



Science writ small: self-assembling erbium disilicide wires (left) may find a use in future generations of memory-rich nanoscale computers. Other groups are making microscopic machinery (right).

Nanotechnology

# Molecular movers and shakers

When nanotechnology became a buzzword about a decade ago, no one was quite sure what it was. Just how the field will develop is still unclear, but the past year has seen a transformation in its ability to attract public investment. The US federal government will almost double its spending on nanotech next year, to more than \$400 million. Japan is planning a budget hike of more than 40%, and several European countries have made nanoscale research a priority. Nanotechnology looks poised to shed its science-fiction image and don the mantle of respectability.

But what opportunities should we expect to see the new funds create? The highlights of the past 12 months give some pointers. One of these is nanotechnology's potential to reinvent and revitalize chemistry. For example, chemists should have fun with nanotech's party piece, the manipulation of individual atoms using the scanning tunnelling microscope (STM).

In September, a team at the Free University of Berlin synthesized a biphenyl molecule from two benzene radicals using the STM<sup>1</sup>. Such piece-by-piece molecule-building, although impressive, is unlikely to replace standard chemical synthesis. But the combination of nanoscale manipulation and spontaneous chemical processes has huge potential.

This was shown in July by researchers at the Steacie Institute for Molecular Sciences in Ottawa, Canada<sup>2</sup>. Robert Wolkow and his colleagues used the STM to remove individual hydrogen atoms from a hydrogen-covered silicon surface. This allowed a styrene molecule to bind to the silicon, setting off a

chain reaction in which a neighbouring hydrogen was displaced, another styrene bound to the silicon, and so on — resulting in rows of molecules up to 13 nanometres long.

In a similar vein, Stanley Williams and colleagues at the Hewlett-Packard Research Laboratories in Palo Alto, California, reported in June that they had made grid-like arrays of self-assembling erbium disilicide nanowires on a silicon substrate<sup>3</sup>. They anticipate using such grids in a memory-rich architecture for a nanoscale computer. And Williams's collaborator James Heath and his team at the University of California at Los Angeles have developed another of the building blocks for such a device: molecular switches that work at room temperature<sup>4</sup>.

The connections in nanoscale circuits could well be made of conducting carbon nanotubes. And the discovery of a simple method for fashioning them into 'Y' shapes broadens their scope for use in electronic circuitry<sup>5</sup>. Conducting organic materials might open the way to a genuine molecular electronics — as was acknowledged by this year's chemistry Nobel.

The cell, meanwhile, is a ready-made toolbox of molecular machines, and biomolecular science is sure to be a big part of nanotechnology. By coupling the ability of specific biomolecules to recognize one another with manipulation using laser beams as optical tweezers, chemist George Whitesides and his colleagues at Harvard University this year explored the frontier with biology, making sculptures from red blood cells tagged with polymer microspheres<sup>6</sup>.

In June, a paper from Angela Belcher and colleagues at the University of Texas at Austin

united protein chemistry with semiconductor technology. They created peptides that can recognize and bind to the surfaces of different semiconductors<sup>7</sup>. This points to the possibility of devices based on biological molecules, such as the motor proteins that power cell movement, that can assemble electronic or other inorganic structures. The exciting beginnings of such a hybrid technology were heralded in November, with the report of a nanoscale metal rotor powered by the enzyme ATP synthase<sup>8</sup>.

Practical applications remain years away. "Nanotechnology doesn't yet exist," says Don Eigler of IBM's Almaden Research Center in San Jose. But there is one concrete sign that nanoscale research will eventually deliver working technologies: the spin-off companies launched by some of the field's academic pioneers. In the past year, Richard Smalley of Rice University in Houston formed Carbon Nanotechnologies, which aims to commercialize the use of carbon nanotubes; and Chad Mirkin and co-workers at Northwestern University in Illinois have launched Nanosphere. This company seeks to use a system based on tiny gold particles to develop diagnostic tests that recognize particular sequences of DNA. ■

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