Directed Self-Assembly for Post-32 nm Lithography

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Abstract

Like many large polyaromatic hydrocarbons (PAHs), C96 self-assembles into well-ordered supramolecular structures due to π-π interactions between adjacent molecules. Because densely packed monolayers of C96 fibers are easily obtained on silicon or silicon oxide (SiO_2) via standard deposition techniques such as spin-coating or drop-coating, C96 is an attractive candidate for microelectronics applications. This project explores the possibility of using directed self-assembly to attain long-range ordering of C96 fibers for use in post-32 nm lithography. In this method, top-down lithography defines the pattern placement, and C96 self-assembly defines the pattern line-width. Experimental results demonstrate consistently strong C96 fiber alignment with 250 nm and 125 nm chromium (Cr) trenches, suggesting that with further process optimization, directed C96 self-assembly may be a viable extension of traditional lithography techniques.

Introduction

In lithography, the term "critical dimension" refers to the smallest feature size that can be accurately reproduced using a given technology. If current rates of progress in electronic device scaling are maintained, sub-16 nm dimensions will be reached within the next decade [1]. Optical lithography, currently the standard lithography technique for large-scale semiconductor fabrication, has achieved critical dimensions at the 32 nm node, but rising costs and fundamental limits may restrict its use at future nodes.

We seek to extend traditional lithography for post-32 nm critical dimensions using a technique called directed C96 self-assembly. C96 is a large polyaromatic hydrocarbon (PAH) that self-assembles on silicon or SiO_2 into long fibers 2-3 nm in diameter, as shown in Figure 1. Looking down over the substrate, C96 self-assembly results in a dense two-dimensional fiber network that can serve as an etch mask to transfer the pattern onto the substrate [2]. In this case, the critical dimension of C96 self-assembly is the fiber width. The primary drawback of existing C96 self-assembly methods is that C96 fibers tend to orient randomly, rendering the resulting patterns unusable for many practical applications.

Our objective is to develop a method to control the orientation of C96 fibers. One candidate is directed self-assembly, in which patterned features created by traditional lithography techniques direct the self-assembly of C96 fibers. Top-down lithography defines the pattern placement, and C96 self-assembly defines the pattern line-width. In our experiment, we qualitatively examine the interaction of C96 fibers with patterned metal trenches and determine the degree to which C96 fiber orientation is correlated to trench direction.

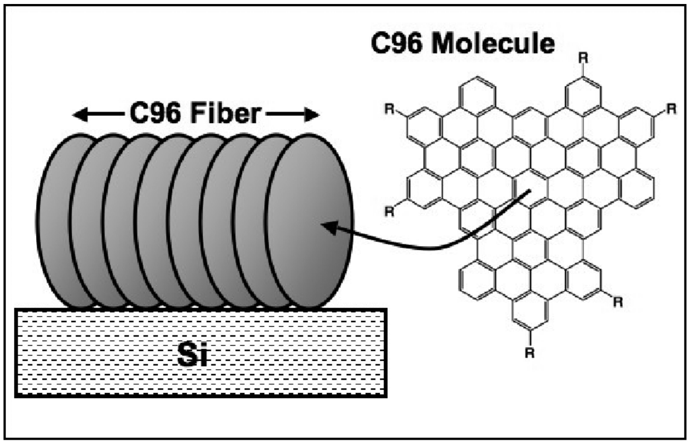

Figure 1: C96 self-assembly mechanism.

Experimental Procedure

A silicon wafer was first patterned via electron-beam lithography (EBL), followed by a metal liftoff. Line/space patterns—parallel lines of fixed width—were patterned onto ZEP 520A resist using a JEOL JBX-9300FS EBL system, with line-widths ranging from 125 nm to 1 μm. After developing the resist, we evaporated 8 nm Cr on the sample and performed a liftoff process using n-methyl-pyrrolidone. The end result was a pattern of parallel Cr trenches, 8 nm deep and 125 nm to 1 μm wide.

