Synthesis of a carbon nanobelt with potential applications in nanotechnology

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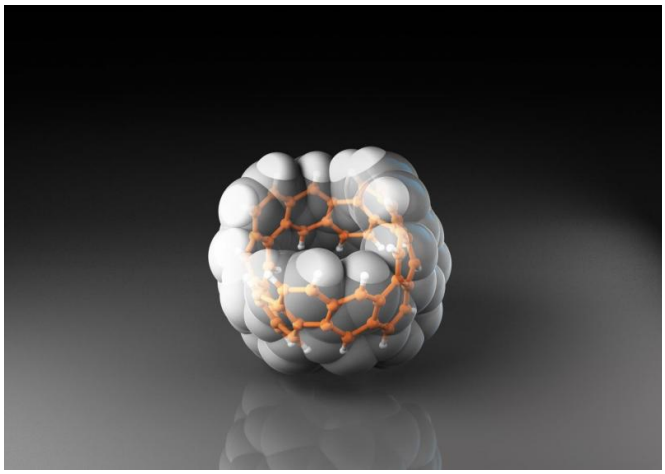

Carbon nanobelt. Credit: Nagoya University

Chemists have tried to synthesize carbon nanobelts for more than 60 years, but none have succeeded until now. A team at Nagoya University reported the first organic synthesis of a carbon nanobelt in *Science*. Carbon nanobelts are expected to serve as a useful template for building carbon nanotubes and open a new field of nanocarbon science.

The new nanobelt, measuring 0.83 nanometer (nm) in diameter, was developed by researchers at Nagoya University's JST-ERATO Itami Molecular Nanocarbon Project, and the Institute of Transformative Bio-Molecules (ITbM). Scientists around the world have tried to synthesize carbon nanobelts since the 1950s and Professor Kenichiro Itami's group has worked on its synthesis for 12 years.

"Nobody knew whether its organic synthesis was even possible or not," says Segawa, one of the leaders of this study who had been involved in its synthesis for 7 and a half years. "However, I had my mind set on the synthesis of this beautiful molecule."

Carbon nanobelts are belt-shaped molecules composed of fused benzene rings, which are aromatic rings consisting of six carbon atoms. Carbon nanobelts are a segment of carbon nanotubes, which have various applications in electronics and photonics due to their unique physical characteristics.

Current synthetic methods produce carbon nanotubes with inconsistent diameters and sidewall structures, which changes their electrical and optical properties. This makes it extremely difficult to isolate and purify a single carbon nanotube that has a specific diameter, length and sidewall structure. Therefore, being able to precisely control the synthesis of structurally uniform carbon nanotubes will help develop novel and highly functional materials.

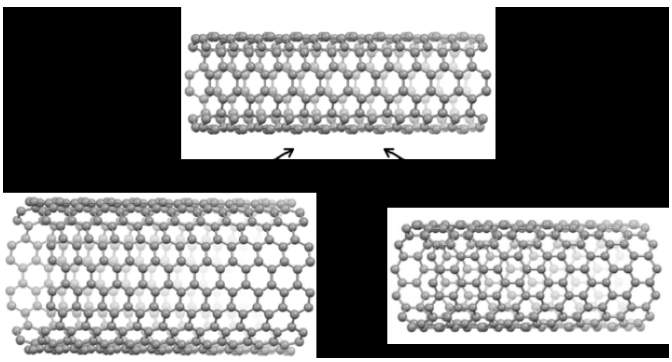

Figure 1. Carbon nanotubes that have different diameters and sidewall structures. Credit: Nagoya University

Carbon nanobelts have been identified as a way to build structurally uniform carbon nanotubes. However, synthesizing carbon nanobelts is challenging due to their extremely high strain energies. This is because benzene is stable when

flat, but becomes unstable when they are distorted by fusion of the rings.

