

Technique for Microfabrication of Polymeric-Based Microchips from an SU-8 Master with Temperature-Assisted Vaporized Organic Solvent Bonding

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Novel means of fabricating polymeric microfluidic devices are presented. An SU-8 master is applied in two-stage embossing, followed by vaporized organic solvent bonding. The primary master is created by standard photolithography; the inexpensive SU-8 primary master is used in a two-stage process to generate microfeatures in hard polymers. A vaporized solvent bonding technique that readily produces complete microfluidic chips, without the need of a sacrificial layer to prevent channel deformation, was used to form complete multilayer microfluidic devices. This technique provides a more direct method to generate hard polymer microfluidic chips than classical techniques and therefore is highly amenable to rapid prototyping. The technique lends itself readily to many polymers, facilitating device production for a variety of applications, even permitting hybrid polymer chips, and provides a rapid, cost-effective, simple, and versatile approach to the production of polymer-based microdevices. The fabrication technique was tested to build microchips to perform several analyses, including chromatographic separations and a quantitative indicator assay. High separation efficiencies of 10 000–45 000 plates/m were obtained using the fabricated liquid chromatography (LC) microchip. The fabrication method was also tested in building a passive micromixer that contained high-density microfeatures and required three polymer layers. A glycine assay using *o*-phthaldialdehyde (OPA) was performed in the micromixer. With glycine concentrations ranging from 0.0 to 2.6 μM , a linear calibration plot was obtained with a detection limit of 0.032 μM .

Widespread interest has developed in microfluidic devices for biomedical diagnostic applications, environmental monitoring, as components of benchtop instruments, and for chemical synthesis. The benefits of microfluidic devices that have stimulated this growth include decreased consumption of reagents and sample, reduced analysis time, more portable instrumentation, and in some instances, lower limits of detection. Novel, versatile, and robust

fabrication methods are needed both to make microfluidic devices more available to the research laboratory and the commercial market.

Glass was the substrate of choice when the field of microfluidics emerged, largely because well-established pre-existing fabrication techniques such as photolithography and chemical etching processes had previously been used to produce devices in the microelectronics industry.^{1,2} However, the use of glass substrates presents multiple drawbacks. The fabrication of glass chips is not only expensive and time-consuming; it also requires the use of harmful hydrofluoric acid in the process. Glass also poses another problem in that it is fragile. Glass fabrication processes can be quite time-consuming, thus making them less than ideal for production-scale manufacturing. Therefore, the need for less rigid substrates that require less expensive, more rapid fabrication processes has arisen and made polymers attractive alternative materials for micro total analysis system (μTAS) fabrication. There are a large variety of polymer materials that are available with different physical and chemical properties that make them suitable for different kinds of microfluidic applications. Some of the polymers that have been widely used in microfabrication include poly(methyl methacrylate) (PMMA),^{3,4} polycarbonate (PC),⁵ poly(ethylene terephthalate) (PETE),^{6,7} and poly(dimethylsiloxane) (PDMS).⁸ The possibility of rapid fabrication and the relatively inexpensive methods used in producing polymer-based microfluidic devices are attractive, as the need for single-use, disposable microchips for chemical and biological analyses has grown rapidly.

Microfabrication of polymeric materials is often performed by a hot embossing process. The process starts by contacting a featureless piece of a hard plastic to a master mold, heating the

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material to its glass transition (T_g) temperature, followed by imprinting the microfeatures by applying pressure to create features that are complimentary to that of the master. In the past, several fabrication techniques have been employed to generate the master from which the replicas are produced, including electroplating of nickel or nickel alloys,⁹ deep reactive ion etching (DRIE) in silicon, hydroxide (KOH) wet etching in silicon,¹⁰ and micromachining.¹¹ These approaches produce durable masters that can be used numerous times. However, complex, multistep manufacturing processes are required and producing these devices can be costly.

For the purpose of testing design concepts for microfluidic devices, low-cost prototyping techniques are highly desirable. As described in our previous work,¹² masters fabricated by CNC machining ensure great precision and are readily manufacturable. This process works well on various materials, such as metals, glass, and plastics. However, masters produced via this technique do not offer smooth surface finishes, high aspect ratios (height to width ratio is limited to less than 2), or good dimensional control (often 10% larger than designed). Moreover, the high initial setup costs do not allow for rapid device design modification, which is needed in the design optimization stage. On the other hand, SU-8-based photolithography, often a sacrificial step in other master fabrication methods, is a significantly cheaper, faster, and simpler method by which to create the primary master. In addition, it provides high aspect ratio, smaller feature sizes, and smoother wall surface (depending on the resolution of photomask used). Creating a primary master from SU-8 is therefore suitable for small-volume production because of the low cost and simplicity of the method.

