STRONG, FAST, POWERFUL, DURABLE, AND CHEAP POLYMER FIBER AND HYBRID NANOFIBER YARN ARTIFICIAL MUSCLES AND THEIR APPLICATIONS

Ray H. Baughman, Alan G. MacDiarmid NanoTech Institute, University of Texas at Dallas, Richardson, Texas, USA

Keywords: Polymer muscles, Nanofiber muscles, Woven muscles, Robotics, Comfort-adjusting clothing

Polymer fiber and hybrid nanofiber yarn artificial muscles that provide spectacular performance will be characterized, theoretically analyzed, and applied. Twisted or coiled polymer muscles (which are cheaply made from fishing line or sewing thread) can be thermally, electrothermally, or chemically powered to spin a heavily rotor to 100,000 rpm, contract by 49%, generate 5 times the gravimetric power of a car engine during contraction, lift 100 times heavier loads than the same length and weight human muscle, or actuate at 7.5 cycles/s for millions of cycles. Our twisted or coiled hybrid carbon nanotube yarn muscles also provide impressive performance as torsional and tensile muscles, but have an advantage over polymer fiber muscles in that their response in driven by the volume changes of a yarn guest that we can choose for diverse application needs. We have engineered our carbon nanofiber muscles to behave as actuating sensors, which detect a chemical or biochemical agent and provide useful muscle actuation in response (such as to open or close a valve). While carbon nanotubes fibers are presently expensive to produce, we will show that carbon nanotubes can be replaced in some applications by less expensive nanofibers, such as electrospun polymer nanofibers. The basic mechanics of our polymer muscles and our hybrid nanofiber muscles are basically the same, volume-expansion drives untwist for twisted muscles and contraction for muscles that are both twisted and coiled with the same chirality (or muscle expansion when these chiralities differ). We will demonstrate that the stroke magnitude for the polymer fiber muscles can be increased to a remarkable 9000% during either expansion or contraction, though the latter seems at first mathematically impossible. Extension of these results to electrochemically powered all-solid-state coiled carbon nanotube yarns will be described, which results in improvements in energy conversion efficiency. Also, radical geometry changes that substantially increase performance will be described, as well as the use of these muscles to harvest electrical energy from waste chemical and thermal energy sources. Finally, the application of these muscles to make morphing composites and comfort adjusting textiles will be described. *This work resulted from collaboration between The University of Texas at Dallas, Hanyang University, Harbin University of Technology, The Jiangnan Graphene Research Institute, The University of Wollongong, Namık Kemal University, and The University of British Columbia.*

SHORT BIOGRAPHY FOR RAY H. BAUGHMAN

Ray Baughman became the Robert A. Welch Professor of Chemistry and Director of the NanoTech Institute at the University of Texas in Dallas in August 2001, after 31 years in industry. He is a Member of The National Academy of Engineering and The Academy of Medicine, Engineering and Science of Texas; the EU Academy of Sciences, a foreign member of the European Academy of Sciences; a Fellow of the Royal Society of Chemistry, the National Academy of Inventors, and the American Physical Society; an Academician of The Russian Academy of Natural Sciences; an honorary professor of 7 universities in China; and is on editorial or advisory boards of *Science* and other journals. Ray has 80 issued US patents and 415 refereed publications, with over 31,200 citations and an H-index of 79.

.