Templated Photo-Ablation of Graphene

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Present applications for graphene nanodevices span a growing range, including quantum-effect transistors and other quantum-electronic devices, high-sensitivity chemical sensors, DNA sequencers, and bandgap engineering by means of atom trapping and doping - with many more anticipated uses. Such applications generally require nano-precise patterning of graphene. Previous efforts to pattern graphene have utilized electron-beam and helium-ion lithography, which meet initial research requirements, but have insufficient throughput for large-scale graphene device production. In addition, many graphene patterning methods use resist-based exposure and etching, which present contamination issues and can interfere with graphene chemistry and surface states. At this time, no known prior attempts have been made to adapt high-resolution parallel nanopatterning methods to graphene. As CVD-grown graphene increases in area (currently up to 100 mm-diameter wafers) such parallel methods become increasingly relevant and desirable. Templated patterning of individual graphene monolayers would allow rapid production of graphene devices over large areas. Direct vaporization or ablation of selected areas of graphene would circumvent the need for resist, solvents, and etching.

In this article we demonstrate ablation of graphene in the interstitial regions of a metal absorber pattern by exposure with Cu_L photons (peak at $\lambda = 4.5$ nm, 275 eV), which break multiple sp^2 bonds (5.42 eV) [1] between carbon atoms and vaporize graphene in the exposed regions.

In an experiment we exposed a few layers of CVD-grown graphene in contact with a copper grid. Graphene was free-standing, suspended across the openings of the grid. The exposure apparatus is shown in Fig. 1(a) and the template and graphene arrangement is illustrated in Figs. 1(b) and 1(c). Graphene samples were exposed for 30 minutes by a Cu_L photon source, in one case with air in the 18 cm beampath from a 1 μm-thick SiN_x vacuum window to the sample and in another case with the samples contained in a 99.99%-pure helium environment. The 4.5 nm photons are known to be absorbed in air, and transmitted through helium. Samples were scanned with an AFM, in a similar location on each sample (within 50 μm), before and after exposures. When air was in the beampath, no difference in the graphene was observed before and after exposure. With helium in the beampath during the exposure, graphene was removed from the interstitial regions of the grid (Fig. 2). Further experiments suggest that free-standing graphene does not ablate when exposed to 193 nm laser illumination. These experiments indicate that graphene can be directly removed and patterned by photo-ablation using 4.5 nm photons.

In the paper we will describe (i) the mechanics of ablation, (ii) the scaling limits of fine patterned graphene features, (iii) the potential for minimization of diffraction blurring with atom-thick membranes in contact with absorber patterns, and (iv) methods for nearly-stress-free manipulation and surface-to-surface transfer of patterned graphene membranes.

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[1] S. Y. Zhou, et al., Phys. Rev. B **80**, 121409 (2009).

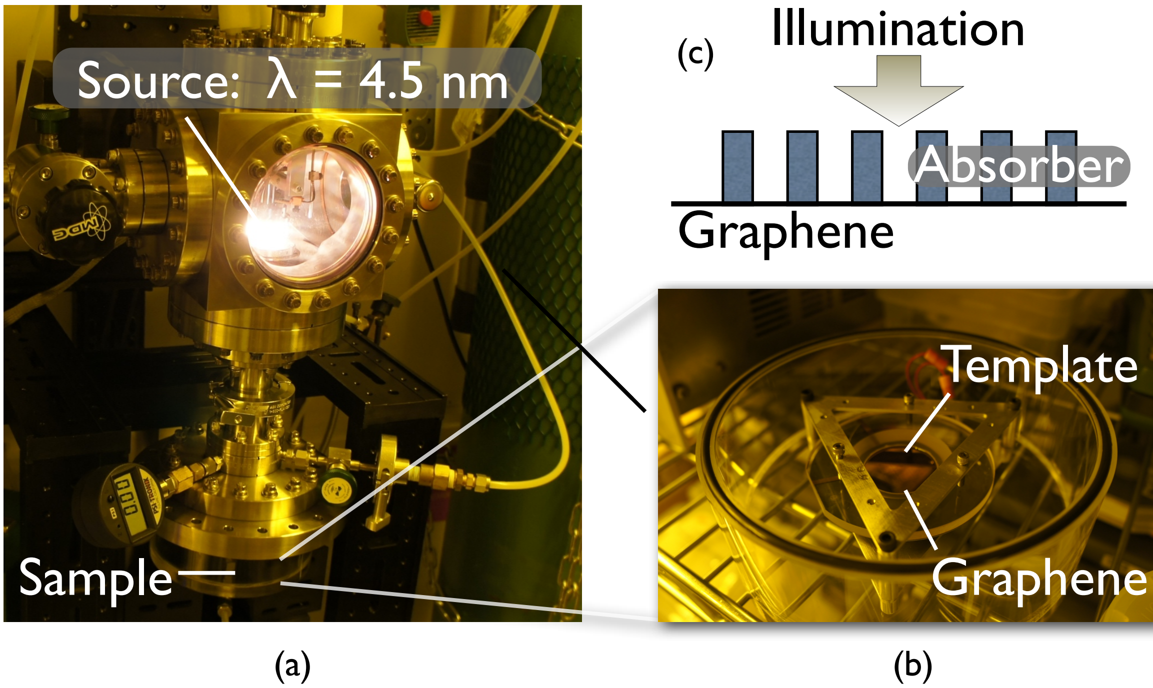

Fig. 1. (a) The experimental apparatus. (b) Graphene/template sample holder. (c) Schematic of template absorber and graphene sample.

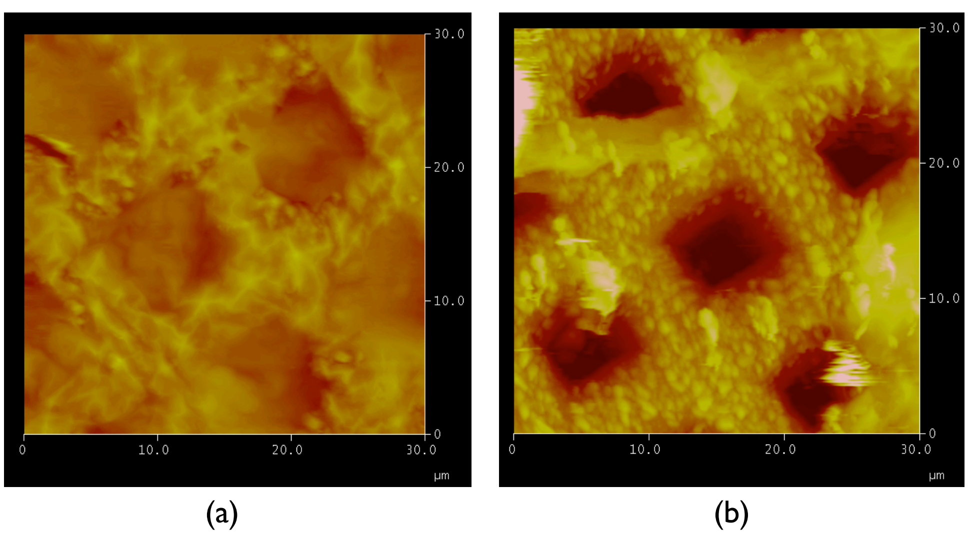

Fig. 2. AFM scans of free-standing, suspended graphene on a copper grid, (a) before and (b) after exposure. Ablation of graphene has occurred, leaving open regions in the grid.