Research on the imprinting parameters of microstructures with different line widths by Hot Embossing Nano-Imprint Lithography

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ABSTRACT

Nanoimprinting lithography has been a high-profile topic in recent years. In this study, we research a home-made nano-imprinter which fabricates zigzag grating with 150 lines/mm and 600 lines/mm. Also the imprinted pattern which fabricated with different temperatures and pressures will be discussed. Using PDMS as an imprinting mold, we aim to transfer the pattern to polystyrene. The results indicate that the temperature and pressure will affect the line width and the depth of the pattern. Thus, we can use these data to investigate the optimized fabri-cating parameters.
Keywords: nanoimprinting lithography, optimized parameter, poly-styrene

I. INTRODUCTION

With the growth of science and technology, more manufacturing processes were proposed for tiny and efficient devices. Moreover, the calculating capability of computer has also increased relatively, and more and more transistors need to be inserted in a chip. The line width also needs to be narrower. The most famous fore-cast of the development trend of transistor density on a wafer is Moore's Law [1].

The traditional micro and nano processing technology is based on the yellow-light lithography process. The principle of this technology is very simple, but the pro-cess is quite complicated. First, the surface of the sub-strate is coated with a layer of photosensitive material, and the light is projected on the light source. Then, a mask is inserting between the photosensitive material and the light source. The pattern on the mask will define the pattern on the photosensitive material. This step is micro-exposure. The photosensitive material is divided into positive photoresist and negative photoresist. The positive photoresist undergoes a chemical change after receiving light energy, and the positive photoresist ex-posed to light will be removed after being developed by a special solvent. The negative photoresist which is ex-posed to light after development will remain. The proce-dures of the lithography process include: surface clean-ing, priming, resist coating, soft bake, exposure, post ex-posure bake, development, hard bake and so on [2]. Because of the complexity of the process, the long pro-cess time of the traditional optical lithography technolo-gy have reached the limit of optical diffraction. If the manufacturers use optical lithography technology to produce the devices, the process methods and equip-ment should be improved. Stephen Y. Chou[3], a scien-tist in Princeton University in the United States, published the first article of nanoimprinting to make nanostruc-tures in 1995. Other scientists also proposed various methods of nanoimprinting to improve the quality and upgrade the manufacturing efficiency. For example, Hot embossing nano-imprint lithography, Laser-assisted di-rect imprint, Roller nanoimprint lithography [4-6] were proposed.

With regard to soft imprinting method, there are two types of soft imprinting: hard mold and soft mold. Alt-hough the hard mold can withstand multi-run operation, the disadvantage of using the hard mold is low transfer efficiency of the middle part of the transfer pattern for large imprinting area. Thus, the pattern cannot be suc-cessfully transferred. We take advantage of the soft mold to fabricate the pattern and to study the aspect ratio of the transfer pattern. However, the larger aspect ratio of the pattern on the mold will bend and deform the structure during the imprinting process. It depends on the material of the soft mold.

The main purpose of this research is to explore the op-timized parameters of the nanoimprint technology in the imprinting process, and finally use the optical micro-scope, aspheric measuring system, and atomic force microscope to study imprinting quality. Also, we study the manufacturing factors that affect the quality of nanoimprinting pattern and optimize it.

II. NANO IMPRINT PRINCIPLE

2.1 HOT EMBOSSING NANO-IMPRINT LITHOGRAPHY

The principle of hot embossing nano-imprint lithography (HENIL) includes two basic steps: 1. Coat a layer of embossed thermoplastic polymer on the substrate, such as

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poly methyl methacrylate (PMMA), polystyrene (PS) when the mold is pressed. When printed on the polymer layer, it starts to heat and the temperature should be above the glass transition temperature. At this time, the polymer material above the glass transition temperature will turn into a viscous liquid. Thus, we can use this feature to fill the cavity and wait until the temperature drops to the room temperature in the demolding action. 2. After demolding, we use reactive-ion etching (RIE) to remove the part compressed during imprinting and etch to the pattern transferred on the substrate. After removing the excess polymer on the substrate, nanoimprinting is completed [7]. The imprinting flow chart is shown in Figure 1.

