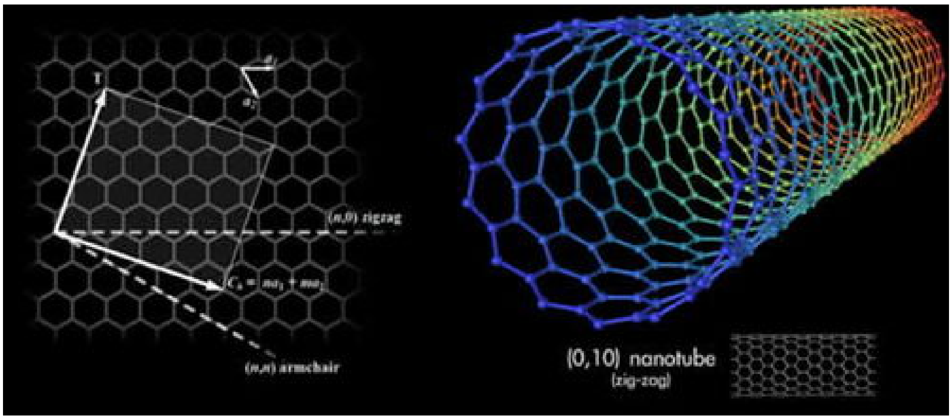
Nanotechnologists demonstrate artificial muscles powered by highly energetic fuels



Carbon nanotubes are the building blocks for producing artificial muscles. In the image shown above, the diagram illustrates a type of carbon nanotube called zig-zag.

University of Texas at Dallas nanotechnologists have made alcohol- and hydrogen-powered artificial muscles that are 100 times stronger than natural muscles, able to do 100 times greater work per cycle and produce, at reduced strengths, larger contractions than natural muscles. Among other possibilities, these muscles could enable fuel-powered artificial limbs, "smart skins" and morphing structures for air and marine vehicles, autonomous robots having very long mission capabilities and smart sensors that detect and self-actuate to change the environment.

While humans on long, strenuous missions are able to carry the food that powers their bodies, today's most athletically capable robots cannot freely move about, since they are wired to stationary electrical power sources. Though batteries can be used for autonomous robots, they store too little energy and deliver it at too low a rate for prolonged or intense activity. To solve these problems, the team from UTD's NanoTech Institute developed two different types of artificial muscles that, like natural muscles, convert the chemical energy of an energetic fuel to mechanical energy.

The breakthroughs are described in the March 17 issue of the prestigious journal *Science*.

The development of these revolutionary muscles was motivated by a visit of Dr. John Main from the Defense Advanced Projects Agency (DARPA) to Dr. Ray H. Baughman, Robert A. Welch Professor of Chemistry and director of the UTD NanoTech Institute. During the visit, Main described his visions of a future that could include such advancements as artificial muscles for autonomous humanoid robots that protect people from danger, artificial limbs that act like natural limbs and exoskeletons that provide super-human strength to firefighters, astronauts and soldiers -- all of which are able to perform lengthy missions by using shots of alcohol as a highly energetic fuel.

The new muscles simultaneously function as fuel cells and muscles, according to Baughman, corresponding author of the Science article. A catalyst-containing carbon nanotube electrode is used in one described muscle type as a fuel cell electrode to convert chemical energy to electrical energy, as a supercapacitor electrode to store this electrical energy and as a muscle electrode to transform this electrical energy to mechanical energy. Fuel-powered charge injection in a carbon nanotube electrode produces the dimensional changes needed for actuation due to a combination of quantum mechanical and electrostatic effects present on the nanoscale, Baughman said.

In another of the described artificial muscles -- currently the most powerful type -- the chemical energy in the fuel is converted to heat by a catalytic reaction of a mixture of fuel and oxygen in the air. The resulting temperature increase in this "shorted fuel-cell muscle" causes contraction of a shape memory metal muscle wire that supports this catalyst. Subsequent cooling completes the work cycle by causing expansion of the muscle.

"The shorted fuel cell muscles are especially easy to deploy in robotic devices, since they comprise commercially available shape memory wires that are coated with a nanoparticle catalyst. The major challenges have been in attaching the catalyst to the shape memory wire to provide long muscle lifetimes, and in controlling muscle actuation rate and stroke," said Baughman. "Students and scientists of all ages will be working on optimizing and deploying our artificial muscles, from high school students in our NanoExplorer program to retired technologists in our NanoInventor program."

Patent applications for the artificial muscles are pending.

Application opportunities, Baughman said, are diverse, and range from robots and morphing air vehicles to dynamic Braille displays and muscles powered by the fuel/air mixture delivered to an engine that are able to regulate this mixture. The more than 30 times higher energy density obtainable for fuels like methanol, compared to that for the most advanced batteries, can translate into long operational lifetimes without refueling for autonomous robots. This refueling requires negligible time compared with that needed for recharging batteries. Since all muscles will not be used at the same time, temporarily inactive muscles of the first muscle type can be used as ordinary fuel cells and as supercapacitors to provide for the electrical needs of, for example, autonomous robots and prosthetic limbs. The properties of the two types of fuel-powered muscles can be merged to provide the benefits of both, Baughman said.

The fuel-powered muscles can be easily downsized to the micro- and nano-scales, and arrays of such micro-muscles could be used in "smart skins" that improve the performance of marine and aerospace vehicles. By replacing metal catalyst with tethered enzymes, it might eventually be possible to use artificial muscles powered by food-derived fuels for actuation in the human body – perhaps even for artificial hearts.

The UTD breakthroughs resulted from the insights of NanoTech Institute scientists from many different countries: Dr. Alan G. MacDiarmid, Nobel Prize winner and the James Von Ehr Distinguished Chair in Science and Nanotechnology, from New Zealand; research scientist Dr. Von Howard Ebron and recent UTD Ph.D. recipient Dr. Joselito Razal from the Philippines; graduate student Jiyoung Oh from South Korea; research scientist Dr. Mikhail Kozlov from the Ukraine; research associate Dr. Zhiwei Yang and recent UTD Ph.D. recipient Dr. Hui Xie from China; and Interim Dean of Natural Sciences and Mathematics Dr. John P. Ferraris, recent UTD Ph.D. recipient Dr. Daniel J. Seyer, graduate student Lee J. Hall and Baughman, all from the United States.

Source: University of Texas at Dallas