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超声波键合能量引导微结构PMMA基片的制作

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摘要:为了用超声波键合的方法实现微流控芯片的封装,采用选择性键合方式在聚甲基丙烯酸甲酯(PMMA)基片的微沟道两侧设计、制作了能量引导微结构,用热压法在同一PMMA基片上一次成形了凸起的能量引导微结构和凹陷的微沟道。用套刻和湿法腐蚀的方法制作了复合一体化硅模具。通过正交实验,确定了优化后的热压工艺参数。实验结果表明,由于同时存在凹、凸微结构,因此优化后的热压成形温度比传统的热压凹陷结构的成形温度提高15~20 ℃,在温度为140 ℃、保压时间为300 s、压力为1.65 MPa的实验条件下,微结构的复制精度达到了99%。

关 键 词:聚甲基丙烯酸甲酯基片;能量引导微结构;微超声键合;热压
中图分类号:TN405;TN305.99 **文献标识码**:A

Fabrication of micro energy director on polymethyl methacrylate substrate for micro ultrasonic bonding

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Abstract: In order to use a micro ultrasonic bonding method to package polymer microfluidic chips, an auxiliary microstructure named micro energy director is designed and fabricated on two sides of the microchannel by a selective bonding method in this paper. A hot embossing method is adopted to fabricate this newly designed Polymethyl Methacrylate(PMMA) substrate containing both convex micro energy directors and concave microchannels, then a complex silicon mold is designed and fabricated by the multi-photolithography and wet etching. By the Taguchi method, the optimized parameters for hot embossing are obtained. Experimental results show that the optimized embossing temperature is 15—20 ℃ higher than that of the simply replicate concave microstructure, since concave and convex micro structures are formed simultaneously. With the optimized parameters in an embossing temperature of 140 ℃,

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holding time of 300 s, and an embossing pressure of 1.65 MPa, the accuracy of replication can be up to 99%.

Key words: Polymethy1 Methacrylate (PMMA) substrate; micro energy director; micro ultrasonic bonding; hot embossing

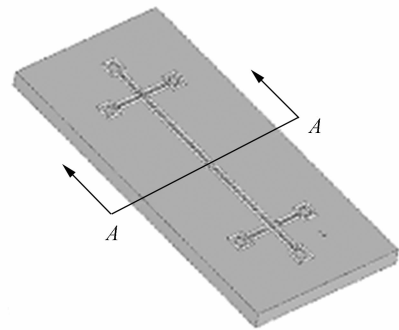
1 Introduction

Polymer microfluidic chip has shown its great success and increased acceptance in various application fields, such as analytical chemistry, biological, pharmaceutical development and chemical synthesis systems[1-4]. Besides the functional enhancements, the dramatic reduction of its fabrication cost is an impressive progress. In the fabrication process of microfluidic chips, bonding is the key procedure. Up to now, several methods for the bonding of polymer substrates have been studied, including thermal bonding in convection oven or in hot embossing machine, gluing and laser lamination[5-7]. Micro ultrasonic bonding is a promising technique in this category. Other than direct thermal bonding, this method has higher efficiency, lower deformation and can realize selective package[8]. In order to ensure bonding precision, an auxiliary microstructure named microenergy director was designed and fabricated on a PMMA substrate.

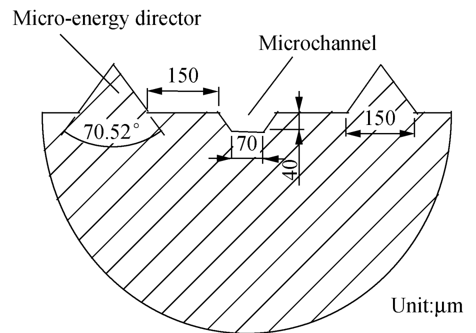
Because of its economy, high precision and fast method, hot embossing is widely employed for replication of micro nano scale structures. Therefore, in this paper, hot embossing method has been used to fabricate the microstructures. However, as to the fabrication of the PMMA substrate for micro ultrasonic bonding by hot embossing method, there is still no systematical research. In this fabrication process, making the complex mold and determining the hot embossing parameters by experiments are significant to the quality of fabricated substrates. In this paper, a silicon mold is designed and adopted, and a fine PMMA substrate is fabricated by hot embossing with the optimized control parameters in the experiments.

2 Experiments

In the fabrication process, making a complex mold and determining the embossing parameters are significant to the quality of the fabricated substrates. The layout of the substrate is shown in Fig. 1.



