Fabrication of nanoscale structures on micro patterned silicon (100) surfaces

Kai Li [a, b], Pradeep Namboodiri [a], Sumanth Chikkamaranahalli [a], Joe Fu [a] and Richard Silver [a]
[a] *National Institute of Standards and Technology, Gaithersburg, MD 20899*
[b] *University of Maryland, College Park, MD 20740*
kaili@umd.edu

The fabrication of novel silicon-based quantum devices or atomically-precise calibration structures requires atomic control of the silicon substrate. One essential requirement is the ability to control the step-terrace patterns at the atomic-scale but there is also a need to locate these devices or structures in tools other than those used to fabricate them. Fabricating fiducial marks that can withstand the high process temperatures needed to create atomically-ordered silicon substrates is real challenge. In this paper we will describe a systematic approach to creating fiducial marks that can be observed with external metrology tools, such as SEM or AFM, which also enables fabrication of large atomically ordered terraces. The method exploits self-organization of step-terrace patterns that can serve as nanometer scale templates. Micrometer scale features are fabricated on Si (100) surfaces using lithographic techniques and thermally processed in an ultra high vacuum (UHV) environment. Samples are flash heated at 1200 °C and further annealed at 1050 °C. The process results in the formation of symmetric, step-terrace patterns with several micron wide atomically flat regions exhibiting highly reproducible step-terrace morphology. The patterns spontaneously transform into a symmetric formation marked by step bunches separated by wide atomic terraces. These features are visible using a conventional optical microscope and can be used as fiducial marks to locate nanoscale features fabricated on the atomically flat terraces.

Nanometer scale features are then patterned on atomically flat, ordered silicon surfaces by an STM probe-induced hydrogen de-passivation and oxidation procedure. First, the lithographically patterned surfaces are reconstructed using high temperature UHV annealing processes as described above. The resulting surfaces having extremely wide terraces are then treated with atomic hydrogen at an elevated temperature of about 300 °C. An extremely sharp STM probe capable of single atom chemical modifications is then used with an electron current density capable of depassivating the hydrogen terminated surface. The STM patterned surfaces are then exposed to an oxygen environment to facilitate the growth of an oxide in the depassivated area. The samples are removed and imaged externally using atomic force microscopy followed by subsequent an RIE etch process to transfer the nanometer scale patterns into the silicon surface. The patterns produced by directly desorbing hydrogen atoms are a potential candidate for meeting the requirements of emerging trends in atom based fabrication and standards needs.