Do nanowires grow from solid or liquid catalysts?

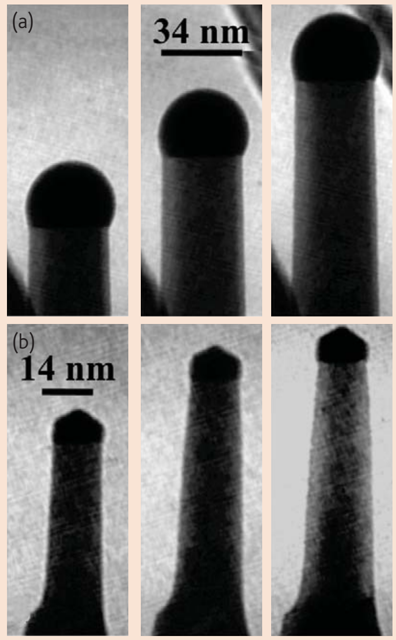
NANOTECHNOLOGY

Ge nanowires have been grown *in situ* in a transmission electron microscope (TEM), allowing researchers from IBM's T. J. Watson Research Center in New York to obtain detailed information on growth kinetics and structure [Kodambaka *et al.*, *Science* (2007) 316, 729].

Forty years ago, Wagner and Ellis suggested that nanowire growth is a vapor-liquid-solid process. Semiconductor material in vapor form is incorporated into the growing nanowire by means of a droplet of liquid catalyst. The nanodroplets, located at the tips of the wire, act as seeds for the growth, thus determining wire diameter.

However, some semiconductor/catalyst systems, including Ge/Au, will grow even below the eutectic temperature. This is the lowest melting temperature for the material and suggests that the catalyst could actually be a solid with growth occurring via a vapor-solid-solid mechanism. Alternatively the catalyst could be liquid, stabilized by nanoscale size effects.

The researchers used TEM to observe Ge/Au nanowire growth below the eutectic temperature. Their results show that the catalysts can be solid or liquid, the state depending on the thermal history and pressure. Nanowire growth persists regardless of the state the catalyst is in.



Series of images showing the two different growth modes (a) with liquid catalysts, and (b) with solid catalysts. (© 2007 AAAS.)

"We can explain the unexpected persistence of the liquid state below the equilibrium eutectic temperature by a model in which the supersaturation of Ge caused by the growth process stabilizes the liquid," says Frances M. Ross. "If this model is relevant for nanowires made from other materials, as we believe, it could explain an ongoing controversy surrounding the catalyst state during GaAs and InAs wire growth, and suggest pathways for controlling wire structure."

As the catalyst state is expected to influence wire growth rate, orientation, and morphology, it is likely to affect interface sharpness in heterostructure nanowires.

Ross and colleagues will now examine the growth of Si wires using other catalysts, and the growth of heterostructures composed of group IV and group III-V segments.

Katerina Busuttil

From plastic bags to nanowire arrays

FABRICATION AND PROCESSING

Researchers from Harvard University and the University of Hawaii at Manoa have taken a low-cost industrial process for making polymer films and successfully adapted it to make well-aligned, large-area films of semiconductor nanowires [Yu *et al.*, *Nat. Nanotechnol.* (2007) doi:10.1038/nnano.2007.150].

Typically used to manufacture garbage bags and food packaging, blown-film extrusion involves inflating a polymer bubble through a die, just like blowing a soap bubble. With a specially adapted rig and a mixture of Si nanowires and epoxy solution, the researchers can routinely blow bubbles of widths over 25 cm and heights greater than 50 cm. A key part of the rig is a metal ring that gently pulls the bubble upwards and keeps it stable. The continual upward flow aligns the nanowires.

The process itself is straightforward, says Charles M. Lieber of Harvard University. The difficult part is creating a homogeneous suspension of nanowires with a polymer – using 5,6-epoxyhexyltriethoxysilane as a covalent modifier gives the desired result.

Using this method, uniform films of Si nanowires were transferred to 150 mm Si wafers (as shown). Optical inspection shows that the angular deviation of the nanowires is less than 10° over the entire substrate, which is a substantial advance over previous studies, the team claims.

"This simple idea could be a breakthrough on this general problem of organizing nanostructures over large areas," says Lieber. Existing techniques such as spin coating or Langmuir-Blodgett assembly tend to produce clusters of nanoparticles or cannot easily be scaled up for commercial applications. Lieber is confident the bubble method will work with other types of nanoparticles, such as nanospheres or carbon nanotubes.

The ultimate goal is the self-assembly of nanoparticles for sensors, integrated electronics, and photonic devices. The team has achieved the fabrication and testing of nanowire-based field-effect transistors (FETs) and, more recently, have produced bubbles made from polymethyl methacrylate (PMMA), a photopolymer used in photolithography to pattern electrodes. The team also plans to build three-dimensional device structures by scrolling or folding the flexible nanowire films.

Transfer of the bubble film to a pair of Si wafers. (Courtesy of Charles M. Lieber/Nature.)

Pauline Rigby