(a) Three dimensional model of PMMA substrate



(b) Cross section of PMMA substrate

Fig. 1 Three dimensional model and cross section dimension of PMMA microfluidic substrate

2.1 Silicon mold

The dimension of silicon wafer is 52 mm × 27 mm × 1 mm, and the mold with micro-energy directors and microchannels for hot embossing is fabricated by multi-photolithography and double anisotropic etching. In the course of this proce-

dure, the first anisotropic etching is performed to fabricate crossing microchannels with 70 μm in width and 40 μm in height. Then within the same wafer, the inverse isosceles triangle cross section shaped micro-energy director with 70.52° in top angle and 150 μm in length of base is performed by the multi-photolithography and the second anisotropic etching. The silicon mold and its details are shown in Fig. 2.

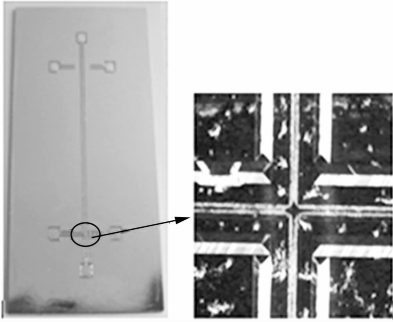


Fig. 2 Silicon mold and its details

2.2 Polymer material

Polymethyl methacrylate (PMMA, from Asahi Kasei Corporation, Japan) substrate is used in hot embossing process because of its good light transmittance and easy fabrication. The main chemical properties in detail are shown in Tab. 1. The PMMA substrate with dimensions of 50 mm×25 mm×2 mm has been cut by laser. Ultrasonic cleaning and soft baking have been used to pre-treat the PMMA substrate.

Tab. 1 Main chemical properties of PMMA (Asahi Kasei, Japan)

Glass transition temperature/℃	105
Thermal deformation temperature/℃	92
Linear expansion coefficient/(cm/cm ℃)	6×10^{-5}
Water absorbency/%	0.3
Light transmittance/%	93

2.3 Embossing machine

Hot embossing process is performed by an automatic hot embossing machine RYJ-II (Fig. 3), which is designed and developed at research center for micro system technology at Dalian university of technology. RYJ- II provides embossing temperatures range from room temperature to 300 ℃ with control precision of 2 ℃, and the pressing force is up to 50 kN with control precision of 0.04 kN. The machine also provides precise control of displacement.

Fig. 3 Hot embossing machine RYJ-II

In this experiment, the placement of silicon mold and PMMA substrate are illustrated by Fig. 4.

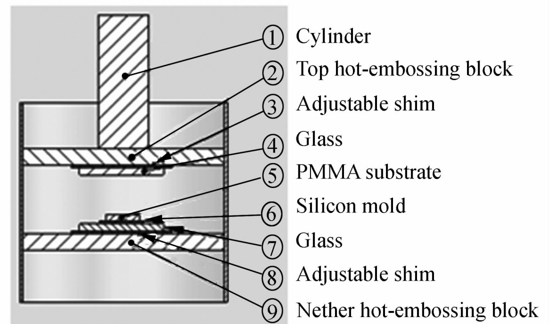


Fig. 4 Placement of Silicon mold and PMMA substrate

2.4 Embossing Process

In the course of hot embossing process, pressure, holding time and temperatures are significant parameters for high replication accuracy. And increasing embossing temperatures is more efficient than increasing other parameters. As to the complex three-dimensional microstructure, higher embossing temperatures is needed to form the microchannels and let the materials of PMMA on the surface of substrate fill the micro inverse isosceles triangle groove on the mold.

However, hot embossing is essentially an open-die compression process. Therefore, high embossing temperature will cause materials overflow the substrate.

By using of Taguchi optimization method, the orthogonal table $L_9(3^4)$ is adopted in this experiment. Based on the contributions of pressure, holding time and temperatures in several pre-experiments, the experimental factors and their levels are determined, which are shown in Tab. 2.

Tab. 2 Level-factor in orthogonal experiment

Level	t/℃	p/MPa	Time/s
1	130	1.35	180
2	135	1.65	240
3	140	1.95	300

The relationship between the time and temperature - pressure in the hot embossing cycle of one experiment is demonstrated by Fig. 5.

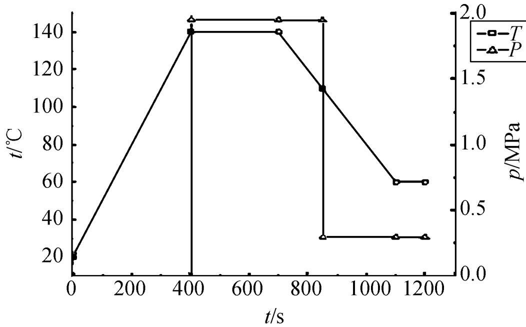


Fig. 5 Temperature-pressure profile for hot embossing cycle in one experiment

During the experiment, the microchannels can be precisely replicated. The main evaluation index for the experiment is replication accuracy of the micro-energy director. Then relative dimension error of micro-energy director is defined as the evaluation index.

$$P_h = \frac{|R_h - M_h|}{M_h} \times 100\% . \quad (1)$$

Where P_h is the evaluation index, R_h is the height of the micro energy director, M_h is the depth of isosceles triangle groove on silicon mold, as shown in Fig. 6.

