

Sealing of Microfluidic Devices using Microwave Technology

by

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Abstract

This project is being conducted at Swinburne University's Industrial Research Institute (IRIS) in collaboration with the CRC for MicroTechnology. It was commenced in the middle of 2001 and is expected to be complete in mid-2004. The purpose of the program is to utilise microwave technology to develop innovative and practical techniques for the sealing of microfluidic devices, which are advanced analytical devices for chemical and biotechnology applications.

1. Introduction

Microfluidics is the manipulation of micro amounts of gases and liquids within channel networks in which the diameter of individual channels is measured in microns. In the work that will be studied here, these channels networks are contained within polymer slides of various polymers, including PC, PMMA, PS and PET. The basic fabrication process for these devices starts with a flat polymer slide. A channel network is laser ablated into this slide to form the prototype. From this prototype, a metal plate with the channel network reproduced in it is fabricated to form the tool for a hot embossing press. A hot embossing press can be used to mass produce the channel network in other polymer slides. After the network structure is embossed into a substrate material, a cover plate must be sealed over the top to produce a four-walled enclosed channel. This final sealing step is the focus of this project.

2. Industrial Implications

Microfluidic devices are a fundamental component of the minaturization of analytical tools for biotechnology and chemical analysis, and the mass commercial production of microfluidic devices will dramatically streamline and simplify the collection of scientific data in these fields.

Currently, fabrication and packaging comprises the majority of both cost and volume for microfluidic devices, and sealing is one of the more difficult aspects of

fabrication and packaging. Therefore, improvements in sealing technology would significantly advance the commercial viability of this technology.

3. Sealing of Microfluidic Devices

Mass production of microfluidic substrates usually involves the use of injection moulding or hot embossing, but it also incorporates a sealing step in which a flat plate is fixed over the open channel network in order to produce a closed channel network.

Currently, sealing of microfluidic devices is being done with a variety of methods, including lamination, gluing and thermal bonding. The lamination method consists of a two-part lamination sheet of PET and PE, with the latter acting as a thermal adhesive (Roberts *et al.*, 1997). One consequence of this technique is that the internal walls of the network channels are inhomogeneous, with three walls of PET and one of PE, which can have a negative influence on the performance on the device (Wu *et al.*, 2002).

Similar to lamination, conventional gluing has been used, where problems of channel blockage occur (Soane *et al.*, 2001), and subsequent development has led to multistage processes where the adhesive is applied, then partially cured to render it non-flowing, and then the cover plate is fixed over the channels (Soane *et al.*, 2001). Thermal bonding involves the application of heat and pressure to produce a seal, but this technique poses the problem of damaging the integrity of the channel network (Paulus, *et al.*, 1998).

The method that will be studied in this project, direct joining of polymer sheets by plasma activation at the surface, is a new technique that has reported success for a few materials, such as PDMS (Duffy *et al.*, 1998; Kim & Knapp, 2001), PET (Wu *et al.*, 2002) and PE (Sapieha *et al.*, 1993) but not some of the more common microfluidic substrate materials such as PMMA and PC (Duffy *et al.*, 1998).

Unfortunately, PDMS at least is an inferior material for microfluidic substrates, since it has a limited lifespan in terms of stable electroosmotic flow, and its poor stiffness may be a drawback in terms of maintaining a stable geometry (Wu *et al.*, 2002). PDMS also has poor chemical properties as well that make it a difficult candidate for microfluidic devices, since the sample is easily absorbed onto the walls of the microstructure or even diffuse into substrate (Wu *et al.*, 2002).

4. Plasma

Plasma has been described as the fourth state of matter besides the solid, liquid and gaseous states. The principal difference between a gas and a plasma is that the plasma is kept in a very high energy level, consisting of neutral, radical and charged

particles and may also be accompanied by UV and UV-vis radiations. Because of this high energy character, plasma is very reactive.

5. Surface Modification by Plasma

The interactions of a plasma with a polymer surface can be divided into four general categories; cleaning, ablation, crosslinking and chemical modification. Of these, this project will deal mostly with the last option, but also partly with the first option. The first option simply relates to the removal of surface contamination from the polymer in order to prevent that contamination from interfering with adhesion processes. The last option involves deliberately altering the surface region to include new functional groups. These functional groups then interact with other functional groups on the opposing surface to produce a direct chemical bond across the interface, effectively turning the two sheets of polymer into one. In the case of PDMS (McDonald et al, 2000), plasma treatment replaces the surface methyl groups (-CH₃) with hydroxyl groups (-OH). When the two opposing layers of hydroxyl groups come into contact, they condense, and each pair of opposing hydroxyls (-Si-OH + HO-Si-) condense to yield (-Si-O-Si-) bonds and a water molecule (H₂O).

6. Progress to Date

The use of plasma surface modification is a recent development in the project, and little work has been done so far in this direction. Most work so far has been done in the areas of literature review and experimental planning and evaluation of various microwave joining ideas including:

- (i) Using a layer of microwave conducting powder that would heat up and melt the substrate in a highly localized fashion, producing a dispersion of microscopic spot welds
- (ii) The use of a microwave conducting mesh, to produce much the same effect as the above method
- (iii) The mixing of thermally cured adhesives with a microwave absorbing powder in order to produce adhesives which had too high viscosity for them to block the channels
- (iv) The machining of “technical channels” alongside the microfluidic channels that would be filled with a microwave absorbing polymer called polyaniline. This polymer would absorb the microwaves, heat up and melt the surrounding polymer, and produce a seal.

These sealing concepts have, for the most part, been rejected, for a variety of reasons, including:

- impracticality
- damaging the optical and aesthetic properties of the device
- presenting only marginal improvements from current technology
- offering limited improvement even if they could be done effectively

7. Research to be Undertaken

Initially the work will be organised in two directions:

- Studying the effects of plasma surface modification
- Optimization of plasma properties to maximize adhesive strength.

The first of these will be a more broad based approach to plasma treatment, while the second has a much narrower focus. Candidate materials include those materials where this technique has been reported successful, PE, PET and PDMS, as well as those materials where it has not, PC, PS, PMMA.

The parameters that will be varied include material, plasma gas, gas flow rate, plasma pressure, distance from the plasma, time of exposure to plasma.

The results will be investigated by a variety of equipment, including contact angles, attenuated total reflectance FTIR, atomic force microscopy, X-ray photoelectron spectroscopy. These techniques are for investigating surface modification; investigation of adhesion strength will be by mechanical testing.

If substantial mechanical strength can be achieved, the technique will be investigated for actual microfluidic devices, and leakage and pressure tests will be used to test the effectiveness of the seal.

8. Conclusions

The purpose of the project is to utilize microwave technology to develop innovative and practical techniques for the sealing of microfluidic devices, which are next generation analytical devices for chemical and biotechnology applications. Literature review was conducted and a variety of concepts were considered for the use of microwave technology, but it would appear that plasma activation of the surfaces holds great promise for technical and commercial viability, and so the project will largely focus on this technology.

9. References

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