Electron beam lithography on irregular surface using grafted PMMA brush

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A challenge in nanofabrication is to fabricate nanostructures on irregular surfaces, because the conventional resist coating method, spin-coating, gives a uniform film only on planar surfaces such as a wafer. Previously we have demonstrated electron beam lithography on irregular surfaces including AFM cantilevers and optical fibers by using evaporated polystyrene resist[1,2]. However, vacuum deposition is costly; and more importantly, most resists cannot be coated by thermal evaporation.

Here we will show that a mono-layer PMMA "brush" can be reliably grafted on irregular surface and can be used to pattern an AFM cantilever by electron beam lithography and RIE pattern transfer. The brush is grafted onto a surface terminated with hydroxyl (–OH) group the same way as forming the PMMA-r-Polystyrene brush that is widely used to provide a neutral surface for self assembly of diblock copolymer PMMA-b-Polystyrene. In fact, the brush may have the same origin as the infamous residual layer after development of PMMA or ZEP resist, which often has to be removed by a brief oxygen plasma etching to ensure a successful subsequent liftoff process.

To form a mono-layer brush, the surface was first cleaned by oxygen plasma, and then coated with PMMA (contains 1.6% MAA, (meth)acrylic acid, to further promote the grafting process as MAA contains the desirable –COOH group). Next, the resist was annealed overnight at 160^{o}C to induce the chemical reaction between –OH on resist and -OH on the surface, leading to the production of water and chemical bonding between the resist and substrate (–CO-O-Si- for silicon substrate). Finally, the bulk of PMMA was washed away by acetic acid, leaving behind a monolayer "residual" that was chemically bonded to the substrate.

As the monolayer is too thin for pattern transfer after electron beam lithography, we developed a pattern transfer process using an intermediate hard mask layer aluminum (can be terminated with -OH), which was patterned by wet etching using the resist brush as mask (Figure 1). Afterwards, the pattern was transferred to the substrate that may have irregular shape by dry etching. As a proof of concept, we patterned an AFM cantilever (Figure 2) with resolution down to 30 nm. Nanofabrication on nonplanar surfaces may find applications in fields such as (AFM) tip-enhanced Raman spectroscopy for chemical analysis[3] and lab-on-fiber technology[4].

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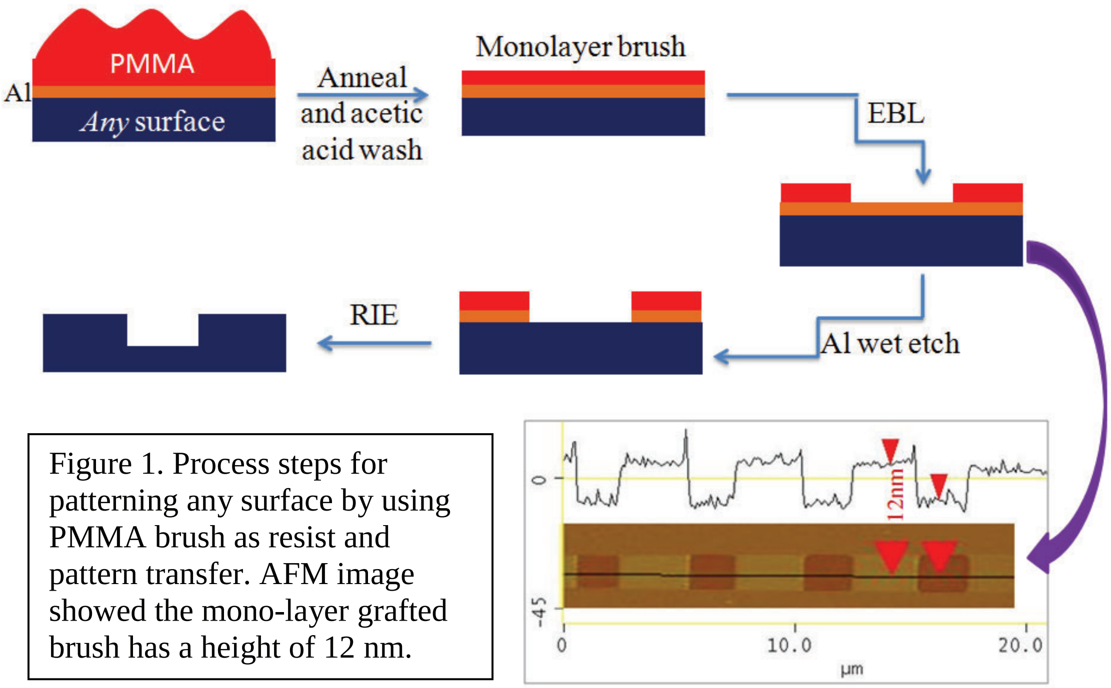

