Multiscale Hydrogen Depassivation Lithography using a Scanning Tunneling Microscope

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As the requirements for positioning accuracy and feature size in quantum devices shrink to scales below the resolution limits of conventional lithographic techniques, new means for bridging the gap between atomic resolution positioning and macroscopic interconnections must become available. Scanning Tunneling Microscopy (STM) continues to provide value for fabricating atomically precise structures such as quantum computers[1], but it is assumed to have low throughput, especially for large patterns.

Working on hydrogen passivated Si(100)-2x1, we create lithographic patterns using an STM tip for localized electro-stimulated desorption of hydrogen. Previously, it has been shown that above 10V the depassivation yield increases by more than an order of magnitude[2] which is very important since the dose required to expose hydrogen below 10V (~50C/cm^2) is very high compared to exposing HSQ (~10mC/cm^2)[3] or PMMA (~500μC/cm^2). Fortunately, at these high voltages with currents in the nA range, the tip has been shown to retract up to 400nm from the surface, permitting relatively rapid tip movement without concern for damaging tip crashes.

By adjusting the voltage and current used during lithography, linewidth and line-edge-roughness can be carefully controlled, with linewidths less than 1nm shown in the past[4]; this is basically a form of variable spot e-beam lithography. We show that large areas can be depassivated at a rate in excess of $2x10^3$nm^2/s using high voltages with fairly large line edge roughness. By following this process with a line-edge correction pattern using a slower, narrow linewidth mode where the tip is closer to the surface permits the patterning of areas on the size scale of 1um^2 with edge roughness of <2nm in less than 5 minutes. Figure 1 depicts an example (500nm)^2 pattern that has been generated using this dual-mode lithography method in less than five minutes.

We will discuss the implicit functional limits of multi-mode lithography with the STM. The parameter space of voltage, current, and dosage will be explored with an emphasis on total patterning time, tip and sample robustness, and pattern fidelity. We will provide an estimation of maximum pattern throughput based upon these issues.

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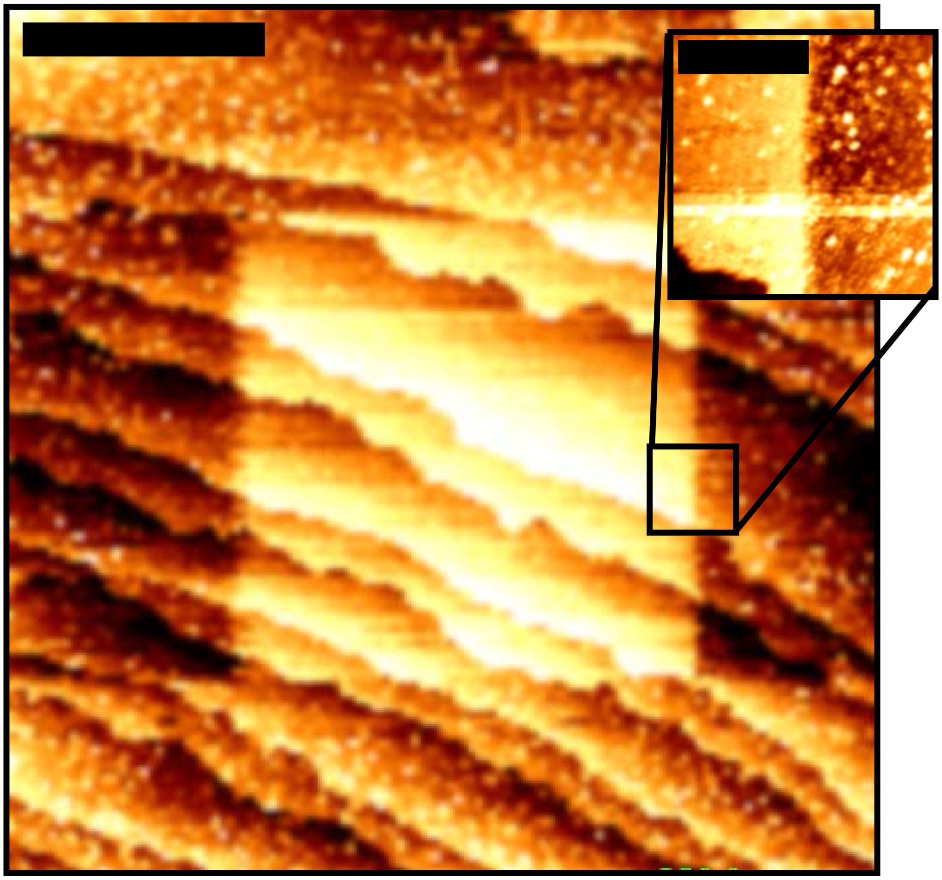

Figure 1: Large Area Patterning using Dual Mode Lithography: A 500nm^2 pattern was written by repeating 500nm horizontal lines with a 20nm pitch. Shown is the first pass of two using 30V, 0.5nA, and a tip speed of 100nm/s. Inset: Close-up of the right edge of the pattern after application of a "bordering" lithography operation using 10V, 0.5nA, and 20nm/s. Scale bars are 250nm in the primary image, 25nm in the inset.