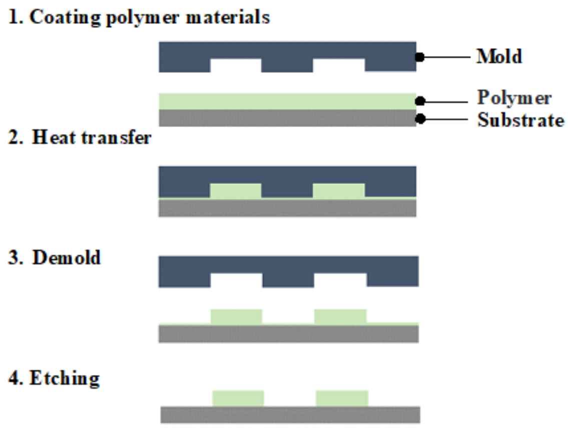

Figure 1. Hot Embossing Nano-Imprint Lithography flowchart

When the temperature is above the glass transition temperature during the imprinting process, the thermoplastic polymer will become a viscous and flowable liquid. This feature makes us to pressurize the mold when the mold is in contact with the polymer layer. Then, the thermoplastic polymer fills the mold, so that the thermoplastic polymer can be released from the mold when it is cooled to form the same pattern as the mold.

2.2 ROLLER NANOIMPRINT LITHOGRAPHY

The principle of Roller nanoimprint lithography (RNL) [8] is different from the thermoforming nanoimprint machine. The mold structure and the method of imprinting are quite different. Generally, RNL can be divided into two types of imprinting methods. As illustrated in Figure 2, the first method is to wrap a nano-structured metal film on the smooth surface of the roller, and the roller is embossed on the thermoplastic polymer film to rotate to form the same pattern as the metal structure on the roller. The second method is different from the method of applying pressure to the thermoforming nanoimprinting. The thermoforming nanoimprinting is pressed down in a large-area, and the roller contact the mold and give pressure to the mold, polymer layer and the substrate. After the imprinting is completed, the compressed part is removed and etched to the substrate by RIE to obtain the desired structure of the substrate.

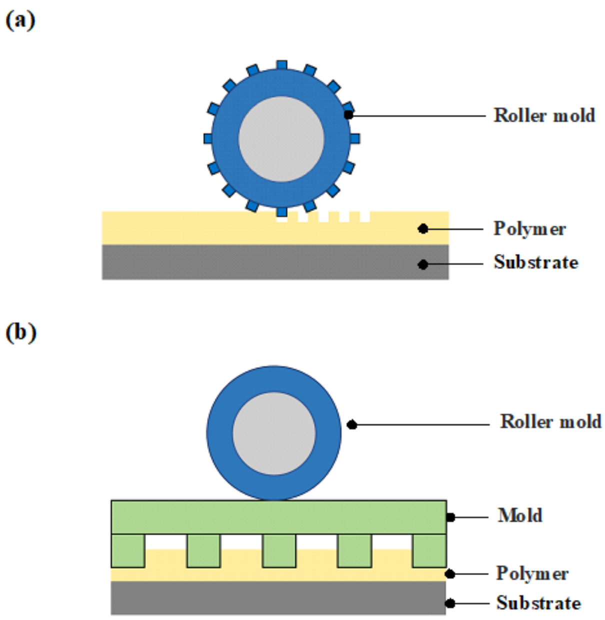

Figure 2. Roller nanoimprint lithography two meth ods (a) The metal film structure on the roller is imprinted with polymer (b) The mold is placed on the polymer material, and the roller is pressed

2.3 LASER-ASSISTED DIRECT IMPRINT

In 2002, Stephen Y. Chou[9] et al. proposed a new nanoimprinting method. This method does not require photoresist or etching, and it can be done directly on metal. This principle is shown in Figure 3. A piece of transparent quartz is used as an imprinting mold core, and the quartz mold core is pressed to the silicon substrate with slight contact, and then the XeC1 excimer laser is used to etch the silicon substrate through the quartz mold. The core melts the surface layer of the silicon substrate (the processing time is about 25ns), and its melting depth can reach about 300nm and can maintain the molten state for about 100ns. When the laser pulse reaches 20 ns, it will immediately perform nano-transfer to the molten silicon surface. In the report, Stephen Y. Chou mentioned that molten silicon metal has excellent fluidity, and its viscosity is only 1/3 of water, so it can be quickly filled into the structure of the quartz mold and solidified.

