PLASMA TREATMENT FOR MICROFLUIDIC DEVICE FABRICATION

Microfluidic devices enable the modeling of large systems or system components on a microscopic scale, increasing the potential for automation and portability while reducing experimental measurement times and costs. This article discusses the benefits of plasma treatment for microfluidic device fabrication, its applications, and some processing guidelines when using our plasma instruments.

Benefits of Plasma Treatment for Microfluidic Device Fabrication

Poly(dimethylsiloxane) (PDMS) is most commonly used material for building microfluidic devices. Plasma treatment quickly renders PDMS surfaces hydrophilic through plasma oxidation [Figure 1]. Following plasma treatment, the PDMS-PDMS or PDMS-glass surfaces may be bonded and sealed irreversibly to create leak-tight channels. Microfluidic channel surfaces may also be rendered hydrophilic to enhance fluid flow and wetting of channels. In addition, alternating hydrophilic-hydrophobic regions may be patterned on microfluidic surfaces by plasma treating devices through a patterned mask.

Example Applications

Microfluidic surfaces and channels can be plasma treated without affecting the bulk properties of the device. As such, plasma treatment has been used to facilitate the fabrication of microfluidic devices for applications such as:

- Study of chemical reactions and fluid flow on micron scale
- Detection of biological organisms or chemical species
- Clinical diagnostics and drug screening for medical research
- Manipulation of fluid on cellular length scale (microns) for biological research
- Growth of cell and tissue cultures

Processing Methods

After patterning a PDMS substrate by replica molding from a master mold, the PDMS is oxidized in air oxygen (O_2) plasma. An air or O_2 plasma removes organic, hydrocarbon material by chemical reaction with highly reactive oxygen radicals and ablation by energetic oxygen ions. This leaves silanol (SiOH) groups on the surface, rendering the surface more hydrophilic and increasing surface wettability. Following plasma activation, the PDMS is immediately placed in contact with another oxidized PDMS or glass surface to form bridging Si-O-Si bond at the interface, creating an irreversible seal.

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Below are suggested process conditions for plasma activation of PDMS-PDMS or PDMS-glass in a Harrick Plasma cleaner (some experimentation may be required to determine optimal process conditions):

- Use oxygen (O_2) or room air as the process gas
- Pressure: 500 mTorr to 1 Torr
- RF power: Typically HIGH
- Process time: 15-60 seconds
- As is the case with experimental processes and fabrication techniques, plasma process conditions reported by users have varied widely, even when plasma treating similar PDMS materials. In our lab tests, optimal PDMS bonding was observed with the following process conditions: 900-950 mTorr air or O_2; HI RF power; 10-20 seconds
- The Simpson Research Group demonstrates their protocol for PDMS plasma treatment using a Harrick Plasma cleaner in this video (minute 5:00-5:40) [1]

Additional Processing Guidelines

- Plasma treatment should not exceed 2 min, as prolonged plasma exposure causes cracking in PDMS and migration of low molecular mass molecules from bulk to surface, decreasing the number of hydrophilic SiOH groups and resulting in weak or incomplete bonding [2].
- Oxidized surfaces should be brought into contact immediately after plasma treatment to achieve strongest bond possible
- PDMS surface recovers hydrophobic properties (aging) with time after plasma treatment (~1 hour) [3,4].

[1] Norred SE, Caveney PM, Retterer ST, Boreyko JB, Fowlkes JD, Collier CP and Simpson ML. "Sealable femtoliter chamber arrays for cell-free biology." J. Vis. Exp. (2015) 97: e52616.

[2] Bhattacharya S, Datta A, Berg JM, Gangopadhyay S. "Studies on surface wettability of poly(dimethyl) siloxane (PDMS) and glass under oxygen-plasma treatment and correlation with bond strength." J. Microelectrom. S. (2005) 14(3): 590-597.

[3] Hillborg H, Ankner JF, Gedde UW, Smith GD, Yasuda HK, Wikström K. "Crosslinked polydimethylsiloxane exposed to oxygen plasma studied by neutron reflectometry and other surface specific techniques." Polymer (2000) 41: 6851-6863.

