Sub-10-nm Half-Pitch Electron-Beam Lithography by Using PMMA as a Negative Resist

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Until now, hydrogen silsesquioxane (HSQ) was the only reported negative resist that could approach sub-10-nm half-pitch resolution for electron-beam lithography (EBL). Herein, we report that sub-10-nm half-pitch dense nanostructures can also be readily fabricated using poly(methyl methacrylate) (PMMA) as a negative electron resist. The initial motivation of this work was two-fold: (1) developing an additional sub-10-nm-resolution negative resist that could be used as an alternative for applications incompatible with HSQ; and (2) developing a new high-resolution EBL process that can be used for comparison with existing HSQ processes [1] to understand better the fundamental resolution limits of EBL.

Figure 1 shows the scanning-electron-microscopy (SEM) images of high-resolution negative PMMA nanostructures, from which we can see that 8-nm-half-pitch dense honeycomb dots and 6-nm-half-pitch nested Ls were realized by using the Raith 150 at MIT with an exposure voltage of 30 kV. To further confirm its high resolution capability, the exposure was also conducted by using ultralow voltage and ultrathin PMMA resist. In figure 2, we can see that the 10-nm-half-pitch nanostructures were well defined even at the exposure energy of 2 keV, and the sensitivity was improved about 15 times relative to 30 keV exposure.

To understand the mechanism of this high-resolution process, we measured the point-spread function and development contrast and compared them with the known performance of the HSQ process [1]. We found that this negative PMMA process had a similar resolution limit as the well-developed high-resolution HSQ process, even though the negative PMMA process had a much lower development contrast.

Considering that negative PMMA is a carbonaceous material and could be graphitized under post-treatment [2, 3], this high-resolution process could also be potentially used to fabricate patterned sub-10-nm graphitic nanostructures directly.

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[2] H. G. Duan, E. Q. Xie, L. Han, and Z. Xu, Adv. Mater., **20**, 3284 (2008).
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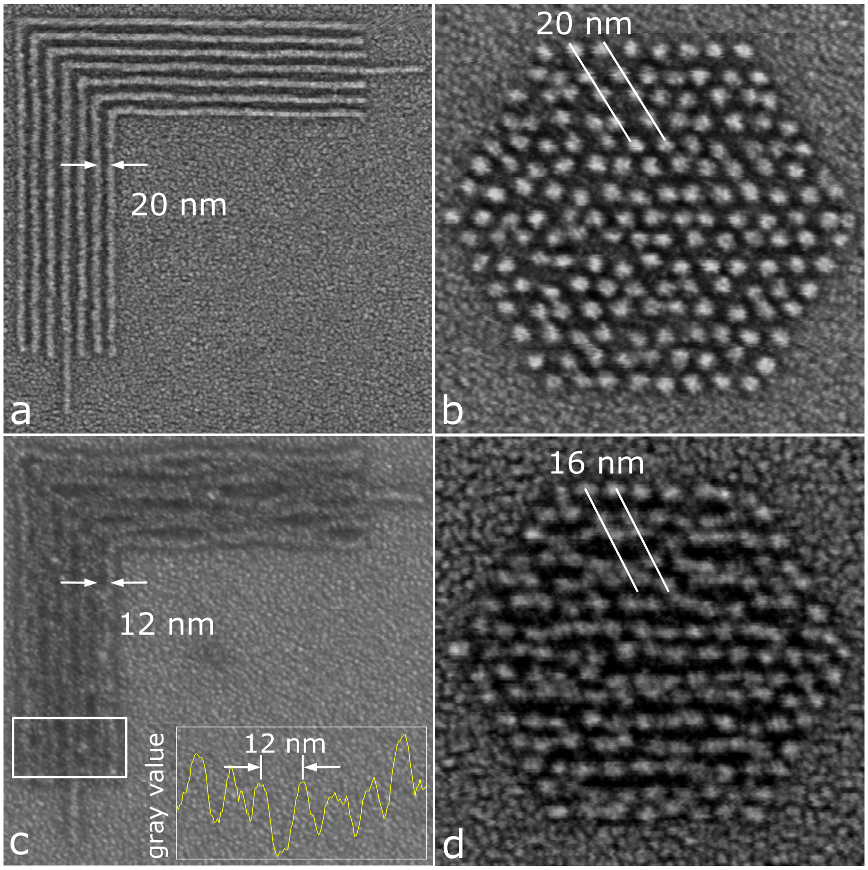

Figure 1. SEM images of ultrahigh-resolution structures fabricated by the Raith150 at MIT at 30 kV using 23-nm-thick PMMA as a negative resist. (a) and (b): 20-nm-pitch nested Ls and honeycomb dots, respectively; (c): 12-nm-pitch nested Ls; (d) 16-nm-pitch honeycomb dots. Inset in (c) is the gray value distribution of the selected box. The development was done in MIBK for 2 min at 30 °C. The SEM images were done by the Raith 150 at MIT at 10 kV accelerating voltage and 6 mm working distance. An Au/Pd layer was deposited on the samples before imaging.

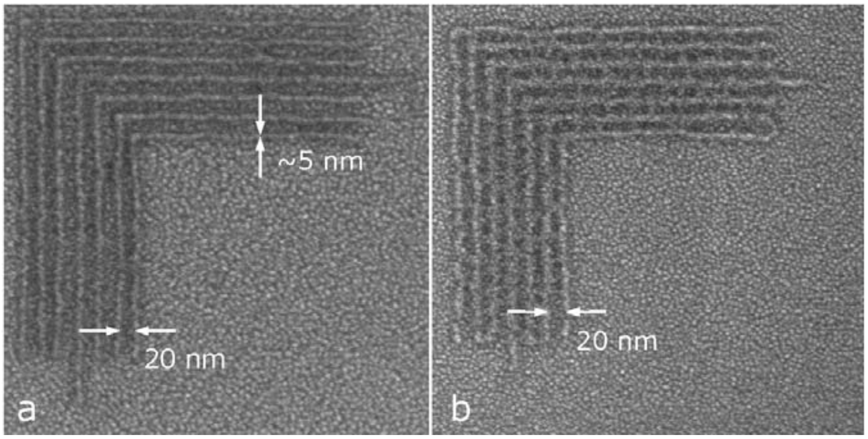

Figure 2. SEM images of 20-nm-pitch nested Ls fabricated by the Raith 150 at MIT at 30 kV (a) and 2 kV (b) using 16-nm-thick PMMA as the resist. The line dose was about 18,000 e^-/nm and 1200 e^-/nm for 30 kV and 2 kV exposures, respectively. The development was conducted in MIBK for 2 min at 30 °C. The SEM images were also done by the Raith 150 at MIT at 10 kV accelerating voltage and 6 mm working distance. An Au/Pd layer was deposited on the samples before imaging.