SOLVENT PROCESSING OF PMMA AND COC CHIPS FOR BONDING DEVICES WITH OPTICAL QUALITY SURFACES

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ABSTRACT

Many prototype microfluidic devices are manufactured by some form of micromachining or injection molding which often leaves poor quality surface. This work presents a simple method that both significantly reduces surface roughness of microfluidic chips and at the same time is used to bond devices. The method has been tested on devices made from poly(methyl methacrylate) (PMMA) and cyclic olefin copolymer (COC). The technique uses a solvent vapour exposure process which creates an irreversible bond between two substrates. It also re-flows the material, producing surfaces with optical quality.

KEYWORDS: Solvent vapour polishing, poly(methyl methacrylate), cyclic olefin copolymer, Microfluidics

INTRODUCTION

Many different methods have been presented for creating features and bonding microfluidic devices [1] from Poly(methyl methacrylate) (PMMA) and cyclo-olefin copolymer (COC). However, few methods address the issue of surface quality in the final devices. Rapid prototyping tools often create a surface roughness in the region of hundreds of nanometers [2] making them unsuitable for manufacturing integrated optical components such as lenses. The application of post-processing treatments such as surface coatings [3] can be used to reduce surface roughness but the effectiveness of these treatments is limited to certain applications. It is desirable to bond the polymer substrates in a repeatable, controlled manner and literature shows this is possible using COC and a 90 second solvent vapour exposure [4]. PMMA bonding has been shown in literature with solvent exposure methods including dipping in acetone [5] and soaking in isopropanol [6]. These methods provide bonding but without reducing surface roughness.

EXPERIMENTAL

PMMA (Röhm, Darmstadt, Germany) and COC (Topas 5013, TOPAS Advanced polymers GmbH, Frankfurt, Germany) were processed with micromilling fabrication techniques to create channels in substrates. Threaded ports for microfluidic connectors MINSTAC (The Lee Company, Connecticut, USA) were machined into the plastics prior to bonding. The design was drawn in CAD software and machined using an LPKF Protomat S100 micro-mill (LPKF laser and electronics AG, Garbsen, Germany). For solvent bonding, the two halves were cleaned with detergent then rinsed with DI water, isopropanol and ethanol and then dried with nitrogen. The two substrates were placed on glass stand offs in a petri dish which was then filled with solvent until the level was 2-3mm below the substrate surface. A lid was placed over the assembly to form a vapour exposure chamber. The whole assembly was placed in a water bath to maintain a constant temperature of 25°C. After solvent vapour exposure the two substrates were then aligned using a homemade corner jig with perpendicular sides. Both structures were pushed into the corner and pushed together to temporarily bond them prior to pressing. This provided an alignment accuracy of typically 20µm. A schematic diagram of the process is shown Figure 1 along with an example of the devices that can be produced.

Figure 1: Schematic of bonding process; substrates are machined, exposed to solvent vapour, pressed together by hand and bonded in a press. Devices show uniform bonding over whole surface. The PMMA chip shown has overall dimensions of 40[w] x 80[l] x 9.5mm[h]
The solvents used were chloroform for PMMA substrates and cyclohexane for COC substrates as these provided softening of the different surfaces at similar rates. The hot press used to process the microfluidic chips was an LPKF Multi-press which was pre-heated to 65°C with a pressure of 140 N/cm² for 20 minutes, then actively cooled to room temperature over 10 mins. The chips were removed from the press and left to settle for 12 hours.

After micromilling and solvent exposure, the micro-channels were examined using Atomic Force Microscope and Scanning Electron Microscopy. The bond strength was characterised with an ASTM D1876 T-Peel test using an Instron 5569 tensile testing machine (Instron, Buckinghamshire, UK).

RESULTS AND DISCUSSION
The change in surface roughness of a channel machined in PMMA is shown in the SEM images in Figure 2. The typical surface quality of the micromilled substrates is rough (typical surface roughness was 100-200 nm measured using AFM) and mis-alignment between machined layers is clear. Post solvent vapour exposure, the surface is smoothed to less than 15 nm roughness and the effect can clearly be seen in Figure 2C.

Using a peel-test, a series of test pieces were bonded together with different bonding parameters and the failure force measured (Figure 3). This allowed optimization of the process allowing strong bonds to be created while avoiding channel collapse.

Figure 2: SEM images of microchannel (200µm depth was achieved with two 100µm cuts) demonstrating the smoothing effect of exposure to solvent vapour; A) PMMA post milling; B) Detail of PMMA post milling; C) PMMA after 4 min. chloroform solvent vapour and 30 min, 60°C heat cycle

Figure 3: (A) Effect of exposure time on the peak peel force (B) Effect of bonding pressure on peak peel force
In order to view the surface smoothing effect on optical components devices were made with integrated lenses. Figure 4 shows light passing through a 150µm diameter lens fabricated by micro-milling onto a fluidic channel. The effect of the surface smoothing reduces scattering and improves the light collimation.

CONCLUSION
Our work provides a low-cost method of surface smoothing (giving <15nm surface roughness) and irreversible bonding in one simple process. We have performed further extensive characterisation with SEM and AFM, and optimization of process parameters to ensure maximum bond strength, minimizing channel collapse and refloowing the polymer to give maximum bond uniformity.

In conclusion we have demonstrated a rapid procedure for the manufacture of microfluidic devices in PMMA and COC. A solvent bonding technique was used to produce bonded devices with channel walls of near optically quality, providing an inexpensive rapid prototyping system for the fabrication of micro-devices with integrated optical components such as lenses.

ACKNOWLEDGEMENTS
This work was supported by funding from EPSRC and NERC.

REFERENCES

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