

Lift-off using solvent for negative electron beam resist by ultra-low energy exposure

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Liftoff and direct etch are the two most popular pattern transfer methods for electron beam lithography. Liftoff is commonly carried out using positive resist such as PMMA. However, for some applications such as patterning hole array in a metal film using liftoff, negative resist would offer significantly less exposure time than positive one unless if using a double liftoff process that is complicated. Unfortunately, liftoff using negative resist is very challenging because: 1) the resist profile is typically positively tapered with base wider than top part due to electron forward scattering, 2) negative resist is cross-linked and thus insoluble in solvents, though a strong chemical such as a hot mixture of H₂O₂ and NH₄OH (RCA cleaning step 1) can be used to dissolve it.

Here we report one approach to circumvent both issues. By using very low energy electron beam whose penetrating depth is less than resist film thickness, only the upper part of the resist layer gets cross-linked. Since the lower part is not cross-linked, it can be dissolved by a solvent. Moreover, the un-cross-linked lower part can be dissolved laterally during the development process, hence an under-cut profile results that is ideal for a clean liftoff.

As a proof of concept, we chose polystyrene resist that is capable of achieving ultra-high resolution by using low molecular weight¹, or ultra-high sensitivity with high molecular weight². We dissolved 260 kg/mol (Mn=64 kg/mol, note that Mn determines resist property³) polystyrene in chlorobenzene and obtained a film of 224 nm after spin-coating. Exposure with area dose of 10 $\mu\text{C}/\text{cm}^2$ was carried out at 5, 2, and 1.4 keV, for which electron penetration depth is approximately 770, 180, and 100 nm, respectively⁴. After development using xylene, 10 nm Cr was coated and lifted off using xylene with ultrasonic agitation. Figure 1 shows the polystyrene structure right before liftoff. As expected, the structure showed a positively tapered profile for 5 keV exposure, but a clear under-cut profile for 2 keV exposure. Figure 2 are SEM images after Cr liftoff, which showed successful liftoff for 2 keV exposure, whereas the polystyrene pillars exposed at 5 keV was not dissolved. Thus we demonstrated the feasibility of our approach.

¹ Ma S, Con C, Yavuz M and Cui B, *Nanoscale Research Letters*, 6, 446 (2011).

² Con C, Dey R, Ferguson M, Zhang J, Mansour R, Yavuz M and Cui B, *Microelectronic Engineering*, 98, 254-257 (2012).

³ Dey RK and Cui B, *Nanotechnol.*, 24, 245302 (2013).

⁴ Heidenreich RD, Thompson LF, Feit ED and Melliar-Smith CM, J., *Appl. Phys.* 44 (9), 4039 (1973).

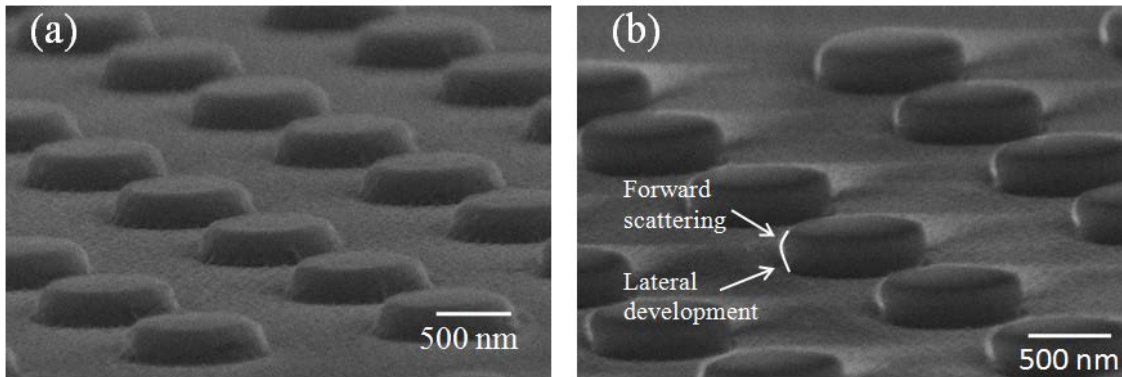


Figure 1. SEM images of polystyrene structures exposed at (a) 5 keV, with positively tapered side-wall profile; and (b) 2 keV, with a clear under-cut profile due to lateral development of the under-exposed polystyrene at the lower part. The upper part is positively tapered due to forward scattering of incident electrons.

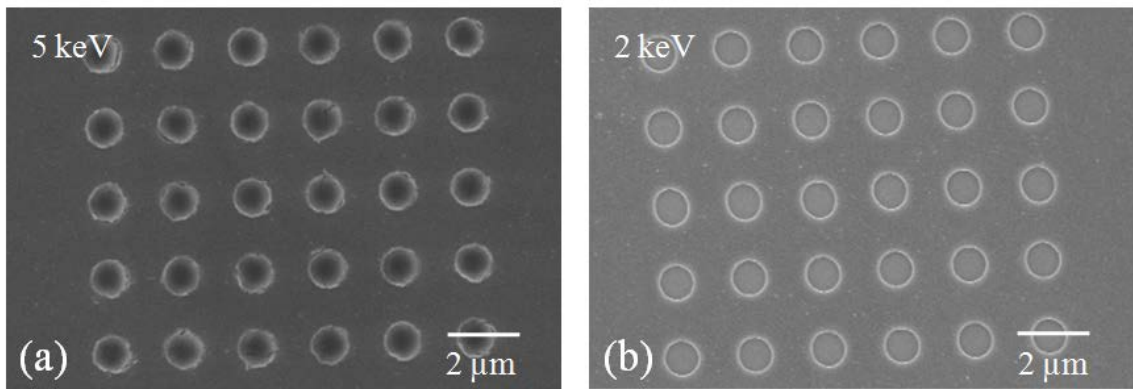


Figure 2. SEM images after liftoff of 10 nm Cr for (a) 5 keV exposure, with failed liftoff (the polystyrene pillars remained on surface after liftoff); and (b) 2 keV exposure, with successful liftoff that resulted in holes inside the Cr layer.