Nanotube factory springs into production

Open innovation and collaboration between industrial, academic, and government stakeholders in Japan HAVE CULMINATED IN THE OPENING OF THE WORLD'S FIRST FACTORY for mass manufacturing SINGLE-WALLED CARBON NANOTUBES.

Nearly a quarter-century ago, researchers worldwide were excited by images of tiny, single-atom thick cylinders of rolled-up carbon captured in a Japanese laboratory. These materials, quickly dubbed carbon nanotubes, were a fraction of the width of a human hair, but could be formed into stronger-than-steel bundles or into coatings with conductivity a thousand times better than copper. Despite these revolutionary properties, carbon nanotubes struggled to establish a foothold in the industrial materials sector due to complex and expensive production processes.

Now, collaboration between Zeon Corporation and Japan's National Institute of Advanced Industrial Science and Technology (AIST) has shown that nanotubes can make the leap from laboratory curiosities to consumer devices thanks to the first-ever industrial facility dedicated to producing these innovative carbon fibers on substrates as large as 50 cm^2.

Pipe dreams

Petroleum processors were among the first to discover intriguing, nanoscale forms of carbon fibers when they characterized the deposits that occasionally plugged their machinery. They, and other researchers, found evidence of extra-thin strands of graphene tubes with a variety of diameters and shapes. At these dimensions, the fibers gain sufficient surface area to turn into energy-storing supercapacitors and have remarkable thermal and mechanical stability.

Kohei Arakawa, president of Zeon Nano Technology, explains how advances in the fabrication of carbon nanofibers set the stage for the eventual high-throughput manufacturing of nanotubes. "When I started research back in 1982, the preferred method of producing nanofibers was to grow them from catalysts on substrates," he recalls. "But these techniques were patented, and my job was to search for another way."

NANOTUBES CAN MAKE THE LEAP FROM LABORATORY CURIOSITIES TO CONSUMER DEVICES

Arakawa helped develop a 'floating' catalyst made from a ring-shaped, iron-containing ferrocene molecule that sped up production rates by nearly 500 times. In this approach, ultrafine droplets of catalyst particles and reactive hydrocarbon gases such as acetylene are sprayed onto samples held in a hot furnace. The catalyst initiates fiber growth and remains embedded in the tip of the carbon thread until its natural activity gives out — yielding highly uniform coatings in the process.

"This production method really fascinated me, and I had big dreams of commercializing it," says Arakawa. "Unfortunately, my employer at the time had a different viewpoint. So I made up my mind and took a new job developing liquid crystal displays. But now, the vapour technique has been widely adapted and is the standard method of manufacturing carbon nanotubes."

Making a super-sized upgrade

In the early 2000s, AIST put together a team to explore ways of adapting vapour depositions for nanomaterial manufacturing. The researchers uncovered a game-changing development when small drops of water were incorporated into a typical nanotube synthesis. While water can sometimes 'poison' catalysts and slow their activity, the humidity exposure had the opposite effect — the water supercharged the catalytic assembly of dense forests of single-walled nanotubes, perfectly vertical and up to 2.5 mm long (top right).

Using this new 'super-growth' technique, AIST demonstrated they could deposit nanotubes onto surfaces with a record-setting purity of 99.98% and an efficiency gain of 1,000 times that of conventional methods. However, one setback remained: the substrates for nanotube growth could not be enlarged beyond a few millimetres. To fix this flaw, the research team asked Arakawa — then developing optical films at Zeon Corporation — for his insights into large-scale fabrication.

"In spite of having previously given up research into carbon nanotubes, I still understood their charm," says Arakawa. "I accepted the proposal to collaborate with AIST and by 2006 we were at work developing a continuous process for larger substrates."

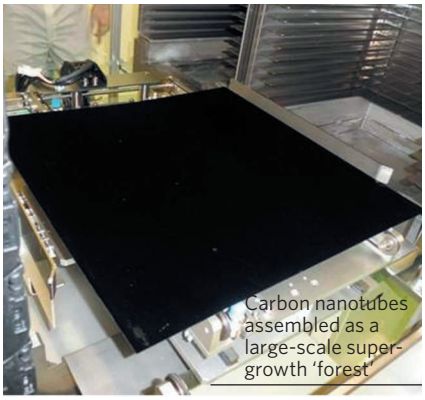
Open for business

Having recruited experts in thermal fluid simulations and catalysis, the new initiative identified several changes needed to scale up nanotube production. For instance, by using metals as deposition substrates instead of silicon wafers, the team found a shortcut that regenerated catalyst particles non-stop and avoided the need for costly reactor shutdowns. Other innovations, including optimising gas flow to improve surface coverage, eventually led to the successful fabrication of nanotube films at centimetre scales.

In November 2015, the ambitions of Zeon Corporation and AIST finally came to fruition

Carbon nanotube compounds can be used to create remarkably strong materials

Carbon nanotubes, like in this small-scale 'forest', can benefit a range of products



Carbon nanotubes assembled as a large-scale super-growth 'forest'

Mass production of carbon nanotubes takes place at Zeon Corporation's plant in Shunan, Yamaguchi prefecture

with the opening of their pioneering nanotube factory in the welcoming climate of Japan's Seto Inland Sea.

Now Arakawa is overseeing the development of products that take advantage of the unique thermal, electrical, and mechanical properties of these nanomaterials.

"We plan to introduce a thermal interface material to the market shortly that removes heat from semiconductor chips with superb performance," says Arakawa. "Products such as ordinary O-rings could benefit from the strength of carbon nanotubes, and venture companies are promoting these coatings for non-volatile semiconductor memory."

Susumu Katagiri, the senior vice president of Zeon Nano Technology, notes that the company's expertise in elastomers can help it to gain access to the projected multi-billion-dollar global market for nanotubes.

"We expect strong synergies with the carbon nanotube business, and welcome collaborators who intend to aggressively develop applications," says Katagiri.

"Meanwhile, we are still searching for ways to reduce production costs by 10 to 100 times in the coming years." ■

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