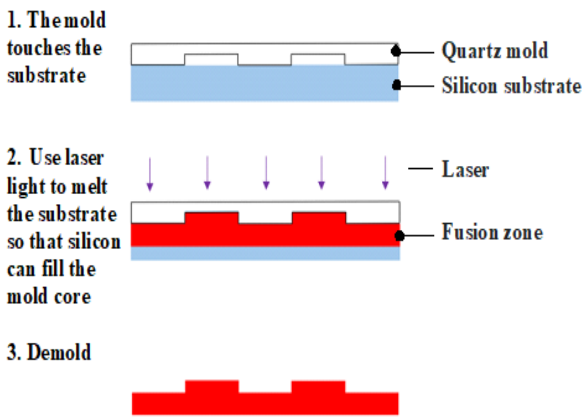

Figure 3. Laser-Assisted Direct Imprint flowchar

III. EXPERIMENTAL METHOD

In this experiment, the zigzag grating was imprinted by the method of thermo-compression molding and nano-imprinting (as shown in Figure 1). The mold used the aluminum film ruled diffraction grating purchased by Edmund Optics, with lines of 150 and 600 line/mm and we use the polydimethylsiloxane (PDMS) as the soft mold of 150 and 600 line/mm. After the pattern transfer process, the PDMS mold is made from the self-made nanoimprinting machine for the imprinting process. We discuss the relationship between pressure and temperature during imprinting with different pressures and different temperatures.

The substrate used in the experiment is BK-7 glass. The glass is immersed with polymer as the material to be transferred, and then imprinted with a self-made nanoimprinting machine. The specification of this imprinting process is shown as Table 1: Material, linear expansion coefficient: $7*10^{-5}$cm/cm*°C, which refers to the ratio of the change in length of a solid substance when the temperature changes by 1 degree Celsius to its length at 0°C, forming shrinkage rate: 0.1 %~0.6% refers to the percentage of the reduced size of the plastic material from the mold and cooled to room temperature to its original uncooled size. The glass transition temperature (Tg) is 105°C, It means that the polymer material is solid at room temperature, and when the temperature of the polymer material reaches the Tg , the thermoplastic polymer will become a flowable liquid.

Table 1. The specification of this imprinting process

	Value (unit)
linear expansion coefficient	$7*10^{-5}$ cm/cm*°C
Forming shrinkage rate	0.1 %~0.6%
Glass transition temperature (Tg)	105°C

In this experiment, the PS film was coated on the glass substrate by immersion plating machine. the PS polymer powder was dissolved into a solution with a solvent, and the glass substrate was clamped by a carrier. After being immersed in a PS solution in the beaker and mix them for 5 seconds. Finally, perform immersion plating at a rate of 15mm/min.

The pneumatic cylinder with output pressure used in this experiment is MCDA-23-32-100 dual-axis double-force cylinder manufactured by Mindman Industrial Co, The minimum output of the pressure cylinder is 0.05Mpa, therefore, in this experiment, the temperature is fixed at 150°C, the interval for each group of 0.05~0.15Mpa is 0.01, and the line widths of 150 and 600 line/mm are imprinted at different pressures as the pressure, and the fixed 0.1Mpa is used for 140 ~180°C, each group has an interval of 5°C, and imprints 600 lines/mm at different temperatures.

In the experimental measurement, we use PGI 840 (Aspherics Measuring System) manufactured by Taylor Hobson and diDimension 3100 (Scanning Probe Microscope SPM system) manufactured by Veeco to measure the mold size and the structural condition and size after imprinting. We use instrument software to measure the size of the structure after analysis. The experimental data of each group is measured five times and the average value is taken. Finally, the error bar of the five data is drawn to know more clearly that the quality of the imprint is stable.

