corresponds to nanotubes with diameters of between 0.8 and 1.3 nm (Ref. 2) (Fig. 1). Nanotubes with diameters and bandgaps in this range are readily available and have already been shown to display useful nonlinear properties[3–5], including saturable absorption for mode-locking applications.

Another feature of nanotubes is that it is difficult to make samples with a narrow absorption spectrum, or to make only semiconducting or metallic nanotubes. This is usually a problem for nanoelectronic applications, and intense efforts to sort nanotubes according to their diameters and/or electronic properties are ongoing[6–8]. For ultrafast optics, however, these characteristics can be an advantage. The presence of metallic tubes increases relaxation speeds, another important property for ultrafast devices. If the excited electron–hole pairs relax back to their ground state quickly, the system rapidly returns to the linear absorption regime and a new saturation–relaxation cycle can begin. This process is naturally very fast in semiconducting nanotubes, and the presence of metallic nanotubes makes it even faster. That is because electrons and holes can tunnel from the semiconducting nanotubes to their metallic counterparts. In addition, the wide absorption spectrum allows for a wide tunability.

Ferrari and co-workers have put all of these characteristics to use. Using nanotubes dispersed in a polycarbonate matrix, they built a fibre laser that generates ultrashort (2.4 ps) pulses, with a wavelength that can be tuned between 1,518 and 1,558 nm. They suggest that wider tunability should be possible with a wider distribution of nanotube diameters. In separate work, Fabian Rotermund of Ajou University and co-workers have demonstrated that nanotube-based saturable absorbers for ultrashort pulse generation can be easily fabricated through both spinning and spraying techniques[9]. The combination of ease of fabrication and wide tunability shows the potential that nanotubes hold for nonlinear optics.

Indeed, the potential applications of polymer-dispersed nanotubes[10] extend far beyond mode-lockers. Nanotube–polymer composites can be made with a low-cost, room-temperature fabrication process, and they are easily manipulated by a variety of methods — such as embossing, stamping, sawing and wet- or dry-etching — which makes them an ideal platform for integrating photonic devices. Moreover, polymers can be synthesized with well-defined optical characteristics such as transparency in selective wavelength ranges, variable refractive indexes and low birefringence. These properties mean that nanotube–polymer composites could prove useful in a large number of applications in optics including flexible transparent conductors, charge-transport layers in light-emitting diodes, displays and photovoltaic cells, nonlinear optical switches, optical limiters and, possibly, new light sources[11]. In addition, they might also be used in biomedical instruments, chemical analysis, time-resolved spectroscopy, environmental sensing, microscopy and surgery.

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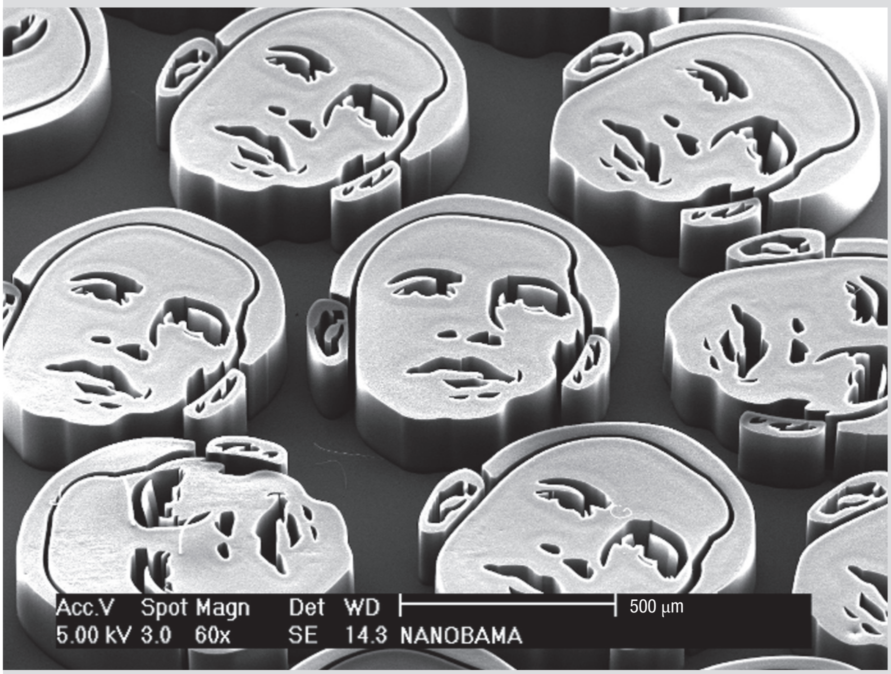
NANOSTRUCTURES

Welcome to nanobama



JOHN HART/SAMEH TAWFICK/MICHAEL DE VOLDER/ WILL WALKER/WWW.NANOBLISS.COM

The giant granite sculptures of George Washington — the first president of the United States — and three of his successors at Mount Rushmore are some of the most famous images in the world. It took more than 14 years and some 400 workers to complete the 18-metre-high sculptures. Now Barack Obama — who will become the 44th president of the US — has been immortalized in carbon nanotubes barely a week after he was elected. John Hart of the University of Michigan and co-workers grew the nanotubes on a silicon wafer patterned with an iron catalyst to produce a variety of images (www.nanobama.com). In the electron micrograph shown here, each face contains about 150 million nanotubes. "We had no political message in mind," says Hart, "other than to draw attention to the science and applications of nanostructures in the hope that people who wouldn't otherwise read about nanotechnology may want to learn a bit more."

Peter Rodgers