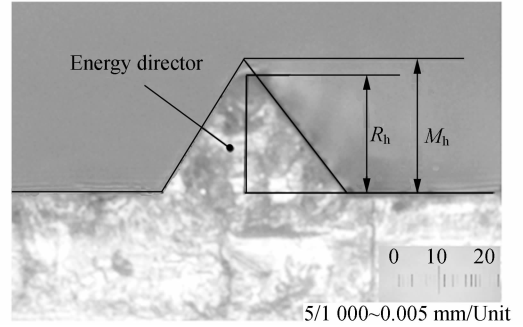


Fig. 6 Schematic of evaluation index in the experiment

3 Results and discussions

Optimized processing parameters are gained by evaluating the relative errors of height in the nine-orthogonal experiment. As shown in Tab. 3, with the temperatures increasing, replication accuracy increases, but the overhigh temperatures will lead to the excessive global deformation of PMMA substrate. Under the same temperature, replication accuracy can be improved by the increase of holding time. The pressure is not the significant factor during this experiment. The silicon mold is too brittle to be used as excess load. Then 1.65 MPa is adopted.

Tab. 3 Evaluation indexes of experiment

No.	t/℃	p/MPa	Time/s	P_1/%
1	130	1.35	180	68.907 6
2	130	1.65	240	65.546 2
3	130	1.95	300	31.092 4
4	135	1.35	300	21.848 7
5	135	1.65	180	28.890 8
6	135	1.95	240	26.571 4
7	140	1.35	240	2.521 0
8	140	1.65	300	0.840 0
9	140	1.95	180	5.882 4

From the displacement and temperature curve of top hot-embossing block shown in Fig. 7, the maximum temperature of the process is about 15 −20 ℃ higher than conventional hot embossing

temperature of microfluidic chips due to the integration of convex and concave microstructure on the same substrate. Consequently, larger deformation which can be represented by the distance of the top hot-embossing block is caused by the increase of the temperatures.

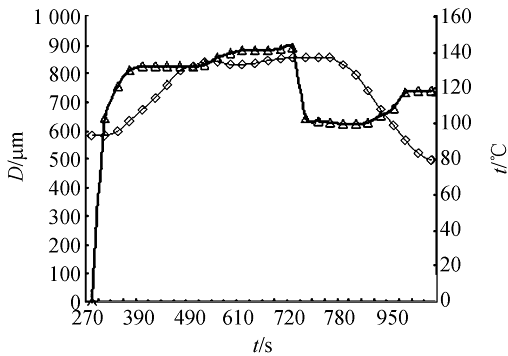


Fig. 7 Curves of displacement and temperature

As show in Fig. 8 and Fig. 9, the optimized parameters for hot embossing are: the embossing temperature is 140 ℃, holding time is 300 s, and embossing pressure is 1. 65 MPa, while the identical microstructures can be replicated with high accuracy.

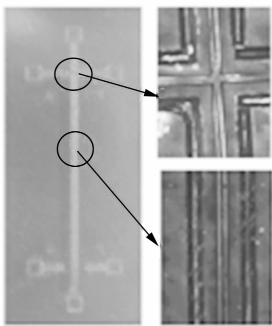


Fig. 8 Photograph of microfluidic substrate

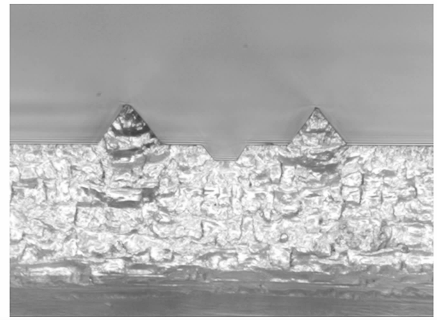


Fig. 9 Photograph of cross section (long channel)

4 Conclusions

In this research, by multi-photolithography and wet etching, the complex silicon mold which contained both convex micro-energy directors and concave microchannels is fabricated. Because the cross section of convex micro-energy directors influences the ultrasonic bonding quality directly, the embossing temperature must be 15 ℃ higher than that of the traditional hot embossing which only fabricates concave microchannels. Using high temperature hot embossing, complex micro structures can be replicated on the PMMA substrate with high duplication accuracy. According to Taguchi method, the optimized parameters are obtained: the embossing temperature is 140 ℃, holding time is 300 s and embossing pressure is 1. 65 MPa. The accuracy of replication is 99%.

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