

Evaluation of Shim Characteristics in Micro Hot Embossing on Polycarbonate Substrate

by

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Abstract

This research paper outlines the research activity being carried out at Industrial Research Institute Swinburne (IRIS) on the evaluation studies of different samples prepared using hot embossing technique. The objective of this research is to investigate microtribology aspects of electroformed shims meant for replication using hot embossing for Micro electromechanical systems (MEMS) applications. Micro hot embossing has been one of the most simple and cost effective route of replication of many MEMS components – using electroformed shim with the features on it to replicate these structures in plastics. There is a need to increase the lifetime of these electroformed shims as this has been recognised as one of major obstacles. This problem can be solved during shim fabrication (by altering electroforming conditions) and also by deposition of wear resistant materials TiN and CrN to improve wear properties of replication tools. As a first step in this direction, we have started work on evaluating the electroformed shim structures and the results of these studies are presented in this paper.

1. Introduction

Hot embossing is a simple method used for quality and precision replication of microstructures. It is the most effective way to achieve low-cost production and high replication accuracy of MEMS components as the demand for these devices is growing rapidly. A schematic representation of the hot embossing system is depicted in Figure 1 (Becker H. *et al.* 1999)

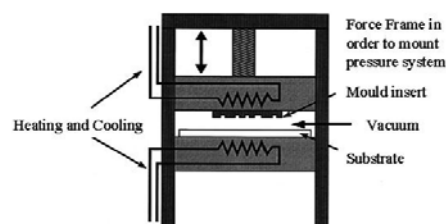


Figure 1.1 - Hot embossing system

An embossing tool, also referred to as a master or shim, is a negative copy of a required microstructure and can be fabricated in various ways. Traditionally CNC machining of stainless steel has been employed to achieve features $>100\ \mu\text{m}$ with no sharp corners or right angles. Smaller features however, require lithographic methods to deliver the desired accuracy (Becker H. and Dietz W., 1998). In this case, laser machined PC sheet was used as a mold to grow the nickel shim by electroforming.

The typical steps involved in a hot embossing process are shown in Figure 2.2. The whole process is performed under vacuum to prevent the formation of air bubbles and also to avoid the detrimental influence of evaporated water on the shim.

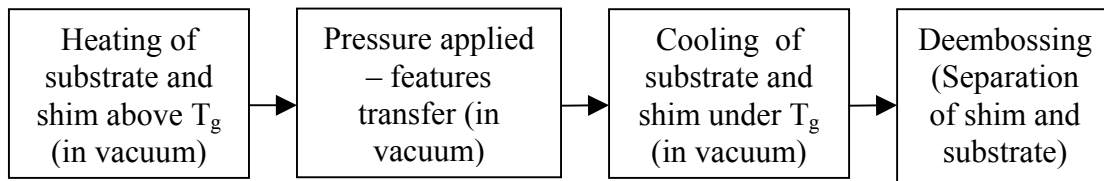


Figure 1.2 - Hot embossing process steps

The mold and substrate are heated up just above the glass transition temperature T_g of the substrate to ease imprint via change of substrate’s material properties. After the embossing time has elapsed the couple is cooled down while vacuum and pressure still applied under T_g to maintain embossed structure in solidified substrate (Becker H. and Gaertner C., 2000). This thermal cycle, the difference between the working and de-embossing temperatures, results in small, thermally-induced stresses. According to this cycle the recommended temperature range can be between 25 and 40 °C, or as small as possible (Becker H and Hein U, 2000). The last step is the separation of the shim and substrate, also known as de-embossing. The substrate with replicated structure is now ready for further optional machining processes.

The process described above is an isothermal embossing (both substrate and shim heated above T_g). Non-isothermal embossing is employed when the heat effect on the process (Juang Y. J. et al. 2000) is to be investigated, and in such a case only one of them the shim or substrate is heated to the embossing temperature. The embossing temperatures, pressures and times recommended in the literature differ significantly. Table 2.1 provides the range of parameters used in this work. These parameters will normally be decided depending on the feature size, geometry and shape of the pattern and finally the shim and substrate contact area.

Source	Pressure (MPa)	Temperature (°C)	Time (min.)
(Juang Y. J. et al. 2000)	0.1 – 0.4	155 - 175	5 – 10
(Becker H. and Gaertner C., 2000)	5 – 20	160 - 175	< 1
(Lee G.-B. et al. 2001)	> 0.1	150	> 10

Table 1.1 - Recommended embossing parameters

This paper presents results of our investigations on the evaluation of shims and the polycarbonate substrates after the embossing runs. Nickel shim with simple experimental cantilever structure was used for embossing on polycarbonate. Results of replication quality and extent at different working pressures during various embossing runs were evaluated using scanning electron, confocal and optical microscopy.