Although masters made from SU-8 can be produced rapidly and are a great low-cost alternative to nickel masters, they do have limited reusability due to the mechanical forces applied in hot embossing. A study conducted by Esch et al.¹⁰ also showed that after about five embossing cycles, slight distortions arise in the SU-8 features. In this paper, the limited reusability of SU-8 master is addressed by the use of two-stage embossing, which at the same time capitalizes on the benefits of using a lithographic master. In this study, an SU-8 master is used as a primary master that is in turn used to emboss a poly(ether imide) (PEI) secondary master. Since this process will only be performed once, repeated use of the SU-8 master is avoided and concerns over feature distortion do not restrict the process. The embossed PEI master can be used repeatedly to emboss lower T_g polymers, such as PC and PMMA. The advantages of using SU-8 to fabricate the master template, coupled with the ease and rapidity of hot embossing, provide for a powerful rapid prototyping method that can easily be translated into a production approach.

Another major challenge of polymer-based microfluidic devices is how to bond parts together; bonding techniques are essential in the fabrication of polymer-based microfluidic devices. Various techniques have been reported for bonding polymer-based microchips, particularly for PMMA substrates. The most widely used

procedure is thermal bonding.^{13,14} Success in microchip lamination has also been shown using other bonding methods, such as microwave bonding,¹⁵ hot water bath embossing,¹⁶ vacuum-assisted thermal bonding,¹⁷ lamination,¹⁸ plasma oxidation,¹⁹ laser welding,²⁰ and the use of adhesives.^{21,22} Different lamination approaches result in various bonding strengths. Higher bonding strengths are generally achieved with solvent welding procedures as compared to thermal bonding. Studies conducted by Lin et al. in comparing the bonding strengths obtained with various bonding procedures suggest that solvent-bonded PMMA chips have a much higher bonding strength (more than 17 times stronger) compared to thermally bonded chips.²³ Moreover, even slight variations in temperature and pressure during thermal bonding in plastic chips may lead to channel deformation, making solvent welding more attractive as long as features can be protected from the welding solvent.

Solvent welding capitalizes on the solubility of a polymer in a selected solvent to achieve entanglement of polymer chains across the interface of two contacting surfaces. Once solvated, the polymer chains become mobile and can diffuse across the solvated layer, leading to entanglement with other similarly dissolved chains from another polymer piece. The solvent eventually permeates through the polymer and evaporates, causing the chains to lose their mobility, resulting in exceptionally strong bonds.

Chlorocarbon solvents such as chloroform, chloromethane, and dichloromethane are effective organic solvents for bonding polymeric substrates.^{23,24} However, they are often causative in channel deformation during sealing since they dissolve the polymers to achieve the desired bond. The use of sacrificial layers to protect the channels from the solvent has been explored.^{23,25–29} Some of the materials that have been used as sacrificial layers are waxes and ice.³⁰ These methods work well in their intended role—they protect microscale features during the bonding

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process—but they also represent an additional step that complicates the bonding process and may alter the final product due to incomplete filling and removal of the sacrificial layer material. Residual materials trapped inside the channel often prove detrimental during usage, i.e., in capillary electrophoresis (CE) analysis, trapped excess sacrificial materials affect electroosmotic flow, and as a consequence the efficiency of the separation may be compromised. We have devised an alternate means of solvent welding that prevents deformation by bonding rigid materials rather than surface-softened sheets. This is made possible by vaporizing solvent trapped in the bulk of the polymer while maintaining close conformal contact of the two pieces within a hydrostatic press.

In this paper, a novel technique for bonding plastic microchips is presented. In this bonding procedure, a blank piece of a hard plastic is immersed in a bonding solvent to soften the surface of the polymer. Then, the excess solvent remaining on the surface is allowed to evaporate until the surface resolidifies and becomes firm. At this point, a previously embossed chip containing the microfluidic features of interest is placed on top of the blank piece, and the two are pressed together at an elevated temperature until they bond. The press temperature is kept slightly above the boiling temperature of the bonding solvent, but below the glass transition temperature to prevent channel deformation. Since the two plastic pieces are pressed together, the solvent from the blank piece permeates across the interface and facilitates bonding of the two polymers. This method has been successfully tested with various polymers and designs. The ease, low cost, simplicity, and versatility of this technique makes it useful for both rapid prototyping and mass production of polymer-based microfluidic devices.

