nanozone news

21 August 2003

Getting wires crossed for nanocomputing

Arrays of criss-crossing nanowires can serve as devices for nanoscale logic and memory circuits. They can be made by the simple, almost century-old technique of Langmuir-Blodgett depositional chemistry.

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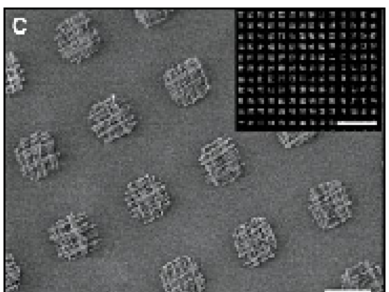

Scanning electron microscopy image of patterned crossed nanowire arrays; scale bar, 10 µm. (inset) Large area dark-field optical micrograph of the patterned crossed nanowire arrays; scale bar is 100 µm. Reprinted with permission from ref. 1, Copyright 2003 American Chemical Society.

Researchers at Harvard University in Cambridge, USA, have used cheap 'wet-chemical' techniques to fashion semiconducting nanowires into organized, hierarchically structured arrays suitable for creating high-density electronic logic circuits and memories[1].

Charlies Lieber and colleagues believe that nanoelectronic devices might come to rely on 'crossbar' arrays of nanoscale wires, in which individual wires cross over one another at right angles. They have demonstrated previously that both carbon nanotubes and long cylindrical nanowires of semiconductors such as silicon can be used to make functional devices in such an arrangement.

For example, at the crossing point of silicon nanowires that are coated in a thin insulating layer of silica, a junction is formed in which charge carriers can tunnel between the two conducting wires. These junctions can display diode- or transistor-like electronic behaviour, controlled by voltages applied at the ends of the wires.

In a crossbar array, a layer of parallel nanowires is overlain by another layer at right angles, producing a regular grid-like array of addressable devices. Small memory arrays constructed on this principle have already been demonstrated.

But they aren't easy to make. Lieber's group has perfected methods for growing free-standing nanowires from semiconducting materials using chemical vapour deposition in the presence of nanoscale catalytic particles.

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But positioning these nanowires into parallel arrays using micromanipulation methods would be very slow and cumbersome.

The technique that the Harvard researchers have now developed is akin to aligning logs floating on the surface of a river. They find that nanowires dispersed in an organic solvent using a surfactant (an alkylamine that binds to the nanowire surface) will form a monolayer when spread at the interface of air and water. In a Langmuir–Blodgett (LB) trough, a moveable barrier at the water surface compresses this monolayer, causing the wires to line up so that they can pack more efficiently. The layer of parallel wires can then be transferred onto a solid substrate by dipping it into the trough and withdrawing it — the technique originally used by Langmuir and Blodgett in the 1920s to make ordered monolayer films of surfactants.

Lieber and colleagues can control the spacing of adjacent nanowires by varying the degree of compression, producing arrays with roughly equal spacings of between about 800 and 200 nm. (The nanowires are typically several tens of nanometres wide.) Below 200 nm the wires begin to clump together — but this can itself be turned to advantage. The researchers made a close-packed array of nanowires consisting of a 25-nm core of silicon and a 10-nm shell of silica (these thicknesses can be precisely controlled during growth of the nanowires). After deposition, they then etched away the oxide layers to produce an array of discrete silicon nanowires with a centre-to-centre separation of 45 nm.

Although the nanowires are aligned, their axial positions are essentially random, so there is no registry between the ends of neighbouring wires even though they have much the same length. But the researchers were able to line up the ends by patterning a layer of aligned wires into small islands using photolithography. They deposited a patterned polymer photoresist onto the nanowire layer which covered 10 $\times$ 10 µm squares spaced 25 µm apart. Nanowires outside the covered patch, or those that protruded substantially beyond it, could then be gently removed from the substrate by sonication.

The researchers used this same approach to make crossbar arrays. Just as multilayer surfactant films can be prepared in the LB method by repeated dipping into the trough, so they could create multilayer films of aligned nanowires. A 90° rotation of the substrate between dips means that the second layer of wires is laid down at right angles to the first. And it is a trivial matter to make successive layers from nanowires of different composition, if this is needed to develop particular device characteristics — you just dip sequentially into different troughs. The photolithographic procedure then generates square, micrometre-scale arrays of crossed wires. By removing sacrificial silica coats from close-packed wires, the Harvard team was able to make crossbar arrays with a spacing of about 50 nm between adjacent crossover junctions. They say that it would also be rather simple to lay down arrays with different electronic functions side by side on a single substrate, by masking certain areas during LB dipping, for example. Then it would be possible to start to build up the kind of complex circuitry needed for nanocomputing.

References

1. Whang D., Jin S., Wu S. & Lieber C. M. Large-scale hierarchical organization of nanowire arrays for integrated nanosystems. *Nano Letters* advance online publication (2003)
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