

# THERMAL BONDING OF POLYMER MICRODEVICES USING A PRESSURE-ASSISTED BOILING POINT CONTROL SYSTEM

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## ABSTRACT

Sealing is a critical process for obtaining closed microchannels in the manufacture of polymer microfluidic devices. A new thermal bonding method using a pressure-assisted boiling point (PABP) control system was developed and tested. The PABP system is able to apply precise temperatures and pressures during bonding. The PABP system was used to seal very low aspect ratio (AR) microchannels ( $AR \geq 1:100$ ) and three-dimensionally (3D) shaped flexible polymer micro channels.

**KEYWORDS:** Thermal Bonding, Thermoplastic Fusion Bonding, Polymer Sealing, Lab-on-a-Foil

## INTRODUCTION

Thermal fusion bonding (TFB) is a relatively easy, simple technique that is widely used for covering microfluidic channels. However, precise control of the bonding conditions is necessary to avoid channel deformation [1].

## EXPERIMENTAL METHODS

Figure 1 shows a schematic of the PABP system. Multiple polymer devices were inserted into a polymer bag (Foodsaver T150-00011-002, Sunbeam Products, Neosho, MO, USA) sandwiched between glass plates to provide reference surfaces, to isolate the devices from the water and immersed in the water-filled pressure chamber. The polymer sealing bag was connected to ambient air through a vent tube. A pressure relief valve on the pressure tube was used to manually manipulate the vapor pressure and to control the boiling point in the pressure chamber. Figure 2 shows the relationship between pressure and boiling point of water. The PABP system provided precise temperature control and generated uniform pressures by using boiling water to produce constant surface temperatures and pressures.

For the experiments, the targeted boiling temperature ( $105.5^{\circ}\text{C}$ ) was monitored using a K-type thermocouple (OMEGA Engineering, Inc., Stamford, Connecticut, USA) in the polymer bag and precisely controlled ( $\pm 0.1^{\circ}\text{C}$ ) by manually adjusting the relief valve. Multiple PMMA devices in the plastic bags were exposed to a temperature of  $105.5^{\circ}\text{C} \pm 0.1^{\circ}\text{C}$  for 15 minutes. Leakage, using food coloring, and rupture tests were used to assess the performance of the bonding method.

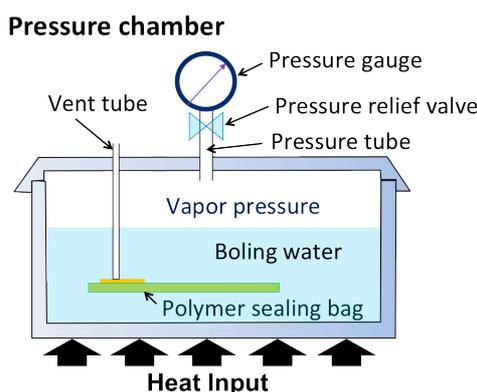


Figure 1: Schematic drawing of boiling point control system.

## RESULTS AND DISCUSSION

Table 1 compares the working pressures of previously reported bonding methods with the PABP system used in these experiments. Although, the applied pressure of 21 kPa was much lower than those reported for previous TFB procedures [2-4], no unbonded, deformed or collapsed functional structures were observed on the test components. Leakage tests revealed no leaks along the microfluidic channels, as shown in Figure 3. A representative cross-sectional view of a low aspect ratio ( $AR=1:100$ , Depth =  $10\ \mu\text{m}$  and Width =  $1000\ \mu\text{m}$ ) microfluidic channel is given in Figure 4. No deformation is present. The minimum rupture pressure measured,

using a gauge, was 496 kPa, which is substantially higher than the working pressures for typical microfluidic devices. Some devices failed at capillary connections at over 620 kPa without device failure or channel rupture. The rupture strengths of the devices tested were comparable to those previously reported with high temperature or high pressure for TFB of polymer microfluidic channels shown in Table 1.