In this study, a microchip fabricated by the two-stage embossing and vaporized solvent welding was successfully utilized in a liquid chromatography (LC) application, where pressure-driven flow was required. The bonding technique also demonstrates that the microchip can withstand the high pressure necessary in this experiment when other fabrication and bonding methods, in both PDMS and thermally bonded hard plastics, have proven to be unsuccessful. The feasibility of the fabrication technique was also tested by making a three-layer, high-feature-density micromixer. The design splits two fluid inputs into 20 fluid streams which are relaminated for rapid and effective mixing of two components. The micromixer is used for the quantification of total protein content in surrogate biological samples. A common method conjugates *o*-phthalaldehyde (OPA) to reduced sulfhydryl groups in a second reagent, in this case β -mercaptoethanol (ME), which in turn reacts with primary amines to generate fluorescent tags that facilitate protein quantification. The micromixer was used for the quantification of total glycine (Gly) in laboratory-prepared samples by mixing the OPA–ME reagent with Gly solutions and evaluating mixer performance.

EXPERIMENTAL SECTION

Microfabrication. SU-8 Master. The primary SU-8 master was fabricated on a silicon wafer using standard photolithography with a unique maskless exposure system. The SF-100 (Intelligent Micro

Table 1. Thermal Embossing Conditions Used for Imprinting Microfeatures^a

temperatures (°C)	pressures (psi)	time (s)
Embossing Program from SU-8 to PEI		
80	0	30
160	0	60
200	0	60
240	0	300
240	900	1800
Embossing Program from SU-8 to Polysulfone		
80	0	30
120	0	60
180	0	60
215	0	300
215	900	1800
Embossing Program from SU-8 to PC		
45	0	30
80	0	60
100	0	60
170	0	300
170	900	1800
Embossing Program from PEI to PMMA		
75	0	60
90	0	60
120	0	150
120	900	300
Embossing Program from PEI to PC		
80	0	60
120	0	60
170	0	150
170	900	300

^a Pressure of 900 psi was applied, and the substrates were demolded when they reached 50 °C.

Patterning, LLC, St. Petersburg, FL) uses micro-optical techniques to project images directly onto the SU-8 without the use of a photomask. SU-8 3050 (Microchem, Newton, MA) was spun on the wafer at a thickness of $\sim 100 \mu\text{m}$. The wafer was prebaked at 65 and 95 °C, with hold times of 15 and 30 min, respectively. After exposure, the wafer was postbaked with hold times of 5 and 15 min at 65 and 95 °C, respectively. The development was performed using SU-8 developer (Microchem). Finally, the wafer was hard baked at 200 °C to enhance the cross-linking of the developed SU-8.

Two-Stage Embossing. In the first step of the embossing process, the SU-8 master was embossed into a PEI substrate (McMaster-Carr, Santa Fe Springs, CA) using a hot press (Fred S. Carver Inc., Summit, NJ) according to a program shown in Table 1. The resulting imprint produced complimentary features in the PEI substrate that served as the secondary mold in the process. In the second imprinting process, features from PEI were embossed into a lower T_g polymer, such as PC or PMMA substrate (McMaster-Carr, Santa Fe Springs, CA). The final embossed polymer chip contains the same features as the primary SU-8 master. The fabrication process used to create the final chip via two-stage embossing was described in a previous work.¹¹ The microfeatures were inspected with an optical microscope, and channel dimensions were measured using a profilometer (Dektak 3 surface profile measuring system, Veeco Instrument Inc., Santa Barbara, CA).

The methodology to create the secondary master was also used with PC and polysulfone (PSU). The procedures employed were the same as those described above; the only differences being

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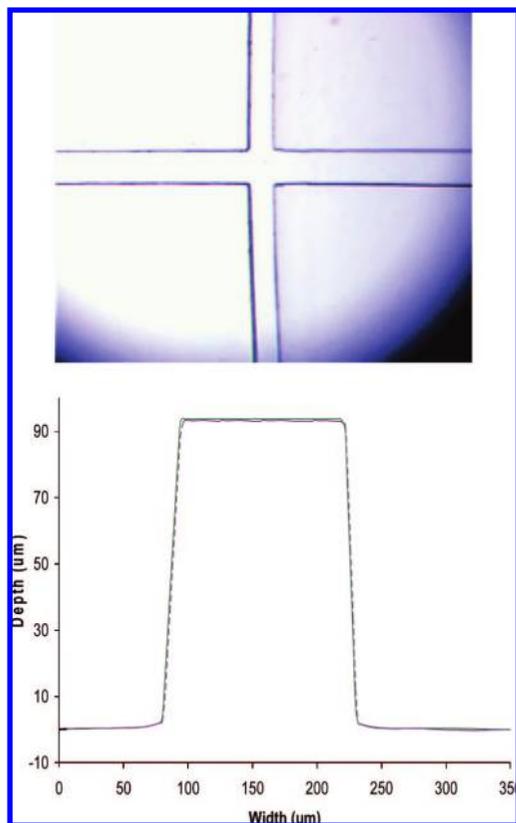