To overcome this problem, Guillaume Povie, a postdoctoral researcher of the JST-ERATO project, Yasutomo Segawa, a group leader of the JST-ERATO project, and Kenichiro Itami, the director of JST-ERATO project and the center director of ITbM, have succeeded in the first chemical synthesis of a carbon nanobelt from a readily available precursor, p-xylene (a benzene molecule with two methyl groups in the 1,4- (para-) position) in 11 steps.

The key to this success is their synthetic strategy based on the belt-shaped formation from a macrocycle precursor with relatively low ring strain. In their strategy, the team prepared a macrocycle precursor from p-xylene in 10 steps, and formed the belt-shaped aromatic compound by a coupling reaction (Fig. 3). Nickel was essential to mediate the coupling process.

"The most difficult part of this research was this key coupling reaction of the macrocycle precursor," says Povie. "The reaction did not proceed well day after day and it took me three to four months for testing various conditions. I have always believed where there's a will, there's a way."

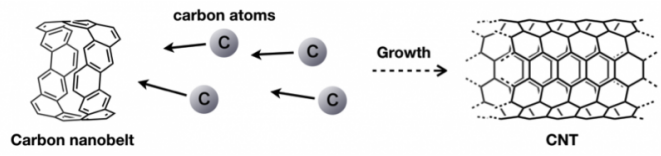

Figure 2. General strategy for carbon nanotube growth using a carbon nanobelt as a template. Credit: Nagoya University

In 2015, Itami launched a new initiative in his ERATO project to focus particularly on the synthesis of the carbon nanobelt. At the so-called "belt festival," various new synthetic routes for the carbon nanobelt were proposed and more than 10 researchers were involved in the project. On September 28, 2016, exactly a year after the start of the festival, the carbon nanobelt structure was finally revealed by X-ray crystallography in front of the Itami group members. Everyone held their breath while staring at the screen during X-ray analysis, and cheered when the cylindrical shape image of the carbon nanobelt appeared on the screen. Itami, Segawa and Povie expressed their joy with a high five.

"It was one of the most exciting moments in my life and I will never forget it," says Itami. "Since this is the result of a decade-long study, I greatly appreciate all the past and current members of my group for their support and encouragement. Thanks to their skill, toughness, sense and strong will of all members, we achieved this successful result."

Figure 3. Synthetic approach towards the carbon nanobelt from p-xylene in 11 steps. Credit: Nagoya University

The synthesized carbon nanobelt is a red-colored solid and exhibits deep red fluorescence. Analysis by X-ray crystallography revealed that the carbon nanobelt has a cylindrical shape in the same manner as carbon nanotubes (Fig. 4). The researchers also measured its light absorption and emission, electric conductivity and structural rigidity by ultraviolet-visible absorption fluorescence, and Raman spectroscopic studies, as well as theoretical calculations.

"Actually, the synthesis part was finished last August but I could not rest until I was able to confirm the X-ray structure of the carbon nanobelt," says Povie. "I was really happy when I saw the X-ray structure."

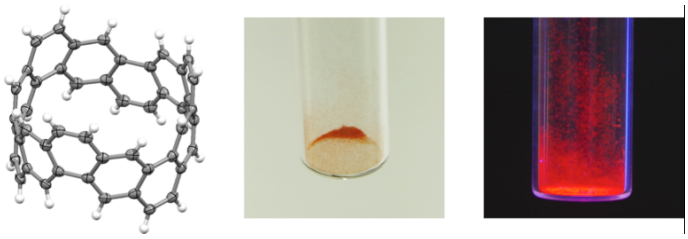

Figure 4. From the left: X-ray structure of carbon nanobelt, crystals of carbon nanobelt under room light, and under UV light. Credit: Nagoya University

The carbon nanobelt will be released to the market in the future. "We are looking forward to discovering new properties and functionalities of the carbon nanobelt with researchers from all over the world," say Segawa and Itami.

More information: Guillaume Povie et al. Synthesis of a carbon nanobelt, *Science* (2017). DOI: 10.1126/science.aam8158

Provided by Nagoya University