The company driving the carbon electronics revolution

NEC IS LEADING the development of carbon nanostructures for a new breed of electronics.

NEC researcher Dr Sumio Iijima first discovered carbon nanotubes in 1991.

Smaller transistors tend to be faster. It's a fact that has led the electronics industry to master the art of shrinking silicon transistors, doubling computing power every two years for the last half-century. Industry experts however predict that scaling will cease within four to seven years.

EVERY RESEARCHER AT NEC AIMS TO BECOME A PIONEER OF NEW TECHNOLOGY. IT'S A PART OF OUR CULTURE.

Just as silicon scaling has stalled, the variety of electronic devices being developed has exploded — and computation speed is often not a primary concern. For example, devices that make up the 'Internet of Things' (IoT) perform tasks like sensing, actuation and communication, rather than raw computation. Leveraging these IoT devices will require new energy-producing/storage devices with high efficiency, density and reliability.

These changes have focused attention on electronic materials beyond silicon, especially carbon. Like silicon, carbon has four valence electrons, and the two elements share some chemical and electrical properties. Unlike silicon, carbon can be easily made to form a variety of nanostructures with exceptional electronic and mechanical properties.

A great deal of work is still needed to make carbon nanostructures a viable material with useful electronic properties. As progress towards this goal gains pace, NEC has established itself as a research and thought leader in the field.

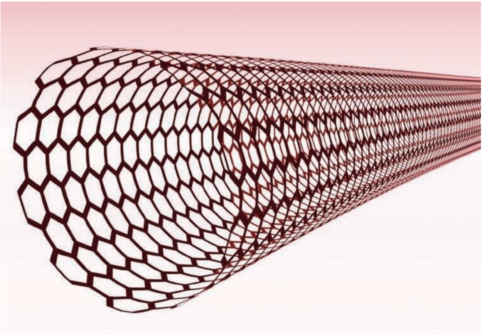
Tiny structures bring big opportunities

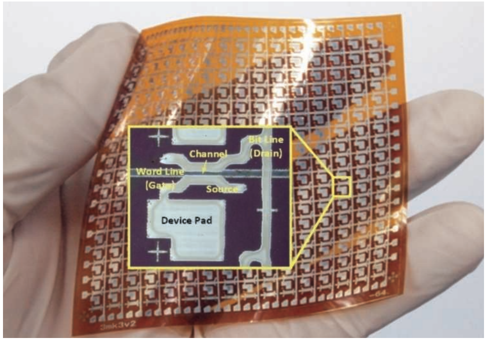
The discovery of carbon nanostructures coincided roughly with the development of the tools that enabled scientists to see them. Dr Sumio Iijima (above), a senior research fellow at NEC and former chief researcher of NEC's Fundamental Research Laboratories, was involved in both.

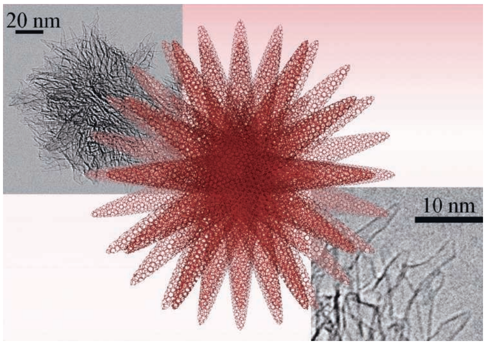
Iijima helped develop the world's first high-resolution electron microscope in the 1970s, and became one of its earliest users. Peering into the nanoscale domain for the first time, he saw an unexpected zoo of structures. There were onion-shaped carbon nanoparticles (these turned out to be fullerenes, which today are used in a number of biomedical innovations), as well as carbon needles scattered in the soot deposited on the electrodes of the arc discharge.

