OPINION

Nanowires take the prize

...Charles Lieber

2001 was a good year for Charles M. Lieber, Mark Hyman, Jr. Professor of Chemistry at Harvard University. A seminal paper [Science (2001) 294, 1313-1317], co-winner of the Feynman Prize, and the topic of his research, molecular electronics, highlighted as the 'breakthrough of the year' by Science magazine.

As the microelectronics industry drives towards smaller and smaller devices, a brick wall, in terms of the physical limits of current silicon technology, is fast approaching. Lieber advocates looking at the problem from a revolutionary perspective. "We need to make a big break and see if one can conceive of building up a computer in a different way," he says, "by taking some well defined pieces, which can be organized by some to-be-defined-method, and get function out of that." Instead of the 'top-down' approach using increasingly sophisticated lithographic techniques to carve out devices of ever decreasing dimensions, Lieber's 'bottom-up' concept uses nano-scale building blocks to create devices. "One defines nanometer length scales by the size of these pieces, the nano-scale building blocks, and the techniques one organizes them by."

"If one is thinking about computing, where information is being moved around in the form of charges, electrons and holes, you need wires. That's why I've focused on this question of making nanometer scale wires," Lieber explains. There are various types of nano-scale wires, nanotubes for example, as well as the semiconductor nanowires that have generated so much recent excitement. One of the unresolved issues with carbon nanotubes is controlling whether they exhibit semiconducting or metallic behavior. "This is really a big problem for many electronic and optoelectronic applications," says Lieber. "That's why we've focused on trying to design materials in which one can control the properties." The great advantage is that these semiconducting materials are very familiar and well understood. While properties do change as the scale is reduced, "you can explain it in essentially textbook quantum mechanics" says Lieber. "We understand quantitatively, it's not just qualitative."

Sounds easy? Although the idea of arrested precipitation (stopping crystal growth at a very early stage) is well recognized for fabricating quantum dots, harnessing that to produce nanoscale wires was a challenge. "That was the biggest conceptual thing we had to come up with," says Lieber. "How does one control the growth?" Various potential techniques exist. "The easiest one to understand I would call template-mediated growth where you take a membrane, such as used for the filtration of biological molecules, and fill the nanometer-scale pores with a material." The problem, explains Lieber, is that the technique is hard to control to produce high quality material. Looking for inspiration from more conventional materials science, Lieber happened upon an old idea from the 1950s and 60s of growing 'whiskers' by vapor-liquid-solid growth. The only problem was that the micron-size whiskers were too big. "We took advantage of ideas from chemistry to generate nano-scale clusters and conduct growth under nonequilibrium conditions so that the clusters don't aggregate and ball up. You can then take this idea and essentially grow any material in a nanoscale-wire format. It's as simple as that." The result, says Lieber, is "something that looks like the hairball of a cat!"

Taking a more controlled approach, a catalyst can be patterned on a substrate to grow nanowires straight out of the surface. An electric field can be applied to direct growth further. "Basically you can do almost anything that you would like to do," says Lieber. "The whole idea is that this general concept can enable, from a vial on a shelf much like any chemical, growth of n- and p-type silicon, gallium nitride, indium phosphide etc. and all those can be grown in a very similar type of apparatus." In traditional semiconducting processing, combining different materials can be difficult. A bottom-up approach makes it easy. "We have these things as chemicals or building blocks there to be manipulated. You can combine things that you just didn't think you could combine. You can bring functionality to the table that really isn't possible by other means."

And those building blocks can be manipulated to create real devices. "The really significant thing," believes Lieber, "is that one can actually make viable devices." By assembling crossed nanowires into junctions, Lieber and his team were able to create simple logic gates. This takes nanowires a step ahead of carbon nanotubes and other single molecule technologies, believes Lieber. "Those are pretty unreliable," he says, "and it's not clear when [assembly into logic gates] is going to be done." Although the work is "just dirty laboratory kind of work", one crucial factor is the achievement of device yields of over 90%. "The fact that we're able to get that high yield of devices, either diodes or field-effect transistor-type structures, allowed us to make these very limited integrated logic gates." While the creation of simple logic gates is impressive, the real challenge of scaling up the concept remains. Lieber believes it's possible. "You can take heart from your body," he says, "and how well that assembles."