IV. RESULTS AND DISCUSSION

4.1 THE RESULT OF IMPRINTING 150 LINE/MM

Figure 4 shows the profile of a 150 line/mm mold measured with an aspheric surface measurement system.

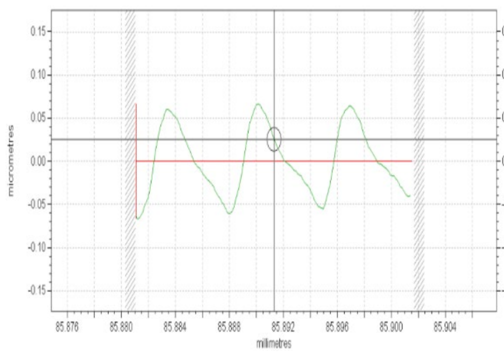

Figure 4. Mould contour of 150 line/mm, the line width is about 6.6 mm and the depth is about 0.14 mm

The experimental results are shown in Figure 5. In Figure 5(a)~(b) are the relationship of line width and the depth for with the pressure of 0.05~0.15 Mpa for 150 line/mm, respectively. Through Figure 5(a) the width of the structure is wider when the pressure is 0.15 Mpa obviously. Moreover, we found under the microscope that the structure has deformed and twisted, as shown in Figure 5(c). The structure at 0.15 Mpa at 150 line/mm has reached the largest structure in the current process Pressure range.

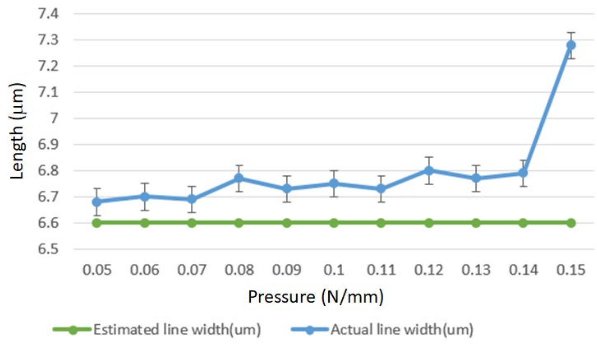

Figure 5(a). The relationship between pressure and line width of 150 line/mm

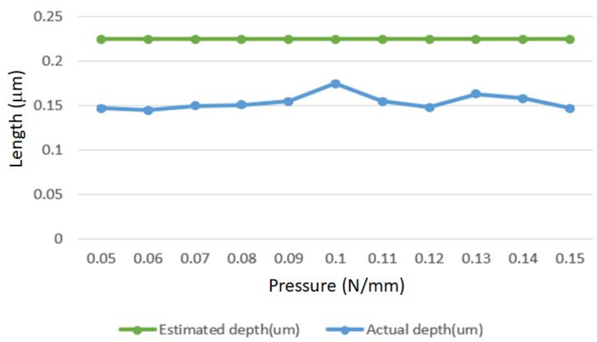

Figure 5(b). The relationship between pressure and depth of 150 line/mm

Figure 5(c). Measured at 1000 times using an optical microscope, it is found that the imprinted structure with 0.15 Mpa is distorted and deformed

4.2 THE RESULT OF IMPRINTING 600 LINE/MM

Figure 6 shows the actual size of a 600 line/mm mold measured with an atomic force microscope. Figure 7(a)~(b) are 600 line/mm, the pressure of 0.05~0.15 Mpa showing the trend graph and standard error of the relationship between line width and depth, respectively. In Figures 7(a), it shows that the distribution of the line width has a pick at 0.07 and 0.09 Mpa. The width at 0.07 Mpa is about 100nm wider than other parameters. And the depth at 0.09 and 0.15Mpa are obviously shallower than other pressures. This is the error range of the current mold itself or the error caused by the manufacturing process.

