7-nm-pitch gratings fabricated on diamond substrates using hydrogen silsesquioxane resists and electron-beam lithography

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Hydrogen silsesquioxane (HSQ) has become a very important resist for nanoscale patterning using electron beam lithography (EBL). This achievement has been aided by the introduction of a salty developer, NaOH/NaCl [1] which has produced 9-nm pitch gratings on silicon. Another solution that has been adopted in this novel class of salty developers is TMAH/NaCl [2]; this has demonstrated a higher contrast in comparison with NaOH/NaCl. Further improvements in contrast have been achieved at elevated developer temperatures for HSQ [3]. Various other lithographic and process parameters such as resist thickness, substrate types, and resist baking temperature need continuous optimization in order to realize the ultimate potential of HSQ resist.

In this work, we present studies on nanopatterning of HSQ on bare diamond substrates and on PMMA/diamond substrates. The surface roughness (~ 2 nm) of the diamond was sufficient to prevent the sticking of patterned HSQ on the bare surface. The spinning of ~ 10 nm-thick PMMA on the diamond enhanced the adhesion of the HSQ. HSQ (Fox-14) resist was used in this work and exposures were conducted using a JEOL JBX-6000FS electron beam nanowriter at 50 kV. Developments were performed using TMAH/NaCl:0.25/0.7N at various temperatures. Contrast curves were determined on silicon and diamond substrates using 50-nm-thick HSQ resists. Figure 1 shows results of contrast curves of HSQ on silicon developed at 30 ^{o}C for various resist baking temperatures ranging from unbaked to 200 ^{o}C. The highest contrast values were achieved for the unbaked samples. Figure 2 shows the contrast curves results of unbaked HSQ resists on silicon and diamond substrates that were developed at 20 ^{o}C and 30 ^{o}C. In general, unbaked HSQ resists on diamond substrates developed at higher temperatures produced the best contrast values.

For experiments on the realization of ultra-dense grating, 10-nm-thick unbaked HSQ was utilized. Gratings with pitches down to 7 nm have been consistently achieved on PMMA on diamond substrate as shown in Figure 3 (a). Figure 3 (b) shows the nanopattern with thin (3 – 5 nm) sputtered Au, the aggregation of the thin Au film is observed. The grain size of metal film will be reduced further with a gold-palladium alloy. To the best of our knowledge, the 7-nm-pitch gratings reported here are the smallest fabricated by direct e-beam writing to date. Detailed results on the repeatability of the fabrication of the ultra-dense lines and pattern transfer will be reported.

[1] J. K. W. Yang and K. K. Berggren, J. Vac. Sci. Technol. B 25 (6), 2025 (2007).
[2] J. Kim, W. Chao, B. Griedel, X. Liang, M. Lewis, D. Hilken, and D. Olynick, J. Vac. Sci. Technol. B 27 (6), 2628 (2009).
[3] M. Yan, J. Lee, B. Ofuonye, S. Choi, J. H. Jang, and I. Adesida, J. Vac. Sci. Technol. B 28 (6), C6S23 (2010).

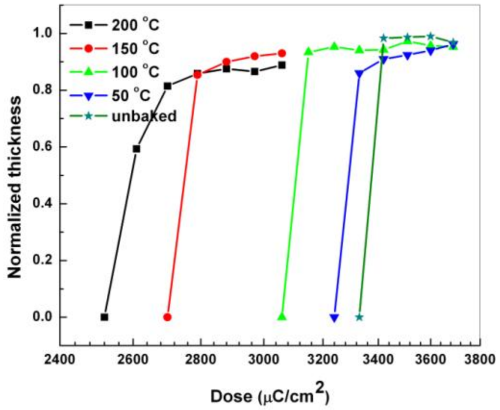


FIG. 1. Contrast curves for HSQ developed with TMAH/NaCl 0.25/0.7N at 30 °C for different baked temperatures on silicon substrates.

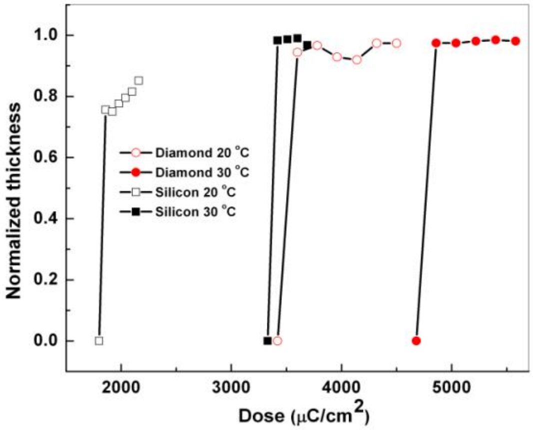
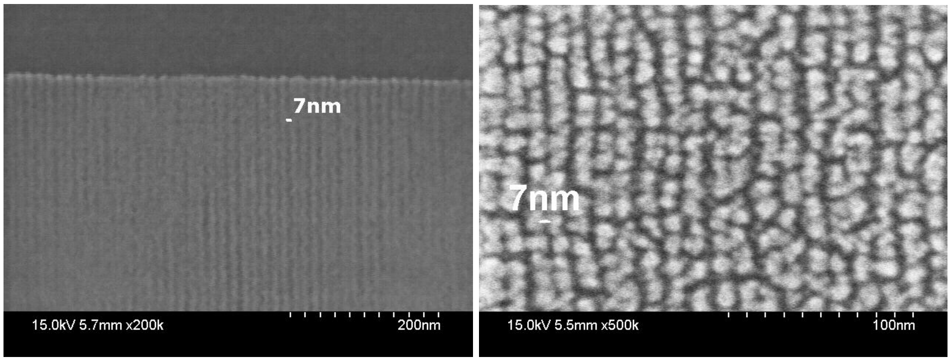


FIG. 2. Contrast curves for unbaked samples on diamond and silicon substrates.



(a) (b)

FIG. 3. (a) 7-nm-pitch HSQ gratings (b) 7-nm-pitch HSQ gratings on a PMMA/diamond substrate with a thin gold film sputtered.