STM lithography and surface stability investigation of halogen-terminated Si(100)-(2x1)

K.J. Dwyer, Michael Dreyer
Department of Physics, University of Maryland, College Park, MD 20740, USA

Jennifer E. DeMell, R.E. Butera
Laboratory for Physical Sciences, 8050 Greenmead Drive, College Park, MD 20740, USA

e-mail: rbutera@lps.umd.edu

Hydrogen depassivation lithography is a well-established fabrication technique using a scanning tunneling microscope (STM) to pattern atomic-scale electronic devices in Si. Subsequent incorporation of donor atoms from PH_3 precursors into lithographic patterns in a Si surface can produce metallic wires, quantum dots defined by electrostatic gates, and allow for precise placement of donor atoms to act as qubits in quantum information (QI) research. However, interest in acceptor dopants and hole-based devices necessitates the development of alternate precursor and/or resist chemistries for STM patterning and device fabrication. Halogen chemistry is potentially more favorable for acceptor incorporation than hydrogen,[1] and to that end we explore halogen-based resists (Cl and Br) for STM-based lithography on Si(100)-(2x1). Additionally, the possibility of scaling up this technology by utilizing it outside of ultra-high vacuum environments in CMOS processes motivates us to study the stability of halogen-terminated Si surfaces in ambient conditions.

Here, we present results on the selective depassivation characteristics of halogen-based STM lithography resists including Cl and Br on Si(100)-(2x1) at low and elevated temperatures (77 K, 300 K, and 400 K)[2]. We explore STM tip-induced desorption and lithography as a function of tip-sample bias, tunnel current, and total electron dose. We demonstrate halogen lithography in an atomically precise mode to depassivate single Si dimer-wide features, as well as a field emission mode useful for patterning large areas (Figures 1 and 2). We then use STM to examine the stability of these halogen-terminated Si surfaces in both vacuum and controlled ambient environments (N_2). We show that the halogen-terminated surface is quite stable and robust for multiple days outside of the vacuum, similar to what has been shown with H-terminated Si(100)[3]. This work moves us closer to realizing a viable resist and acceptor precursor combination to use in advanced fabrication techniques for CMOS and STM atomic scale, hole-based devices for advanced computing and QI.

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[1] *Langmuir* 2011, 27, 6, 2613-2624
[2] arXiv:1808.05690
[3] Appl. Phys. Lett. 78, 886 (2001)

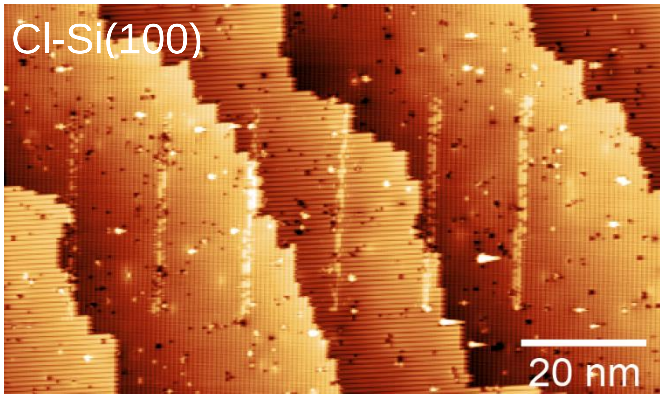

Figure 1. Filled state STM image of a Cl-terminated Si(100)-(2x1) surface. Six atomic precision lithographic lines were written by depassivating Cl with a bias of -6.5 V and tunnel currents ranging from 1 nA to 100 nA. The lines produced are Si dangling bonds approximately two dimer rows wide.

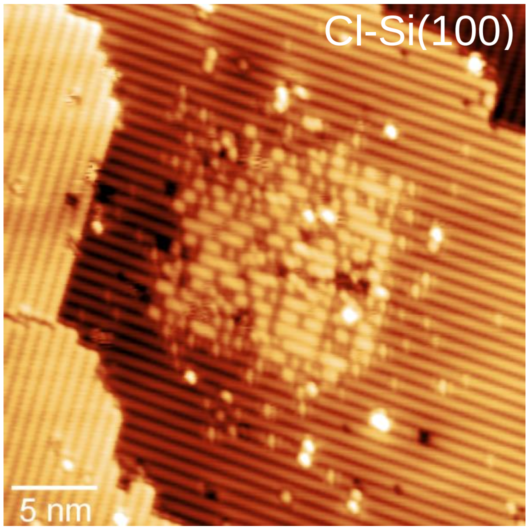

Figure 2. Filled state STM image of a Cl-terminated Si(100)-(2x1) surface. A square was lithographically patterned in the surface using field emission with a bias of +8.5 V and a tunnel current of 3 nA. Within the pattern, Cl is depassivated and Si dangling bonds are exposed