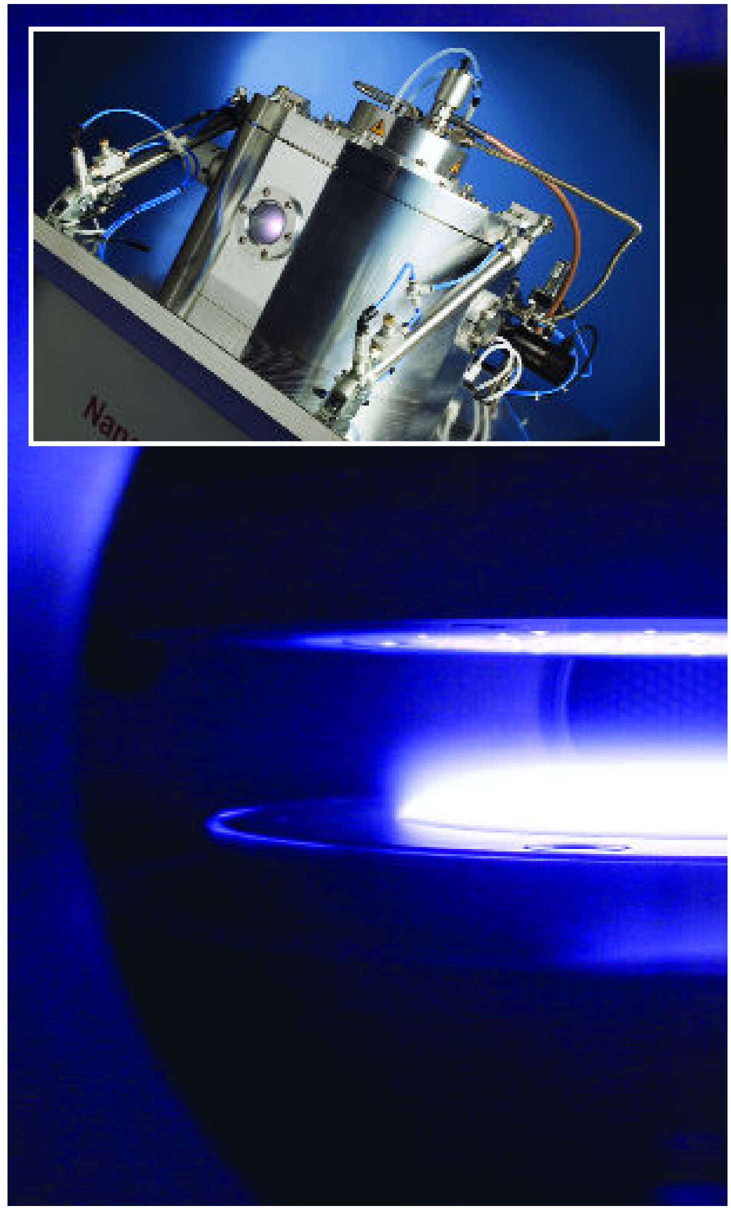


Size is everything

The tiny technology of carbon nanotubes has enormous potential. Ben Hargreaves meets a company that has developed a tool to make the 'growing' processes easier

At the distinctly low-tech setting of Newhaven docks, a high-tech enterprise that believes small is beautiful is busy dreaming up products that could play a role in the development of the next generation of computer microprocessors.

Tucked away at the back of an industrial estate in East Sussex, Surrey NanoSystems may present an unassuming face to the world, but inside the company's engineers are animated. "This is an exciting time for us," enthuses chief technology officer Ben Jensen. "There's a lot of interest in our technology and we're getting orders. And it's great that this is UK stuff — you don't have to go to America or Japan to find it."

Jensen and his team has designed a sophisticated tool that helps researchers and companies "grow" carbon nanotubes. This tiny material has enormous potential in many applications but is principally thought to be the way forward in semiconductor production as computer chips approach their limits.

