Micro- and Nano-fabrication of COC polymer microfluidic devices

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Introduction

Microfluidic devices are widely used for various kinds of bio/chemical analyses. Microfluidic chip networks benefit from the increase in surface area to volume ratio accompanying miniaturization that translates into reduced chemical requirements, improved control, faster processing and tremendous potential for parallel processing and process integration[1]. Initially silicon and glass was widely used for fabricating microfluidic device. However, the high cost involved in fabricating glass or silicon based devices limits their usage as disposable devices. Therefore, there is much interest in utilizing alternative materials that are cheaper, such as polymers, for making microfluidic devices. Moreover, polymers are cheap (necessary for a cheap disposable device) and can rapidly be manufactured through implementation of replication technologies for mass production [2]. In this article we have used hot embossing technique for manufacturing TOPAS (cyclic olefin copolymer) based microfluidic device.

The objective of this work is to study the behavior of the TOPAS (6015 grade) material during hot embossing process, with the aim of providing an optimized manufacturing process for microfluidic devices. The focus of the experiments is on the effect of three important parameters, namely: embossing temperature, embossing load and embossing time on the formation on microchannels.

Experimental

Sample preparation

In this study, Topas (6015 grade) provided by TICONA was used. It is a glassy polymer at room temperature, with glass transition temperature of approximately 160 ^{0}C. Each substrate with a thickness of 1mm were fabricated from Topas pellets using a Battenfeld injection molding machine and cut to 25mm × 25mm in size.

Fabrication of Si mold

The silicon mold was prepared using UV-photolithography technique followed by deep reactive ion etching process which contain an array of microchannels having 50 micrometer width and 100 micrometer spacing between the channels. The size of the mold was 20 mm × 20 mm and its thickness was 5 mm. The channel depth was maintained constant at 20 micrometer.

Characterization of microchannel

The 3D topography and channel profile (depth, top & bottom width) of the embossed channels were measured by PLμ Confocal microscope. For each dimension, eight measurements were taken and the average and standard deviations were determined and plotted. The surface morphology was inspected using a scanning electron microscope (SEM).

Throughout our studies, three key dimensions of the embossed microchannel, namely: the channel depth, top width and bottom width were determined.

Results and discussion

Effect of temperature on channel dimensions

To investigate the effect of embossing temperature, the temperature was varied from 160 to 175 ^{0}C while keeping the embossing load (2.94 kN) and time (180 seconds) fixed Fig. 1 shows the results of percentage change in channel dimensions with varying temperature It is clear from Fig. 1 that temperature has no significant effect on channel depth over the range of temperatures considered. In contrast, temperature had a significant effect on both the channel top and bottom widths. The variations in channel top and bottom widths were much higher at 160 ^{0}C and 165 ^{0}C than at higher of 170 ^{0}C and 175 ^{0}C. This is because the viscosity of TOPAS (6015 grade) was higher at the lower temperatures and therefore cannot flow as easily to fill up the microcavities during embossing than at higher temperatures. Moreover, the lower polymer viscosity at higher temperatures enables the microcavities to be filled easily thus resulting in less variation in the top and bottom widths. At 170 ^{0}C, excellent replication with that of the mold was obtained such that the variation in channel dimension was only about -1.2%. The variation in channel top and bottom width at 175 ^{0}C is higher compared to that at 170 ^{0}C. This may be due to the larger recovery of compressive elastic strain after demolding at 175 ^{0}C.

