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Electronic Supplementary Information for

Controlled roughness reduction of patterned resist polymers using laser-induced sub-millisecond heating

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Pattern characterization method using SuMMIT. Following either hot-plate or laser-induced hardbake, resist patterns containing 30 nm lines/spaces were imaged using a Leo 1550 FESEM with constant magnification at 200k. SuMMIT[1] was used to quantify the critical dimension (CD) and line width roughness (LWR) from a minimum of eight lines from a single SEM image. In SuMMIT, the relative threshold for edge detection was 50%. Line length used for evaluating LWR was 375.0 nm on 30 nm half-pitch features. At least 8 lines were averaged to give LWR and CD values. Threshold reference was performed using averaged lines and linear edge detection algorithm.

SEM images of additional polymer systems after laser hardbake. In addition to hybrid polymer A, two additional polymer systems were studied. One was an acrylate-based polymer where the deprotection mechanism during PEB converts esters along the polymer backbone into carboxylic acids. The other was a temperature-sensitive hybrid polymer B. SEM images of the patterns at varying laser hardbake temperatures for 500 μs are shown in Figures S1 and S2 for acrylate-based polymer and hybrid polymer B respectively. For both polymer systems, the original pattern shows significant edge roughness before noticeable smoothing as the hardbake temperature increases.

