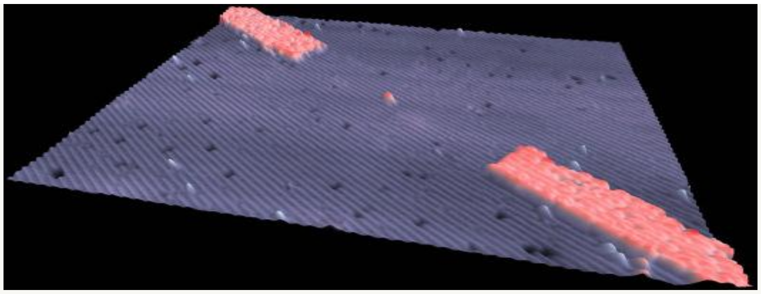
TRANSISTORS REACH THE SINGLE ATOM LIMIT

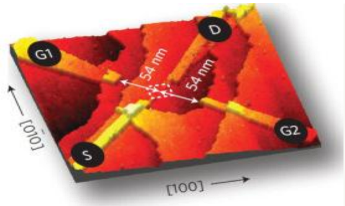


A scanning tunnelling microscope image of a single-atom transistor during fabrication. The pink colours represent the areas where a single phosphorus atom (centre) as well as phosphorus source and drain contacts will be placed. The gate contacts that control the transistor action from the side are not visible here. Credit: Martin Fuechsle

When Gordon Moore made his observation in 1965 that the number of transistors integrated on a single silicon chip is doubling roughly every two years, the only logical end point for such a trend would be a transistor made from a single atom. This point has now been reached. Writing in *Nature Nanotechnology*, Michelle Simmons from the University of New South Wales in Sydney and colleagues report a single-atom transistor, the world's smallest, on a silicon chip. The transistor is based on current flowing through a single atom of phosphorus embedded in a silicon wafer.

Phosphorus is a natural choice for such a transistor, as it is relatively easy to integrate into silicon. There it acts as an electron donor because it has an additional electron compared to silicon. This additional charge can be used for conventional electronic devices such transistor, but also more complex schemes are possible. For example, the magnetic property of this single excess electron, its spin, can be used for new types of quantum computing. Indeed, I have previously blogged about such efforts from another research group in Sydney using multiple phosphorus atoms for silicon-based quantum computing.

One of the key challenges in making a single-atom transistor is to place a single phosphorus atom into silicon in a controlled fashion. Here, this is achieved by the careful placement of three phosphine (PH_3) molecules on the surface of silicon using a scanning tunneling microscsope. In a number of reaction steps these molecules dissociate and cause the ejection of a silicon atom from the surface and the incorporation of a single phosphorus atom in its place.



The single-atom transistor structure. The electric current between source (S) and drain (D) contacts, through the phosphorus atom in the centre, is controlled by the two gate contacts (G1,G2) (c) 2012 Nature Nanotechnology

Once incorporated into silicon, the energy level of the phosphorus’ outer electron states lies below that of the surrounding silicon. The precise match between silicon and phosphorus energy levels can be controlled by the electrical potential applied between two gate electrodes on either side (see figure on the right). This voltage controls the electric current between source and drain, and through the atom. If the energy levels of silicon and the phosphorus atom do match up, it is possible for electrons to pass through the phosphorous atom one by one. If the voltage between the two gates is set so that the silicon and phosphorus energy levels do not match up, there is no electric current.

There are, however, a few drawbacks in the present approach. So far this transistor only works for really low temperatures, barely above absolute zero. And in the current implementation the contacting electrodes are still several tens of nanometres apart – hardly on the single atom scale. Also, the fabrication of the structure with a scanning tunnelling microscope doesn’t allow to make billions of them in the same efficient way as commercial computer chips are fabricated.

Still, such single atom transistors could already be of interest for the quantum computing schemes investigated for phosphorus atoms, where the low temperature is less of an issue. Either way, considering that according to Gordon Moore’s law commercial silicon transistors are only expected to reach single atom scales beyond 2020, this study certainly is ahead of the curve.

Source: http://allthatmatters.heber.org/2012/02/19/transistors-reach-the-single-atom-limit/