Determining Tip Position Tolerances for Atomically Precise STM lithography of Si(001):H

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Our objective is to create atomically precise structures on H-terminated Si(001)[1], using STM-stimulated depassivation of H as our patterning tool[2]. Our immediate goal is to be able to define the edges of these patterns with zero roughness.

The yield of STM lithography is sensitive to the exact position of the STM tip with respect to the middle of the dimer row. For tip positions at the centre of the Si dimers, both H atoms are removed with our standard conditions (4V, 4nA, 1-4 mC/cm), and the depassivation is confined to a single dimer row with an atomically sharp edge. However, for tip positions over the trench between the dimers, we find greater disorder; either no depassivation, or else removal of H atoms from 2 dimer rows, giving a large line edge roughness.

Figure 1 shows examples of patterns written at room temperature. The boxes (Fig. 1a) show a number of errors, including unwanted background depassivation, and lateral angular misalignment of the boxes with respect to the dimer rows. The lines (Fig.1b) are well confined to single dimer rows, except for one, which has failed to draw, probably due to the tip being accidentally located over the dimer trench.

Control of the relative position of the tip with respect to the dimer row is therefore crucial to enable us to draw with the desired precision and thus we are quantifying the tolerances for the writing process.

In Figure 2, a series of lines has been drawn at a deliberate misalignment to the dimer rows of 2°. In each case, the written line comprises areas of ordered depassivation of a single dimer row, separated by sections of greater disorder. By assuming that the ordered regions result from a tip located over the dimers, we have determined the tolerance for single-dimer row depassivation to be ±1.5Å from the dimer centre, or a 2° maximum acceptable misalignment for a pattern size of 20 dimers.

1: J. N. Randall, J. W. Lyding, S. Schmucker, J. R. Von Ehr, J. Ballard, R. Saini, H. Xu, and Y. Ding J. Vac. Sci. Technol. B **27** 2764-2768 (2009)

2: J. W. Lyding, T.-C. Shen, G. C. Abeln, C. Wang, and J. R. Tucker
Nanotechnology **7** 128-133 (1996)

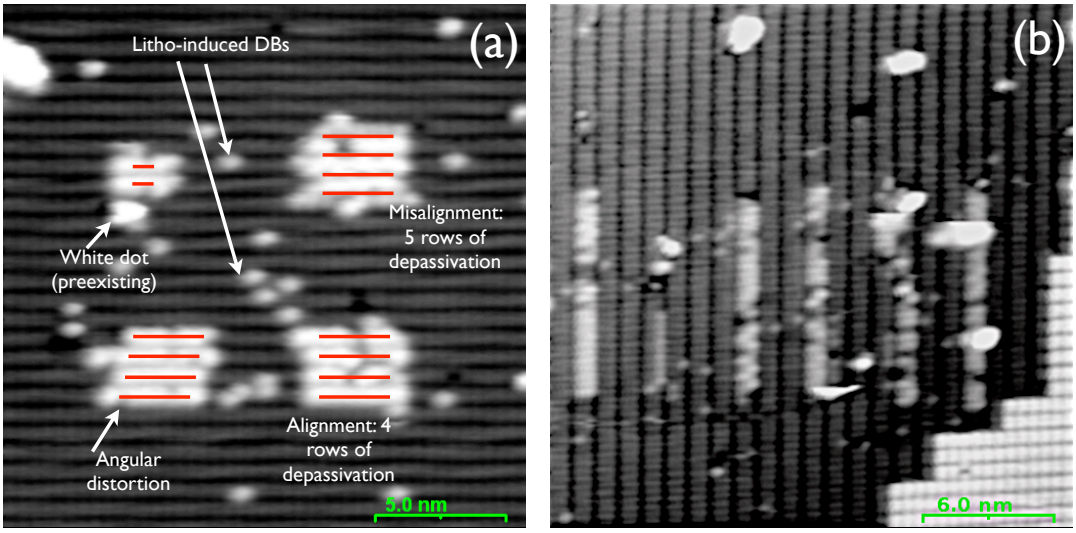

Figure 1: (a): STM image of 4 boxes of different dimensions. Various types of errors are labelled. (b): STM image of 6 vertical lines written in a Si(001):H surface using STM lithography at 4V, 4 nA, 4 mC/cm.

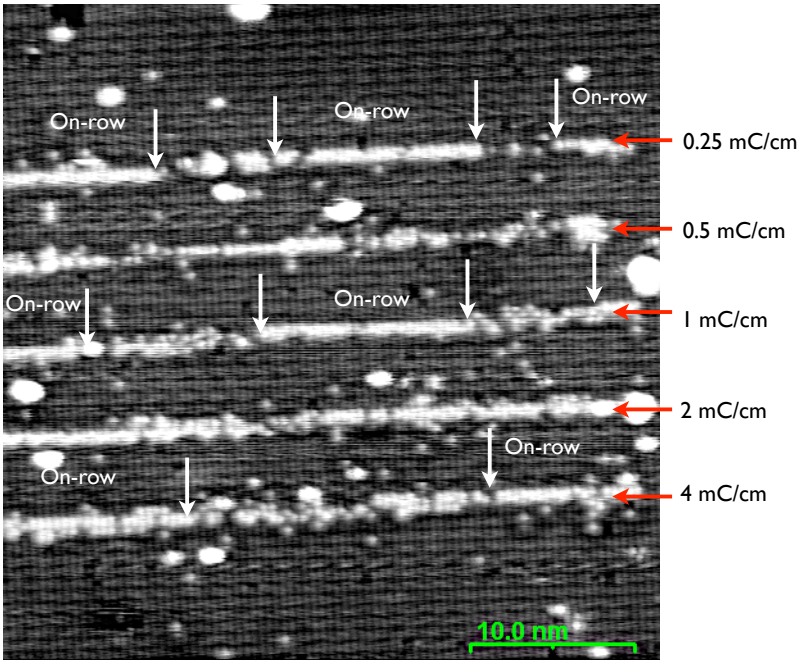

Figure 2: STM image of 5 horizontal lines written in a Si(001):H surface using STM lithography at 4V, 4 nA, 0.25 - 4 mC/cm, with a deliberate misalignment of 2° with respect to the dimer rows. The ‘On-Row’ areas, where the tip was on top of the dimers, have produced well-ordered depassivation, while the ‘Off-Row’ areas are more chaotic.