Digital STM lithography for P-in-Si qubit devices

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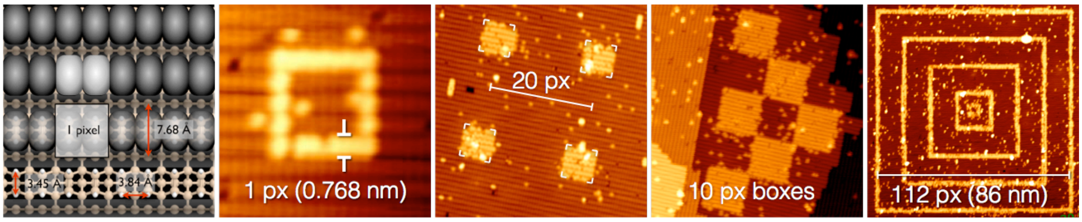

Atomic-scale devices have been created using H depassivation lithography to create patterns on Si(001), which are filled with P atoms, forming the 'single-atom transistor' and 1.5 nm wide wires with Ohmic conductivity [1,2]. The precise distances between the different elements of these devices have a strong effect on their properties. Thus, in future multi-qubit P-in-Si devices where yield and reproducibility of their properties become critical, the accuracy and precision of the fabrication technology needs to be improved.

We have developed a control system to perform automated STM patterning. Following the atomic structure of the surface, we have defined a pixel size of two dimers on one dimer row on the Si(001) surface, which is a 7.68 Å square. The tip moves directly to the area to be patterned, and writes along vectors whose directions are defined by the surface lattice, rather than rastering across the whole area. Sources of error such as thermal drift and piezo creep are corrected in real time to maintain atomic precision in the tip position. As a result, within an area of about 100 nm, we can draw arbitrary patterns with an error of at most 1 px. Furthermore, the use of scripts allows for automation of the patterning process greatly improving reproducibility of the final device pattern.

While this approach works well for elements such as source and drain electrodes, a critical pattern to be drawn for P-in-Si qubit devices is the 3-dimer pattern, which is required for placement of a single P atom, as in the 'single-atom transistor'. For such small features, i.e. lines just a few pixels long and with non-integral lengths, end effects and tip variability become significant. We have developed scripts that begin and end the write vector at different locations within the patterning pixel, so as to explore the effect of precise tip positioning on the line ends. In this way, we can calibrate the optimal subpixel start and end points for each tip before beginning a pattern, so as to maximise the yield of the desired length for arbitrary atomic-scale patterns.

1. Weber *et al*. Science **335**, 64-67 (2012).
2. Fuechsle *et al.* Nature Nanotechnology **7**, 242-246 (2012).