Figure 1. Embossed cross-design microchannel in PC; 15 \times magnification (top). Profile trace of the microchannel features embossed in PC (solid line) and polysulfone (— — — line) (bottom).

the embossing temperatures used for PC (~ 170 °C) and PSU (~ 215 °C). The channel features in the embossed PC and PSU chips were characterized using a profilometer and shown to give reproducible results when compared to those obtained in PEI. A photomicrograph of the embossed PC and its profile data are shown in Figure 1.

Solvent Welding. A featureless polymer sheet complimentary in dimensions to the embossed chip was immersed in a bonding solvent to soften the surface of the polymer. Immersion time and the types of bonding solvent used vary depending on the types of polymers used and were determined experimentally (detailed in Table 2). Then, the excess solvent remaining on the surface was allowed to evaporate until the surface resolidified and became firm. Next, the embossed chip and the featureless complement were pressed together at an elevated temperature (slightly above the boiling point of the solvent) to bond the two layers. A schematic of the bonding procedure is shown in Figure 2. In addition to bonding like materials, this method can be used to bond dissimilar polymers, i.e., PMMA to PC, to generate hybrid chips. Bonding procedures for various combinations of polymers are presented in Table 2.

The microchip was frozen with liquid nitrogen and fractured to obtain cross-sectional images of the microchip. Morphology of the solvent-bonded microchips was studied using an Amray (Bedford, MA) scanning electron microscope (SEM) operated at 10 kV.

LC Separation Analysis. The microchannel of the fabricated chip was slurry-packed with C-18 octadecylsilane (ODS) porous sorbents Nucleosil, 7 μm , 4000 Å (MetaChem, Torrance, CA) and

Table 2. Bonding Procedure for PMMA Materials Using Solvent Welding

Bonding of PMMA–PMMA-Based Materials	
solvent type	chloroform
boiling point of solvent (°C)	61
soak time in solvent	1.5 min
dry time	2.5 min
pressure applied (psi)	400 psi
temperature (°C)	65
bonding time	20 min
Bonding of PMMA–PC-Based Materials	
solvent type	chloroform
boiling point of solvent (°C)	61
soak time in solvent	5 s
dry time	2 h
pressure applied (psi)	400 psi
temperature (°C)	65
bonding time	20 min

were retained in the channel using filter frits as shown in Figure 3. Introduction of mobile phase was facilitated by attachment of nanoports on the microchip inlet and outlet, which are connected to an LC pump (HP Agilent 1100, Foster City, CA) and UV–vis detector, respectively. A sample mixture containing caffeine (CF), benzoic acid (BA), methyl paraben (MP), and butyl paraben (BP) with concentrations of 5 mg/L each was introduced and separated on the C-18-packed channel on the microchip. A gradient elution of water and methanol was used with a flow rate set at 100 $\mu\text{L}/\text{min}$ to perform the separation of the sample mixtures.

Micromixer Analysis. Preparations of Standard Solutions. A series of dilutions ranging from 0.0 to 2.6 μM in glycine concentration were prepared using 50 mM borate buffer as the diluent. To prepare the borate buffer, 3.09 g of boric acid (J. T. Baker, Phillipsburg, NJ) and 7.91 g of sodium tetraborate (Integra Chemical Co., Renton, WA) were diluted with water to a final volume of 1 L. The buffer was adjusted to pH 9.0 using 0.1 M NaOH and 0.1 M HCl solutions. Reagent solutions consisted of 100 mg of OPA, 0.2 mL of ME, and 5.0 mL of dimethyl sulfoxide (DMSO), diluted to a final volume of 100 mL in borate buffer. The OPA, ME, and DMSO were purchased from Sigma (Sigma, St. Louis, MO).

Fluorescence Analysis in the Micromixer. Nanoports were epoxied on each of the microchip inlets. The glycine and OPA solutions were pumped into the microchip through the nanoports using a Harvard PHD 2000 dual-syringe pump (Harvard Apparatus, Holliston, MA) with a flow rate of 300 $\mu\text{L}/\text{min}$. Mixing occurred in the microchip, and the mixed solutions were collected at the outlet, and the fluorescence was measured with a 350 nm excitation and 450 nm emission wavelength. A schematic of the micromixer is shown in Figure 4.