C96 deposition was accomplished using one of two methods, dropcast or spincast. In both methods, we first dissolved crystalline C96 in chloroform ($CHCl_3$) at a concentration of 10^{-5} M. Dropcasting involves applying several drops of the C96 solution directly onto a patterned sample and allowing the solvent to evaporate overnight. Spincasting differs from dropcasting in that we spun the sample at 1000 rpm for 60 seconds immediately after depositing the C96 solution, eliminating the need for overnight evaporation.

Before imaging the sample, all C96 molecules that had not bonded covalently to the silicon substrate were removed with chloroform via Soxhlet extraction. Once clean, the sample was imaged using an atomic force microscope (AFM), which allowed us to determine the location and orientation of the C96 fibers. Though the AFM has excellent vertical resolution, lateral resolution is dependent on the width of the probe tip, approximately 25 nm. Therefore, imaged fibers appeared about ten times their actual width of 2-3 nm, limiting our ability to quantitatively analyze the surface patterns.

Results

Samples were prepared using the experimental procedure for Cr line-widths of 1 μm, 250 nm, and 125 nm. Our conclusions are based on qualitative observations regarding the correlation between the C96 fiber orientation and the trench walls, as seen in AFM images.

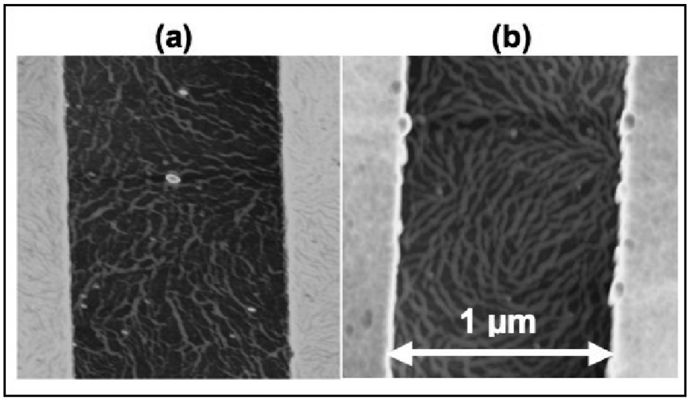

Figure 2: 1 µm trenches, (a) spincoated and (b) dropcoated.

We first noted that dropcast deposition is preferable to spincast deposition. The spincast samples, such as the sample shown in Figure 2a, demonstrated incomplete C96 fiber formation and limited correlation with the trench direction. In Figure 2b, a dropcast sample with the same 1 μm Cr line-width yielded much more robust fiber formation, but equally lacked correlation with the trench direction.

For 250 nm and 125 nm Cr line-widths, however, dropcast samples demonstrated excellent C96 fiber alignment, as shown in Figures 3 and 4. Additionally, on the 125 nm samples, we observed consistency perpendicular to the trench direction—there were approximately two C96 fibers in parallel in each trench. These results confirm the ability to influence C96 fiber alignment using a directed self-assembly method.

Conclusions

We developed and tested a procedure that allows for long-range control of C96 fiber alignment using a directed self-assembly method. First, we showed that C96 fibers tend to self-align with 250 nm-wide patterned Cr trenches. Later, in 125 nm trenches, we observed a significant degree of control over the number of fibers that align in parallel in each trench.

We conclude that, with optimization, directed C96 self-assembly has the potential to be used in large-scale semiconductor fabrication as a practical lithography technique offering sub-32 nm critical dimensions.

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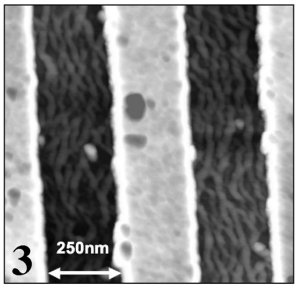
[2] J. Jarvholm, "Etch resistance for highly aromatic monomolecular etch masks," Atlanta: Georgia Tech, 2007.



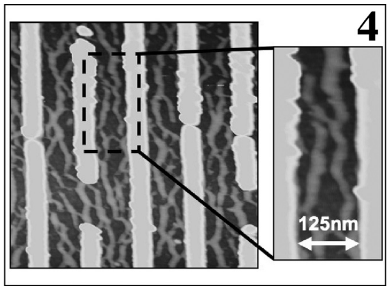


Figure 3, left: 250 nm trenches, dropcoated.

Figure 4, right: 125 nm trenches, dropcoated.