Coiling and twisting nanotubes: From fundamental nanoelectromechanics to nanocoils and nanogyros

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Carbon and inorganic nanotubes have unique mechanical and electronic properties, which make them attractive building blocks for nanoelectronic and nanoelectromechanical systems (NEMS). This talk will focus on two different lines of research, one related to the formation and properties of carbon nanotube coils, and the other on the torsional behavior of carbon and inorganic nanotubes.

A highly desirable geometry for nanotube-based electronics and electromechanics is a coil. Following the observation of carbon nanotube serpentines several years ago [1], we have recently demonstrated the spontaneous self-coiling of single-wall carbon nanotubes into defect-free coils of up to more than 70 turns with identical diameter and chirality [2]. Magnetic measurements show that the coils are highly conductive. Yet, adjacent nanotube segments in the coil are more highly coupled than in regular bundles of single-wall carbon nanotubes, owing to their perfect crystal momentum matching, which enables tunneling between the turns. This behavior does not yet enable the performance of these nanotube coils as inductive devices. However, it does point a clear path for the realization of nanotube coils. Current efforts with double-wall carbon nanotube coils could provide the proper sheathing to create functional inductive devices, such as electromagnets, dynamos, transformers and motors.

What happens when you twist a nanotube? Do nanotubes of different materials get twisted in the same way? We studied the torsional behavior of carbon nanotubes (CNTs) [3,4], and inorganic nanotubes of tungsten disulfide (WS_2) [5] and boron nitride (BN) [6], and found intriguing differences between all of them. Upon torsion, carbon nanotubes undergo conductance oscillations, which can be attributed to metal-semiconductor periodic transitions. When an external torque is applied to a multi-wall carbon nanotube, only its outermost wall is twisted, while the inner walls remain relaxed due to the weak mechanical coupling between the graphitic walls. When an external torque is applied to a WS_2 nanotube, all its walls initially stick and twist together, until a critical torsion angle, at which the outer wall slips and twists around the inner walls, further undergoing a series of stick-slip torque oscillations. Torsion invariably increases the conductance of WS_2 nanotubes [7]. When a BN nanotube is twisted, all its walls twist together with a similar Young's modulus as carbon nanotubes. This makes BN nanotubes up to ten times stiffer and stronger than carbon nanotubes. Although BN nanotubes are insulating, hybrid BCN nanotubes are semiconducting, and display an electrical response to torsion two orders of magnitude higher than that of CNTs [8]. Recently (unpublished), we have been able to create torsional resonators based on inorganic nanotubes, and found them to have higher resonant frequencies and quality factors than those based on carbon nanotubes. This demonstrates that inorganic nanotubes could be attractive building blocks for NEMS, including nanogyroscopes.

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Invited by: Prof. Jordi Arbiol

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