RESULTS AND DISCUSSION

The use of SU-8 as a primary master in a two-stage embossing technique provides an inexpensive, straightforward, accessible method to produce polymer microchips. The whole procedure, from start to finish, can be completed in less than 24 h. By combining the complex design advantages of photolithography with the ease and robustness of hot embossing, a powerful rapid prototyping approach is realized. This is especially useful during the design optimization stage when feature geometries are

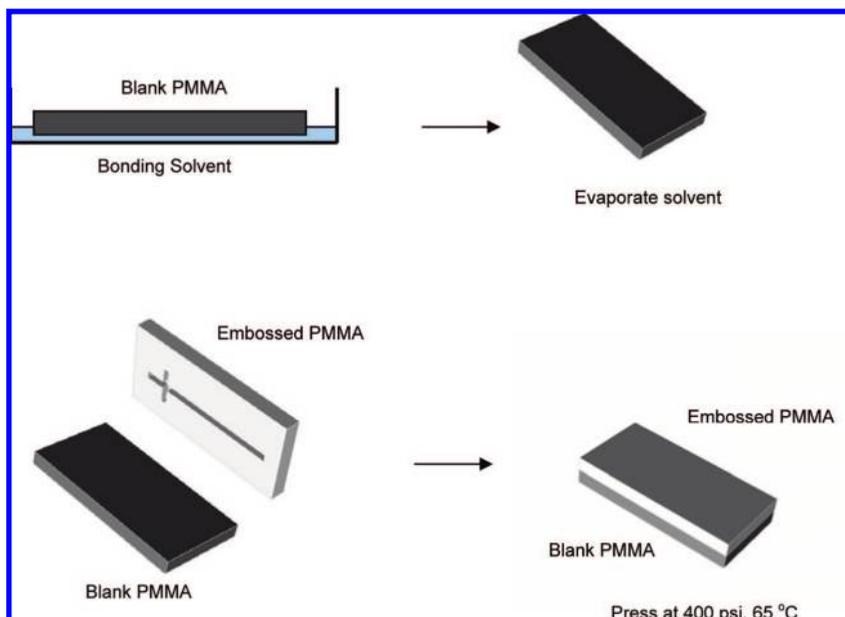


Figure 2. Schematic of the bonding procedure to create channels in the microchip. A featureless piece of PMMA was immersed in a bonding solvent to soften the surface of the polymer. The excess solvent left on the surface was allowed to evaporate at room temperature until the surface resolidified and became firm. Next, the two pieces were pressed together at 400 psi, 65 °C until bonding occurred.

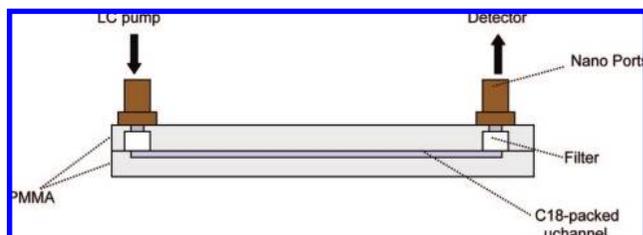


Figure 3. Schematic of a PMMA microchip packed with C-18 sorbents to perform LC separations.

frequently modified. Additionally, the reproducibility of embossing, strength of the vaporized solvent bond, and low cost of the technique also make it attractive for industrial manufacturing.

Dimensions of the SU-8 microchannels were measured by profilometry. For the simple cross-channel design, the microchannels were shown to be 130 μm in width and 93 μm in depth. The PEI secondary master was thermally embossed into a blank PMMA piece to obtain the final product. The feasibility and reproducibility of the two-stage embossing technique was demonstrated in a previous study by repeating the embossing cycle 20 times.^{11,24} In no instance did channel widths or heights in the PMMA replicas exceed those of the primary mold by more than 1% and 4%, respectively. The W/H aspect ratios of the 20 PMMA replicas were calculated and plotted, and they ranged between 2.58 and 2.74 as compared to the W/H aspect ratio of the primary mold of 2.67. The results demonstrate that the profile of the channel in final product corresponds well to that of the primary mold and indicates good homogeneity of the imprinting process.

The data demonstrate that the profiles of the SU-8 and PMMA channels correspond well. A slight decrease in the depth ($\sim 1 \mu\text{m}$; 1%) of the PMMA substrate as compared to the primary mold was observed. Successful features transfer using the SU-8 primary mold to the final substrates illustrates that the two-stage embossing technique is reproducible and can be applied in the area of microfluidic fabrication.