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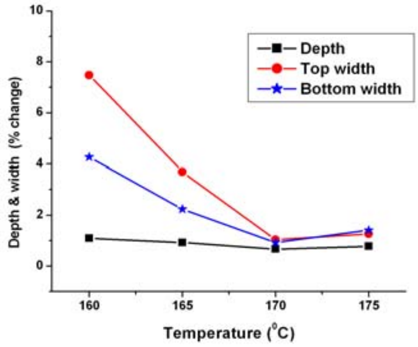

Fig. 1 Effect of embossing temperature on channel depth & width

Effect of embossing load on channel dimensions

To investigate the effect of embossing load on the replication process, the embossing load was varied form 1.46 kN to 2.94 kN whilst the embossing temperature (170 ^{0}C) and time (180 seconds) were kept constant. It can be seen from Fig.2 that the replication accuracy on channel dimensions increases as the embossing load was increased The depth of the microchannel increased as the load was increased. Full replication of the channel depth was obtained when the applied force was at least 2.5kN. For the channel top and bottom widths, the degree of replication also increased with embossing load. Excellent replication with dimensional variations of less than -0.98% was obtained when the load was 2.94kN. This is not surprising because at lower embossing loads, the polymer cannot completely fill the microcavities resulting in variations in the replicated widths. Larger embossing loads are required to ensure complete filling of the microchannels resulting in better replication of the mold

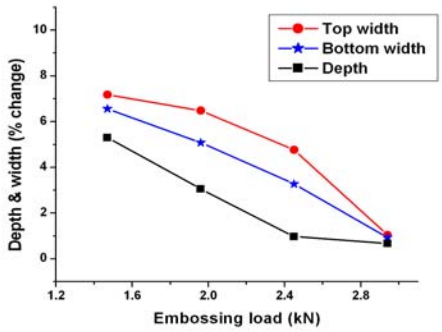

Fig. 2 Effect of embossing temperature on channel depth & width

Effect of embossing time on channel dimensions

To investigate the effect of embossing time on the replication process, the embossing time was varied form 60 seconds to 240 seconds whilst the embossing temperature (170 ^{0}C) and load (2.94 kN) were kept constant. It is clear from Fig. 3 that the replication accuracy on all the three channel dimensions increases as the embossing time was increased and reached an optimum at 180 seconds.

The replication accuracy decreased when the embossing time was more than 180 seconds. It can be seen from Fig. 6 that it was easier to replicate the depth compared to the microchannel widths. Full replication of the channel depth was obtained when the embossing time was at least 120 seconds. In comparison, the channel top and bottom widths were not fully replicated when the embossing time was 120 seconds but at 180 seconds

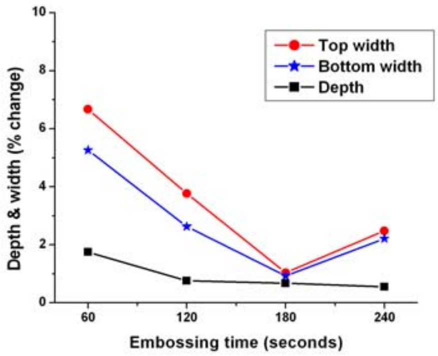

Fig. 3 Effect of embossing temperature on channel depth & width

Conclusion

We have demonstrated the fabrication of microchannel on COC (Topas-6015 grade) substrate through hot embossing technique which allows low cost, flexible fabrication of polymeric Microsystems. Excellent replication could be obtained when the COC embossing parameters, including temperature, force and time were optimized. For Topas 6015 excellent replication was obtained when the embossing force the embossing temperature and embossing time were 2.94kN 170 ^{0}C and 180 seconds respectively shown in Fig. 4.

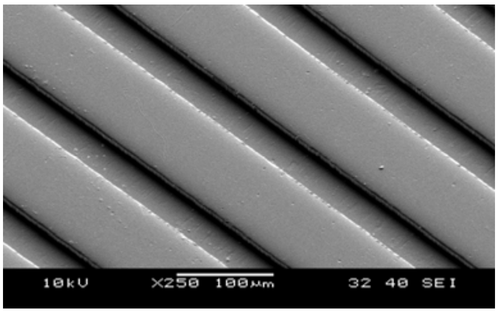

Fig. 4 SEM image of embossed microchannels at optimized parameters

References

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2. H. Becker and C. Gartner, "Polymer microfabrication methods for microfluidic analytical applications," *Electrophoresis*, **21**, pp. 12-26, 2000.