Optical and Electron Beam Patterning for Graphene Nanoribbon Devices

Nathanial Sheehan
Electrical Engineering, University of California, Santa Barbara

NNIN REU Site: Nanofabrication Center, University of Minnesota-Twin Cities, Minneapolis, MN
NNIN REU Principal Investigator: Dr. Steven J. Koester, Electrical Engineering, University of Minnesota-Twin Cities
NNIN REU Mentor: Yoska Anugrah, Electrical Engineering, University of Minnesota-Twin Cities
Contact: nsheehan@umail.ucsb.edu, skoester@umn.edu, anugr002@umn.edu

Abstract and Introduction:

Graphene is a monolayer material that could allow for smaller, high-performance field effect transistors. Transistor scaling has allowed the microelectronics industry to advance over the last forty years, leading to denser, higher performance systems that consume much less power. However, silicon scaling has reached fundamental limits and a replacement material that can be scaled more is needed, leading to further performance improvements. The carrier mobility of graphene has been shown to be roughly an order of magnitude higher than silicon, making it a possible replacement [1]. Graphene must be sliced into nanoribbons less than 5 nm wide to induce a band gap (due to quantum confinement) suitable for room temperature transistor operation [2]. This width is beyond the patterning ability of traditional optical lithography, thus novel lithographic techniques that will work with graphene processing techniques are needed.

This research explored using block copolymers (BCPs) as a mask for etching graphene nanoribbons (GNRs). BCPs are composite materials containing two or more homopolymers. They can be induced to phase separate and align to existing lithographic guiding structures. The research performed in this REU project focused on fabrication of guiding structures for the alignment of straight, parallel BCP patterns. The effect of the depth of optically patterned guiding structures on BCP alignment was investigated. Electron-beam lithography (EBL) was also employed to pattern narrow-width guiding structures to determine how the width of narrow guiding structures affects alignment.

Method:

Figure 1 outlines the process used to fabricate optically patterned guiding structures. The result was patterned channels in the silicon nitride (Si_3N_4) with different initial nitride layer thicknesses. We chose to make Si_3N_4 depths of 20, 40, 60, and 80 nm. The width and length of the channels also varied in a large array pattern (Figure 2), with a minimum width of approximately 300 nm. The wafer was then cleaved, BCP spun on it, and it was solvent-annealed to phase separate and align the BCPs. The alignment efficacy

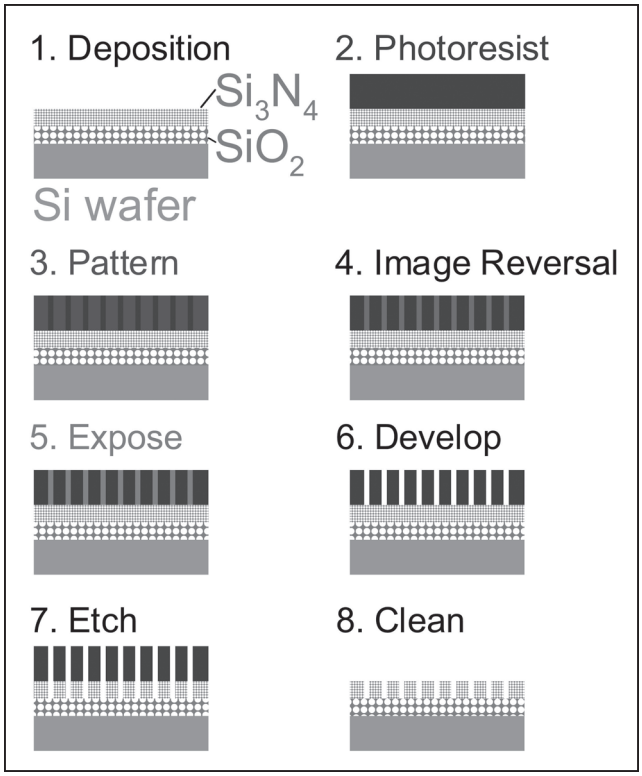

Figure 1: Optically patterned wafer process outline. Different shades of gray represent different layers, and different processes in steps 2 through 5.

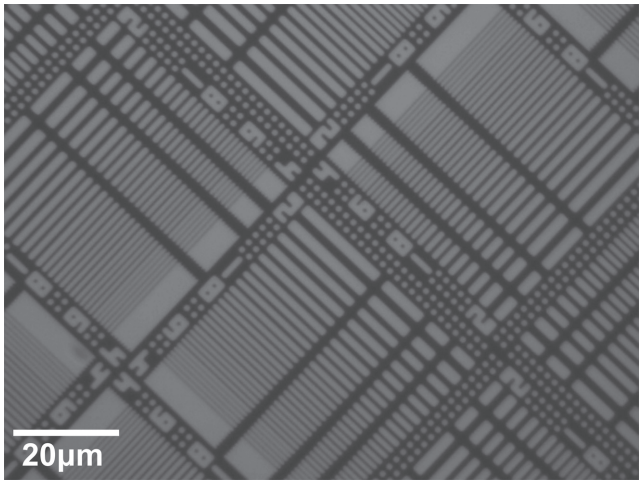

Figure 2: Close up microscope image of completed 60 nm deep guiding structures. Nitride is dark and the raised part.