In this work, 1,2-dichloroethane and chloroform were used as the solvents for bonding the two polymer pieces together. Two types of polymers, PMMA and PC, were selected as a proof-of-concept media for the proposed method. After soaking the polymer in and then allowing the solvent to evaporate from the surface, presumably some of the solvent remains trapped in the bulk. In the bonding method, this trapped solvent is utilized for bonding the blank piece to another piece of plastic that contains the microfeatures. The remaining solvent will eventually permeate out from the surface of the blank piece and into the embossed piece. The surface of the embossed piece that was in direct contact with the blank piece will also be exposed to the solvent through evaporation. When the two pieces are exposed to the vaporized solvent in this manner, the polymer chains in both pieces can diffuse more readily and entangle with one another. Once the solvent has completely permeated out of the chip, the polymer chains lose mobility, leaving a solid mass of bulk polymer material and effectively bonding the two pieces.

The bonding was performed at a temperature slightly above the boiling point of the bonding solvent. This was done to assist evaporation and permeation of the trapped solvent from the featureless piece to the patterned piece. Since the bonding was performed by permeation of solvent from one piece to another, to facilitate effective bonding, the surfaces of the two pieces must be in close conformal contact with one another. When tested on a piece with an uneven surface, poor bonding was observed. The irregularity of the surface caused bonding to occur only in locations where the two pieces were in direct contact with each other. The success of bonding technique was evaluated using methylene blue dye as shown in Figure 5 to check for leaks resulting from incomplete bonding. No leaks were detected in the microchip or between channels. Figure 6 shows the SEM image of a PMMA–PMMA solvent-bonded microchip. As can be seen from the image, channels that correspond well to the features on the master were obtained without evidence of channel

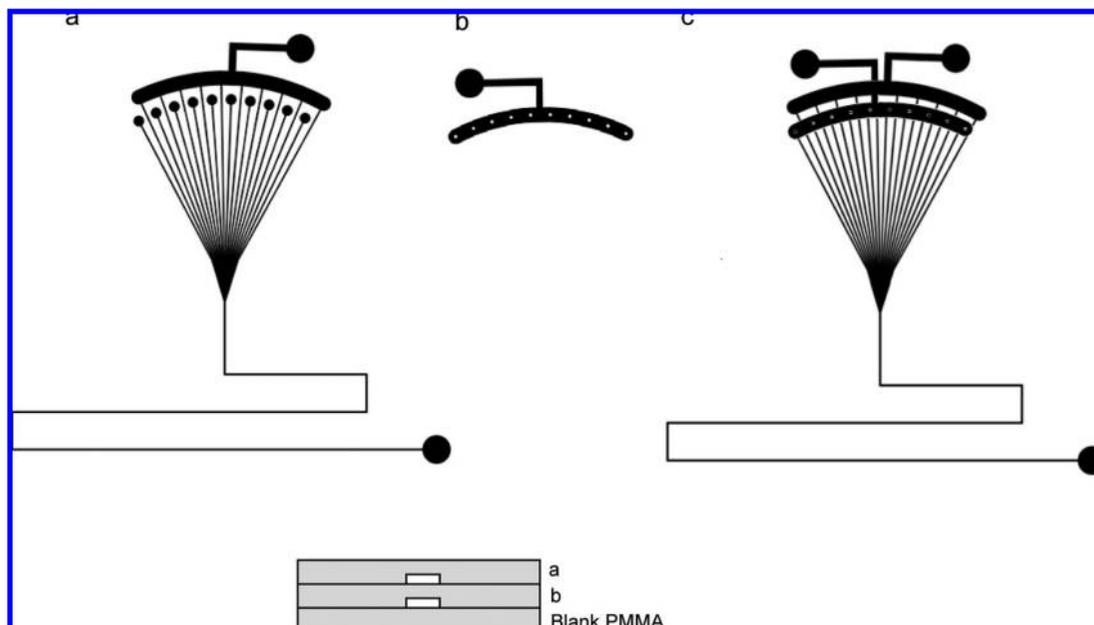


Figure 4. Schematic of the micromixer. The microchannels on the first layer (a) are sealed and bonded to the second layer (b), and the channels of the second layer were sealed to a blank PMMA piece to produce the final microchip (c). Bottom graphic shows the cross section of the final chip.