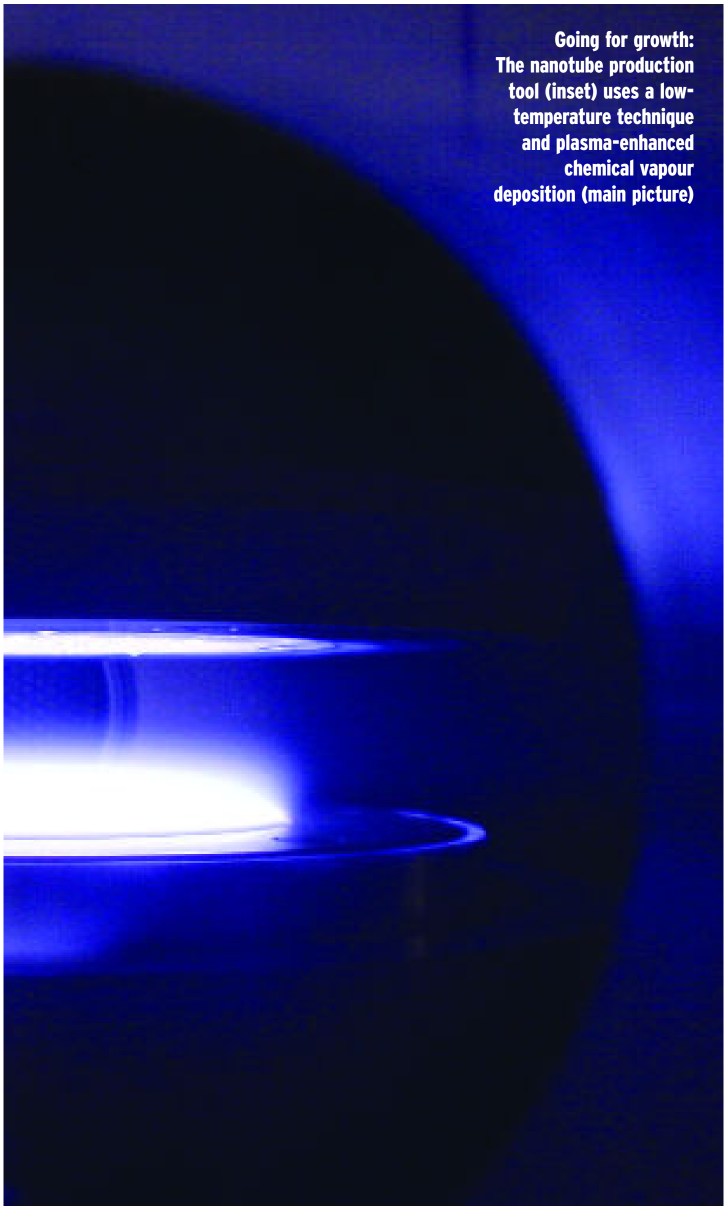
Carbon nanotubes have a number of special properties. They are strong, small — typically with a diameter about 50,000 times smaller than the width of a human hair — good at conducting heat and electricity and, being carbon-based, relatively easy to form.

"In the last 15 years carbon nanotubes have been studied extensively by universities and large corporations because they have such interesting properties," say Jensen. "Theoretically, they can carry more than a billion amps per square centimetre of current, compared with about 100 million for copper. They are virtual superconductors of heat and extremely strong — about 200 times the tensile strength of steel — and also extremely small, with a typical size range from 1nm to 50nm. They are novel, and that's why there has been so much interest."

The majority of interest has come from microchip producers, and it's easy to see why. "They are bound by Moore's Law," says Jensen. Gordon Moore, a co-founder of Intel, famously observed in 1965 that the number of transistors on an integrated circuit for minimum component cost needs to double every two years. Jensen adds: "The need is to get the feature size smaller, the speed up, and increase the transistor density. But they have a finite amount of 'real estate', and in that real estate they've got to get electrons through as fast as possible on the die area, while keeping power and heat down. To do that they need to go down in feature size.

"Further, for the production process to be economical, they have to go up in substrate size so each wafer going through is bigger and instead of producing one hundred chips they are producing a thousand."

Current techniques and materials for producing complementary metal-oxide-semiconductor (CMOS) chips are approaching their limits, Jensen explains, and it is here that some believe carbon nanotubes could be the answer. Copper, which is used as an interconnect material between layers in a chip, requires a tantalum-nitride barrier to stop it diffusing into the surrounding silicon when it gets warm. But as feature sizes have shrunk, the amount of tantalum nitride required to prevent diffusion remains the same, so less copper is available, slowing the passage of



Going for growth: The nanotube production tool (inset) uses a low-temperature technique and plasma-enhanced chemical vapour deposition (main picture)

electrons through the semiconductor and generating more heat.

