Spinning high-strength polymer nanofibers

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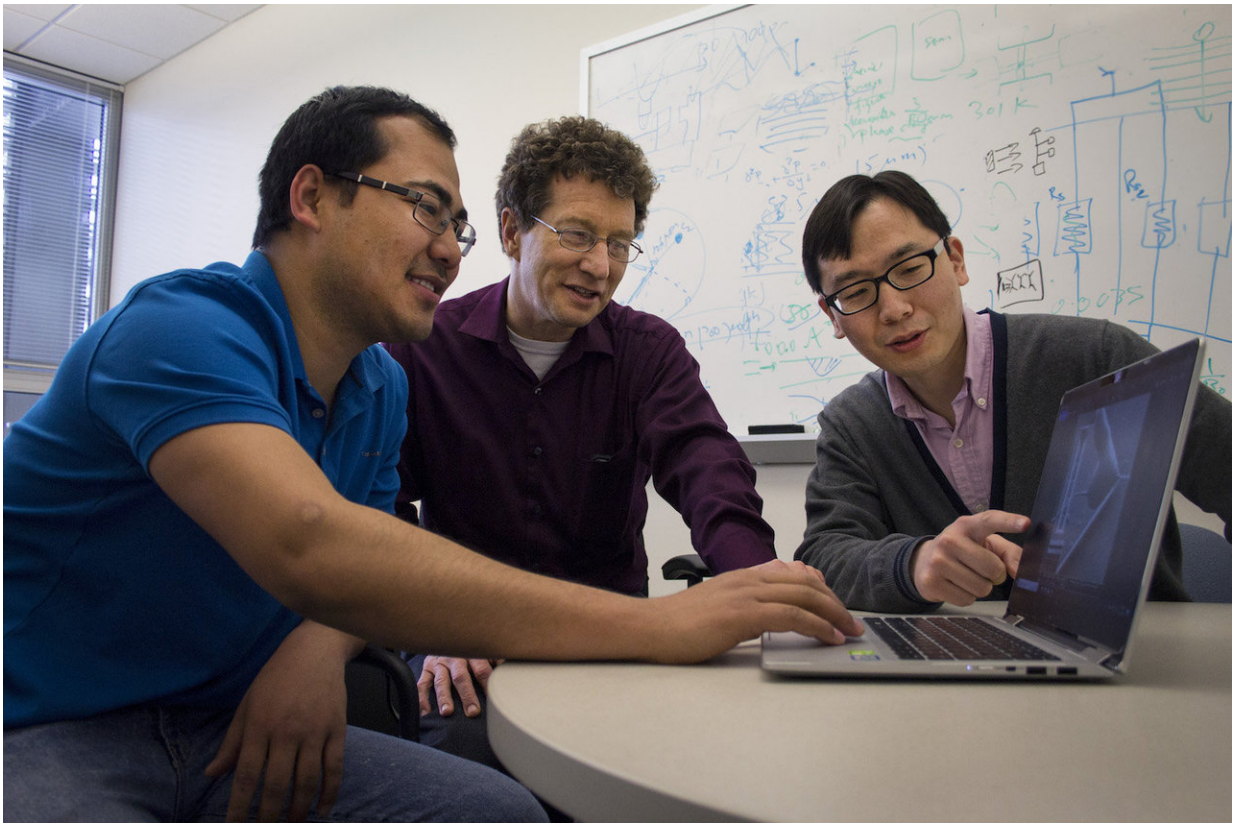

Ramesh Shrestha, Maarten de Boer, and Sheng Shen have transformed polymers from soft and thermally insulating materials to an ultra-strong and thermally conductive material. Credit: College of Engineering, Carnegie Mellon University

Spiderman has it figured out.

It's no coincidence then that when Sheng Shen talks about his work with

polymer nanofibers he compares it to a spider spinning its web.

"Just as a spider synthesizes silk from protein polymer to form a fiber with strength similar to high tensile steel, polymers can be spun and drawn to form high-strength materials with exceptionally high thermal conductivity," said Shen, associate professor of mechanical engineering at Carnegie Mellon University.

Shen and his team have developed a polymer nanofiber that is strong, lightweight, thermally conductive, electrically insulating, and bio-compatible. They accomplished all of this in a single polymer fiber strand measuring less than 100 nanometers.

According to Shen, the potential impact of this development is tremendous. The characteristics of his polymer nanofiber give it application in aerospace and automotive systems, civil and structural engineering, medical devices, and robotics.

In their simplest form, polymers are lots of identical molecules joined together over and over. The molecules could be joined in "simple" chains or more complicated structures. Either way, the resulting polymer has the same characteristics as the molecules used to create it. This means a polymer could be sticky, solid, pliable, or any number of other physical characteristics contained in its molecules.

Traditionally, said Shen, polymers are "the general material platform (used) to develop multifunctional materials," including plastics, nylons, and rubbers. Polymers are easily processed at relatively low price points, but do have their drawbacks.

Prototypical bulk polymers are often amorphous, meaning their molecule chains are randomly coiled and lacking a defined shape and form. This lack of definition can lead to reduced strength, reduced

thermal conductivity, and increased defects like voids and molecule entanglements.

The challenge was to develop a polymer that is both ultra-strong and thermally conductive.

For Shen, the place to do this was at the nano-level. At this level—one-billionth of one meter— Shen can engineer individual molecules to join together in exactly the way he wants them to join together.

"At the nanoscale, the polymer chains become highly oriented and defects that lower strength and thermal conductivity can be eliminated," Shen said.

The resulting polymer nanofiber has a Young's Modulus (the measure of the stiffness of a solid material) and a strength that Shen said are 300-times greater than bulk polymers.

As for thermal conductivity, Shen reports that his polymer nanofiber measures a conductivity rate of 100 W/mK. On average, the conductivity rate of steel is 54 W/mK and the rate of iron is 73 W/mK.

"These nanofibers provide a low-cost route to achieving highly effective heat removal in electronic systems," said Shen. "They can also be bio-compatible heat spreaders for improving patient care."

To date, Shen and his team have tested single nanofibers. On the strength of the results from those tests, they have turned their attention to creating an innovative manufacturing approach that will allow for the mass production of the polymer nanofibers.

Shen is confident that he and his team have invented a product that will have practical and large-scale impacts sooner rather than later.

"We really believe this is a game-changing technology by transforming polymers from soft and thermally insulating materials to ultra-strong and thermally conductive material," Shen said.

Ph.D. candidate Ramesh Shrestha and Maarten de Boer, a professor of mechanical engineering, made significant contributions to this research. Findings were published in *Nature Communications*.

More information: "Crystalline polymer nanofibers with ultra-high strength and thermal conductivity," *Nature Communications*, DOI: 10.1038/s41467-018-03978-3

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