

# OXYGEN PLASMA-FREE MICROFLUIDIC DEVICE SEALING

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## ABSTRACT

In the current work we describe the development of an oxygen plasma-free microfluidic device sealing method with tunable properties. In particular, it allows the end-user to bond PDMS-glass microfluidic devices using nothing more than some mild acidic buffer, and access to an oven, and achieve burst pressures of more than 80 psi, or 0.55 MPa. The minimal requirements on the processing steps make microfluidic diagnostics involving non-injectable components such as solid tissues samples in resource-poor countries both technically and economically viable.

**KEYWORDS:** Polydimethylsiloxane-Glass Bonding, Oxygen Plasma-Free, Medical Diagnostics, Developing World

## INTRODUCTION

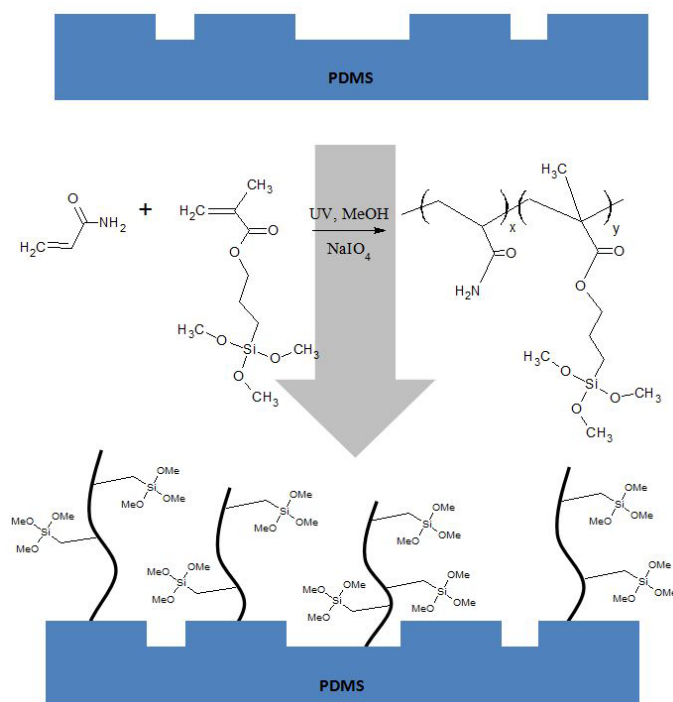
Microfluidic devices are typically created by casting the elastomer, polydimethylsiloxane (PDMS) onto a patterned mold, which is then peeled off the mold and sealed by oxygen plasma bonding onto glass [1]. While highly effective, bonding must be performed minutes after plasma activation, which is undesirable because it limits the adoption of the devices to users with access to a plasma etcher, or to applications where the samples are fully solubilized in the carrying phase.

Offering end-users a way to seal the devices in a simple manner, using easily accessible chemicals and conditions enables them to introduce different components into the device, including solid samples and assay reagents. Such flexibility of bonding allows for a general-purpose chip design that can be customized, greatly reduces the cost of development and manufacturing, which renders the technology economically viable.

In part to address this issue, chemical bonding methods have been devised by several groups, though these often result in clogging of microchannels with the adhesive [2]. Im, et al, managed to address many of these challenges, though the preparation of the device interface is fairly complicated, and not amenable to scale-up. In addition, their method required a curing time of almost 12 hours, and the full strength was only 50 psi [3].

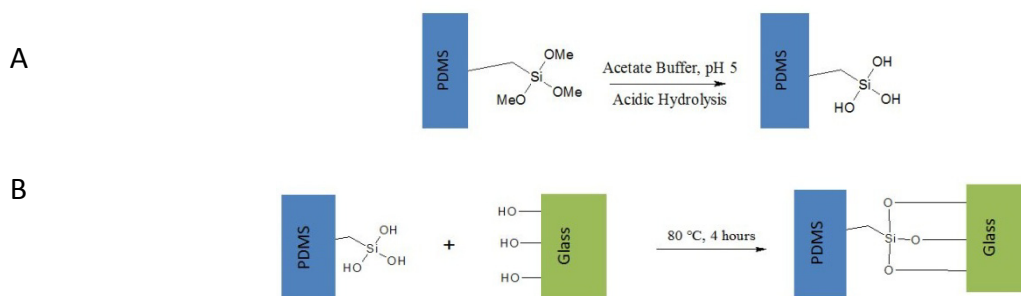
## THEORY

We performed a PDMS surface modification reaction that involves a simple UV-mediated, simultaneous polymerization and grafting reaction that can be easily scaled up (Scheme 1), based in part on reported techniques [4].



