Measurement of the Helium Ion Point-Spread Function on Ultrathin Membranes

R. O'Meara, V. Dhyani, R.G. Hobbs
Centre for Research on Adaptive Nanostructures and Nanodevices (CRANN) and the SFI Advanced Materials and Bio-Engineering Research Centre (AMBER), Dublin 2, Ireland; School of Chemistry, Trinity College Dublin, The University of Dublin, Dublin 2, Ireland
omeararo@tcd.ie

Helium-ion-beam lithography (HIBL) offers significant advantages over electron-beam lithography (EBL) for the fabrication of dense arrays of nanostructures on surfaces. The probe size, or beam diameter, in a helium-ion microscope has been reported to be as small as 0.35 nm, and the convergence angle of the beam at the sample is typically lower than that of an electron beam of equivalent energy in a scanning electron microscope[1,2]. Thus He^+ ion beams have reduced diffractive effects, and a larger depth of field than equivalent electron beams[1,2]. He^+ ions typically produce a larger secondary electron (SE) yield than electrons of equivalent energy, resulting in more efficient lithographic exposure due to improved resist sensitivity[3,4]. He^+ ion beams also exhibit a reduced proximity effect relative to electron beams of equivalent energy[5]. Reducing proximity effects is of particular importance to lithography as proximity effects limit the size of the smallest feature that can be patterned and the density of patterned nanostructures per unit area on a substrate.

A point-spread function (PSF) measures the response of an imaging system to a point source of radiation. PSFs for electron and ion beam systems can be measured experimentally by performing point exposures in a resist material for a series of doses and measuring the size of the features formed at each dose. PSFs provide information about the lateral distribution of energy deposited by the incident beam in the resist[6]. When patterning dense arrays of nanostructures overlapping dose tails of neighboring features can result in unwanted indirect exposure of regions between directly exposed features. An accurate description of the PSF can determine how closely printed structures can be resolved and can also be used to calculate corrections for the local dose when patterning small features.

Here, we measure the PSF of 30 keV He^+ ions in both polymethyl methacrylate (PMMA) and a fullerene-based resist on ultrathin silicon nitride membranes and compare the results to both calculated PSFs for each resist, and to similar work by Manfrinato *et al*[7]. measuring the PSF of 200 keV electrons in PMMA using an aberration-corrected scanning transmission electron microscope (STEM). PSFs were calculated using the method developed by Winston *et al.*[8] Our results show that the He^+ ion/PMMA PSF decays more rapidly with distance from the point of incidence of the beam than the corresponding aberration-corrected electron beam/PMMA PSF. This result implies that there is less lateral spread of energy for the 30 keV He^+ ion beam in PMMA than there is for the aberration-corrected 200 keV electron beam. This work provides further evidence that HIBL offers distinct advantages over EBL for high-resolution and high-density patterning.

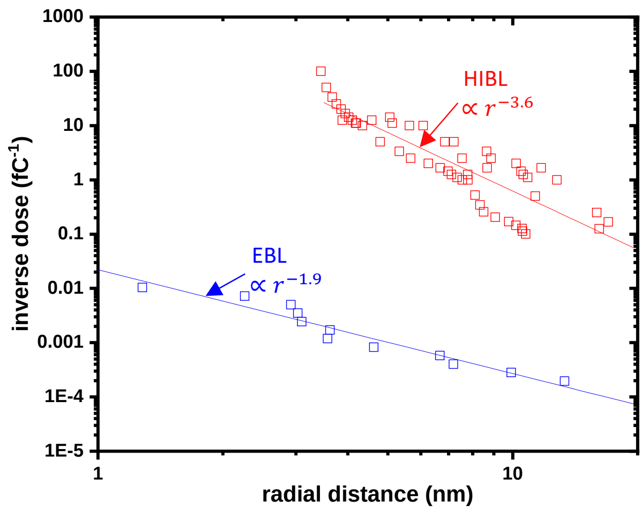

Figure 1: Comparison between experimental data from this work using He^+ ion beam lithography and experimental data from the work of Manfrinato et al[7]. using an aberration-corrected STEM to perform electron-beam lithography. In both cases the data were generated for the exposure of single-pixel dots of negative-tone PMMA having similar thickness. Results from this work using HIBL are shown in red. Results from the word using the aberration-corrected STEM are shown in blue.

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