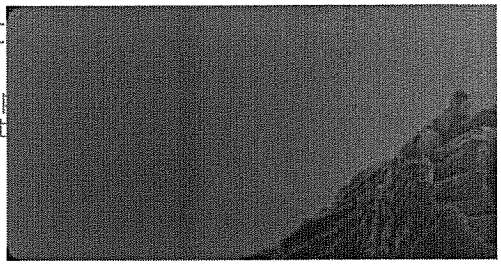
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Posted: Nov 14, 2008

Nanotechnology e-textiles for biomonitoring and wearable electronics

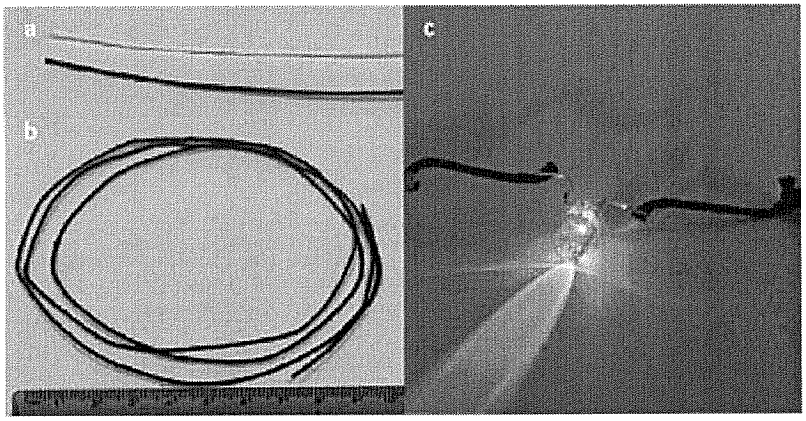
(*Nanowerk Spotlight*) If current research is an indicator, wearable electronics will go far beyond just very small electronic devices or wearable, flexible computers. Not only will these devices be embedded in textile substrates but an electronics device or system could ultimately become the fabric itself. Electronic textiles (e-textiles) will allow the design and production of a new generation of garments with distributed sensors and electronic functions. Such e-textiles will have the revolutionary ability to sense, act, store, emit, and move – think biomedical monitoring functions or new man-machine interfaces – while ideally leveraging an existing low-cost textile manufacturing infrastructure.

Early e-textiles were bulky and not very user friendly garments, full of wires and sensors, and they were not suitable for mass production. But as researchers have started to make transistors in yarn form, public funding for this field increased (see for instance the European project PROETEX), advances in nanotechnology promise to dramatically advance the development of futuristic electronic textiles. Point in case is a recent research report that proposes to make conductive, carbon nanotube-modified cotton yarn. This would offer a uniquely simple yet remarkably functional solution for smart textiles – close in feel and handling to normal fabric – yet with many parameters exceeding existing solutions.

"Although attempts have been made to fabricate nanotube yarns or impregnate fabric fibers with nanotubes, the vast majority of the studies on textile modification with nanomaterials was carried with nanoparticles" Dr. Nicholas Kotov tells Nanowerk. "There were various reasons for adding metal and semiconductor nanoparticles to fabrics such as fashionably glittering colors, antimicrobial function, UV protection, wrinkle resistance, and anti-odor function."

In contrast, Kotov and his team developed a method to coat regular cotton yarns with single-walled and multi-walled carbon nanotubes (CNT) and polyelectrolytes. The scientists point that their process provides a fast, simple, robust, low-cost, and readily scalable process for making e-textiles.

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Photographs of CNT-cotton yarn. (a) Comparison of the original and surface modified yarn. (b) 1 meter long piece as made. (c) Demonstration of LED emission with the current passing through the yarn. (Reprinted with permission from American Chemical Society)

