Automated position corrections for Atomically Precise STM lithography of Si(001):H

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We are developing a process for automated atomically-precise lithography using an STM tip on the H-terminated Si(001) surface. Coupling a patterned fiducial mark with the crystallography of the Si(001)-H surface[1] enables automated position corrections to be incorporated into more complex manufacturing processes.

Our process starts with imaging the surface and analyzing it to identify the position of individual atoms (or dimers) in the image. At the end of the process we should be able to return the STM tip to the same locations on the actual surface with sub-dimer accuracy in order to apply the lithography. The schematic of the process is presented in Figure 1.

Based on an initial reference image, we use the periodic silicon lattice as our global fiducial grid (as similarly used in e-beam lithography[2]). The dimers and dimer rows are identified using Fourier analysis, giving the dimer orientation and size. Due to piezo creep and hysteresis, the principal surface directions in the image are not necessarily orthogonal, and the dimers may also have different horizontal and vertical scaling in the image. We use the Fourier analysis to create a grid, which represents the lattice, as shown in Figure 2.

In order to better identify an absolute position and break the symmetry of the lattice, we draw a small 2-dimer row sized square to use as our local fiducial mark. Using this fiducial, we cross-correlate repeated scans to fix our position over this mark, correcting for one of the more difficult imaging perturbations, namely drift, with dimer row accuracy.

By exploiting the periodicity of the Si(001) surface and the small fiducial mark, the grid has sub-dimer row precision and accuracy, respectively. Moreover, we can extrapolate this grid outside the image area and still have sufficient accuracy. This allows for smaller scans, which has a double advantage. First, the smaller tip movements reduce piezo creep. Second, the shorter scan times reduce sample drift. The Fourier analysis also gives us a metric for the quality of the scan, which can be used to optimize the scanning conditions[3].

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[3]R. A. J. Woolley, J. Stirling, A. Radocea, N. Krasnogor, and P. Moriarty,
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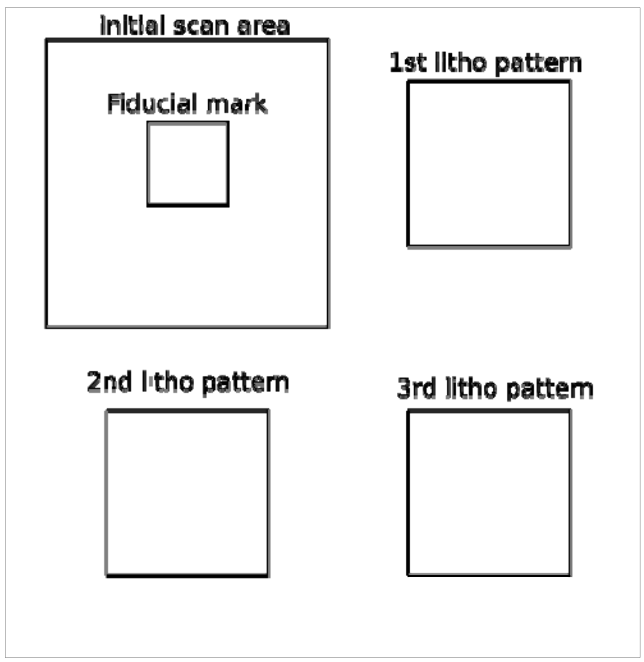
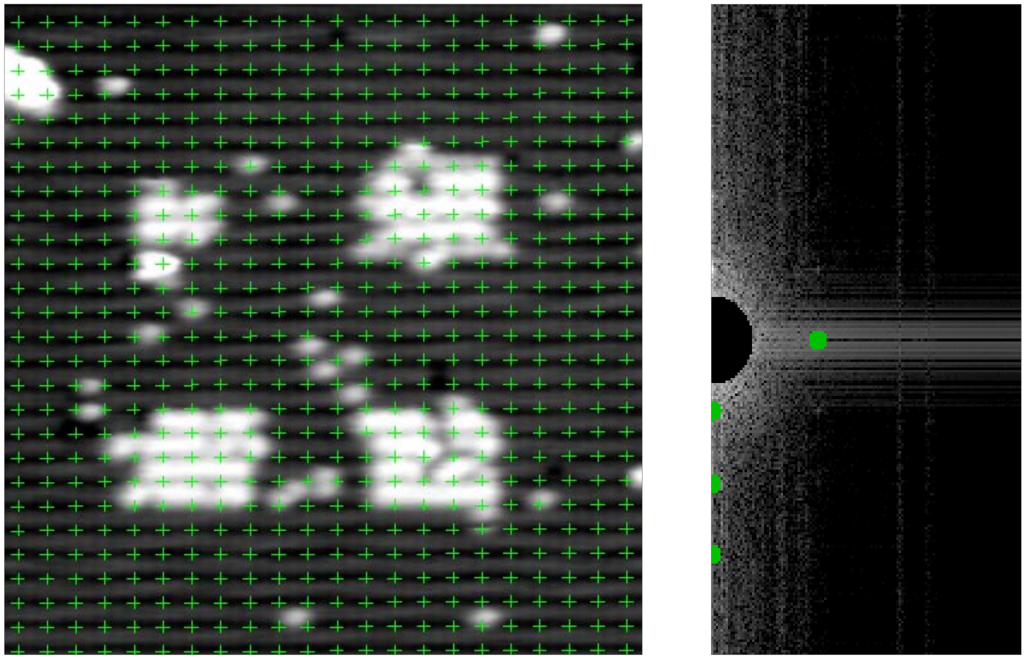


Figure 1: Schematic view of our process. We start by making a fiducial mark in our initial scan area. We then precede to do patterned lithography, returning to the fiducial mark after each pattern to reposition the tip.



(a) (b)

Figure 2: Sample experimental result is shown in figure (a) with the identified lattice overlaid on it. Figure (b) shows the same image in Fourier space with the identified dimer peaks and higher harmonics marked.