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Based on Hot Embossing Lithography Preparation of High-Precision Micron-Level Pattern

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Abstract: Compared with UV embossing and micro-contact imprinting, hot embossing technology is the first to be used in nano-imprint lithography, and is access to copying the parallel structure in micro-nano-scale at low cost and relatively faster speed. This paper explores which factors influence some pattern transferring accuracy appearing in the experiment: the adhesion between mold and polymethyl methacrylate, the main factors of affecting embossing plastic flow including imprinting pressure, temperature, time and the plastic filling effect affected by mold pattern, the effect on the viscosity of embossing adhesive by temperature and the effect on the viscosity of embossing adhesive by embossing pressure and time. The parameters affecting the accuracy of pattern transfer are optimized via the IntelliSuite simulation designed specifically for Micro-electro-mechanical systems. A micro-level pattern with high-precision by the use of nano-imprint Obduct machine is eventually made. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Nano-imprint lithography, Hot embossing lithography, MEMS, IntelliSuite, Micro-scale patter.

1. Introduction

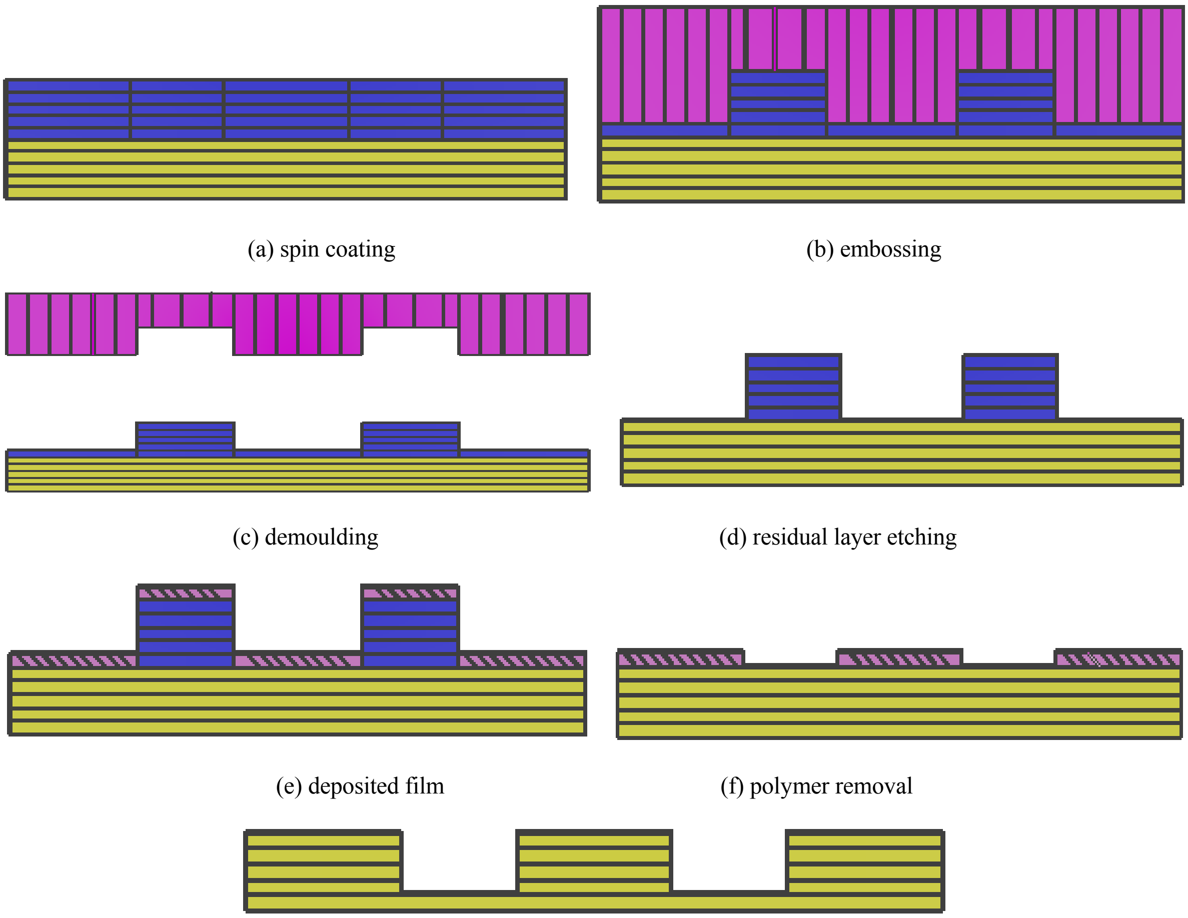
Nano-imprint technique comes from soft-engraving technique development. In order to obtain nano-scale pattern, we use rigid die painted nano-pattern to extrude the polymer film on a chip, then, the stamping parts is treated by etching, peeling, and other processing, nano-structures and devices are made. At present, nano-imprint technology has been widely used in the field of microfluidic chip manufacturing [1, 2].