"Semiconductors are getting smaller but when you hit the 32nm node the interconnect would have so much tantalum nitride that it would be almost equal with the amount of copper," says Jensen. "It would make it highly resistive — the electrons can't travel through the chip very easily and serious electron migration issues occur. More heat is generated and the problems multiply. Silicon and copper are about to hit a brick wall so we're working with industry leaders on swapping the copper interconnects for carbon nanotubes."

The growth tool Surrey has developed has a number of features that make it suitable for research into semiconductor production, the key one being that it can operate at relatively low temperatures. It is easier to grow tubes at temperatures of 600-1,000°C, but Surrey's tool will produce repeatable tubes at 350-400°C, within the parameters required for microchip production. "If you go any higher you start to distress the device," explains Jensen. "As you build up the device you need to drop the temperature otherwise it destroys the layer below. You can't allow parts of the wafer to be destroyed by thermal stresses."

Surrey believes it has stolen a march on its competitors thanks to the low-temperature aspect of its tool. It also works with a number of processes for producing carbon nanotubes, including chemical vapour deposition and plasma-enhanced chemical vapour deposition. The former method produces tubes "like a clump of spaghetti", says Jensen, while the latter has the advantage of aligning the tubes in straight rows.

Meanwhile, university researchers have been looking for a method of producing the tubes that can achieve repeatable results, and are keen on the tool for that reason, says Jensen. "Scientists have been studying carbon nanotubes with homemade equipment," he says. "This caused issues when they published papers and people in other universities would try to repeat their experiments and couldn't. We are giving them a standard — a tool that produces repeatable results. It should help them move on to the next level in their research.

"They can spend their time developing something interesting, instead of spending months and months trying to produce a stable material. That's been such a problem."

Surrey NanoSystems, which began life as part of the University of Surrey, was set up with funding from government and an investment by the IP Group, a venture capital company that specialises in tech spin-outs from universities. "Everyone involved in Surrey, from the chairman down, is over the moon that we've managed to retain the business in this country — and we want to keep it that way.

"There's no doubt that our universities have some of the best technologies but so often it seems it's only possible to get the required levels of venture capital or private equity funding for production abroad.

"It's very frustrating. We've seen so many innovations snapped up and taken away, and they never come back to these shores."

Down by the docks at Newhaven, he is hoping to change that.

STRENGTH IN NUMBERS

Carbon nanotubes came to prominence in 1991 when a researcher at NEC in Japan, Sumio Iijima, produced the first clear high-resolution images of the material. Allotropes of carbon, the tubes are cylindrical and typically a diameter of the order of a few nanometres and a thickness of one atom. They are related to "buckyballs", which are spherical members of the fullerene structural family discovered earlier. Carbon nanotubes are composed of chemical bonds like those of graphite and stronger than the bonds found in diamond.

Aside from the electronics industry it is believed there are many potential applications for the material because of its unique properties. "They could be used to replace composites," notes GuanYow Chen, Surrey NanoSystems' lead scientist. "You can imagine nanotubes being used to replace carbon fibres, but because they are smaller and stronger you could reduce a lot of weight, while keeping the same level of performance."

BMW has already patented an extremely tough, scratch-resistant paint from nanotubes, says Jensen. Other possible applications include biological sensors, fuel cells, and electromagnetic shielding. "Almost every week there's a new application announced by a major university," says the scientist. "Four years ago, if you did a search on the number of papers out there you'd get a few thousand – now it's up in the millions. But the thermal problems are a drawback, helping to keep the technology a novelty, and that's just one of the areas where we can help."

Jensen says the slow pace and low volumes of current production equipment is another complicating factor. "The limits on using carbon nanotubes as a replacement for composite materials are in the production processes. Most equipment that grows nanotubes works in kilos per week, not kilos per hour. They need to get to kilos per minute if they are going to start incorporating this material as a replacement for composites.

"But if they can do that, the potential is amazing, because the strength of nanotubes compared with conventional carbon fibre is phenomenal."