[4] Duffy DC, McDonald JC, Schueller OJA and Whitesides GM. "Rapid prototyping of microfluidic systems in poly(dimethylsiloxane)". Anal. Chem. (1998) 70: 4974-4984.

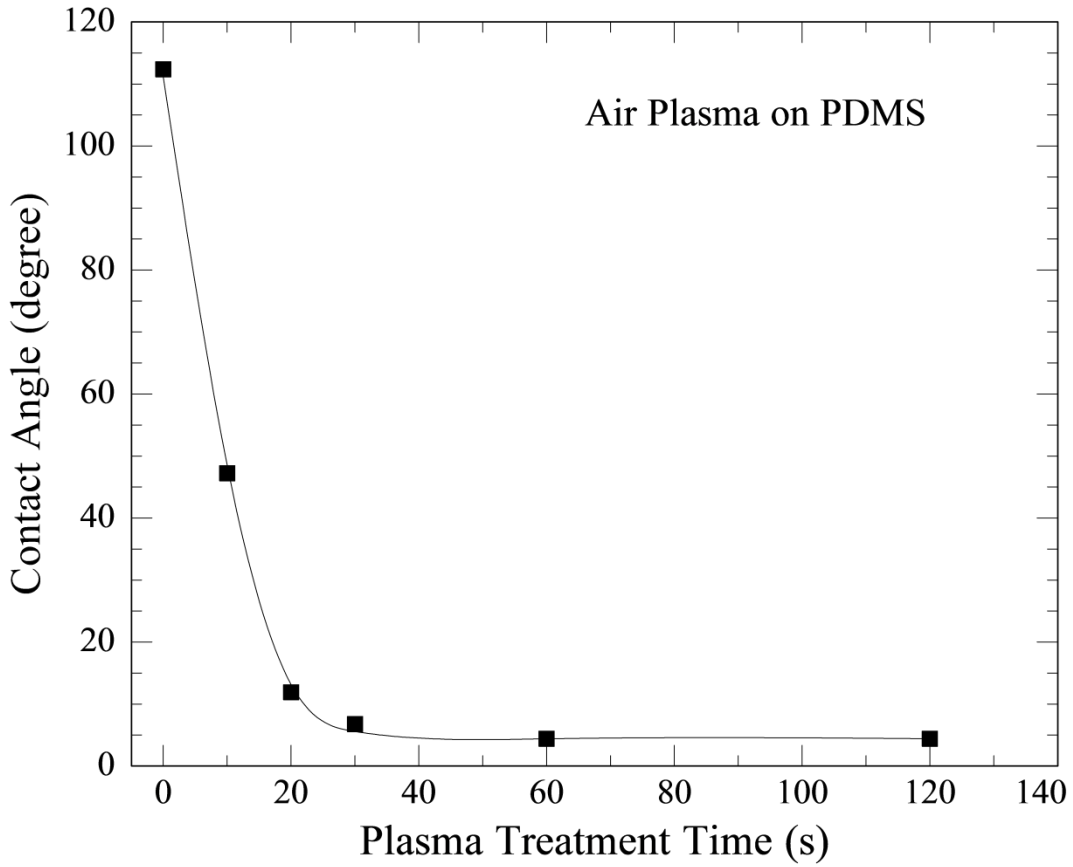

Figure 1. Water drop contact angle on a blank poly(dimethylsiloxane) (PDMS) surface as a function of air plasma treatment time using a Harrick Plasma cleaner.

Data from Jiang, X., H. Zheng, S. Gourdin, P. T. Hammond. "Polymer-on-Polymer Stamping: Universal Approaches to Chemically Patterned Surfaces." Langmuir (2002) 18: 2607-2615; Zheng, H., M. F. Rubner, P. T. Hammond. "Particle Assembly on Patterned "Plus/Minus" Polyelectrolyte Surfaces Via Polymer-On-Polymer Stamping." Langmuir (2002) 18: 4505-4510.