

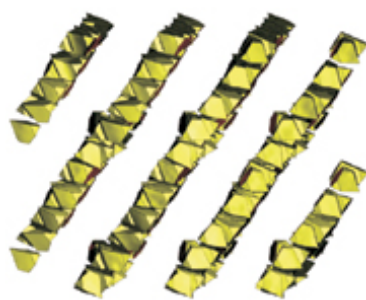
## nanozone news

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### Sheets that make themselves

**Controlling the aggregation of nanoparticles may be the key to making nanostructured materials. Now there's a simple way to do it in two dimensions.**

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Tetrahedral nanoparticles with anisotropic inter-particle forces may aggregate into sheet-like arrays, as illustrated in this computer simulation. Image by C. R. Iacovella, University of Michigan. Reprinted with permission from ref. 1. Copyright 2006 AAAS.

technologically useful property. Whereas nanoparticles have previously been arranged into two-dimensional sheets at interfaces, such as the free surface of a liquid<sup>2</sup>, the sheets in this case need no such template: they are free-floating in solution.

Kotov and co-workers have previously found that CdTe nanoparticles will organize themselves in one dimension, forming chains that then aggregate into nanowires<sup>3</sup>. In that case the nanoparticles were roughly spherical, and the researchers attributed aggregation to dipole-dipole interactions, akin to those that promote chain formation in electrorheological 'smart fluids'. The formation of sheets, on the other hand, requires a rather more subtle balance of inter-particle forces.

A solution of CdTe nanoparticles in water may be stabilized by coating the

If you want to build functional materials from nanoparticles, self-assembly looks the most attractive way to do it: get the structures to build themselves. Nicholas Kotov of the University of Michigan and his co-workers have discovered a new self-assembly process that arranges nanocrystals into sheets<sup>1</sup>, essentially enabling them to make semiconductor thin films under mild conditions in solution rather than using the high-vacuum techniques of conventional microelectronic technology.

These sheets form spontaneously from tetrahedrally shaped nanoparticles of cadmium telluride (CdTe), and retain the particle-size-dependent light emission of the constituent nanoparticles — potentially a

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particles with organic molecules that have hydrophilic end groups — in this case Kotov and colleagues used amine-terminated molecules. They found that the sheets formed spontaneously from a solution of such particles, and were visible in the electron microscope as flat, partly folded or wrinkled.

The sheets varied in size from just a few to several tens of micrometres across, and were not necessarily broken up by gentle stirring. They have a thickness equal to the nanoparticle size of 3.4 nm, indicating that they are just one particle thick.

What forces promote sheet formation rather than simple three-dimensional aggregation into clumps? For starters, the particles are predicted to have a dipole moment — an uneven distribution of charge. They have a roughly tetrahedral shape, reflecting the tetrahedral packing of the underlying CdTe crystal lattice; but some of the apices of the tetrahedra are truncated to lower the surface energy, and quantum-chemical calculations show that this produces the dipoles.

But that's not all. The organic molecules on the surface, being in fact dimethylamines, have two hydrophobic groups (methyls) as well as the amine hydrogen-bonding groups. So there is a degree of hydrophobic interaction between particles too. And some of these molecules are predicted to be protonated, giving a small positive charge to the surfaces. So the interactions between particles include dipole–dipole, hydrophobic and electrostatic forces, distributed anisotropically on particles of complex shape.

The researchers used a model of 'patchy' nanoparticles, proposed previously by two of them<sup>4</sup>, to predict what this combination of forces might imply for aggregation. They found that the calculations indeed generated two-dimensional sheets — but only if all the relevant forces were included, and only if precisely three of the four corners of the tetrahedral nanoparticles are truncated. They speculate that nanoparticles with other numbers of truncated corners might be incorporated into the sheets as defects.

This kind of aggregation driven by a combination of interactions, including hydrophobic and electrostatic forces, is reminiscent of what happens with some proteins. In particular, the class of so-called surface-layer (S-layer) proteins forms monolayers at bacterial cell surfaces in a manner that Kotov and colleagues regard as directly analogous to the sheet formation they have discovered in nanoparticles.

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