Surface Micromachining of Microfluidic Devices

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Abstract:

Micro-through-holes were fabricated in thin-films of polydimethylsiloxane (PDMS). Standard photolithography was used to pattern photoresist coated on the PDMS substrate, while reactive ion etching (RIE) using both a capacitively coupled plasma (CCP) system and an inductively coupled plasma (ICP) system was used to transfer desired through-hole patterns from photoresist to underlying PDMS layers. By investigating the independent effects of RF power, total pressure, and gas composition (SF_6:O_2), an optimal etch recipe was identified for each RIE system. Optimal recipes were defined by the fastest PDMS etch rate with a respective etch selectivity over photoresist greater than one. Although the ICP system proved to be more time efficient, both systems were able to generate a desired 6 μm diameter through-hole pattern with relatively vertical sidewall profiles.

Introduction:

Reactive ion etching (RIE) of thin-films of PDMS has been used to fabricate micro-through-holes for microfluidic devices [1-3]. Previous research has investigated PDMS etch rate trends under varying plasma conditions using hard masks such as aluminum [2-4]. Recently, a new surface micromachining technique reported by Chen, et al. introduced a method to pattern PDMS directly using conventional photolithography [1]. This method serves as an inexpensive patterning technique; however, research regarding the selectivity of the etch is limited. Additionally, the disparities between etching PDMS on a capacitively coupled plasma (CCP) system and inductively coupled plasma (ICP) system have not been characterized.

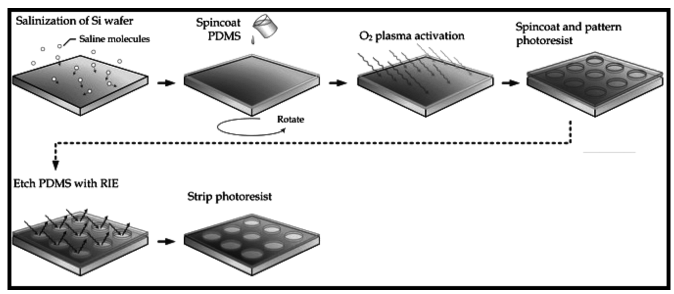

Figure 1: A schematic depicting the surface micromachining protocol used to fabricate micro-through-holes in thin-films of PDMS.

In this report, we present optimal recipes for etching thin-films of PDMS on both a CCP and ICP system. The plasmas studied were composed of varying ratios of SF_6 and O_2. As proof of concept, optimal recipes were used to etch 6 μm diameter through-holes in a 10 μm thick PDMS layer. While both systems fabricated the desired feature, the PDMS etch rate was an entire order of magnitude greater on the ICP system. The etch was more selective using the CCP system; however, qualitative assessments found the ICP system generated less surface roughness and cracking of the PDMS in addition to more uniform features.

Experimental Procedures:

Etch rates of PDMS and photoresist were studied by varying total pressure, gas composition (SF_6:O_2), and RF power on both the CCP system (PlasmaTherm 790, Unaxis, Schwyz, Switzerland) and ICP system (LAM 9400, Lam Research, Fremont, CA). Thicknesses of thin-films of PDMS and photoresist were measured using a Dektak XT surface profilometer before and after each etch recipe, in which the difference divided by the total etch time was found to be the respective etch rate. Each recipe was done in triplicate.

Optimal etch recipes were determined based on PDMS etch rate, etch selectivity, and quality of transferred pattern. Optimal etch recipes were used to fabricate 6 μm diameter holes in a 10 μm thick PDMS film (Sylgard 10:1 base:curing agent), which was achieved by spin-coating PDMS pre-polymer at 7,200 rpm for 35 sec. This fabrication method is illustrated in Figure 1 and adopted from [1].