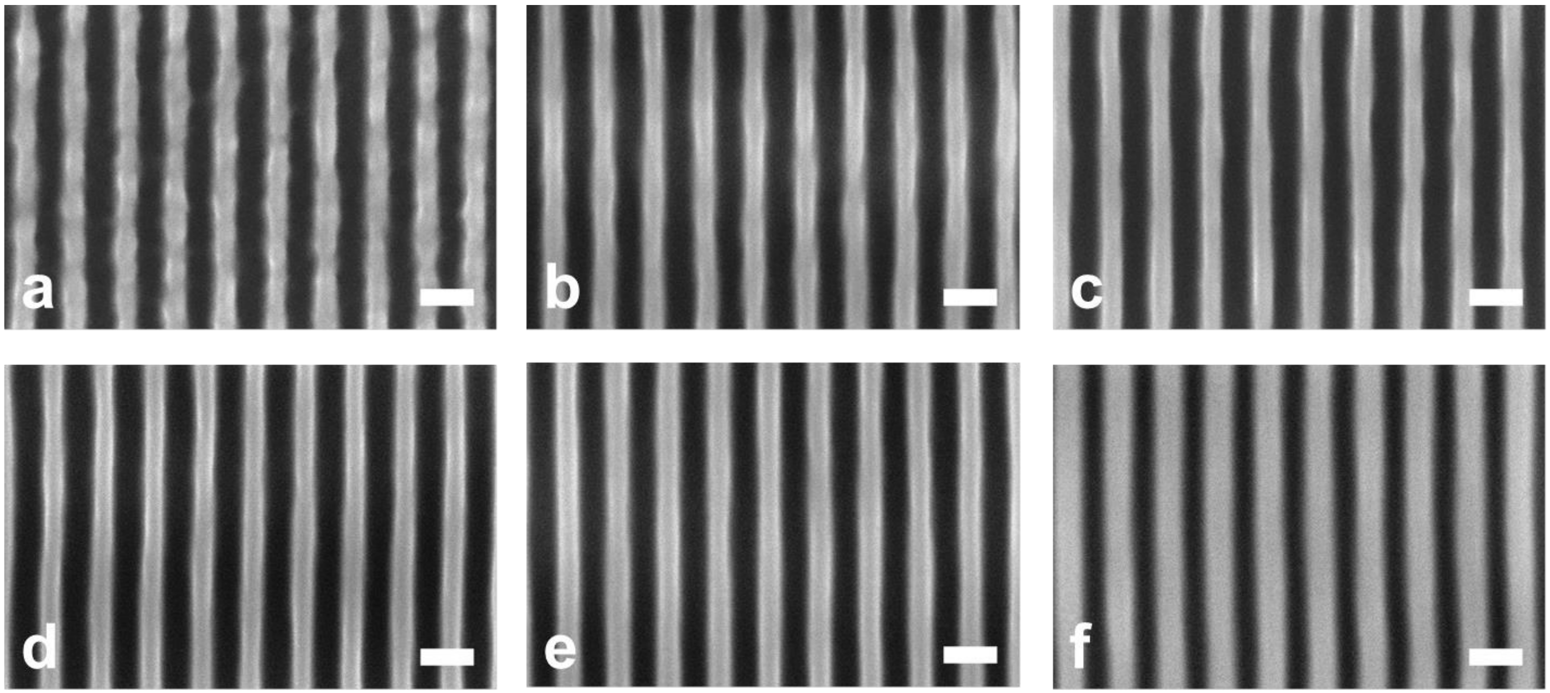

Figure S1. SEM images of 30 nm line/space patterns generated using a acrylate-based resist polymer and EUV lithography followed by laser-induced hardbake for 500 μs. Images show a) the original pattern, and patterns after heating to b) 295 °C, c) 355 °C, d) 385 °C, e) 420 °C, and

f) 450 °C. While the original pattern shows significant roughness on line edges, resist smoothing through polymer flow is observed for increasing hardbake temperatures. By 450 °C however, excessive flow is apparent as the CD is significantly changed. All scale bars correspond to 60 nm.

