperature ($T_g$), a pressure ($P_1$) is applied between the mould and polymer. The pressure will be held constant for a certain period of time ($t_1$) to force the polymeric material into the mould completely, and then followed by cooling. After being cooled down to certain temperature ($T_2$) that is below its $T_g$ the polymer is then separated from the mould with the reversed microstructures replicated onto the polymer.

![Diagram of nanoimprinting process](image)

(a) Process flow of nanoimprinting                       (b) temperature / pressure sequence

**Fig. 1 Process description of nanoimprinting**

An 8-inch silicon mould with patterns ranging from micrometers to sub-micrometers is used in the nanoimprinting process. The mould is coated with a thin layer of FDTS (1H,1H,2H,2H,-perfluorodecyltrichlorosilane) as the anti-stick layer. Wafers with 200 mm diameters are used as the substrate. The surface roughness of the wafers is less than 5 nm. The silicon wafers are cleaned with 40% nitric acid, deionized water, isopropanol and O$_2$-plasma ashing before resist coating. The resist used in this investigation is NEB-22 (Sumitomo Chemical Co.), which is a negative tone photoresist. The layer thickness of about 300 nm can be obtained using a standard coating process.

The surface of the polymer coating is characterized using an AFM (Atomic Force Microscope) and a spectroscopic ellipsometer to monitor the local and global thickness uniformity of the polymer film. The thickness uniformity of the coated film will affect the imprinted pattern profile, the residual layer and even the yield of imprinted structures. The thickness uniformity is measured at 25 points over the 8-inch silicon wafer. The thickness uniformity is around ±0.11%, which is well acceptable for nanoimprinting process.

While using NEB-22 as the imprinting material, the imprinting temperature ($T_1$ in Fig. 1) and pressure ($P_1$) are set at 130°C and 40 kN, respectively. The holding time ($t_1$) and demoulding temperature ($T_2$) are 10 minutes and 80 °C, respectively.
3. Results and Discussions
Fig. 2 shows an optical micrograph of imprinted patterns on an 8-inch wafer substrate using an 8-inch silicon mould, with NEB-22 as the polymeric material. The thickness of the coated NEB-22 layer is about 300 nm. AFM is used for measuring the detailed profiles of the imprinted structures. The grating patterns with a pitch of 720 nm are picked up for investigating the imprinted uniformity. As shown in Fig. 3, the same patterns at the 4 edge-points as well as the central point of the substrate are measured. The width and depth of the grating patterns in these selected areas are almost identical. More precise measurement with quantitative analysis reveals that the uniformity of line depth is about ±1.5% and that of line width is about ±0.17% for the selected grating patterns.

Fig. 2 Micro- and nano- scaled structures imprinted on an 8-inch substrate

Fig. 3 Investigations of imprinted uniformity of selected grating patterns using AFM
As illustrated in Fig. 1, a residual layer will be left on the bottom of the imprinted patterns, the thickness of this residual layer ranges from several nanometers to hundreds nanometers, depending on the parameters of imprinting process. This residual layer can be cleaned off by O$_2$-plasma ashing, which will etch away polymer resist with a uniform rate. Figs. 4(a)-(c) show AFM images of the grating patterns on the mould, imprinted replications on NEB-22 layer and the ones after 10 minutes of O$_2$-plasma etching. Fig. 4(d) illustrates the cross-sectional profiles of imprinted gratings before and after O$_2$-plasma etching. It is found that the top surfaces become rougher and trench width of the gratings increased slightly. It can be estimated from the roughness of bottom surface of the trench that further O$_2$-plasma etching is necessary in order to etch away the residual polymeric layer completely.

Nanoimprinting is also a promising technique to manufacture micro- and nano-fluidic-related devices such as channels and filtering devices. Fig. 5(a) illustrates the nano-scaled channels and holes on the silicon mould. Fig. 5(b) shows the structures imprinted on NEB-22 polymeric layer after 10 minutes of O$_2$-plasma etching. The nano-scaled holes on the mould correspond to nano-scaled pillars on the imprinted layer, which can be used as fluidic-related filtering device. The zoomed AFM image demonstrates that the pillar has a height of 230 nm with the diameter at the bottom and top being 400 nm and 300 nm respectively.

Fig. 4 Characterizations of imprinted grating patterns by AFM
4. Conclusion

The nanoimprinting process with an EVG nanoimprinter has been developed at SIMTech, Singapore. Features with linewidths down to 50 nm and uniformity with less than $\pm 1\%$ over an 8-inch wafer has been obtained. The excellent uniformity means that the yield of the developed process would be suitable for actual manufacturing applications. It is found that O$_2$-plasma etching on the imprinted patterns results in higher surface roughness of the polymer and an increase in the trench width of the grating patterns. The end point of the O$_2$-plasma etching (in removing the residual layer completely) can be determined by measuring the surface roughness of the bottom surface of the trench.

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