Manufacturing Gold Nano-Jewellery

by Neville Fletcher, Robert Elliman and Taehyun Kim
Research School of Physics and Engineering
Australian National University

Jewellery is an important feature in the life-style of humans worldwide, but what market for nano-jewellery? A typical element in a necklace is a few millimetres in size compared to a typical human at about two metres in height, so something like a factor of 1000 emerges. If we start from something that is a few tens of nanometres in size, an application of the same ratio suggests we should look for things a few tens of micrometres in size, and what do we find? Bacteria – and there are trillions not just billions of them! So if we can make nano-jewellery that is the right size for bacteria, the potential market is immense.

Recent work reported in an article by us in the journal *Nanotechnology*[1] shows how we can manufacture strings of gold nano-beads encased in a thin transparent filament of glassy silica – just the thing for nano-jewellery and made from gold as well. Products derived from this technology could really take off in the world of microorganisms, unfortunately though they will not greatly enhance the profits of gold mines.

The technology involved is itself quite simple. We start with a crystalline silicon wafer of the sort used in semiconductor devices and deposit on its surface a very thin film of gold. Another bare silicon wafer is then placed at a very small distance above the coated wafer and the whole sandwich heated to a temperature of about 1100 °C for 60 minutes in an atmosphere consisting of nitrogen or argon with about 3 to 5 parts per million of oxygen. The first thing that happens is that the gold film breaks up into tiny drops because of the influence of surface tension and at the same time the oxygen in the surrounding atmosphere attacks the surface of the upper wafer to create a vapour concentration of silicon monoxide SiO. This SiO then dissolves in the gold drops, along with some of the oxygen from the vapour, and the two combine to form silica (SiO_2) molecules. Because silica is not very soluble in gold, it tends to precipitate at the interface

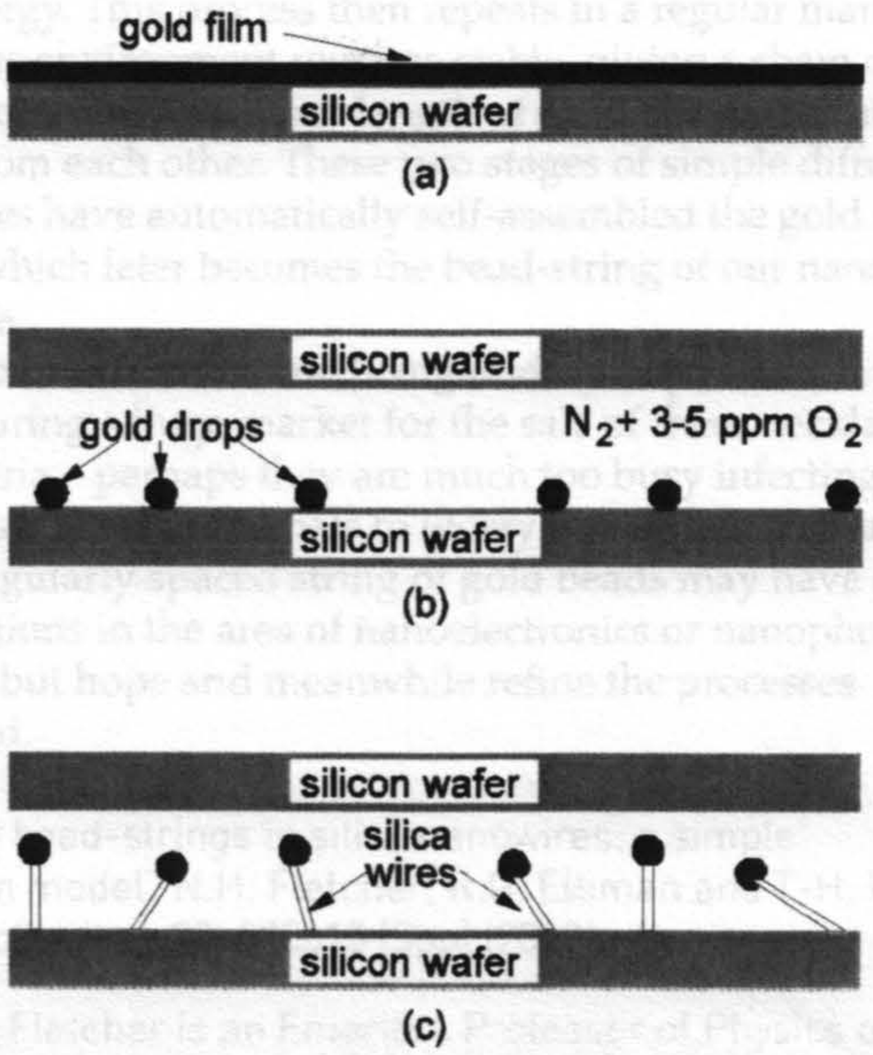

Figure 1. The growth technique described here for silica nanowires: (a) a gold film is deposited onto a silicon wafer; (b) the wafer is capped by another bare wafer and heated in an inert gas atmosphere with 1 to 5 ppm of oxygen and the gold film condenses into a distribution of small gold drops; (c) silica wires grow from the base of the gold drops, bearing them aloft.

between the gold and the silicon substrate and the gold drop is lifted up on a column of amorphous silica. This results in the growth of a population of silica whiskers, or wires as they are often called, each capped with a liquid gold drop which continues the growth process as shown in Figure 1.