Nano-imprint technology mainly includes hot embossing (HEL), UV embossing (UV-NIL) (Step – Flash Imprint (S-FIL)) and micro-contact imprinting (μCP) three kinds. Among them, hot-pressing process is good at obtaining micro-nano-scale structure of a parallel copy, and it is low-cost and fast, the same structure can be copied to large surfaces by one mode. This paper introduces the process of hot embossing, analyzes the factors influencing the accuracy of pattern transfer.

This article describes the process of hot embossing, and explores which factors influence some pattern transferring accuracy appearing in the experiment. The parameters affecting the accuracy of pattern transfer are optimized via the IntelliSuite simulation designed specifically for MEMS. A micro-level pattern with high-precision by the use of nano-imprint Obduct machine is eventually made.

2. Process of HEL

The process of HEL is illustrated in Fig. 1. Initially, the positive silicon mold pattern are fabricated using HEL technology, including the following steps: spin coating and baking of the HEL thermoplastic polymer over the two inches silicon wafer, imprinting process, residual layer etching by an oxygen plasma, depositing film, polymer removal and etching.



(a) spin coating (b) embossing

(c) demoulding (d) residual layer etching

(e) deposited film (f) polymer removal

(g) etching

Fig. 1. The process of HEL.

3. Experiment

3.1. Equipments & Materials

Equipment: P6708D spin coater; nano-imprint obduct machine; DM RXE HC Metallurgical Microscopy; BOC EDWARDS AUTO306 vacuum coating machine; MMM vacuum drying oven; 1530VP field emission scanning electron microscope (SEM); Oxford Plasmalab 80 plus RIE; Nanoscope 4 scanning probe microscopy.

Material: PMMA particles purchased from ACROS, (glass transition temperature is 105°C, molecular weight Mw=35K; glass transition temperature is 122 °C, molecular weigh Mw=350 K), 1H, 1H, 2H, 2H-perfluorodecylsilane (F13–TCS) purchased from perimed, anisole (molecular weigh: 18.14), acetone solution (analytically pure), HF solution (analytically pure), HCL solution (analytically pure), H_2O_2 solution (analytically pure), H_2SO_4 solution (analytically pure), 2 inches P-type polished silicon wafers etc.

3.2. Equipments Processes

Nano embossing experiments conducted in clean room, Initially, Configuration Mw=35 K and Mw=350 K of PMMA plastic, (PMMA particles dissolved in anisole 10 % (wt)), spin coating over the two inches silicon wafer, in order to complete curing PMMA plastic, baking 1h at 170 °C in vacuum oven. After drying, scanning probe microscopy (SPM) measures the film thickness is 1 µm. In the experimental processes, temperature range 190 °C~200 °C; pressure range of 40~50 Bar; time range of 180~540 s, mold release temperature range 80 °C~90 °C. 3 impressing conditions are shown in Table 1.

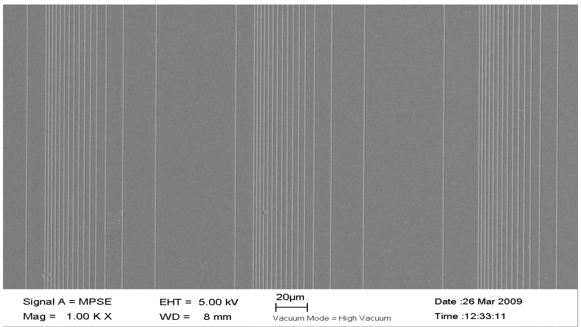
Table 1. Embossing condition.

Experiment	PMMA (Mw)	Embossing Pressure (Bar)	Embossing Time(s)	Mold removal temperature (°C)	Embossing Temperature (°C)
1	350 K	40	300	90	190
2	350 K	50	300	80	190
3	35 K	50	500	80	200

3.3. Some Problems of Microscale Pattern Transfer

There are concave mold box array and line graphics on micron size mold graphics. The width of square array is 5 µm, the depth of step is 0.7 µm, and interval period is 4 µm. The mold graphics is illustrated in Fig. 2.