Figure 1. Process steps for patterning any surface by using PMMA brush as resist and pattern transfer. AFM image showed the mono-layer grafted brush has a height of 12 nm.

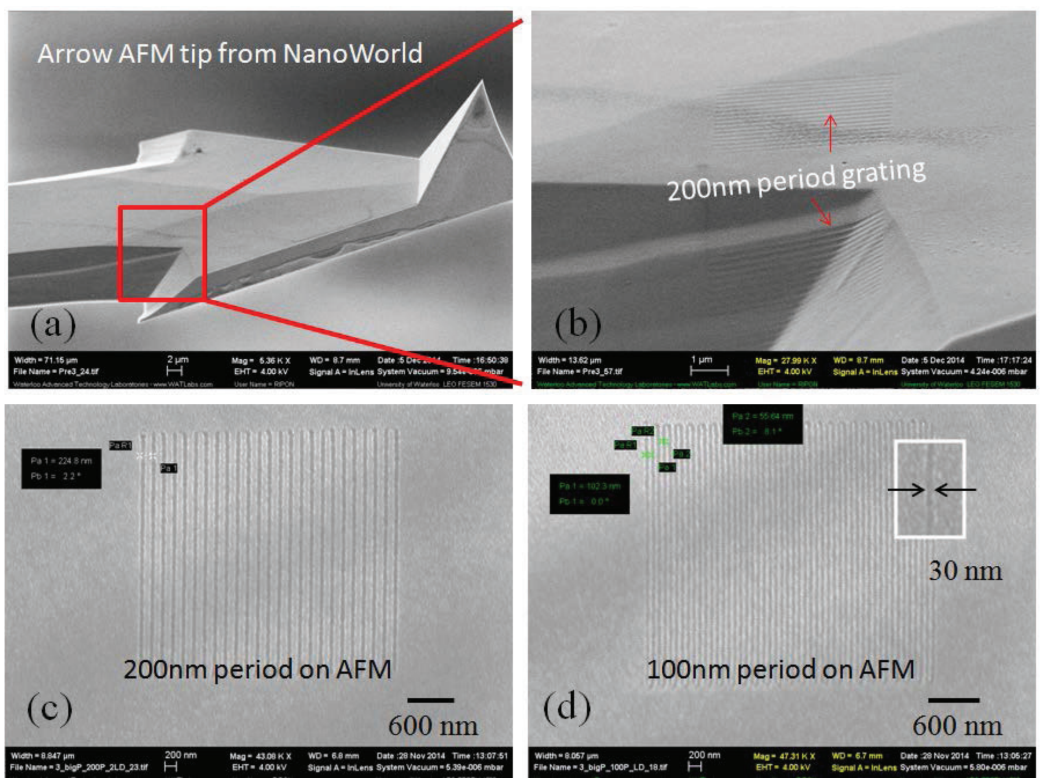

Figure 2 SEM images of grating structures fabricated on an AFM cantilever using monolayer PMMA “brush” as resist. (a) Low magnification view; (b) Zoom in of (a) showing 200 nm period grating; (c-d) 200 nm and 100 nm period grating on the flat part of the AFM cantilever, with high resolution line of 30 nm wide.