

HIGH ASPECT RATIO PARYLENE ETCHING FOR MICROFLUIDICS AND BIOMEMS

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Abstract

A novel technique for producing high aspect ratio parylene structures via switching chemistry plasma etching is presented. Parylene C, or poly(monochloro-*p*-xylylene), has become an increasingly popular MEMS material for its excellent properties and biocompatibility. However, the inability to fabricate closely-spaced high aspect ratio (HAR) structures severely limits the use of parylene, particularly in microfluidic and bioMEMS applications. A novel method was developed to etch thin film parylene deposited on silicon substrates. Several masking materials were investigated to optimize this process. This low-temperature (<120 °C) technique is compatible with standard MEMS processes and can accommodate post-CMOS processing. Etching recipes have already been applied to bioMEMS devices and can greatly extend the range of possible structures for bioMEMS and microfluidics applications.

Keywords: parylene, DRIE, high aspect ratio, bioMEMS, microfluidics

1. Introduction

Robust polymer structures are frequently required in microfluidics and bioMEMS applications. These can be produced with polymer micromachining techniques such as embossing, soft lithography, and laser micromachining. However, to achieve compatibility with standard surface and bulk micromachining techniques and take advantage of batch fabrication, dry etching techniques must be used. Previously, plasma [1, 2] and reactive ion [3] etching of parylene in oxygen environments has been reported. These studies presented results on the etching of thin parylene films (only a few microns thick) without any attempt to develop processes to achieve HAR structures. To further complicate matters, Yeh [3] also observed that etch selectivity between parylene and standard photoresist masking materials is near unity due to their organic nature. New developments in HAR etching of silicon has inspired similar efforts in producing HAR polymer structures. Zahn [4] has reported achievable aspect ratios of 20:1 by employing Bosch-like switching chemistries in the etching of polymethylmethacrylate (PMMA). Based on these promising results, a similar technique has been created to etch parylene and photoresist.

2. Experimental

Two types of patterned test coupons were fabricated on silicon wafers and diced before etching: (1) 12µm AZ4620 photoresist masked by 0.5µm of Al and (2) 10µm of parylene masked by 14µm of AZ4620 photoresist. Sputtered amorphous silicon (0.5µm) and oxide (0.3µm) were also examined as possible masking materials. Etching was performed in a PlasmaTherm SLR-770B DRIE system using programmable switching chemistry etches. Etches are composed of repeated etching cycles, or loops. Each loop consists of three steps: (1) deposition of Teflon-like material from C₄F₈ plasma, (2) etch "A", and (3) etch "B." As in the Bosch process, the deposited fluoropolymer layer protects feature sidewalls from lateral etching. Etch "A" preferentially removes the fluoropolymer layer, exposing the parylene to the etching plasma. This step includes

SF₆ which was found to aid in the removal of the deposited fluoropolymer layer. Etch “B” uses both oxygen and argon and serves to remove any remaining fluoropolymer and etch parylene.

3. Results and Discussion

To provide a starting point from which to evaluate switching chemistry etches, photoresist samples were etched using just oxygen plasma in a Technics PEIIA plasma etcher. Samples exhibited significant lateral etching and severely tapered profiles (Figs. 1-2). Thus, in order to achieve desired geometries, precious device real estate and aspect ratio sacrifices are necessary. In contrast, results were vastly improved by using switching chemistries (Fig. 3). Undercutting is minimal and the sidewalls are nearly vertical. Recipes and results for the etched parylene samples are summarized in Table 1 and Figure 5. Figure 4 shows the etch depth versus time for both materials. The trends are linear and the materials have similar etching rates as expected. The etching at sharp corners and other masking materials (α -Si and sputtered oxide) were also examined (Figs. 6-7). Preliminary results indicate that an aspect ratio of at least 2:1 can be achieved for etching parylene. In addition, nearly vertical sidewall profiles are maintained. Traditional oxygen plasma etching techniques of parylene yield at best a ratio of 1:1 (Fig. 8). It has been determined that the removal rate of the fluoropolymer layer can contribute significantly to the total etching process time. Further investigation will target increasing the aspect ratio and reducing etching time by optimizing gas ratios, process pressures, cycle times, and plasma biasing schemes.

Developed etching recipes have already been used to produce working devices. 4 μ m thick parylene neuro-cages for the study of live neural networks have been successfully demonstrated (Figs. 9-10) [5, 6]. Previously, neuro-wells were fabricated using complicated bulk micromachining techniques [7, 8]. The development of this etching technique along with other parylene processing tools has made it possible to realize a biocompatible polymer neuro-cage device. Neuro-cage structures require mechanical robustness for the support of neuron cultures and also demonstrate the possibility of machining thick-walled parylene channels for microfluidic applications.

