Good Vibrations in the Nanoworld

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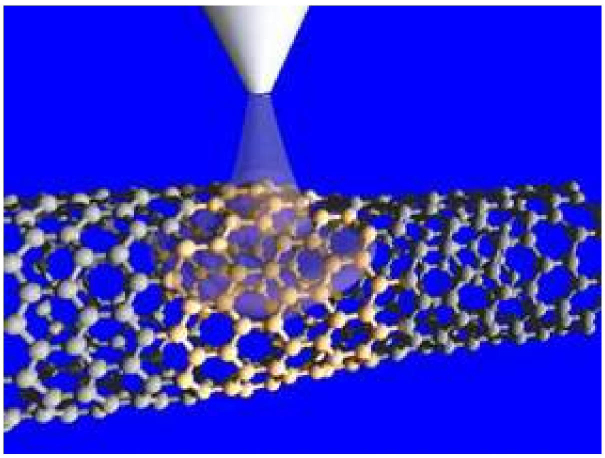

Local defects tune the vibrational modes of carbon nanotubes

Accessing vibrational modes of molecular chains at the site of a specific atom in molecules is no longer a dream. **Using a scanning tunneling microscopy technique (STM), the vibrational modes of carbon nanotubes have been mapped with sub-nanometer spatial resolution**. This allows the study of the role of local defects and demonstrates the crucial importance of nanotubes for the electronic and mechanical properties of nanotubes.

Since their discovery in 1991, carbon nanotubes have offered exciting perspectives for technological applications. These strings of the nanoworld made out of rolled-up carbon sheets with diameters 10.000

times smaller than a human hair have sparked the imaginations of nanoengineers, who use them in numerous ways as molecular components in nanoscale devices.

The electronic properties of nanotubes, which vary from metallic to semi-conducting character, have led to the design of novel mesoscopic devices such as nanotransistors, long-life supercapacitors, gas sensors, flat-panel field emission displays etc.. In addition to their electronic properties, carbon nanotubes have extraordinary mechanical properties: Since the carbon-carbon bond is among the strongest in nature, carbon nanotubes are extremely resistant to forces along the axial direction. The stiffness of the material is about 5 times larger than that of steel and yet, carbon nanotubes are highly flexible as they can withstand compression and twisting distortions. Due to these mechanical properties carbon nanotube reinforced composites are promising materials for use as bumper layers and lightweight building material for spacecraft applications.

The unique electrical and mechanical properties of nanotubes are highly dependent on the absence or presence of defects on the atomic scale. Very much as the sound of a violin string degrades when the string is damaged, the vibrational motion of carbon nanotubes reflects mechanical strength or softness and depends critically on the perfection of the carbon structure on the atomic scale. To extend our knowledge about how defects influence mechanical properties it is highly desirable to be able to map the vibrational motion of atoms in the carbon nanotube.

Researchers of the Max Planck Institute for Solid State Research have now succeeded in measuring the vibrational modes of these nano-strings with atomic resolution and demonstrated that the vibrations are substantially modified near defects. Translated into the language of music, different pitches can be sustained by nanotubes of different diameters and defects modulate the pitch of a nanotube. Furthermore, silent sections develop between neighboring defects. A scanning tunneling microscope operating at a temperature of 6 Kelvin has been used as a local probe technique accessing the atomic world of vibrations. The vibrational modes of the nanotubes become accessible with the sub-nanometer precision typical of that instrument when tunneling electrons transfer energy to the carbon lattice, as shown schematically in the figure. The results are fundamental for understanding the flow of heat and electrical charge in carbon nanostructures. Vibrational motion of atoms decreases the electrical conductivity of nanotubes and limits the performance of nanotransistors and other electronic devices based on them. Similarly, the stiffness of a nanotube and its capability for transporting heat is reduced with increasing defect density.

Original work:
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