# Dry liftoff of metal and organic materials

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Liftoff and direct etch are the two most popular pattern transfer methods used for nanofabrication. Liftoff is typically carried out using a solvent that dissolves the resist. A strong solvent aided by ultrasonic agitation and/or heating is sometimes needed if the resist is difficult to dissolve due to, for example, cross-linking by exposure to electron beam or plasma. Another serious issue with conventional liftoff process is that the metal debris may stay at the active device area after drying. To avoid the above issues, dry liftoff using mechanical approach may be utilized. Here we report a simple dry liftoff technique by using a scotch tape to peel off the resist film.

For dry liftoff, it is critical to control the interface energy between the resist film and the substrate. Too high interface energy leads to strong adhesion and makes peeling-off impossible, whereas too low substrate surface energy makes spin-coating difficult. For some resists such as polycarbonate[1], no substrate treatment is needed since it adheres poorly to bare silicon wafer. But polycarbonate is a low-contrast resist that gives tapered resist profile, making clean dry liftoff challenging. So we have chosen PMMA and treated the silicon wafer with low surface energy perfluorooctyltrichlorosilane (FOTS). We put the wafer and a drop of FOTS inside a box (no vacuum) and optimized the treatment time (optimal 30 min) such that the surface energy is suitable for both peeling-off and spin-coating of PMMA dissolved in a non-polar solvent toluene. Alternatively, for substrates that are incompatible with FOTS treatment, a low surface energy thin fluorocarbon film can be coated using $CHF_3$, $C_4F_8$ or $CF_4/H_2$ plasma, which was found to work equally well for dry liftoff (not shown).

After exposure at 20 keV, the resist was developed in IPA: $H_2O$=7:3 or MIBK:IPA=1:3 for 1 min. Next, Cr or organic materials including polystyrene[2,3] and Alq3 (that is one of the most important organic conducting materials) was coated respectively by electron beam and thermal evaporation, followed by dry liftoff using a scotch tape to peel off the film (see Figure 1). Figure 2 shows SEM images of Cr line array pattern after dry liftoff with resolution down to ~50 nm. Higher resolution is possible by using thinner PMMA. For over-exposed large square patterns, peeling off was not obtained, which is because PMMA becomes negative resist at very high doses and the cross-linked PMMA adheres strongly to the FOTS treated substrate. Since the process is a dry process, for the first time, we demonstrated the liftoff of organic materials as shown in Figure 3.

[1] Abbas AS, Yavuz M and Cui B, “Polycarbonate electron beam resist using solvent developer”, Microelectron. Eng., 113, 140-142 (2014).
[2] Zhang J, Con C and Cui B, “Electron beam lithography on irregular surfaces with evaporated resist”, ACS Nano, revised manuscript submitted.
[3] Con C, Zhang J and Cui B, “Nanofabrication of high aspect ratio structures using evaporated resist containing metal”, Nanotechnology, revised manuscript submitted.

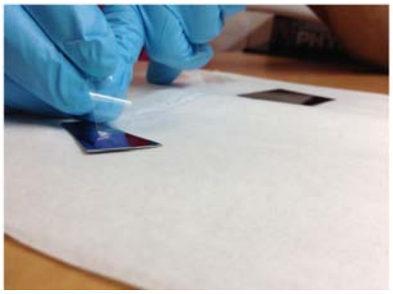


Figure 1. Photograph showing the peeling off of the resist film using scotch tape.

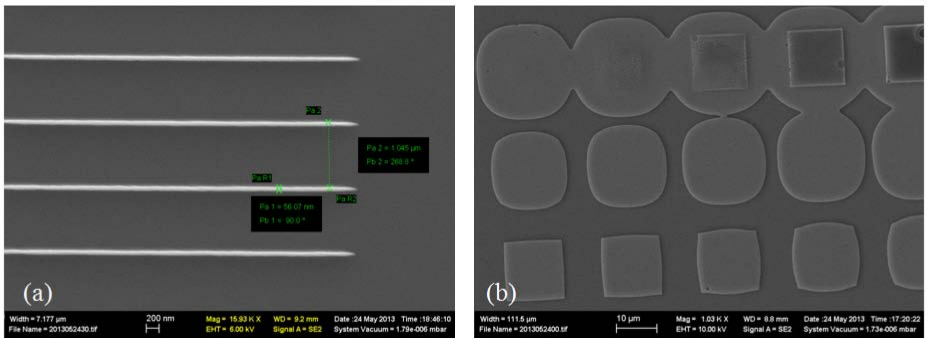
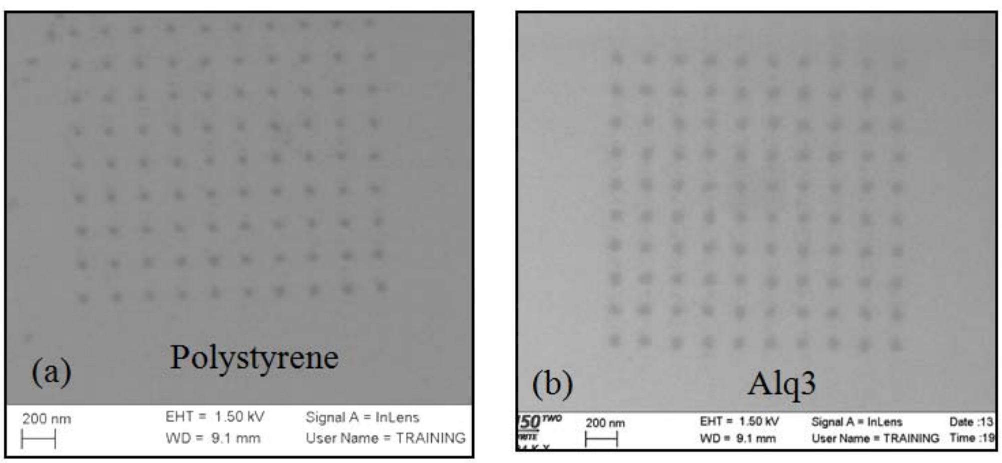



Figure 2. SEM images of Cr patterns after dry liftoff of 10 nm Cr. Here the substrate Si was etched by RIE in order to obtain higher image contrast. (a) Line array with 56 nm line-width; (b) Large squares having doses increasing exponentially from lower left to upper right. The size increases at higher doses is due to proximity effect. At very high doses, PMMA becomes a negative resist and the cross-linked area (the three squares at upper right) was not peeled off.



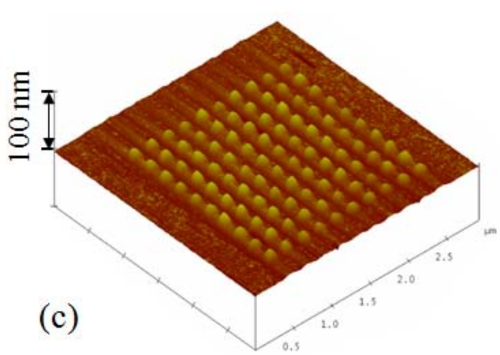




Figure 3. SEM images of dry lifted off 15 nm-thick polystyrene (a) and 18 nm-thick Alq3 (b), with array period of 200 nm and dot diameter of 50-60 nm. (c) AFM images of Alq3 dot array with 200 nm period.