Feynman's unfinished business

Irrespective of what he got right and what he got wrong in his famous 1959 lecture, Richard Feynman's vision and imagination have had an important role in the development of nanoscience and nanotechnology, as **Richard Jones** reports.

No one can doubt that Richard Feynman's 1959 lecture, 'There's plenty of room at the bottom', has been central to the process by which the nascent discipline of nanotechnology has developed its identity over the past two decades. However, as Chris Toumey has convincingly shown[1], the significance of the lecture was attached retrospectively. Feynman's lecture was, in truth, a very minor incident in his brilliant career, but if we were to look for the source of its later power, the starting point must be the figure of Feynman himself. He was, of course, a towering intellectual figure, but he also became the subject of his own developing myth as the trickster genius of American science, so it was doubly attractive to associate his name with the foundation of a new field. To a reader coming to the lecture many years after it was delivered, though, when its status as a founding document of nanotechnology had been established, what perhaps would be striking about it is the way, like much prophetic writing, it could be read as a mixture of promises fulfilled and promises yet to be realised.

Of the promises that have been fulfilled, the most striking are surely those relating to writing on the nanoscale. The famous image of the letters IBM spelt out with a scanning tunnelling microscope[2] easily surpassed Feynman's expectations, and opened the way for every nanolaboratory in the world, it seemed, to publish some nanoscale version of their college crest or corporate logo executed in the nanowriting technique of their choice.

Curiously, what turned out to be the main practical significance of being able to pattern surfaces on very fine scales was not picked out in Feynman's lecture. He recognized the importance of being able to miniaturize the components of computers, but he didn't connect this to the problem of tiny writing. The key to this problem was already known when Feynman spoke — in early 1959 Jack Kilby and Robert Noyce had filed the crucial patents for the idea of replacing the separate transistors in the computers of the time with integrated circuits. So the trajectory that has led to the various electronic devices that are the main application of nanotechnology today was not signalled at that time by Feynman.

What he did point out, though, was the huge range of possibilities for making materials with new electrical and magnetic properties if one were able to arrange different types of atoms in arbitrary three-dimensional patterns. The subsequent history of bandgap engineering in semiconductor heterostructures, made possible by the technique of molecular beam epitaxy[3], has amply justified the promise of "layered structures with just the right layers."

Going beyond layered materials, Feynman speculated about "a piece of material in which we make little coils and condensers 1,000 or 10,000 ångströms in a circuit". This is a signpost to recent developments in metamaterials, where the inclusion of precisely shaped nanostructures made of a conducting material in a dielectric matrix leads to unique optical properties. But the potential of optical metamaterials, and the promise of perfect lenses and invisibility cloaks, does not by any means exhaust the possibilities that are opened up if one could create arbitrary three-dimensional nanostructures consisting of materials with different electrical and magnetic properties. Such materials would erode the distinction we make between a material and a device, allowing precise control of the interaction between light and electrons, and opening up the possibility of entirely new ways of processing information[4].

As befits the contribution of a theoretical physicist, Feynman's lecture is focused more on what one might be able to do with nanostructures and devices, rather than the practical issues about how one might make them. Although Feynman visualized "a billion tiny factories, models of each other, which are manufacturing simultaneously, drilling holes, stamping parts, and so on", nanofabrication in practice took different paths. On the one hand, we have the planar processing route, based on cycles of depositing layers, writing patterns and revealing them by etching, which has been successful for the semiconductor industry. On the other, we have the biologically inspired paradigm of self-assembly, with its information flow from designed molecules to nanostructures. What we are nowhere near is Feynman's vision of making synthetic chemists redundant: "it would be, in principle, possible (I think) for a physicist to synthesize any chemical substance that the chemist writes down". The use of the tip of a scanning tunnelling microscope as a tool to direct chemical reactions at the single-molecule level has been demonstrated[5], but the technical difficulties in the way of the general adoption and extension of these techniques still seem formidable.

Perhaps the most notorious of Feynman's predictions is what was later to be termed the 'nanobot' — the idea of a miniaturized robot surgeon injected into the bloodstream or implanted in an organ. In fact, Feynman didn't claim credit himself for this idea, but attributed it to his friend, the space scientist Al Hibbs. Given that Hibbs had a central role in the design of the USA's unmanned space exploration programme at the Jet Propulsion Laboratory, it is all too appropriate that this has become the defining image of nanotechnology in science fiction and popular culture. The nanoscience community seems to have a view of the nanobot idea that is conflicted, to say the least. Although most of the nanoscience community deplore the classical depiction of a nanobot for its lack of realism, its manifest unfeasibility and its associations with the speculative excesses of the more futuristic projections of nanotechnology, some are happy to exploit the image to convey something of the promise of fields such as advanced drug delivery.

Perhaps Feynman can be credited, above all, for making nanotechnology a field driven by imagination and visions of the future. Something else that we might usefully take from his lecture is the importance of a spirit of play and the drive to achieve new technical feats just because you can. Ultimately, what's important is not what you can imagine, but what you can make. ❐

Richard Jones is in the Department of Physics and Astronomy at the University of Sheffield.
e-mail: r.a.l.jones@sheffield.ac.uk

References

1. Toumey, C. *Techné* **12,** 133–168 (Fall 2008).
2. Eigler, D. M. & Schweizer, E. K. *Nature* **344,** 524–526 (1990).
3. McCray, W. P. *Nature Nanotech.* **2,** 259–261 (2007).
4. Engheta, N. *Science* **317,** 1698–1702 (2007).
5. Hla, S. W. & Rieder, K. H. *Annu. Rev. Phys. Chem.* **54,** 307–330 (2003).