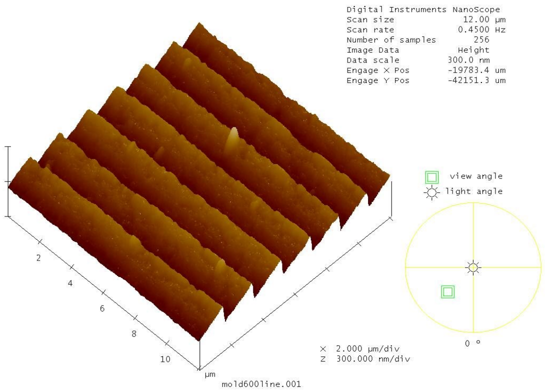

Figure 6. The mold profile of 600 line/mm, the line width is about 1.8 μm and the depth is about 131.47 nm

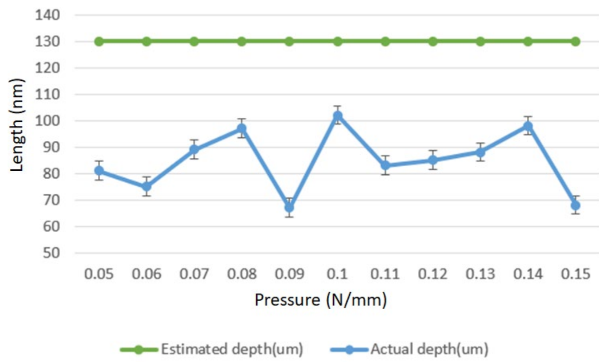

Figure 7(a). The relationship between pressure and line width of 600 line/mm

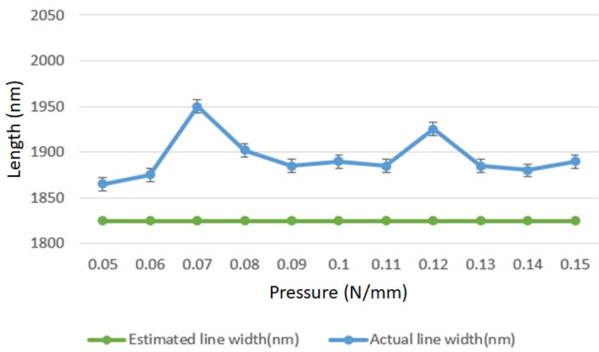

Figure 7(b). The relationship between pressure and depth at 600 line/mm

This study also discusses the influence of temperature on the imprinting microstructure during the nanoimprinting process. The imprinting experiment is performed at intervals of 5°C between 140 and 180 °C with a fixed imprint pressure of 0.1 Mpa. This study investigates the results of the embossing of 600 bars/mm structure at different temperatures.

The experimental results are shown in Figure 8 and Figure 9, where the line width of Figure 8 at 145℃ is smaller than originally expected. This may be because the entire mold was not filled when the PDMS mold core was retransferred, but it may also be due to 600 lines/mm mold is damaged in some parts, resulting in a slight error in the data at 145°C. As far as the line width part is concerned, the imprinting result of 600 lines/mm is about 1850~2000 nm. Compared with the experiment of fixed temperature and changing pressure, the temperature change will not directly cause the change of the line width parameter.

The depth of the embossed result at 140℃ in Figure 9 is from the original expected depth of 131.47 nm. After embossing, it is only about 20~30 nm. We believe that a wider line width of 600 lines/mm should be filled better, but the required filling volume is relatively large. Therefore, the filling volume required due to poor fluidity during filling is relatively large, which makes PS thermoplastic polymer unable to fill the mold.

