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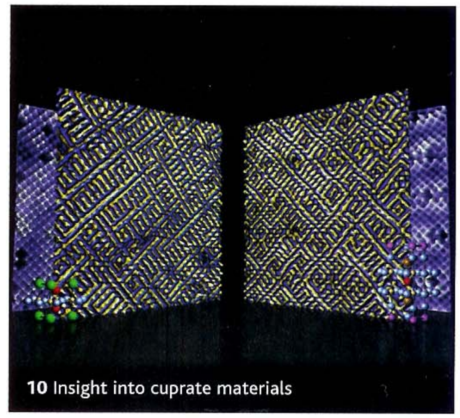
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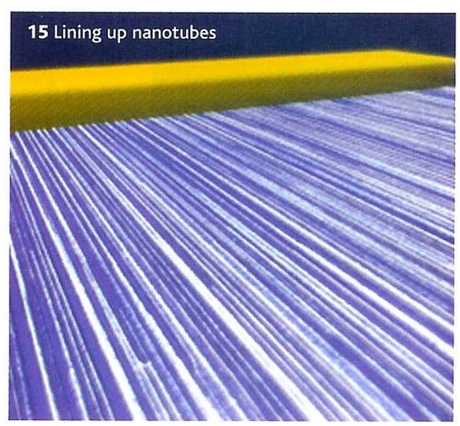
15 Lining up nanotubes

Rods arrange into rings

NANOTECHNOLOGY

Researchers from Rice University have shown how to trigger the self-assembly of nanorods into ring-shaped arrays, even though theory predicts that nanorods should preferentially align side-by-side in parallel fashion [Khanal and Zubarev, *Angew. Chem. Int. Ed.* (2007) **46**, 2195]. Their technique could simplify the production of novel optical materials that rely on ring-like nanoassemblies for their functionality.

Bishnu P. Khanal and Eugene R. Zubarev coupled long carboxybiphenyl-terminated polystyrene chains to Au nanorods. The pair dissolved the hybrid organic-inorganic nanorods in dichloromethane and allowed the solution to dry on a carbon grid. Ring-shaped superstructures were left with diameters varying from 300 nm to a few microns. Transmission electron microscopy shows the orientation of nanorods in most rings is random, although at low concentrations the rods line up head-to-tail around the circumference.

The self-assembly process occurs around tiny microdroplets of water that condense from the air when the CH_2Cl_2 evaporates, Zubarev explains. "It only takes a few seconds for a drop to evaporate, and when it does, there are thousands, if not millions of rings formed on the substrate."

The researchers are currently exploring how to control the size of the rings produced, so that they can generate periodic arrays of uniform rings. This means controlling the size of water droplets condensing from air.

They would also like to measure how the optical properties of nanostructures alter when they self-organize into rings. "This is a very challenging technical problem, but it is currently the most important task," says Zubarev.

Paula Gould

Nanotubes line up for electronics

NANOTECHNOLOGY

Single-walled carbon nanotubes (SWNTs) may have exceptional electronic properties, but incorporating them into usable devices and integrated circuits presents many practical difficulties. Densely packed arrays of nonoverlapping SWNTs could be easier to work with, and would retain the attractive properties of individual nanotubes. The tubes' parallel configuration should provide a high current output, while the large number of SWNTs would lead to good device reproducibility despite the range of individual nanotube conductivities.

Researchers at the University of Illinois at Urbana-Champaign, Purdue University, and Lehigh University have demonstrated how such an array could operate as a thin-film semiconductor material [Kang *et al.*, *Nat. Nanotechnol.* (2007) doi:10.1038/nnano2007.77].

This approach to SWNT electronics relies on arrays of linear nanotubes with a high degree of alignment. Seong Jun Kang and colleagues achieve this by guiding SWNT growth on cut quartz wafers using patterned stripes of an Fe catalyst. They produce SWNTs with average individual diameters of ~1 nm, lengths of up to 300 μm, and densities approaching ~10 SWNTs/μm. More than 99.9% of the SWNTs are oriented along the $[2\bar{1}\bar{1}0]$ direction of the quartz.

P- and *n*-type transistors using these arrays, comprising ~2100 SWNTs, reveal device-level mobilities of ~1000 cm^2/Vs and scaled transductances approaching 3000 S/m. Devices using interdigitated electrodes show current outputs up to ~1 A. The team also built simple *p*-type and complementary metal-oxide semiconductor logic gates.

Colorized scanning electron micrograph of an SWNT array (blue and white) with artist drawings of the device electrodes (gold). (Courtesy of John A. Rogers.)

This sort of material could have immediate applications in large area, transparent, and/or flexible electronics, according to John A. Rogers. "Aligned arrays might be viewed as a very high performance class of thin-film 'organic' semiconductor that could more effectively address technical needs in flexible electronics than relatively low-performance polymers or small-molecule systems," he says.

The group is working to increase the packing density of SWNTs in the arrays. "We have room to improve this value by a factor of ten or more," says Rogers.

Paula Gould

Carpet of nanorods makes for low-index films

NANOTECHNOLOGY

You'd almost think it wasn't there. Researchers at Rensselaer Polytechnic Institute and Crystal IS, Inc. have reset the bar for antireflection coatings, creating massively broadband, incident-angle-independent coatings from nanorods [Xi *et al.*, *Nat. Photonics* (2007) **1**, 176].

The research makes use of graded-index layers – that is, thin films with progressively lower refractive index. The antireflection properties of such layers have been known since 1880, but have awaited new approaches and materials to reduce the refractive index of each layer. While highly efficient single-layer coatings exist, they are limited to very narrow wavelength bands and angles of incidence.

To reduce reflectance from an interface, the difference in refractive index between the two materials should be as small as possible. For the best performance in an antireflection coating, the refractive index of the first layer should be close to that of air.

But no dense material amenable to very thin films has such a low index. Previous approaches, such as glass etching, interference patterning, and sol-gel processes, do not result in highly controllable refractive indices.

Instead, the team led by E. Fred Schubert deposited SiO_2 and TiO_2 nanorods on an AlN substrate using a method called oblique-angle deposition, a vapor-deposition technique that results in controllably nanoporous films. The porosity of the films makes for a lower refractive index, and the researchers found that the ultimate index of the films varies with the angle of incidence of the vapor. For example, TiO_2 layers show indices from 2.7 to 1.3. By building up a quintic index profile with the layers, the team demonstrate a broadband coating that has a reflectance of just ~0.1% throughout the visible spectrum. The final layer has an index of just 1.05, the lowest ever reported.

D. Jason Palmer