Researchers create nanotubes that change colors, form 'nanocarpet' and kill bacteria

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Implications include developing materials that both detect and kill biological agents

University of Pittsburgh researchers have synthesized a simple molecule that **not only produces perfectly uniform, self-assembled nanotubes but creates what they report as the first "nanocarpet,"** whereby these nanotubes organize themselves into an expanse of upright clusters that when magnified a million times resemble the fibers of a shag rug. Moreover, unlike other nanotube structures, these tubes display sensitivity to different agents by changing color and can be trained to kill bacteria, such as E. coli, with just a jab to its cell membrane.

How a mere single-step synthesis of a hydrocarbon and a simple salt compound produced these unique nanotube structures with antimicrobial capability is described in a paper posted on the Web site for the Journal of the American Chemical Society. The findings have implications for developing products that can simultaneously detect and kill biological weapons.

"In these nanotube structures, we have created a material that has the ability to sense their environment. The work is an outgrowth of our interest in developing materials that both sense and decontaminate chemical or biological weapons," said senior author Alan J. Russell, Ph.D., professor of surgery at the University of Pittsburgh School of Medicine and director of the university's McGowan Institute for Regenerative Medicine.

The research, funded by the Department of Defense's Army Research Office, has as its goal the development of a paint that in the event of biological or chemical agents being deployed would change color and simultaneously destroy the deadly substances.

The researchers thought that by combining a chemical structure called a quarternary ammonium salt group, known for its ability to disrupt cell membranes and cause cell death, with a hydrocarbon diacetylene, which can change colors when appropriately formulated, the resulting molecule would have the desired properties of both biosensor and biocide. Remarkably, in addition to being able to kill cells, the resulting reaction mixture had the ability to self assemble into beautiful nanotubes of uniform structure. After searching for what was forming the tubes, the researchers discovered that synthesis of a secondary salt and diacetylene, thereby creating a lipid molecule, also resulted in production of absolutely pure self-assembling nanotubes, all having the same diameter (89 nanometers) and wall thickness (27 nanometers). By comparison, a human hair is about 1,000 times wider.

When dried from water and other solvents, and under magnification, these nanostructures look much like a heaping serving of Kraft macaroni or ziti pasta. Incredibly, when coaxed with simple processing, the tubes align into the more formal pattern of a nanocarpet. Just like any rug, a backing, also self-assembled from the same material, holds it all together. The nanocarpet measures about one micrometer in height, approximately the same height as the free-form nanotubes.

"This alignment of nanotubes in the absence of a template is an accomplishment that has eluded researchers," said Dr. Russell, who also is a professor of chemical and bioengineering at the University of Pittsburgh School of Engineering.

"To our knowledge, the remarkable self-assembly of this inexpensive and simple lipid is unprecedented and represents an important step toward rational design of bioactive nanostructures. In addition, because they form within hours under room-temperature conditions, the significant costs of synthesizing carbon nanotubes can be reduced," explained Sang Beom Lee, Ph.D., research assistant professor of bioengineering in the School of Engineering, who is listed as first author.

To test the nanostructure's potential as a biosensor and antimicrobial, the authors conducted studies using the water-based nanotubes. Normally a neutral color, when exposed to ultraviolet light the nanotubes changed to a permanent deep blue. The process also chemically altered the nanotubes so that they became polymerized, giving them a more firm structure. Polymerized, these nanotubes could change from blue to other colors, depending on its exposure to different materials. For instance, in tests with acids and detergents, they turned red or yellow.

The most critical tests, say the researchers, were those involving E. coli, which were conducted to assess the material's interactions with living cells. In the presence of E. coli, some strains of which are food-borne pathogens, the nanotubes turned shades of red and pink. Moreover, with the aid of an electron microscope, the researchers observed the tubes piercing the membranes of the bacteria like a needle being inserted into the cell. Both the polymerized (those that can change color) and the unpolymerized nanotube structures were effective antimicrobials, completely killing all the E. coli within an hour's time.

"We are very encouraged by these results and we will be continuing our investigations of this novel material in collaboration with our colleagues here at the University of Pittsburgh and the U.S. Army Research Office," added Dr. Russell.

Source: University of Pittsburgh Medical Center