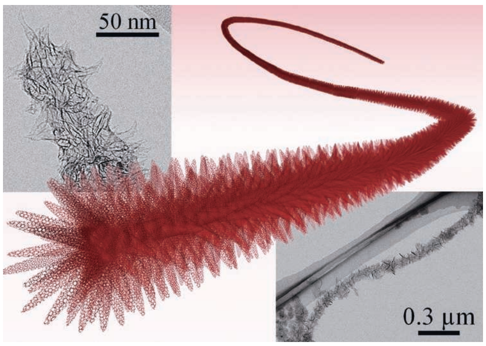
Iijima called the needles 'carbon nanotubes' (pictured opposite, at top left), after rejecting the alternative names 'NEC tubes' and 'Iijima tubes'. His 1991 paper describing the discovery has been cited an astounding 43,000 times. The new carbon structures had unprecedented strength and electrical conductivity, and together with fullerenes kicked off the new field of carbon nanostructure research.

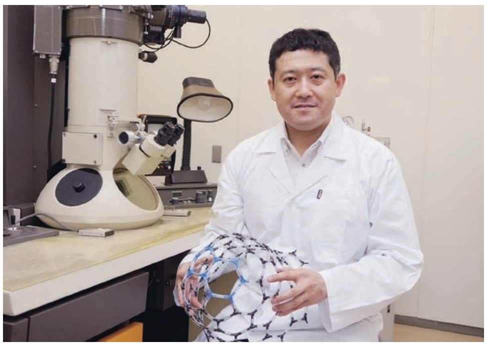
NEC researchers have since followed in Iijima's footsteps, continuing the company's tradition of leadership in carbon nanostructure research. For example, a critical problem facing the field since its inception has been the separation of metallic from semiconducting











nanotubes, which have very different electronic behaviours, but are produced as a mixture. NEC has been able to advance the use of electrophoresis to achieve a separation in excess of 98%, and recently scaled up the method, explains Dr Fumiyuki Nihey, a principal researcher at NEC. This success, he says, will boost the commercialization prospects of carbon nanotube transistors (above, top right). It has, for example, allowed Nihey and his colleagues to create patterned mats of semiconducting tubes into flexible large-area devices using low-cost printing techniques.

More opportunities for novel products have also emerged since Iijima's 1998 discovery of carbon nanohorn aggregates, where thousands of conical sheets of carbon (carbon nanohorns, pictured above, at centre left) assemble radially to form a spherical aggregate. These are attractive materials due to a high dispersibility in solutions and large specific surface area: they have the potential to be applied to energy devices such as supercapacitors or fuel cells. Large-scale production equipment for carbon nanohorns was first developed by NEC (above, at centre right).

Scientists at NEC labs have also demonstrated that there are more fascinating carbon nanostructures waiting to be discovered and exploited. Last year, Dr Ryota Yuge (above), a principal researcher at NEC, reported the discovery of the carbon nanobrush (above, at bottom left) — a structure of fibrous aggregates composed of radially assembled carbon nanohorns. The nanobrush has an unprecedented combination of electrical conductivity and the ability to disperse in solution, along with a large surface area. "This makes the carbon nanobrush a promising candidate for electrode materials in supercapacitors, electrochemical actuators, fuel cells, lithium ion batteries and sensing devices," explains Yuge.

New types of devices bring new flexibility

NEC researchers are excited by the great potential of carbon nanomaterials for completely new kinds of devices. "Consider a flexible sensor attached to a living body," says Yuge. "It can extract biometric information for health maintenance or the early detection of disease. Or think about large-area pressure sensor sheets for product management. The flexibility, high speed and durability required for devices like these can be achieved through the use of nanocarbons."

Similarly, energy devices live or die by the surface area and conductivity of their component materials. Nanocarbons are uniquely positioned to provide both, says Yuge, with immediate potential applications in lithium ion batteries, supercapacitors and fuel cells. He adds that carbon nanomaterials also offer opportunities to create devices that balance cost and performance.

As their work progresses, Yuge and Nihey draw inspiration from NEC's history of innovation. "Every researcher at NEC aims to become a pioneer of new technology," says Yuge. "It's a part of our culture." ■

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