

PLASTIC-PDMS HYBRID DEVICES FOR HIGH PRESSURE HYDROLYTICALLY STABLE ACTIVE MICROFLUIDICS

Kevin S. Lee¹ and Rajeev J. Ram¹

¹*Research Laboratory of Electronics, MIT, USA*

ABSTRACT

Active devices such as pumps and mixers have been fabricated in plastic-PDMS hybrid devices. By utilizing functionalized silane primers, bond strength between Polycarbonate or PMMA and PDMS improved in dry and aqueous environments. Plastic-primer-PDMS layers exposed to acid and base solutions at 70 C for 2 hours showed no signs of delamination at 30 psi for pH -1 to 15 and 60 psi for pH 0 to 15. A peristaltic pump fabricated in polycarbonate achieved consistent flow rates up to peristaltic cycle frequencies of 10 Hz in water, 10M HCl, and 10M NaOH solutions.

KEYWORDS: Plastic-elastomer bonding, silane, surface modification, active valve

INTRODUCTION

PDMS is a common material for fabrication of microfluidic devices. Elasticity provided by PDMS enables active devices which can utilize pressurized membranes such as pumps and mixers. However, for structures requiring dimensional stability, rigidity, or disposability, plastics have the required properties for microfluidic chip fabrication [1]. Plastics can be manufactured using mass fabrication technologies such as injection molding and hot embossing with well established bonding processes [2], but at the cost of sacrificing active device functionality. A new fabrication process combining plastic substrates with PDMS membranes enables active microfluidic devices inside dimensionally stable systems, merging the functionality of PDMS with established plastic fabrication technologies.

BACKGROUND

Irreversible bonding between PDMS and plastics for fluidics requires interfaces which can handle high pressure and harsh chemical environments. Hydrolytic stability under acidic or basic conditions is particularly important for chemical reactions as well as cell growth. While direct bonding between PMMA and PDMS has been explored [3], results indicated that direct interfaces only withstood 2.5 psi before failure. To improve bond strength between dissimilar materials, primers are most commonly used. These primers consist of a silicon-carbon bond, with the carbon atom linked to organic groups such as amide or vinyl groups. These groups provide covalent bonds with organic substrates such as plastics and polymers. In contrast, the silicon atom is bonded to hydrolysable ethyl or methyl groups which can react with other silanols or metal oxides forming inorganic covalent bonds. Polycarbonate (PC) and PMMA surfaces have been shown to react with amine functional silanes such as AminoPropylTriEthoxySilane (APTES) to form amide bonds on the surface [4]. While these silanes then crosslink into a polymer leaving ethyl or methyl groups

on the surface, as shown in Figure 1, and has been shown to plasma bond to PDMS [5], no data on hydrolytic stability was shown. We found that exposing monolayer primer coatings to plasma bonding processes resulted in degradation of silane films, resulting in DI water induced bond failure and delamination below 15 psi.

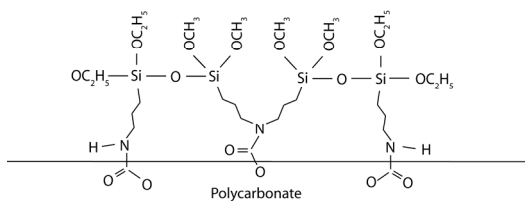


Figure 1: Schematic of a possible configuration at the PC-Primer interface showing covalent bonds to the substrate and surface groups.

EXPERIMENTAL

Two dipodal silanes were investigated for improving bond strength, BisTriEthoxySilylEthane (BTESE) and Bis(TriMethoxySilylPropyl)Amine (BTMSPA). For BTESE, primers consisted of a two step process, where a functional silane was first coated onto the plastic substrate for covalent bonding followed by coating with BTESE. Bis(TriMethoxySilylPropyl)Amine (BTMSPA) was also added to APTES for thick single step coatings to explore its effects on hydrolytic stability. 5% wt silane with 0.2% wt Titanium Butoxide solutions in isopropanol were prepared and wipe coated on plasma treated plastic substrates. After curing, the layers were plasma bonded to PDMS substrates and allowed to cure for 24 hours.

RESULTS AND DISCUSSION

Devices with PDMS membranes suspended over 25 μL fluid reservoirs were fabricated in PC and PMMA to test interface robustness using blister test structures as shown in Figure 2. Devices were fabricated using primer solutions with varying ratios of APTES and BTMSPA with and without BTESE. For the test device, membrane ruptures occurred instead of delamination at 60 psi for both PMMA and PC, suitable for active valves [6]. For hydrolysis testing, blisters are subjected to NaOH and HCl solutions from the PDMS side at 70 C for 2 hours followed by pressure testing. From Figure 3, hydrolytic stability is shown to improve over direct APTES primers with the addition of BTMSPA for

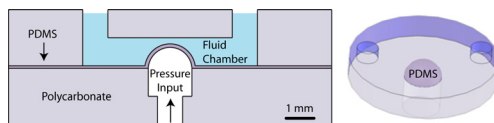


Figure 2. Schematic of the aqueous blister test structure utilized to test hydrolytic bond failure. PDMS membranes were 70 μm thick over 915 μm diameter circles.

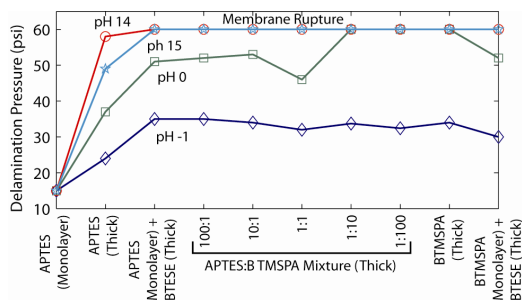


Figure 3. Plot of the delamination pressure versus primer type at pH extremes. Hydrolytic stability increases with addition of BTMSPA or protection by BTESE.

thick coatings or BTESE secondary layers for monolayer coatings. A test chip utilizing the highest performance primer containing peristaltic pumps and mixers was fabricated and shown in Figure 4. Pump rate versus frequency was measured as shown in Figure 5.

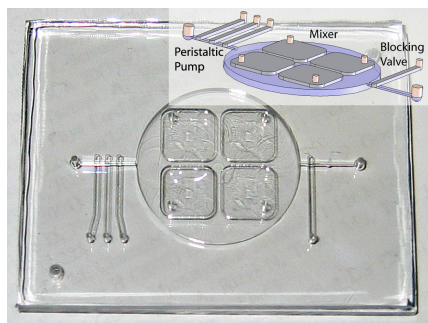


Figure 4. Schematic and picture of the test device fabricated in polycarbonate with a 70 μm PDMS membrane.

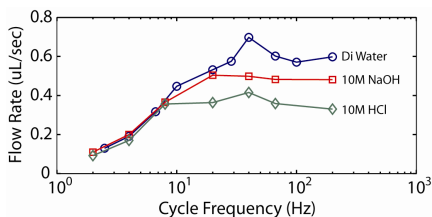


Figure 5. Plot of the flow rate versus frequency for different pH solutions at 15 psi for an $800 \times 600 \mu\text{m}^2$ cross section membrane peristaltic pump. Performance degradation at higher frequencies likely results from valve sticking due to acid/base modification of the PDMS and silane surfaces.

CONCLUSIONS

By utilizing two stage silane primers on PC and PMMA surfaces, we have shown that hydrolytically stable hybrid plastic-PDMS devices consisting of valves, pumps, and mixers can be fabricated consistently. The interface is stable through 30 psi for pH -1 to 15 and greater than 60 psi for pH 0 to 15.

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