(a)



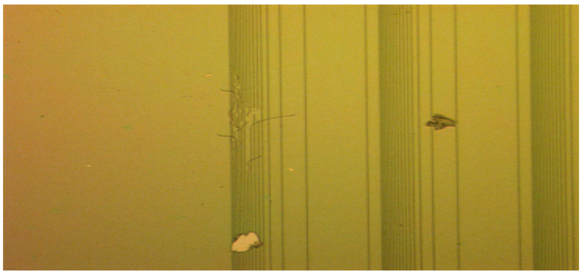
(b)

Fig. 2. (a) the metallographic microscope bright field image of mold box array; (b) the SEM image of the line.

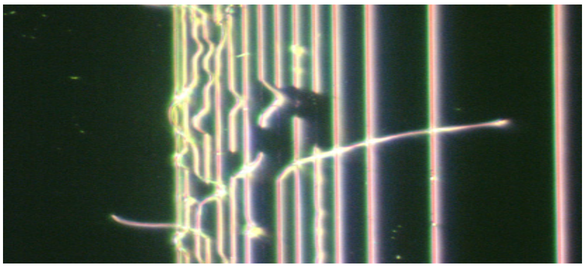
3.3.1. The Adhesion between Mold and PMMA

Fig. 3 illustrates the torn line because of excessive adhesive force between mold and PMMA.

In 2001, the founder of hot stamping technology Stephen Y Chou has realized the adhesion between PMMA and mold and put forward a 1H, 1H, 2H, 2H-Perfluoro octyl trichlorosilane (F13-TCS) prepared Si anti-adhesive layer. We used 1H, 1H, 2H, 2H-Perfluoro octyl trichlorosilane (F13-TCS) materials to prepare anti-adhesive layer of mold by vapor phase in this study, and the effect is very good.



(a)



(b)

Fig. 3. (a) the metallographic microscope bright field image of torn line; (b) the metallographic microscope dark field image of torn line.

3.3.2. The Embossing Plastic Fluidity

Incompletely plastic filling effect is shown in Fig. 4. We must take into account the above factors of affecting embossing plastic fluidity.

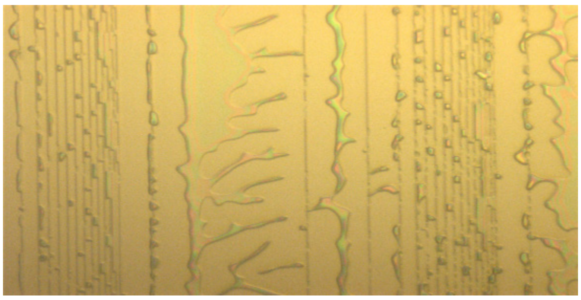


Fig. 4. The phenomenon of PMMA plastic incompletely fluidity.

3.3.2.1. The Effect on the Viscosity of Embossing Adhesive by Temperature

Temperature is higher than the glass transition temperature of embossing adhesive in hot embossing process, but the temperature is too high, molecular chain structure of embossing adhesive may be damaged, which makes graphics cause a lot of embossing defects. The low temperature will lead to incomplete filling and insufficient embossing plastic fluidity. Equation (1) illustrates the ratio of polymer viscosity relationship varies with temperature.

$$\log\left(\frac{\eta}{\mu_0}\right)=\frac{\left(-c_1\left(T-T_0\right)\right)}{\left(c_2+\left(T-T_0\right)\right)}, \qquad (1)$$

where η is the viscosity of the polymer, T is the absolute temperature, τ_0 and η_0 are the values of τ and η at reference temperature respectively. Temperature T_0=Tg (Tg is the glass transition temperature of embossing adhesive), the constant c_1=17.44 K, c_2=51.6 K [3]. Viscosity ration of embossing adhesive decreases exponentially with the embossing temperature increase. The smaller molecular weight of embossing adhesive and the smaller embossing viscosity, embossing plastic fluidity is better. However, higher temperature damages the embossing equipment and the embossing base badly. And the demoulding temperature is low, too high temperature will greatly increase the embossing cycle.

3.3.2.2. The Effect on the Viscosity of Embossing Adhesive by Embossing Pressure and Time

L. J. Heyderman et al. deduced (1) which is about transfer time [4]:

$$t_f=\frac{{}^{1}\!/_{h_f^2}-{}^{1}\!/_{h_o^2}}{2P}\eta * S_2, \qquad (2)$$

where t_f is the embossing time, η is the viscosity of polymer, S for the graphical area, h_f the polymer height after embossing, h_0 is the initial polymer height, P is the pressure. When the average molecular weight, thickness, template size and imprint temperature are constant, the embossing pressure and time selection depends on the viscosity of the polymer. Yoshihiko Hirai et al. deduce (3) by experiment [5].

$$t_f \propto \frac{\eta}{P^{2n}}, \qquad (3)$$

When viscosity is constant, increasing the embossing pressure will shorten the embossing time. However, increasing the temperature is more effective than increasing the pressure. The ratio of polymer viscosity changes with exponential relationship by temperature.