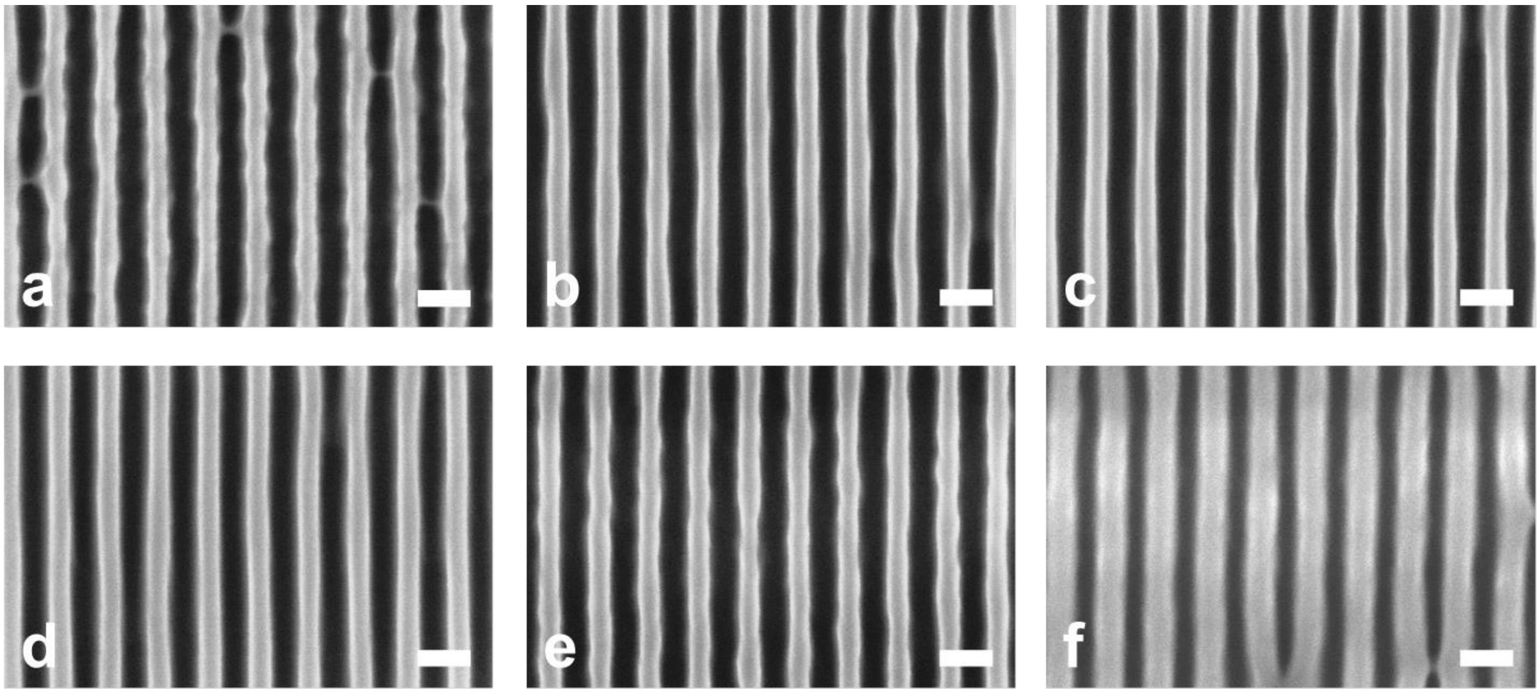

Figure S2. SEM images of 30 nm line/space patterns generated using a temperature-sensitive hybrid polymer B and EUV lithography followed by laser-induced hardbake for 500 µs. Images show a) the original pattern, and patterns after heating to b) 265 °C, c) 295 °C, d) 325 °C, e) 355 °C, and f) 420 °C. While the original pattern shows significant roughness on line edges, resist smoothing through polymer flow is observed for increasing hardbake temperatures. By 420 °C however, excessive flow is apparent as the CD is significantly changed. All scale bars correspond to 60 nm.

Power spectral density of patterns at optimal hardbake conditions. Power spectral densities (PSD) (Fourier amplitude as a function of spatial frequency of the line patterns) before and after laser hardbake at optimal temperature were compared for three investigated resist polymers as shown in Figure S3. The optimal heating condition was chosen for maximum reduction in LWR with less than 1 nm CD change. While the shape of curves is comparable before and after laser hardbake (confirming minimal CD change), original patterns show random peaks in PSD at low frequencies up to 10 μm^{-1} corresponding to the significant roughness on pattern edges which are reduced upon laser hardbake.

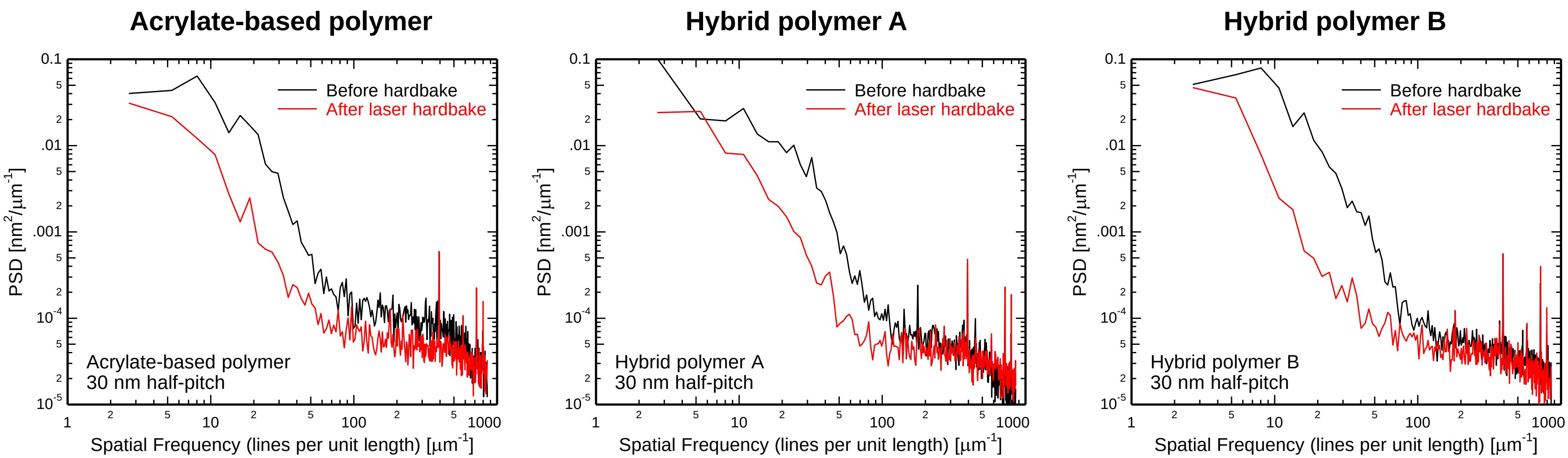

Figure S3. Power spectral density (PSD) as a function of spatial frequency for three polymers before and after laser hardbake at optimal heating conditions. Compared to the original patterns, significant smoothing of the curve in the frequency range from 10-100 μm^{-1} confirms the roughness reduction while the similarity in PSD curve shape suggests minimal change to the overall CD. Calculated slopes for before and after laser hardbake are –3.3 and –3.0 for acrylate-based polymer, –4.0 and –2.9 for Hybrid polymer A, and –3.3 and –2.7 for Hybrid polymer B.

References

1. M. D. Shumway, P. Naulleau, K. A. Goldberg and J. Bokor, *J. Vac. Sci. Technol. B*, 2005, **23**, 2844.