2. Experimental

The schematic of the cantilever pattern used in this work is shown in figure.3.1

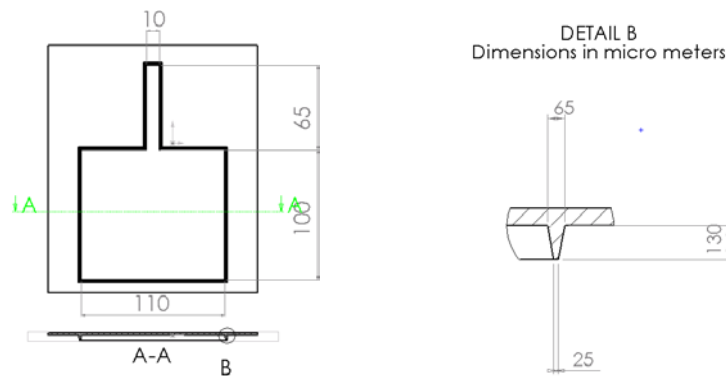


Figure 2.1 - Experimental cantilever structure

In hot embossing, the pressure, temperature and process time are the most important variables contributing to the quality of the embossed structure. In the following experiments, the effects of these parameters are presented with respect to the quality of the embossed structure.

The experimental setup showing a position of the PC substrate and the nickel shim is depicted in Figure 2.2. Substrate and the shim are placed between two aluminium plates and inserted into the embossing chamber. A thin steel sheet is placed between PC and the plate to prevent both sticking and embossing of features on a plate on the PC sample.

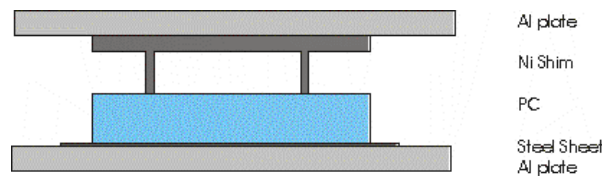


Figure 2.2 - Embossing sandwich setup

The working temperature was fixed just above the glass transition temperature of PC (150°C) as previously determined by differential scanning calorimetry (DSC).

The pressure is varied between 130 and 160 bars (supplied by hydraulic pump – pressure value indicates the pressure in the cylinder (\varnothing 38 mm, area of 1133,5 mm²), not the pressure applied to the sample). The shim and the substrate were of the same size 31 x 31 mm (total area of 961 mm²). A simple formula can be used to calculate the pressure applied to the substrate (1).

$$K = \frac{A_{Cylinder}}{A_{Substrate}} = \frac{P_{Substrate}}{P_{Cylinder}} \quad (1)$$

In this case, the pressure applied to the substrate is higher than the cylinder pressure due to the area difference (coefficient $K=1,18$). The working pressures then range between 153 – 190 bars.

After the sandwich is introduced into the heated embossing chamber, vacuum is applied to deliver appropriate environment during the process. When the temperatures of both the top and the bottom plate stabilize at the working temperature of 150°C, the pressure is applied. The cycle time was fixed at 5 minutes. Hence the pressure was applied for 5 minutes, and the sandwich was air-cooled down to 110°C (ca. 7 minutes) under the same vacuum and pressure conditions. After reaching 110°C, the sandwich was removed from the chamber and the substrate and the shim were separated.

Two more embossing runs were carried out at temperatures of 150 and 165 °C respectively, without applying any pressure externally. As no bending was observed in either of these shims, it is clear that the pressure effects appear to be more dominant than temperature, even though the thermal expansion coefficient for PC is typically 4x larger than that of Nickel (13µm/m°C).

3. Results

A combination of an increase in pressure and the number of embossing runs cause walls of the shim's feature to bend outwards. This might be due to the plastic flow of the substrate material due to increased pressure. As the material is enclosed by feature's wall, it tends to maintain its volume with decreasing vertical dimension as depicted in Figure 3.1. The results of this study and relevant observations are summarised in Table 3.1.

Parameter	Run1	Run2	Run3	Run4	
Working pressure (bars)	153	177	165	190	
Total Number of cycles	10	10	1	1	
Observations	After 1st run	Shim	Without significant change or damage, only traces of debris and silver (seedlayer) from electroforming removed		Damaged, walls bent under up to 45°, some areas with parts of the walls broken off
		PC	Channel transfer without problems		Lips of up to 40 μm, feature transfer poor due to the high pressure and damage
	After 5th run	Shim	No change or damage observed	Shortest wall bent outwards, other walls slightly too.	
		PC	Channels of good quality, some defects occur	Lips on edges of the channels. the bend is transferred too.	
	After 10th run	Shim	Wall conditions satisfactory, larger areas slightly bent	Walls heavily bent, broken off, even corners damaged	
		PC	Lip present on edges of channels, structure damage transferred.	Lip present on edges of channels. All structure damages transferred	

Table 3.1 - Results of embossing with various pressures and numbers of runs

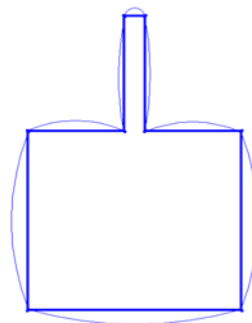


Figure 3.1 - Sketch of feature's damage

4. Conclusions

This study mainly concentrated on identifying the important parametric effects during the microembossing runs, which could affect the quality of replication of a given sample. This study clearly showed that the pressure, temperature and embossing time are the three important parameters, which together decide the quality of replicated feature with respect to the master. These results also indicated that the pressures above (approximately) 150 bars are not suitable, as this appears to lead to a structural damage due to the substrate flow effects. Finally, these preliminary investigations lead to a conclusion that the difference in thermal expansion coefficients of the shim and the substrate materials may not seriously affect the Nickel to poly carbonate embossing process.

5. Acknowledgments

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6. References

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