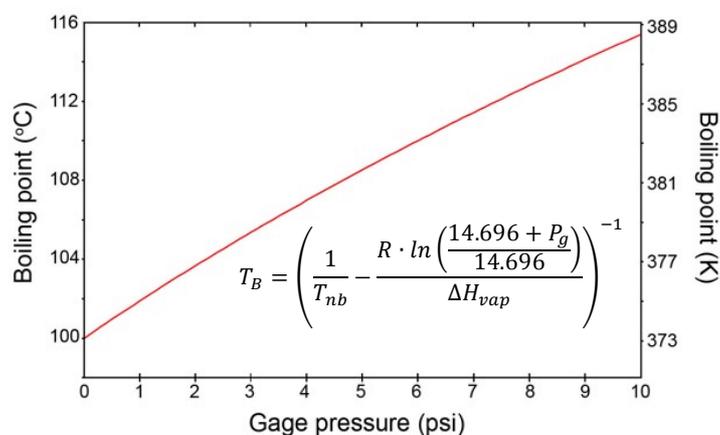


Figure 2: Pressure vs. boiling temperature using the Clausius-Clapeyron equation. Here,  $T_B$ : boiling temperature at a given pressure [K],  $T_{nb}$ : the normal boiling point [K],  $R$ : ideal gas constant, 8.314 [J/K·mol],  $P_g$ : gauge pressure [Pa] and  $\Delta H_{vap}$ : heat of vaporization of the liquid [J/mol].

As a further demonstration of the utility of the method, flexible 250  $\mu\text{m}$  thick PMMA microfluidic devices were sealed with 250  $\mu\text{m}$  thick PMMA cover slips using the PABP system. A representative 3D shaped flexible PMMA device and the associated leakage test are presented in Figure 5 (a) and (b). No leakage or clogging in the sealed devices was visible.

Table 1. Bonding pressure and temperature for PMMA devices and resulting bond strength.

	PABP	Ref.[2]	Ref. [3]	Ref. [4]	Ref. [5]
Applied Pressure [MPa]	0.021	1.225	0.020	1 - 3	-
Applied Temperature [°C]	105.5	135	165	95	140
Bond Strength [MPa]	0.5	1.6	2.15	0.35	2.5 - 5

## CONCLUSIONS

The PABP system is amenable to scaling up for mass production, since the size of the pressure chamber can be increased and multiple chips can be contained in a single polymer bag. The PABP system enables thermal fusion bonding of large area devices and can be applied to the sealing of structures patterned on flexible 3D polymer devices, double side patterned devices, or labs-on-a-foil [6].



Figure 3: Sealing and leakage test of bonded microfluidic device using a red food dye diluted in water.

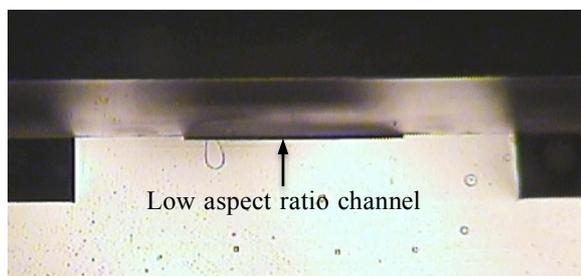


Figure 4: Cross-sectional view of very low aspect ratio channel ( $AR = 1:100$ , Depth: 10  $\mu\text{m}$  and Width: 1000  $\mu\text{m}$ ).

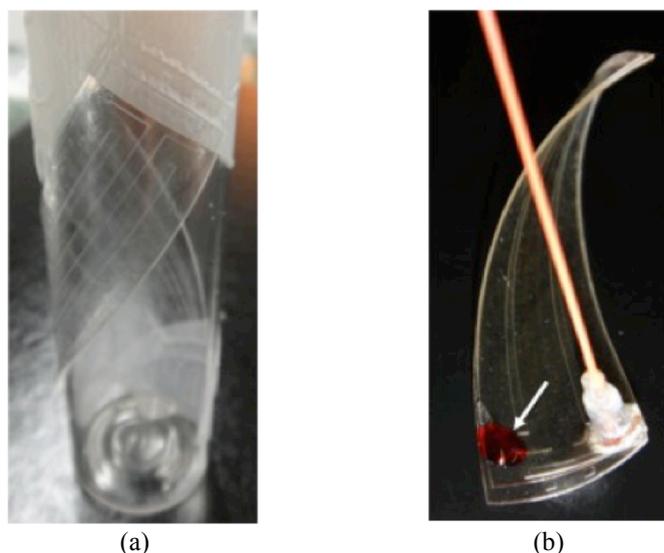


Figure 5: Sealing of a 3D-shaped flexible micro channel; (a) formation of 3D shape and (b) leakage test of the PMMA sealed foil-on-a-chip (Arrow indicates food dye at the outlet). The flexible PMMA devices and cover slips were wrapped around a glass tube and inserted in the polymer sealing bag for sealing.

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