

# Nanotechnology and nucleotides

Donald Bethell and David J. Schiffrin

THERE are many advantages to making things small, such as the potential speed and compactness of nanometre-scale electronic components, and the remarkable, size-dependent physical properties that very small particles can have. Building complicated structures on this scale isn't easy, but the problem is being tackled from several directions. Mucic *et al.*<sup>1</sup> and Alivisatos *et al.*<sup>2</sup> (respectively pages 607 and 609 in this issue) now describe how they have used oligonucleotides to organize metal clusters in superlattices, and produced materials that are a halfway house between simple synthetic structures and biological materials.

Michael Faraday, in the 1856 Bakerian Lecture<sup>3</sup>, observed that "gold wire deflagrated by explosions of a Leyden battery produces a divided condition, very different to that presented by gold leaves." The ruby colour of the deposit observed on transmission could be transformed to the green colour of gold leaves by applying a compressive force. This was, perhaps, the first observation that the properties of very small particles can differ from those of the bulk material, and that the control of their separation and coalescence leads to profound changes in their properties.

More recently, self-organization of nanoparticles has promised a powerful route to new materials, in particular the synthesis of superlattices — solid, periodic arrays of structures having different electronic properties<sup>4,5</sup>. A possible way to achieve this is to prepare the nanosized components of the three-dimensional structure by colloidal chemistry, and then use self-assembly as a way of joining them together. The difficulty with this approach is that imperfections in the superlattice can result from inadequate chemical recognition by the constituents. This can be a considerable limitation in making nanostructured materials for electronic applications, where long-range order is important.

Biological systems must be able to cope with complex recognition problems, and DNA in particular is suited to transmit well-defined chemical information, making use of the pairing properties of nucleotide bases. Mucic *et al.*<sup>1</sup> and Alivisatos *et al.*<sup>2</sup> report their initial successes in this form of self-assembly using inorganic particles, in this case colloidal gold, using base-pairing between complementary chains of attached oligonucleotides to provide the link between the particles. Because of the specificity of base-pairing, this procedure in principle allows complex patterns of interlinked gold particles with predetermined separations to be assembled using a standard technique.

The binding is noncovalent and so the

linking can probably be readily reversed. That could allow complex networks of particles capable of molecular recognition and signal transduction by virtue of having variable electronic properties. Such materials could find application in biosensors.

The organization of pre-fabricated

An early nanotechnologist — Faraday was the first to study metal colloids.

structures has been attempted before by ordinary self-assembly techniques, using solutions of colloidal nanoparticles as the starting point and two-ended linker molecules for building up superlattices<sup>6</sup>. Such organic synthetic methods can be devised to be highly specific, but they require a range of functional groups and reaction conditions that do not have the simplicity offered by this new use of oligonucleotides. They do, however, offer the possibility of varying the physical properties of the link by the inclusion of donor or acceptor moieties at specific points within the superlattice, for example.

The attachment of reactive groups to clusters is another important approach in attempts to build structures of well-defined electronic properties from small building blocks. For example, in a recent publication Royce W. Murray and co-workers<sup>7</sup> have shown that thiol-stabilized nanoclusters can be used as a starting point for further modification by substituting individual ligands with thiols that have functional groups at the end of their hydrocarbon chain. These are capable of chemical reaction to produce two- and three-dimensional networks. The materials produced in this way can best be described as intermediate in nature between a continuous material and an organic molecular solid.

The synthesis of new nanostructured

materials requires homogeneity in particle size. Leff *et al.*<sup>8</sup> and Whetten *et al.*<sup>9</sup> both used classical preparation and separation methods such as fractional precipitation to achieve size control of metal particles bearing self-assembled monolayers. The latter group has isolated nanocrystals of precise sizes, determined by the 'magic numbers' that relate surface area to volume and correspond to local energy minima. Furthermore, the crystallization of these materials into two-dimensional superlattices has been demonstrated.

All of these discoveries must be viewed against the background of attempts to synthesize new materials with unusual optical and electronic properties. There is at present a confluence of technological developments and basic science that has a good chance of creating controlled structures that can lead to new electronic devices. An example of these incipient technologies is the work of Y. Wada and colleagues on nanoscale devices<sup>10</sup> — they are attempting to make ultra-fast switches by arranging atoms or molecules on a surface one by one, using a scanning tunnelling microscope (STM). This same group has now produced a micromechanical STM on a chip<sup>11</sup>, using the electronic techniques originally developed to make high-capacity memory chips. The dramatic cost reduction that can be envisaged in such devices will make it practical to manipulate clusters, or individual atoms, for the manufacture of ultraminaturized electronic circuits.

The work now described by Mucic and Alivisatos is a major development in that it refines the control of supramolecular self-assembly. These and other recent advances in the synthesis of nanosized components that can be handled like simple organic compounds, and in the methods of self-assembly of structures, are all leading towards fabrication of electronic components on a molecular scale. The worldwide effort in this and related areas will surely lead to exciting developments in new electronic materials over the next ten years. □

Donald Bethell and David J. Schiffrin are in the Department of Chemistry, University of Liverpool, Liverpool L69 3BX, UK.

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