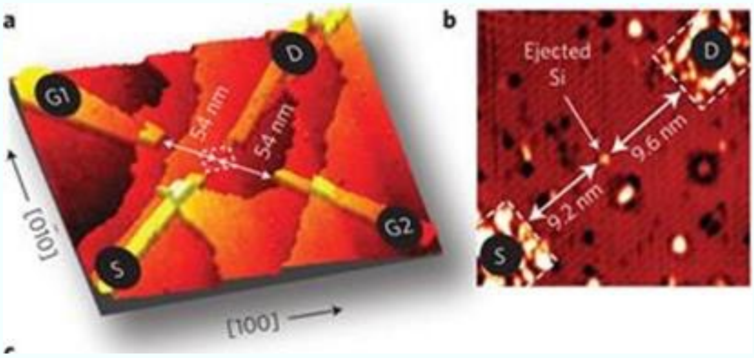
A single-atom transistor

M Fuechsle, JA Miwa, S Mahapatra, H Ryu, S Lee, O Warschkow, LCL Hollenberg, G Klimeck and MY Simmons
Nature Nanotechnology 7, 242 (2012)



a. Perspective STM image of the device, in which the hydrogen-desorbed regions defining source (S) and drain (D) leads and two gates (G1, G2) appear raised due to the increased tunnelling current through the silicon dangling bond states that were created.

b. Close-up of the inner device area (dashed box in a), where the central bright protrusion is the silicon atom, which is ejected when a single phosphorus atom incorporates into the surface.

The ability to control matter at the atomic scale and build devices with atomic precision is central to nanotechnology. The scanning tunnelling microscope1 can manipulate individual atoms2 and molecules on surfaces, but the manipulation of silicon to make atomic-scale logic circuits has been hampered by the covalent nature of its bonds. Resist based strategies have allowed the formation of atomic-scale structures on silicon surfaces3, but the fabrication of working devices — such as transistors with extremely short gate lengths4, spin-based quantum computers 5–8 and solitary dopant optoelectronic devices9—requires the ability to position individual atoms in a silicon crystal with atomic precision. Here, we use a combination of scanning tunnelling microscopy and hydrogen-resist lithography to demonstrate a single-atom transistor in which an individual phosphorus dopant atom has been deterministically placed within an epitaxial silicon device architecture with a spatial accuracy of one lattice site. The transistor operates at liquid helium temperatures, and millikelvin electron transport measurements confirm the presence of discrete quantum levels in the energy spectrum of the phosphorus atom. We find a charging energy that is close to the bulk value, previously only observed by optical spectroscopy10.

LINK TO FULL PAPER (SUBSCRIBERS ONLY):
http://www.nature.com/nnano/journal/v7/n4/pdf/nnano.2012.21.pdf