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References

- [1] Wang, X.-Q., Q. Lin, and Y.-C. Tai, *MEMS '99*, 177-182 (1999).
- [2] Nowlin, T.E. and D.F. Smith, Jr., *Journal of Applied Polymer Science*, **25**, 1619-1632 (1980).
- [3] Yeh, J.T.C. and K.R. Grebe, *Journal of Vacuum Science & Technology A-Vacuum Surfaces & Films*, **1**(2), 604-608 (1983).
- [4] Zahn, J.D., K.J. Gabriel, and G.K. Fedder, *MEMS 2002*, 137-140 (2002).
- [5] He, Q., E. Meng, Y.-C. Tai, C.M. Rutherglen, J. Erickson, and J. Pine, *Transducers 2003*, 995-998 (2003).
- [6] Meng, E., Y.-C. Tai, J. Erickson, and J. Pine, *Micro Total Analysis Systems 2003*, 1109-1112 (2003).
- [7] Maher, M.P., J. Pine, J. Wright, and Y.C. Tai, *Journal of Neuroscience Methods*, **87**(1), 45-56 (1999).
- [8] Wright, J.A., S.T. Lucic, Y.C. Tai, M.P. Maher, H. Dvorak, and J. Pine. *ASME Int. Mechanical Engineering Congress and Exposition*, 333-338, (1996).

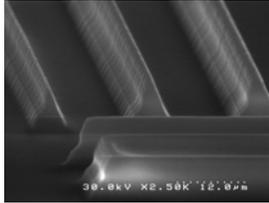


Figure 1. Isotropic AZ4620 etch results

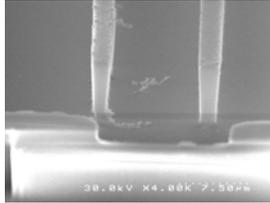


Figure 2. Anisotropic AZ4620 etch results

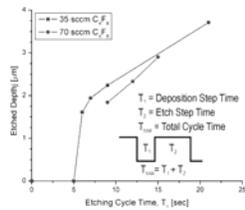


Figure 3. Etch time dependence of switched chemistry etching of AZ4620

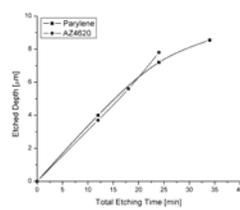


Figure 4. Etch trends for parylene and AZ4620

Recipe	Phosoresist	Parylene 1	Parylene 2	Parylene 3
O_2 Flow Rate (sccm)	40	40	50	60
C_2F_6 Flow Rate (sccm)	70	25	25	25
SF_6 Flow Rate (sccm)	0	0	50	50
Ar Flow Rate (sccm)	40	40	40	40
Etch Coil Power (W)	625	625	625	625
Etch Proton Power (W)	20	20	5, 20	5, 20
Deposition Coil Power (W)	625	625	625	625
Deposition Proton Power (W)	1	1	1	1
Etch Time (sec)	0	0	2, 0	2, 0
Deposition Time (sec)	2	2	2	2
Average Etch Rate (µm/min)	0.062	0.065	0.1	0.07
Average Etch Rate (µm/min)	0.32	0.53	0.4	0.25

Table 1. Summary of etching results

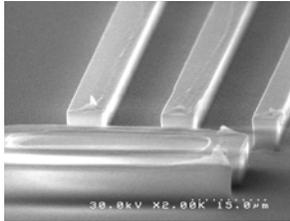


Figure 5. Typical parylene etching results

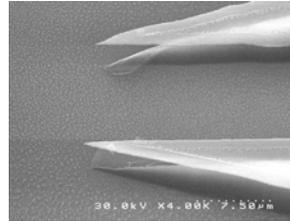


Figure 6. AZ4620 etching at sharp corners

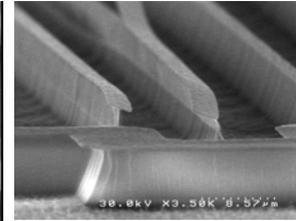


Figure 7. Parylene etched through α -Si mask

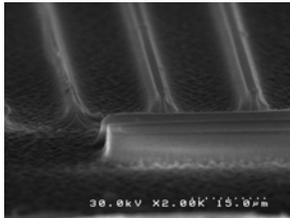


Figure 8. Isotropic etching results for parylene

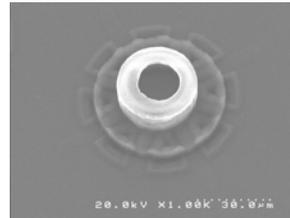


Figure 9. Single parylene neuro-cage structure

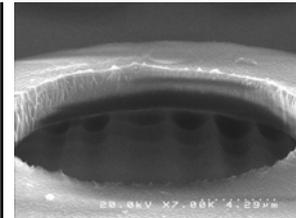


Figure 10. A 15 μ m opening in neuro-cage for loading neurons