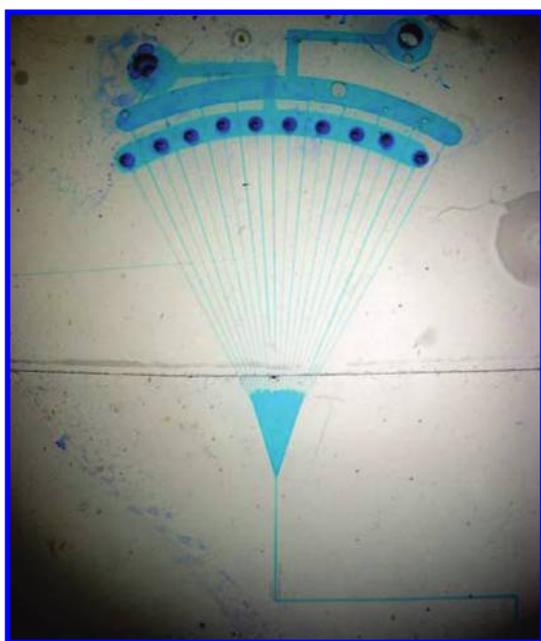


Figure 5. Micromixer bonding test with methylene blue dye to check for leaks.

deformation. The bonding procedure was repeated 10 times for each combination of PMMA–PMMA and PMMA–PC to demonstrate the reproducibility of the technique. All chips were leak-free when tested using the methylene blue dye.

The vaporized solvent bonding technique offers several advantages. The primary benefit of this approach is the elimination of the need for a sacrificial layer to protect the channels from deformation during bonding. Therefore, concerns of incomplete filling and removal of the sacrificial material are nonexistent and a step is removed from the fabrication process. With the use of the vaporized solvent bonding technique, only the featureless layer (or, as the case may be, the less feature-laden layer) is subjected

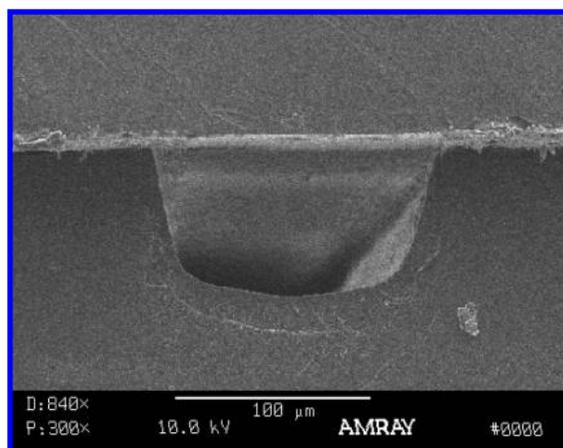


Figure 6. SEM image of a PMMA–PMMA microchip showing the microchannel cross section (fractured after freezing in liquid nitrogen).

to direct solvent exposure. The heat-assisted permeation of the trapped solvent to the embossed piece preserves microfeatures without the need of a sacrificial layer.

The vaporized solvent welding technique can be applied to various types of polymer plastics by utilizing appropriate bonding solvents. Procedures can readily be altered and optimized depending on the type(s) of polymer(s) used. As can be seen in Table 2, when using chloroform as the bonding solvent, PMMA must be soaked for 1 min, while PC requires only a 5 s soaking time in the same solvent to achieve qualitatively similar bonding results. The significant differences in soaking times for the polymers are attributable to the different solubilities/swelling ratios for different solvents. The room temperature evaporation time for PMMA is significantly shorter than PC for the same reason. Consequently, the drying time for PMMA at room temperature is only 2 min, while PC must remain at room temperature for nominally 2 h before the surface resolidifies and is ready for bonding.