So far there is nothing very special about this process, but then something strange happens: in a proportion of the growing wires ranging from 1% to 80% the gold drop begins to leave behind it a trail of small gold droplets with nearly regular spacing, the diameter of each droplet being about one fifth to one half of the wire diameter but more like one tenth of the diameter of the main growth drop at the end of the wire. Examples are shown in Figure 2, some irregularity being introduced by the presence of neighbouring wires.

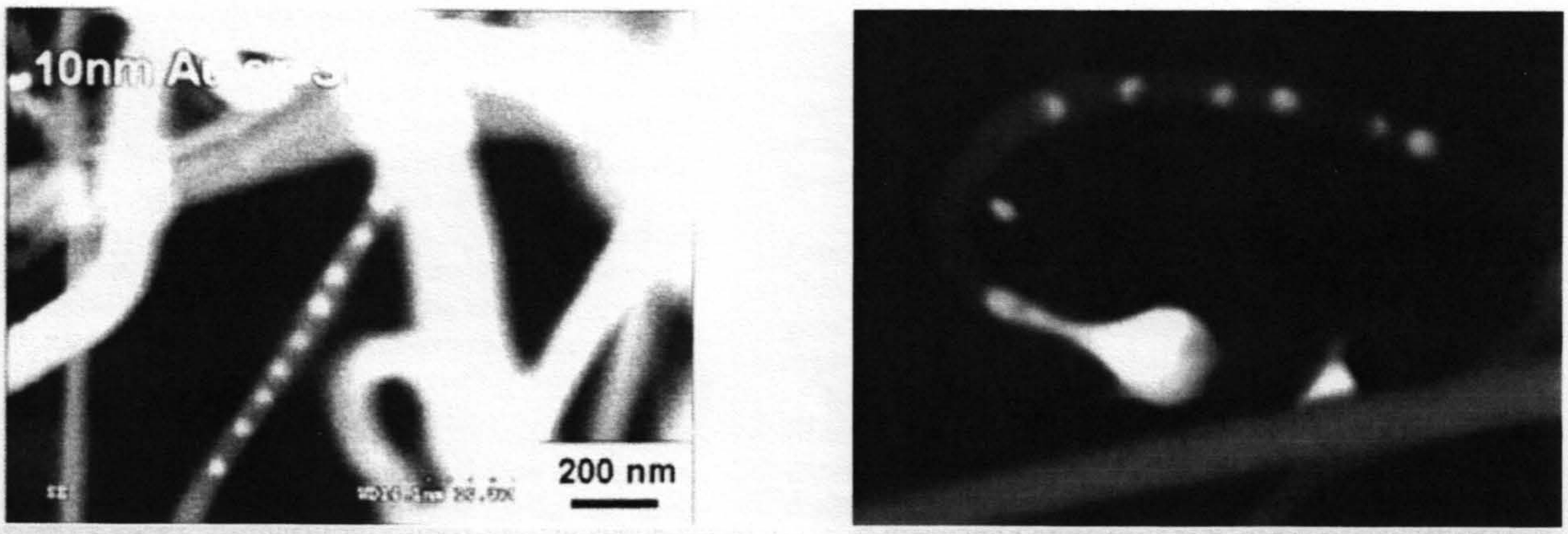

Figure 2. (a) Typical nearly-regular growth of gold bead strings within the silica nanowires;
(b) the diffusive pinch-off effect behind the gold drop at the end of the silica wire. The image width in each case is about 2μm so that the diameter of the main drop is about 300 nm and that of the droplets or beads about 30 to 100nm.

So there we have the ready-made gold bead-strings for our nano-jewellery. All that remains is to seek publicity (this article!) to advertise it to the bacterial community – except that, being scientists, we would like to understand how the process works. A clue to this may be seen in Figure 2(b), in which the main gold drop seems to be dragging a gold tail behind it in the wire and this tail is pinching off to form a droplet. Indeed this is just what happens in a regular fashion, and the question is "Why?"

Products derived from this technology could really take off in the world of microorganisms, unfortunately though they will not greatly enhance the profits of gold mines.

As we saw before, the large gold drop absorbs SiO and oxygen from the surrounding atmosphere and the SiO_2 that is produced diffuses through the drop to deposit at its interface with the growing wire. Because the concentration gradient is larger near the edges of this circular interface than at the centre, the edges grow more rapidly and the interface develops an almost conical depressed shape. After this has reached a moderate depth, its top opening begins to close under the influence of diffusion and ultimately seals off, leaving a small volume of liquid gold within the wire. The enclosed liquid gold volume then gradually becomes a spherical droplet under the influence of its interfacial free energy. This process then repeats in a regular manner if the gas environment remains stable, giving a chain of gold droplets with a short length of solid silica separating them from each other. These two stages of simple diffusion processes have automatically self-assembled the gold droplet string which later becomes the bead-string of our nano-necklace.

It may be true that we are being unduly hopeful in conjecturing a huge market for the sale of these necklaces to bacteria – perhaps they are much too busy infecting humans and other animals to worry about their appearance. But a regularly spaced string of gold beads may have other applications in the area of nanoelectronics or nanophotonics. We can but hope and meanwhile refine the processes involved.

1. "Gold bead-strings in silica nanowires: a simple diffusion model" N.H. Fletcher, R.G. Elliman and T-H. Kim Nanotechnology 20, 085613 (5pp) (2009)

Neville Fletcher is an Emeritus Professor of Physics of the University of New England and former Director of the CSIRO Institute of Physical Sciences. Robert Elliman is Professor and Head of the Department of Electronic Materials Engineering at ANU where Taehyun Kim is a PhD student and Neville Fletcher a Visiting Fellow.

Both Neville and Rob have been Presidents of the Australian Institute of Physics.