MASS PRODUCTION OF FULLERENES TAKES OFF

As the demand for fullerene-based nanomaterials increases, A SCALABLE METHOD for producing them comes of age.

A unique carbon nanomaterial, first discovered by astrochemists studying the formation of molecules around distant stars, could be critical to successfully harnessing energy from our Sun.

Derived from the soccer-ball-shaped 'buckminsterfullerene' molecule, fullerene-based nanomaterials are a key ingredient in some of the first commercial, high-performance, organic photovoltaic (OPV) solar cells. As the production of these sustainable, lightweight and flexible solar cells grows to meet market demand, fullerene mass manufacture is itself poised to mature.

"Our customers report that the demand for their OPV products is really expanding," says Koichi Oshima, president of fullerene-manufacturing company Frontier Carbon Corporation in Japan.

Established in Japan in 2001, the company has been developing and refining its fullerene-production processes for more than 20 years. In 2013, it launched a joint venture with Mitsubishi Corporation and Showa Denko. "These days, our fullerenes are attracting a lot of attention, especially for organic electronic devices such as OPV solar cells," Oshima says. "After 20 years of incubation, we're now ready to expand to meet industry needs."

FRONTIER CARBON CORPORATION IS POISED TO SCALE UP ITS OPERATIONS TO REACH MASS PRODUCTION.

The strong industrial interest in fullerenes stems from their unique combination of characteristics. As a carbon nanomaterial — a family that includes carbon nanotubes and graphene — fullerenes offer exceptional heat resistance, chemical stability and electronic properties.

LIGHT TOUCH

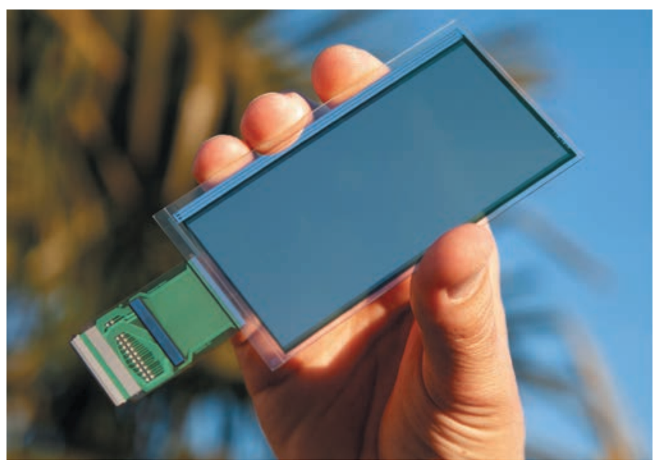
"At the same time, they also possess the character of low-molecular-weight organic compounds," says Kunio Kondo, vice president of Frontier Carbon Corporation. "For example, we can form thin films from them by vacuum evaporation and then modify their molecular structures by chemical synthesis." Molecular side chains can be attached to modify properties such as solubility, electronic behaviour and thin-film formation, he explains. A further key difference from other carbon nanomaterials, is that fullerenes are soluble in organic solvents, expanding the options for processing in solutions.

OPVs are one application where the multifunctional properties of fullerenes come to the fore. Whereas conventional solar cells use heavy, rigid silicon slabs, the light-harvesting semiconductors used in OPVs are thin, flexible films of organic molecules. OPVs are attracting particular interest for applications unsuitable for silicon photovoltaics, such as covering the curved surfaces of buildings or wind-turbine poles.

Fullerenes are high-performance OPV electron-acceptor materials, transporting light-generated negative charges to the edges of the device, where they are captured by the electrodes. Fullerenes excel at this because of the large, delocalized clouds of electrons that coat their spherical surfaces.

"For most organic molecules, adding an electron greatly affects their molecular structure, making it very unstable," Kondo says. "In contrast, fullerenes are inherently stable and adding an electron to the electron cloud affects them very little."

Fullerenes are also processable into a very thin but stable functional semiconductor layer with very few defects. They could play a role in other nascent solar technologies.



▲ A photodetector based on fullerenes (left) could be integrated in smartphones and enhance their security by turning the whole screen into a fingerprint reader. The curved surface of a wind-turbine pole (right) is covered with solar cells that incorporate fullerenes.