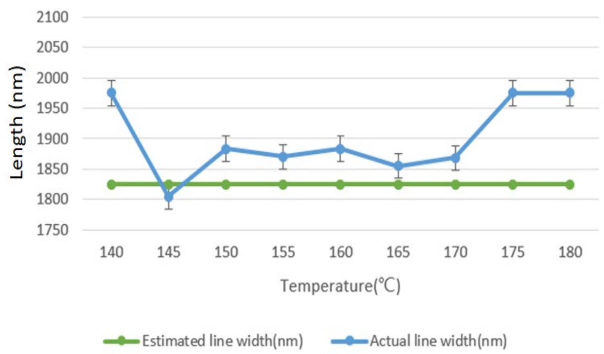

Figure 8. 600 bar/mm temperature and line width relationship diagram

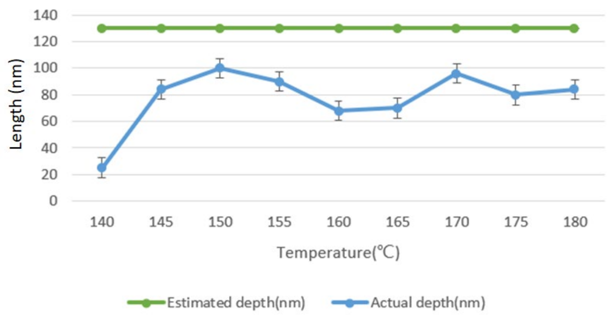

Figure 9. 600 bars/mm temperature and depth relationship diagram

V. CONCLUSIONS

According to the current experimental results of imprinting 150 line/mm, different pressures are not very sensitive to the line width and depth. However, when the line width suddenly expands at 0.15Mpa, the depth does not change much. In this part, we did three times of the same experiment and got the same result, so we think that in this part, it may reach the range of the maximum imprinting force of 150 line/mm.

According to the experimental results of 600 line/mm, the pressure of 0.05~0.15 Mpa is within the allowable range of imprinting, and the imprinting structure of 600line/mm under the pressure of 0.15 Mpa is also twisted and deformed. As far as the experimental results are concerned, the effect of depth mostly comes from the temperature during transfer. The high temperature increases the fluidity of the polymer, and it is more advantageous when filling the mold core. But the high temperature is not what we want. Because the change between heating from low temperature to high temperature and then from high temperature to low temperature is quite drastic, it may cause some unnecessary factors. In addition, the higher the temperature during transfer, the time will increase and the process will become more time-consuming. Therefore, it is best to choose a better temperature during embossing to get better results. At present, we use PS thermoplastic polymer materials between 145 and 180 ℃, which are more suitable parameters for embossing.

During the learning process, students often feel flustered due to the subject's brainstorming process, production methods, integrated sensors, or not knowing how to correct them. They can make corrections through constant teacher-student discussions and observe peers' works to increase their self-energy. Strengthen learning confidence and find specific learning and application directions. There are frustrations in the process, but when I see the results, I feel a sense of accomplishment.

In response to the different theme units of each design, you need to learn and understand the professional knowledge of each aspect, and at the same time in-depth exploration of the field. In the creative process, you can also try composite media and materials for design, and find answers to questions in the process of hand-made models. , To implement the concept of learning by doing and learning by doing. Students who learn through the innovative STEAM teaching model have the ability to integrate and cross-domain, and are also keen on observing things, and can actively explore and answer and get used to the teamwork atmosphere, which helps Talent characteristics and creative practical ability requirements in future employment.

In the future, the unit results of this course will be gradually introduced into other related experience courses, and more diverse materials and sensing devices will be added, which will help students have the motivation to explore problems independently in their learning, and at the same time, they will simulate the way the project is carried out. Subject exploration, problem-solving, finding answers, learning cross-domain knowledge, applying it to works, and finally appraising works. It will help enhance students' interest in learning and cross-domain learning capabilities in overall learning, and make learning more practical and practical. Industry docking.

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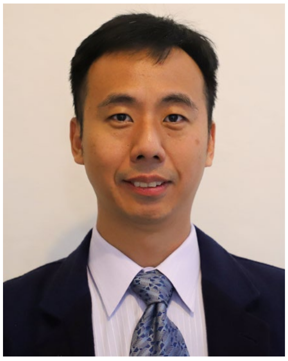

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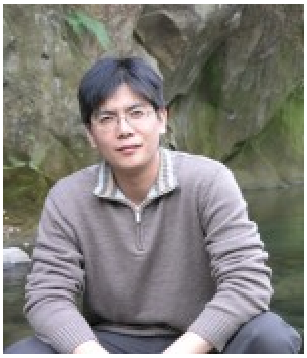

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