Sub−100 nm Feature Definition Optimization using Cold Cs Beam Exposed Self−Assembled Monolayers on Au

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Over the last ten years, considerable research efforts have been devoted to developing processes for nanoscale feature definition below the diffraction limit. Utilizing resists in neutral atom nanolithography (< 100 nm) provides both a high sensitivity to neutral atoms and a high resolution [1]. To achieve useful contrast to chemical etchants between exposed and unexposed regions, a sufficient dose of atoms must be provided, but it must not over-expose to outlying regions. In this paper, we present the results of a study into the dependency of SAM coverage, subsequent post-etch pattern definition and minimum feature size on the quality of the Au substrate used in both physical mask and optical mask atomic nanolithographic experiments.

Si(100) substrates with a 4 nm Cr adhesion layer were coated with 30 nm Au layers by sputtering and thermal evaporation. A 1 nm thick, self-assembled monolayer of 1-nonanethiol was then adsorbed onto the surface. All samples were exposed to a Cs flux from either a 2D cooled Cs beam or a 3D cooled Cs flux from a magneto-optical trap.

AFM, STM and GIXRD studies of the sputtered and evaporated surfaces used, show that sputtered Au surfaces exhibit a much lower degree of roughness. Furthermore, sputtered Au surfaces contain a higher density of {111} oriented Au grains, a distinct advantage for the adsorption of alkanethiols [2]. Evaporated Au surfaces however, are not only rougher, but contain grains of multiple crystal orientations. The {111} equiorientation of grains is beneficial for uniformity of alkanethiol coverage [2]. Phase imaging non-contact AFM and lateral force contact AFM techniques to characterize the SAM/Au surface. Although grain size and surface roughness contribute, our studies have revealed that the coverage uniformity depends first and foremost on the crystal orientation of the grains. Figure 1 shows a non-contact AFM image of the 1-nonanethiol covered sputtered surface with a corresponding phase image. The results indicate that the surface must have minimal roughness, a prerequisite for maximum coverage. Secondly, the degree of uniformity in the monolayer is increased if the Au surface is composed of grains with a single crystal orientation. With an atomic beam of Cs, transversely collimated and cooled by optical molasses, we have exposed the alkanethiol resists through a material mask (TEM grid). Thus, employing a Cs atomic beam with a flux of 10^{12} atoms cm^{-2} s^{-1}, a minimum Cs density is estimated to be approximately 7.5×10^{14} atoms cm^{-2}, which represents a minimum of ≈2 Cs atoms per SAM molecule. Therefore ≈2 monolayers of Cs are required to sufficiently alter the monolayer to render it susceptible to wet etching. Simultaneously acquired atomic and lateral force images in Fig. 2 show that this dose effectively renders the SAM exposed while not affecting the surface topography. Studies of the etching of the exposed SAM indicate that an etching rate of 2.2 nm min^{-1} allows for controlled and complete etching of the Au under exposed areas and the best feature definition. These optimizations allowed us to produce 65 nm holes and 50 nm lines using an optical standing wave mask.

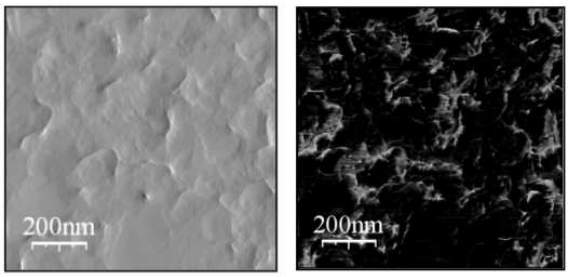

Fig. 1 *Tapping mode AFM image of the alkanethiol monolayer covered sputtered surface, and its corresponding phase image.*

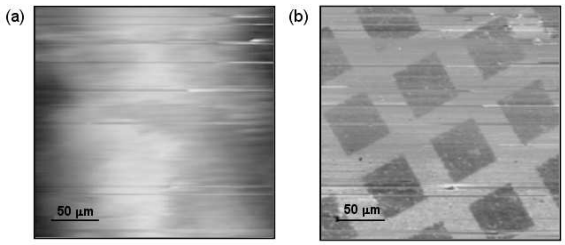

Fig. 2 *(a) AFM image (b) LFM image of the alkanethiol covered sputtered surface after 15 mins exposure to the Cs beam.*

References

[1] J. H. Thywissen et al., *J. Vac. Sci. Technol. B*, *15*, 2093 (1997)

[2] C. O'Dwyer, G. Gay, B. Viaris de Lesegno, J. Weiner, submitted to *Langmuir*