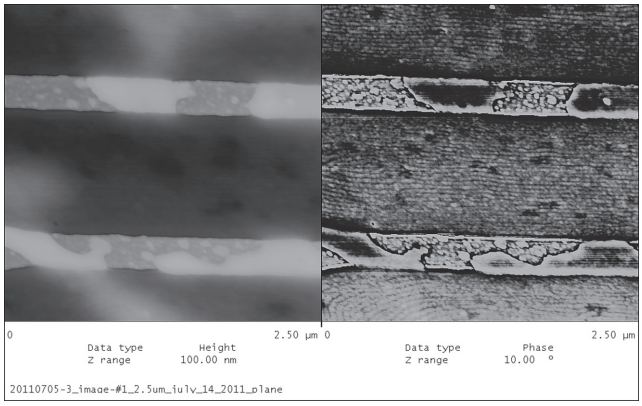

Figure 3: AFM showing parallel BCP alignment; 60 nm depth, 1 µm width guiding channel. Figure is typical of imaged results.

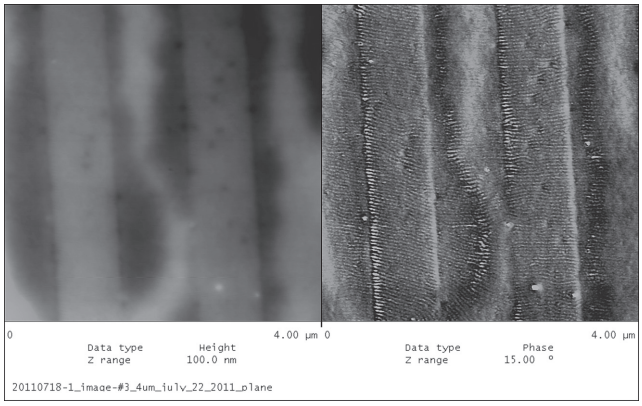

Figure 4: Preliminary AFM image showing BCP alignment perpendicular to guiding channels; 20 nm depth, 0.95 µm width.

of the variously dimensioned channels was determined by atomic force microscopy (AFM).

EBL was explored to make guiding structures of narrower widths, in the range 50 to 500 nm, with the depth varying as above. The process was similar to the optical process. We determined the proper EBL exposure strength by performing scanning electron microscopy on patterned test chips.

Results and Discussion:

The 60 nm deep guiding channels were shown to align some of the BCPs in large width (2 μm) channels, which is promising because this allows for optical lithographic patterning of the guiding structures (Figure 3). It was observed that the deposition and annealing conditions for the BCP film play a large role in the quality of the alignment to the guiding structures. These conditions affected film uniformity, which is required for high quality alignment. The height of the film was non-uniform in some channels, leading to misalignment of the BCP. This may be due to dewetting and flow of BCP on the regions between channels, i.e. the BCP "balled up" in raised regions and later flowed back into the channels, creating non-uniform thickness in some areas.

Preliminary AFM scans of the 20 nm deep channels showed some unexpected results (Figure 4). The BCP film was continuous over the mesas, and was still aligned in areas of high film uniformity. However, the direction of BCP alignment was perpendicular to the alignment channels instead of the expected parallel alignment. This suggests the topography of the guiding structures, and not just the conditions under which the BCPs are aligned, plays a large role in alignment direction [3].

Analysis was performed on how EBL exposure conditions affected the EBL-defined guiding structure dimensions. We found that channels of the same target width for doses of 600 μC/cm^2 and 800 μC/cm^2 had similar dimensions, but the smallest channel widths (50 nm) were not resolved at the higher dose. All of the channels were too wide, so further refinement of the initial pattern is needed.

Future Work:

We would like to investigate the effect of the other optically patterned nitride channel depths (40 and 80 nm) to determine the best conditions for optimal BCP alignment. The EBL guiding structure fabrication process must also be refined to allow narrow-width EBL written channels to be fabricated, so that they may guide the BCPs. Once the optimum guiding dimensions are found, a process for transferring the BCP-defined patterns into graphene must be developed. Finally, the guiding structures must be integrated with a graphene transistor process flow to enable functional devices.

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References:

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