Results and Discussion:

The determined optimal etch recipes as well as their respective rates and selectivities are reported in Table 1. Optimal etch recipes were determined by selecting the recipe with the fastest

P
R
O
C

Plasma System	RF Power (Watts)	Total Pressure (mTorr)	Gas Composition	Etch Rate (nm/min)	Etch selectivity
CCP	100	30	100% SF_6	188	2.6
ICP	500	10	94% SF_6	1,180	1.8

Table 1: Optimal etch recipes for fabricating micro-through-holes using the surface micromachining method.

PDMS etch rate with a corresponding selectivity greater than 1.0 on both the CCP and ICP systems. A selectivity greater than 1.0 ensured that the 10 μm thick PDMS layer would be etched through prior to the patterned photoresist completely removed by RIE. Because the CCP system was not equipped with a cryogenic chuck, the photoresist would char as either RF power or total pressure increased. As a consequence, desired patterns would erode forming indistinguishable features. Therefore, the quality of the photoresist was also considered when defining an optimal recipe.

The etch rate of the optimal ICP recipe is an entire magnitude greater than the optimal CCP recipe. While the etch mechanism of PDMS is unknown [3] significant difference in etch rates can be attributed to the RF power and gas composition. A cryogenic chuck present on the ICP system allowed for a greater power supply while maintaining the quality of the photoresist. Additionally, the added oxygen was seen to increase the etch rate of PDMS, most likely by readily exposing the silicon in the PDMS to reactive fluorine species of the plasma [4]. Limitations on the CCP system prevented this idyllic ratio of SF_6 to O_2, and a plasma comprised of 100% SF_6 was seen to be optimal.

The features generated by the optimal etches can be seen in Figure 2 (a,b). Each system was able to fabricate features within 100 nm of expected diameter; however, the ICP system produced a clean, vertical sidewall. In contrast, the CCP system generated features with a rough perimeter.

Conclusions:

Both CCP and ICP systems can fabricate the desired micro-through holes. The ICP system proved more time efficient and generated less surface roughness. Due to the high cost of RIE, the possibility of a wet etch should be investigated.

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References:

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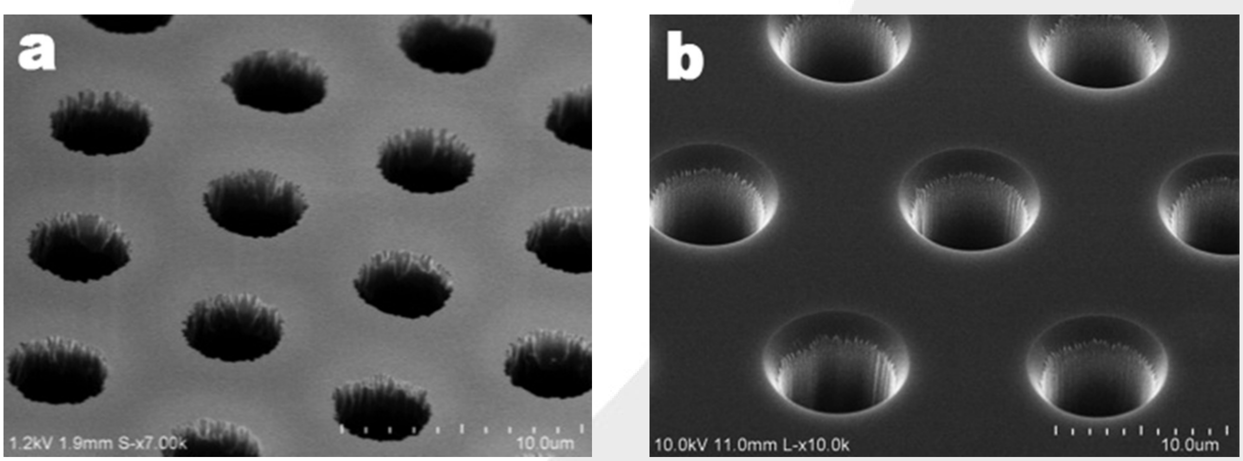

Figure 2: Fabricated 6 µm through-holes using the surface micromachining method etched by; a) CCP system, and b) ICP system.