Focused ion beam (FIB) patterning of surface nanobubbles

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Surface-attached nanoscale gas bubbles forming on a solid/liquid interface present an intriguing prospect for potential top-down and bottom-up nanoscale patterning. It is well known that the physical and chemical properties of the substrate significantly influence the formation and characteristics of the surface-attached nanobubbles. This study introduces a novel approach using focused ion beam (FIB) milling to spatially control the nucleation of surface nanobubbles with a precision of 75 nm. Employing atomic force microscopy, the spontaneous formation of nanobubbles on alternating lines of a self-assembled monolayer (octadecyltrichlorosilane, OTS) patterned by FIB is observed for the first time. The investigation delves into the influence of chemical *vs.* topographical surface heterogeneity on nanobubble formation by comparing samples with OTS coating applied in both pre-and post-FIB patterning. The findings confirm that nanoscale FIB-based patterning is an effective means to control the position of surface nanobubbles precisely through chemical heterogeneity.

A Si surface is coated with the hydrophobic self-assembled monolayer OTS. Upon exposure to the FIB, the monolayer is selectively removed from the Si substrate. Two types of nanostructured surfaces, namely, “Hydrophobic-hydrophilic (HB/HL)” and “Hydrophobic-hydrophobic (HB/HB)” were fabricated using FIB-based patterning of the OTS monolayer. The first sample (HB/HL) follows the intended nanopatterning approach of OTS coating, followed by FIB milling. For the second sample (HB/HB), the Si surface was first exposed under FIB followed by the same OTS coating procedure.

Figure 1 provides schematic (Figure 1a-c) and SEM (Figure 1d-f) images of nanopatterned surfaces fabricated *via* FIB milling, including uncoated Si (Figure 1a,d); the HB/HL surface (Figure 1b, e); and the HB/HB surface (Figure 1c, f). All surfaces display a regular pattern of trenches with a width of 75 nm and a period of 500 nm. When immersed in water, surface nanobubbles will form on the HB/HB and HB/HL nanopatterned surfaces. In the case of HB/HB patterns, nanobubbles formed on both the upper stripes and within the trenches between the stripes (Figure 2a). For the HB/HL patterns, surface nanobubbles are visible on the upper, hydrophobic stripes but not in the hydrophilic trenches (Figure 2b). This talk will present the FIB nanopatterning process used for the controllable generation of nanobubbles. We will discuss the fluid AFM imaging conducted on HB/HL and HB/HB nanopatterned substrates to investigate the presence of nanobubbles on the surfaces *vs.* in the trenches of both samples (Figure 2).

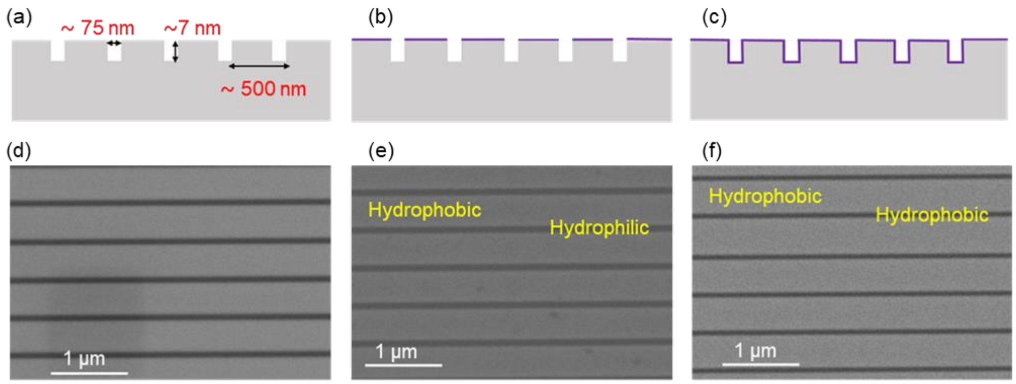

Figure 1: (a-f) Schematic and SEM images of: a, d) uncoated Si after FIB milling; b, e) HB/HL nanopatterned surface; and c, f) HB/HB nanopatterned surface. Schematic diagrams indicate surface regions coated with OTS (purple shading).

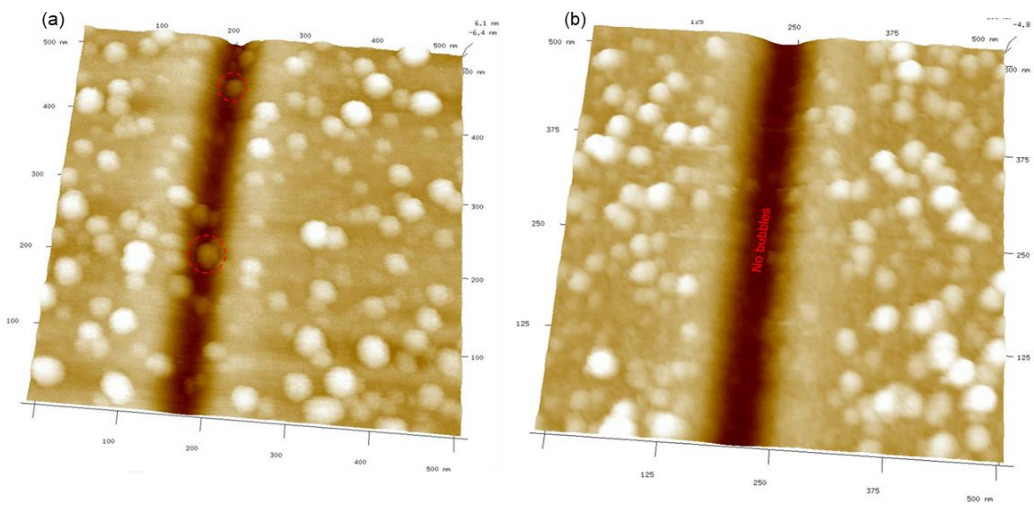

Figure 2: Fluid AFM imaging of nanobubbles on the HB/HL and HB/HB substrates. (a) The nanobubbles formed inside the trench of the HB/HB surface can be seen clearly (red circle). (b) No bubbles formed inside the hydrophilic trench of the HB/HL surface.