Spinning the unspinnable: Using biscrolling technology invented at UT Dallas

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Nanotechnologists at The University of Texas at Dallas have invented a broadly deployable technology for producing weavable, knittable, sewable, and knottable yarns containing up to 95 weight percent of otherwise unspinnable guest powders and nanofibers. A minute amount of host carbon nanotube web, which can be lighter than air and stronger pound-per-pound than steel, confines guest particulates in the corridors of highly conducting scrolls without interfering with guest functionality for such applications as energy storage, energy conversion, and energy harvesting.

Using conventional technology, powders are either held together in a yarn using a polymer binder or incorporated on fiber surfaces, and both approaches can restrict powder concentration, powder accessibility for providing yarn functionality, or the strength needed for yarn processing into textiles and subsequent applications.

In the Jan. 7 issue of the journal *Science*, coauthors working in the Alan G. MacDiarmid NanoTech Institute of UT Dallas describe the use of biscrolling to solve these problems, and demonstrate the feasibility of using their biscrolled yarns for applications ranging from superconducting cables and electronic textiles to batteries and fuel cells containing flexible woven electrodes.

Biscrolled yarns get their name from the way they are produced: a uniform layer of guest material is deposited on top of a web of carbon nanotubes, which is called the host. This bilayer guest/host stack is then twisted to form a biscrolled yarn. Depending upon end constraints and the symmetry of applied stresses, twist insertion results in distorted versions of either Archimedean, dual Archimedean, or Fermat scrolls, which are three-dimensional extensions of the Archimedean and Fermat spirals and spiral combinations found in nature and revered by diverse cultures for thousands of years.

The carbon nanotube webs that the inventors used for biscrolling are not ordinary carbon nanotube sheets - they can be drawn at up to two yards/second from forests of carbon nanotubes, which look like bamboo forests in which two-inch diameter bamboo trees rise a mile into the sky. Four ounces of these sheets would cover an acre and they are about 50 nm thick when densified, which is about a thousand times thinner than a human hair or a sheet of ordinary paper.

These strong carbon nanotube webs hold together biscrolled yarns that are mostly powders and even enable machine washing of textiles containing biscrolled yarns without significant powder loss. Web thinness means that hundreds of scroll layers can be accommodated in a biscrolled yarn having about the diameter of a human hair. At the same time, the nanotube web provides electrical conductivity to the yarn, and the porosity needed for access of the particles trapped in webs corridors to liquids and gasses for electrochemical and sensor applications.

The choice of guest determines the functionality of biscrolled yarns. Using as guest up to 95 weight percent LiFePO¬¬4¬, a remarkable material for lithium-ion batteries, high performance lithium ion battery electrodes were demonstrated by UT Dallas researchers, and shown to have the battery performance, flexibility and mechanical robustness needed for incorporation in energy storing and energy generating clothing. Biscrolling nitrogen-doped carbon nanotube guest provided highly catalytic fuel cell cathodes for chemical generation of electrical energy, which avoid the need for expensive platinum catalyst. By biscrolling a mixture of magnesium and boron powders and thermal treatment, superconducting MgB2 yarns were produced, which eliminated the thirty or more draw steps used for conventional production of superconducting wires. Using photocatalytic titanium dioxide guest, biscrolled yarns for self-cleaning fabrics were obtained.

"UT Dallas's biscrolling technology is rich in application possibilities that go far beyond those we described in *Science* magazine. For instance, our collaborator Professor Seon Jeong Kim of Hanyang University in Korea has already used biscrolled yarn to make improved biofuel cells that might eventually be used to power medical implants," said the article's corresponding author, Dr. Ray H. Baughman, Robert A. Welch Professor of Chemistry and director of the UTD's NanoTech Institute. "I am especially proud of two of our former NanoExplorer high school students, Carter Haines and Stephanie Stoughton, who are undergraduate coauthors of both our article in Science magazine and our internationally filed patent application on biscrolling."

Provided by University of Texas at Dallas