A Quantitative Comparison between Helium Ion and Electron Beam Lithography on PMMA Resist

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Helium ion beam lithography (HIBL), an emerging technique that uses a sub-nanometre focused beam of helium ions to expose resist, has introduced an alternative to electron beam lithography (EBL) to extend beyond existing minimum feature sizes. HIBL has several advantages over EBL, including a higher patterning resolution due to a smaller spot size [1] and a reduced proximity effect due to low ion backscattering and deflection [2, 3]. However, there is yet to be a direct comparison of these two techniques on thin layer resists. Here, we present a quantitative and direct comparison study on EBL and HIBL with respect to sensitivity and proximity effects using poly(methyl methacrylate) (PMMA), an established benchmark EBL resist, leading to a demonstration of high resolution HIBL patterning of line arrays.

PMMA 495 diluted with anisole was spin-coated onto HF cleaned silicon chips to a thickness of approximately 20 nm. Following a pre-exposure bake, the samples were exposed in the helium ion microscope (HIM, Zeiss Orion Plus) and field emission gun scanning electron microscope (SEM, Zeiss NVision 40) to 30 keV focused helium ion and electron beams, respectively. The patterns were developed in MIBK/IPA (1:3) and were then characterized using HIM, SEM and atomic force microscopy (AFM).

The dose response curves (Figure 1) obtained from large area exposures reveal that PMMA behaves similarly in EBL and HIBL, exhibiting positive first then negative tone with an increase in dose. However, HIBL at only ~ 2 μC/cm^2 is found to be 60 times more sensitive than the EBL at ~120 μC/cm^2. To compare the proximity effect, the doughnut method described by Stevens et al. [4] was adopted. Arrays of doughnuts with a fixed outer radius and varied inner radii and doses were fabricated using HIBL and EBL and imaged after development (Figure 2). By fitting the experimental data to a Gaussian approximation of the proximity equation, the ranges of the backscattered ions/electrons (β) were then determined to be 67.1 nm and 3.26 μm for HIBL and EBL, respectively (Figure 3), suggesting that HIBL is capable of producing patterns with a higher density owing to its almost 50 times smaller proximity effect. To demonstrate the benefit of the reduced proximity effect, high resolution single pixel lines were exposed using HIBL at pitches ranging from 118 nm down to 30 nm (Figure 4). The measured average critical dimensions remain the same at around 11.5 nm as the pitch is reduced, indicating a very high resolution and small proximity effect associated with HIBL.

With standard processing conditions, these results collectively demonstrate the potential of HIBL as a high exposure efficiency, high resolution and low proximity effect patterning technique for nanofabrication.

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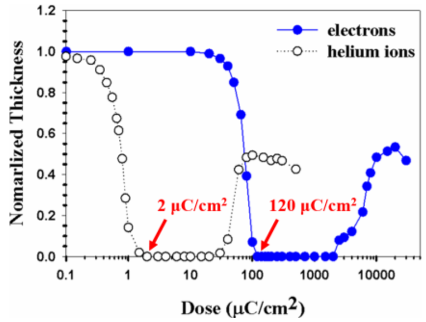


Figure 1. Comparison of the dose response curves for 20 nm thick PMMA in HIBL and EBL. The sensitivities are measured to be 2 μC/cm^2 and 120 μC/cm^2, respectively, revealing a 60 times sensitivity improvement in HIBL.

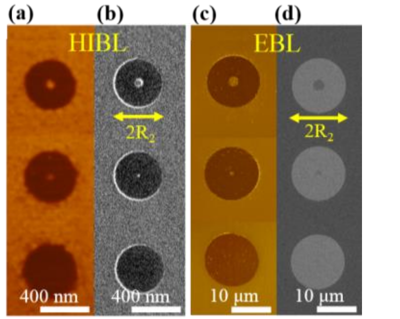


Figure 2. **(a)** AFM and **(b)** corresponding HIM, **(c)** AFM and **(d)** corresponding SEM images of doughnuts fabricated using HIBL and EBL with fixed outer radii (R_2) of 200 nm and 7 μm, respectively, and varied inner radii (R_1).

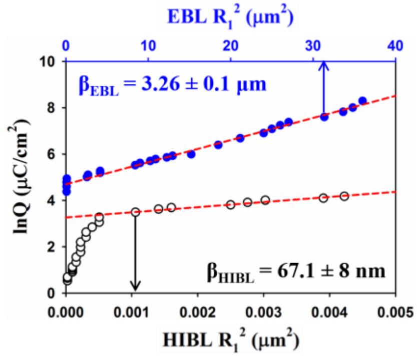
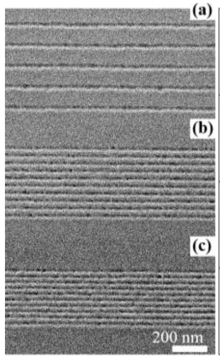


Figure 3. Comparison of the proximity effect for HIBL and EBL on 20 nm thick PMMA. The ranges of the backscattered ions/electrons are calculated to be 67.1 nm and 3.26 μm for HIBL and EBL, respectively, revealing an almost 50 times proximity reduction in HIBL.



Pitch (nm)	Average Critical Dimension (nm)
118	11.8
38.5	11.9
30	11.3

Figure 4. HIM images of single pixel lines fabricated using HIBL with a line dose of 4 pC/cm at pitches of **a)** 118, **b)** 38.5 and **c)** 30 nm on 20 nm thick PMMA. Critical dimension of approximately 11.5 nm remains the same for all pitches as shown in the table.