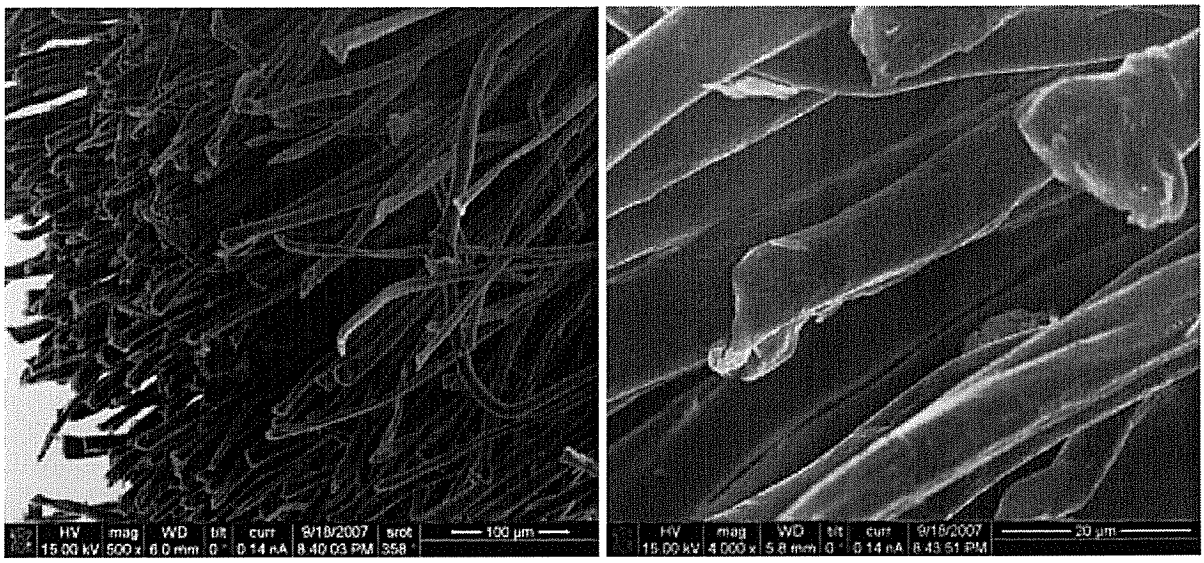
"The proof-of-principle CNT-cotton yarns that we fabricated showed high electrical conductivities as well as some functionality due to biological modification of internanotube tunneling junctions" explains Kotov. "When our CNT-cotton yarn incorporated antialbumin, it became an e-textile biosensor that quantitatively and selectively detected albumin, the essential protein in blood. The same sensing approach can easily be extended to many other proteins and biomolecules."

Kotov, a Professor in the Department of Chemical Engineering at the University of Michigan, worked with members of his group and colleagues from UMichigan's Departments of Materials Science and Biomedical Engineering as well as from Prof. Chuanlai Xu's group at Jiangnan University in Wuxi, China. They published their findings in the November 7, 2008 online edition of *Nano Letters* ("Smart Electronic Yarns and Wearable Fabrics for Human Biomonitoring made by Carbon Nanotube Coating with Polyelectrolytes").

In their very simple process, the researchers repeatedly dipped a regular cotton thread in a CNT dispersion and then let it dry. After several repetitive dips, the cotton thread became conductive, with a resistivity as low as 20 Ω/cm (a level low enough that it would allow for convenient sensing applications that may not require any additional electronics or converters). Interestingly, once the adsorbed CNT-cotton threads were dried, it was impossible to remove the adsorbed CNTs from the fibers by exposure to solvents, heat, or a combination of both.

"We found that the incorporation of CNTs into the cotton yarn was much more efficient than their adsorption into carbon fibers, which was tried elsewhere" explains Bong Sup Shim, a PhD student in Kotov's group and first author of the above paper. "This could be a result of the efficient interaction of polyelectrolytes with cotton and other natural polysaccharide and cellulose-based materials, such as paper, which is well known in industry. Additionally, the flexibility of the CNTs allowed them to conform to the surface of the cotton fibers."

The scientists point out that polyelectrolytes are essential for the stability of the CNT coatings on fibers and they are also essential for comfortable wearing because they are hydrophilic.



SEM images of CNT coated cotton yarns. (Images: Bong Sup Shim)

He believes that further development of this CNT-cotton material could lead to several useful applications:

- reversible sensing schemes for relevant biological compounds/markers;
- various sensors for body functions including monitoring of degree of contusion/blast damage (of great interest to the project's funder, the Air Force); and
- multiplexed sensing of five to six analytes with yarns modified in different ways.

"We also might add that energy harvesting materials and fabrics with charge storage capabilities become a possibility for the fabrics described here" says Kotov. "The latter goal could be the most challenging but nevertheless suitable for the nanotube-cotton composite because of the nature of CNTs, the fairly high conductivity obtained, and supercapacitor properties of carbon nanotubes."

Future aspects of this research will deal with incorporating reversibility in the sensing mechanism and developing virtually permanent coatings of carbon nanotubes on cotton and other fabrics.

One issue the research team is very well aware of are toxicological concerns surrounding CNTs. Although their extensive cell-culture data indicates that the solid CNT-polymer composites are largely benign, they nevertheless emphasize the need to further investigate the long-term contact between skin and nanotubes.

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