Isorg (left); Heliatek GmbH (right)

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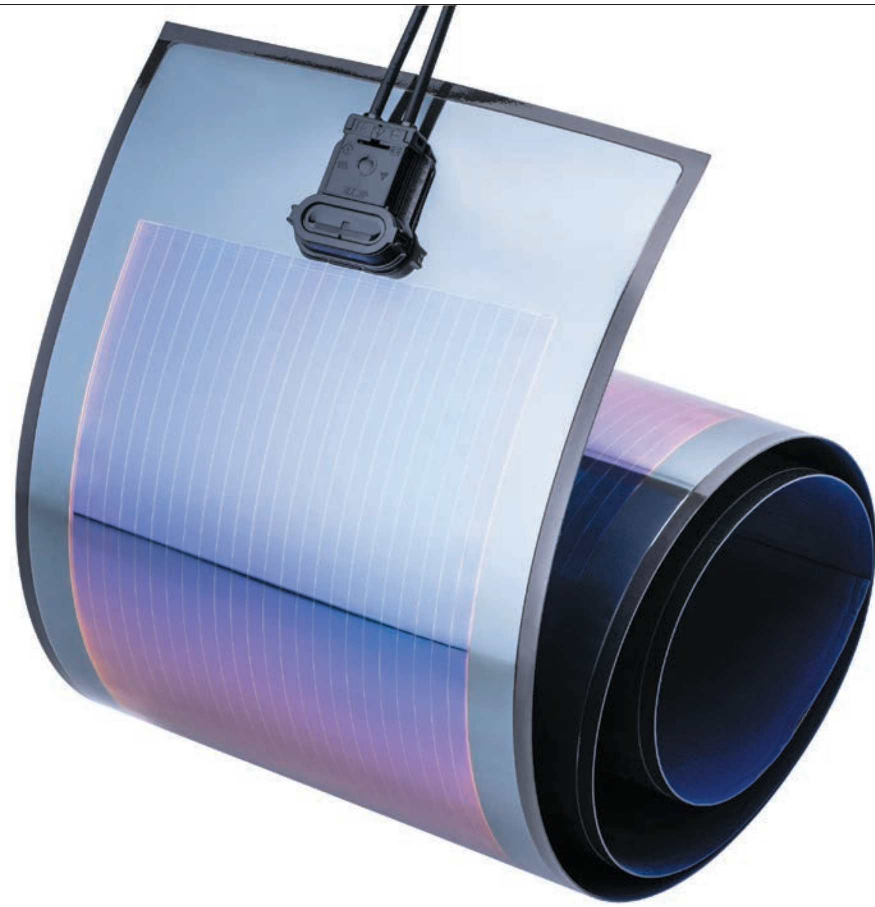

▲ A flexible organic photovoltaic solar cell employing fullerenes. It could find application in harvesting sunlight from curved surfaces.

MEETING THE DEMAND

The rapidly rising demand for fullerenes for OPV technology requires a scalable method for producing them. "The traditional, and still most popular method, for making fullerenes is the arc method," Kondo says. Fullerenes can be isolated from the soot formed when a strong electrical current is used to produce an arc between two graphite electrodes. The method is simple and inexpensive, but it isn't scalable.

"Our production method is very different," Kondo explains. "We combust organic materials at high temperature in a low-oxygen atmosphere, producing a soot from which fullerenes can be extracted using an organic solvent." The combustion method can be readily scaled for mass production, although controlling the reactor conditions to maximize yield is complex. "We need a very highly sophisticated plant design as well as operational know-how," Kondo says.

After two decades of development, Frontier Carbon Corporation is poised to scale up its operations to reach mass production. "We think we are the only company in the world in this position," Oshima says.

Beyond OPV solar panels, smart phones could be the next devices to benefit from the multifunctionality of fullerenes. Fullerene thin films can operate as organic photodetectors, converting incoming light into an electrical signal. One application close to commercialization uses fullerene photodetectors to dramatically enhance the digital security of electronic devices.

"Our customers are developing full-screen fingerprint recognition for smartphone displays," Oshima says. An organic layer that includes fullerene below the display turns the entire phone screen into a fingerprint reader. Light from the screen is reflected by the user's fingertips and detected by the organic photodetector, unlocking the device only after scanning up to four fingerprints.

NUMEROUS USES

Compared to a single fingerprint, multiple-fingerprint recognition would offer significantly enhanced security for sensitive applications such as banking or health care information. "Fullerenes are almost the only materials that could be used to make n-type organic thin films with large areas by coating," Kondo says. The flexibility of fullerene films means they could be readily integrated into devices with curved or folding screens.

Fullerenes' multifunctional nature could have impact far beyond organic electronic devices. For example, fullerenes are highly effective at trapping damaging free radicals, and fullerene additives have shown great promise for extending the lifetimes of resins.

Another very different application advancing towards real world use employs fullerenes for high-performance lubricating oils for engines and machinery. "A tiny amount of fullerene, around just 100 parts per million, drastically reduces the wear of moving metal parts," Kondo says. This jump in performance appears to be related to the thick oil coating each fullerene acquires. "We call it the frog-egg mechanism," Kondo says. "Like a cluster of frogspawn, aggregations of oil-coated fullerenes cover the metal surface to suppress wear very effectively."

Such fullerene-enhanced oils may find their first use in space — returning them to the environment where fullerenes were originally detected. "The first application of the oils may be to lubricate gyroscopes in satellites, which require very long reliability," Kondo says.

And perhaps the same satellites will also incorporate fullerenes in efficient, lightweight OPV solar panels absorbing the energy of the Sun. ■

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