'Amplified' nanotubes may power the future

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Rice University scientists have achieved a pivotal breakthrough in the development of a cable that will make an efficient electric grid of the future possible.

Armchair quantum wire (AQW) will be a weave of metallic nanotubes that can carry electricity with negligible loss over long distances. It will be an ideal replacement for the nation's copper-based grid, which leaks electricity at an estimated 5 percent per 100 miles of transmission, said Rice chemist Andrew R. Barron, author of a paper about the latest step forward published online by the American Chemical Society journal *Nano Letters.*

A prime technical hurdle in the development of this "miracle cable," Barron said, is the manufacture of massive amounts of metallic single-walled carbon nanotubes, dubbed armchairs for their unique shape. Armchairs are best for carrying current, but can't yet be made alone. They grow in batches with other kinds of nanotubes and have to be separated out, which is a difficult process given that a human hair is 50,000 times larger than a single nanotube.

Barron's lab demonstrated a way to take small batches of individual nanotubes and make them dramatically longer. Ideally, long armchair nanotubes could be cut, re-seeded with catalyst and re-grown indefinitely.

The paper was written by graduate student and first author Alvin Orbaek, undergraduate student Andrew Owens and Barron, the Charles

W. Duncan Jr.-Welch Professor of Chemistry and a professor of materials science.

Amplification of nanotubes was seen as a key step toward the practical manufacture of AQW by the late Rice professor, nanotechnology pioneer and Nobel laureate Richard Smalley, who worked closely with Barron and Rice chemist James Tour, the T.T. and W.F. Chao Chair in Chemistry as well as a professor of mechanical engineering and materials science and of computer science, to lay out a path for its development.

Barron charged Orbaek with the task of following through when he joined the lab five years ago. "When I first heard about Rice University, it was because of Rick Smalley and carbon nanotubes," said Orbaek, a native of Ireland. "He had a large global presence with regard to nanotechnology, and that reached me.

"So I was delighted to come here and find I'd be working on nanotube growth that was related to Smalley's work."

Orbaek said he hasn't strayed far from Barron's original direction, which involved chemically attaching an iron/cobalt catalyst to the ends of nanotubes and then fine-tuning the temperature and environment in which amplification could occur.

"My group, with Smalley and Tour's group, demonstrated you could do this -- but in the first demonstration, we got only one tube to grow out of hundreds or thousands," Barron said. Subsequent experiments raised the yield, but tube growth was minimal. In other attempts, the catalyst would literally eat -- or "etch" -- the nanotubes, he said.

Refining the process has taken years, but the payoff is clear because up to 90 percent of the nanotubes in a batch can now be amplified to significant lengths, Barron said. The latest experiments focused on single-walled carbon nanotubes of various chiralities, but the researchers feel the results would be as great, and probably even better, with a batch of pristine armchairs.

The key was finding the right balance of temperatures, pressures, reaction times and catalyst ratios to promote growth and retard etching, Barron said. While initial growth took place at 1,000 degrees Celsius, the researchers found the amplification step required lowering the temperature by 200 degrees, in addition to adjusting the chemistry to maximize the yield.

"What we're getting to is that sweet spot where most of the nanotubes grow and none of them etch," Barron said.

Wade Adams, director of Rice's Richard E. Smalley Institute for Nanoscale Science and Technology and principal investigator on the AQW project, compared the technique to making sourdough bread. "You make a little batch of pure metallics and then amplify that tremendously to make a large amount. This is an important increment in developing the science to make AQW.

Adams noted eight Rice professors and dozens of their students are working on aspects of AQW. "We know how to spin nanotubes into fibers, and their properties are improving rapidly too," he said. "All this now has to come together in a grand program to turn quantum wires into a product that will carry vast amounts of electricity around the world."

Barron and his team are continuing to fine-tune their process and hope that by summer's end they can begin amplifying armchair nanotubes with the goal of making large quantities of pure metallics. "We're always learning more about the mechanisms by which nanotubes grow," said Orbaek, who sees the end game as the development of a single furnace to grow nanotubes from scratch, cap them with new catalyst, amplify them and put out a steady stream of fiber for cables.

"What we've done is a baby step," he said. "But it verifies that, in the big picture, armchair quantum wire is technically feasible."

Orbaek said he is thrilled to play a role in achieving amplification, which Smalley recognized as necessary to his dream of an efficient energy grid that would catalyze solutions to many of the world's problems.

"I'd love to meet him now to say, 'Hey, man, you were right,'" he said.

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