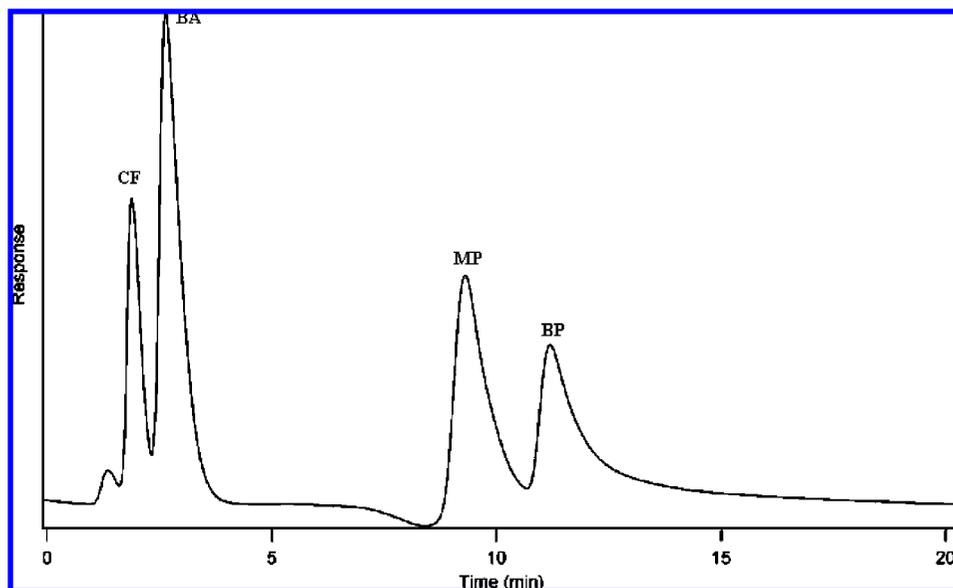


Figure 7. Separation of 5/7/7/5 ppm caffeine/benzoic acid/methyl paraben/butyl paraben performed on a C-18-packed microchip.

The stability of the solvent vapor welded chips was evaluated by measuring the bonding strength of the bonded chips. No bond failure was observed in experiments in which pressures of up to 1800 psi were applied: microchips fabricated using this technique demonstrate a high bonding strength under significant pressure. Our results indicate the potential of chips manufactured using this approach for use in applications where high backpressures are required. In high-performance liquid chromatography (HPLC), where high internal pressure is required, common plasma-bonded, adhesive-bonded, or thermally bonded plastic chips will delaminate or break when used at high pressure. The higher bonding strength produced by our technique presents an ideal alternative for polymer microchip bonding.

A microchip fabricated using the two-stage embossing and vaporized solvent welding was utilized in an LC application to separate four different compounds (CF, BA, MP, and BP). Successful separation of the four compounds can be seen in Figure 7. As can be expected, the more hydrophobic compounds (methyl and butyl parabens) were retained longer, whereas the slightly hydrophobic compounds (caffeine and benzoic acid) eluted faster from the channel. Separation efficiencies of 10 000–45 000 plates/m were obtained using the LC chip. This result demonstrates that the current LC chip confirms the feasibility of the fabricated microchip LC to be used as a separation device and shows its potential use in adapting the conventional LC methods. This separation data shows as proof-of-concept that the packed-channel LC microchip fabricated via this method was feasible to be operated under pressure-driven flow, which is an essential analysis component.

A micromixer fabricated via this method was employed to perform a glycine assay by mixing OPA–ME and Gly. To demonstrate the mixing efficiency of the micromixer, the OPA–ME and Gly solutions were introduced from the two inlets at the same flow rate. The assay depends upon the interaction of OPA and the primary amines to form a fluorescent moiety. Fluorescence intensity was measured for Gly with concentrations ranging from 0.0 to 2.6 μM . A calibration plot was generated from the data, and the results show that the Gly concentrations directly correlate

with the fluorescence signal. The plot shows very good linearity ($R^2 = 0.9982$) with a detection limit of 0.032 μM . These results demonstrate that the fabrication technique can successfully be applied to produce functional multilayered microfluidic chips with complex designs and high feature densities. The technique is ideally suited to the fabrication of microfluidic devices that can perform a variety of analyses, including separations, mixing, and assay studies.

CONCLUSION

A novel method for the fabrication of polymer-based microdevices was presented. An SU-8 primary master was employed in a two-stage embossing procedure, followed by a novel vaporized solvent bonding technique that readily produces complete microfluidic chips without the need of a sacrificial layer to prevent channel deformation. This method of fabrication provides a rapid, cost-effective, simple, and versatile approach to the production of polymer-based microdevices and, therefore, is amenable to rapid prototyping. The technique lends itself readily to many polymers, facilitating device production for a variety of applications and even permitting hybrid polymer chip formation. This fabrication method may provide means for researchers who are attempting to bridge the gap between proof-of-principle demonstrations of microfluidic devices and those attempting to build manufacturable microchips.

The LC microchip and the micromixer, both produced via the two-stage embossing technique in combination with solvent vapor welding, demonstrate the versatility of the fabrication technique: it was successfully used to build devices to perform chromatographic and colorimetric microassays. This work demonstrates that the fabrication technique is applicable to the construction of highly functional multilayered microfluidic chips with complex designs and high feature densities. The experimental data shows that the technique is reproducible on various polymer types and designs and can provide alternative solutions to overcome some of the limitations in fabricating polymer-based microchip devices, making chemical and biomedical analyses on them more attractive.

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