We conducted embossing tests under the conditions of experiment 2 of Table 1. There are many central holes in each array element, or near the center, as shown specifically in Fig. 2 (a).

We simulated embossing process by MEMS-specific design software IntelliSuite under the conditions of experiment 2 of Table 1.

Fig. 5 illustrates the simulation results.

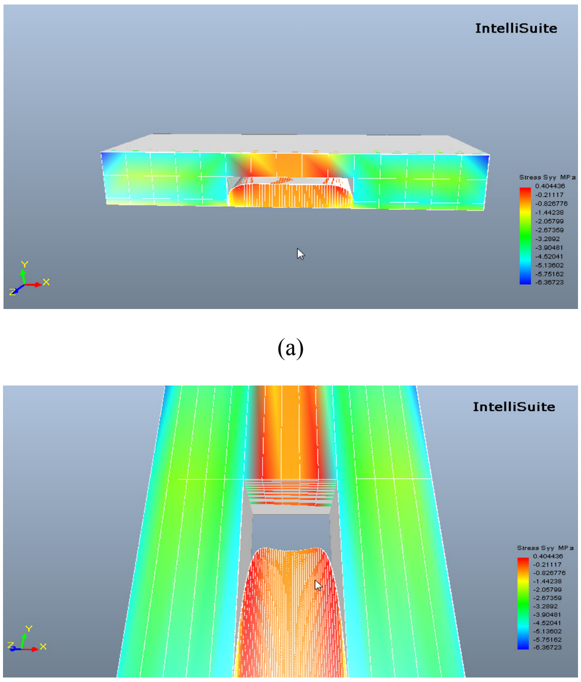


Fig. 5. Force simulation results.

It is clear that upward force is largest within the region box array. In order to facilitate viewing the simulation results, Y-axis values are enlarged 10 times, Fig. 5(b) illustrates the result.

Residual PMMA is removed by RIE, pattern is transferred to the silicon wafer by use of Cu mask, Fig. 6 shows the result.

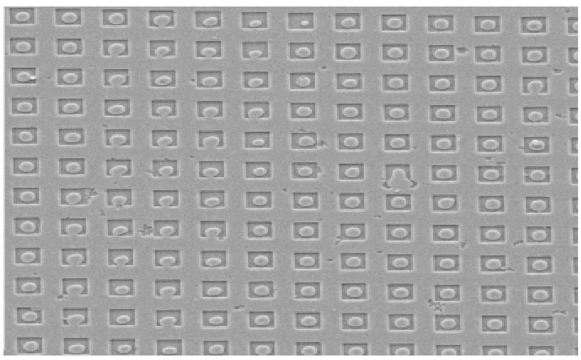


Fig. 6. Pattern transferred to the silicon wafer.

Fig. 6 shows pattern transferred to the silicon wafer has been severely deformed. We find optimal conditions and prepare high-precision micro-level graphics via comprehensive analysis on the embossing plastic fluidity and test equipment limitations. Fig. 7 shows the embossing result.

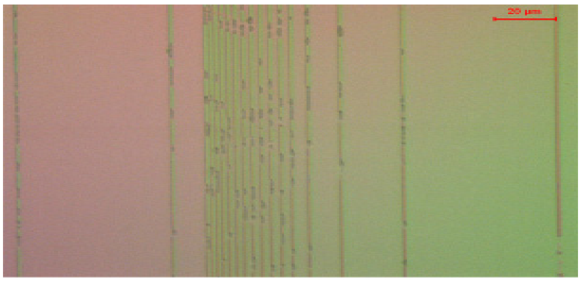


Fig. 7. High-precision micro-level graphics.

4. Conclusions

Hot embossing technology is a new type of micro-nano structure manufacturing technology. Its applications are not limited to the manufacture of micro-electronic structures, the rapid development of micro fluidic chip greatly broadens its application scope [6]. Some relevant parameters are analyzed, and polymer filling processes are simulated by MEMS-specific design software IntelliSuite. Micron high-resolution graphics are prepared by nano-imprint Obduct machine.

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