*Scheme 1: Monomers, PDMS slabs, and  $\text{NaIO}_4$  are placed in a flask with methanol as solvent, and reacted for 18 hours under a UV lamp with stirring. UV light is used to generate radicals on the PDMS, which simultaneously initiates polymerization and grafts the nascent polymer chain onto the surface. Methacryloxypropyl-trimethoxysilane (MAP-TMS) is co-polymerized with acrylamide, which acts as a spacer, at a 2:1 molar ratio.  $\text{NaIO}_4$  acts as an oxygen scavenger. Methylmethacrylate can also be used as a hydrophobic spacer.*

Exposure to ultraviolet source generates radicals on the PDMS surface, which then initiates a radical chain polymerization on the surface of methacryloxypropyl-trimethylsilane (MAP-TMS), using monomers in the solution. The polymerized MAP-TMS contains three alkoxy silane moieties for each incorporated monomer, which increases strength of the bond through higher avidity. Co-polymerization of the MAP-TMS with different types of acrylates or methacrylates confers different properties to the grafted surface. For example, using more hydrophilic monomers (e.g. acrylamide) reduces stability of the grafted groups, consequently reducing the duration of the bonding steps.



*Scheme 2: Grafted poly(trimethoxysilanes) are hydrolyzed to poly(trisilanols) at pH 5 for 1 hour (A), before bonding to glass via condensation reaction with surface hydroxyl groups on glass at 80°C (B). The high density of methoxysilanes ensures high avidity, thus ensuring high bond strength.*

## EXPERIMENTAL

### i. PDMS Surface Treatment

PDMS slabs in a reaction flask with MAP-TMS, methyl-methacrylate or acrylamide, NaIO<sub>4</sub> and methanol are degassed by a freeze-pump-thaw procedure. The reaction flask is stirred under a UV lamp overnight. The PDMS is then washed with methanol and dried with an air gun before storing in a dessicator.

### ii. Bonding Protocol

PDMS slabs are placed in a 30mM pH 5 sodium acetate buffer at room temperature for one hour (acrylamide co-polymer) or at 80°C for an hour (methyl methacrylate co-polymer) to hydrolyze the TMS groups into active trisilanols. Microwave oven can be used to hasten this step to as few as several minutes. They are then rinsed with deionized water and placed on unmodified soda lime glass and baked at 80°C for 4 hours (Scheme 2).

### iii. Bond Strength Burst Pressure Testing

For burst pressure testing, holes are punched on the PDMS using sharpened 25G needle before bonding at either end of a pre-formed microchannel. A tubing of appropriate size is then filled with water and inserted into the device. Since PDMS is gas-permeable, it is necessary to test all burst pressures with an incompressible fluid. A regulated gas tank is then used to apply different pressures to the device through the tube.

## RESULTS AND DISCUSSION

The bond achieves full strength within 4 hours (Table 1), being able to withstand more than 80 psi, or 0.55 MPa (the highest pressure our precision regulator is able to put out) without any signs of damage. Attempts to remove the PDMS off the glass resulted in the tearing of the polymer, suggesting that the full strength approaches the fracture strength of PDMS (at ~2 MPa) (Figure 1). PDMS that has been aged for one week do not show any changes in terms of its properties, and further ageing is being investigated.

The primary mechanism precipitating the loss of bonding strength is the hydrolysis of the trimethoxysilanes, followed by the condensation reaction that crosslinks the grafted polymer network within itself. By changing the grafting polymer composition, we are able to tune the surface properties in favor of longer storage or faster bonding protocol. Storage under vacuum and in a dessicator also resulted in improvements of bonding strength.

*Table 1: Bond strength at various bonding times*

Sample	Burst Pressure (psi)
Unmodified PDMS, 24 hr	5
1 hr	8
2 hr	25
4 hr	> 80

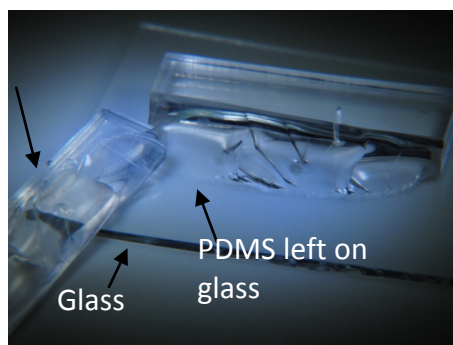


Figure 1 After 4 hours, attempts to peel PDMS from the glass resulted in the failure of the bulk material, leaving a layer of firmly bonded PDMS at the interface.

Currently, applications involving parallel assays are being explored. The ability to incorporate non-injectable components opens up many possibilities for our research, including solid tissue or soil samples that can be processed on-chip.

## CONCLUSION

We recognize that in any chemical bonding scheme, five S's have to be addressed: *Stability* of modified surfaces in storage; *Simplicity* of modification and bonding schemes; *Strength* of final bond; *Speed* at which the full strength can be attained; and *Scaling-up* of the process. We consider our method to address all of them adequately. Further, since the polymerization/grafting step involves free radical generation through UV-cleavage of the polymer backbone, the method is easily transferrable into other types of elastomeric materials. We believe that our method will allow for new applications for microfluidic devices, wherein solid or semi-solid samples can be introduced by the end-user into the devices, prior to sealing. In particular, this technology will enable deployment of microfluidic diagnostics in resource-poor countries.

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