NANOTUBE BASED THERMAL MOTORS: SUB-NANOMETER MOTION OF CARGOES DRIVEN BY THERMAL GRADIENTS

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There is a growing effort in the scientific community to design and fabricate ever more versatile nanoelectromechanical systems (NEMS). Because carbon nanotubes are very small, mechanically robust and chemically inert, they have attracted considerable interest as NEMS components. In addition, their one-dimensional tubular shape offers a natural track for motion. This tubular shape restricts the motion to only a few degrees of freedom (typically translation or rotation), much as bearings do in every-day machines.

A new generation of nanotube based motors has been envisaged that takes advantage of the atomic corrugation for a new class of tracks [1]. For example, the motion of two coaxial nanotubes relative to one another is given by the track that results from the mutual atomic interaction between the nanotubes. In some cases, the track follows energy minima that can consist of helical orbits ranging from pure rotation to pure translation. In some others, the energy barrier for motion contains local minima and maxima, arranged e.g. as a twisted chess-board like pattern (see some examples in Fig. 1 C-E) [2].

Here we report on an artificial nanofabricated motor (Fig. 1 A,B) in which one short nanotube moves relative to another coaxial nanotube and we present two major advances. First, the atomic interaction between the nanotubes is shown to generate distinct kinds of motion for different devices, namely rotation and/or translation along the nanotube axis. Figure 2 shows an example of a translational motion. Second, we show that the motion is actuated by imposing a thermal gradient along the nanotube, allowing for sub-nanometer displacements. More specifically, the thermal gradient generates a phononic current in one nanotube that hits and drags the second tube. This is, to our knowledge, the first experimental demonstration of displacive actuation at the nanoscale by means of a thermal gradient; we believe that thermal gradient actuation offers many possibilities in the design of novel nanoelectromechanical systems.

References:

[1] R. Saito, R. Matsuo, T. Kimura, G. Dresselhaus, M.S. Dresselhaus, Chem. Phys. Lett. **348** (2001) 187.
[2] A. Barreiro, R. Rurali, E. R. Hernández, J. Moser, T. Pichler, L. Forró, A. Bachtold, Science **320** (2008) 775.

Figures:

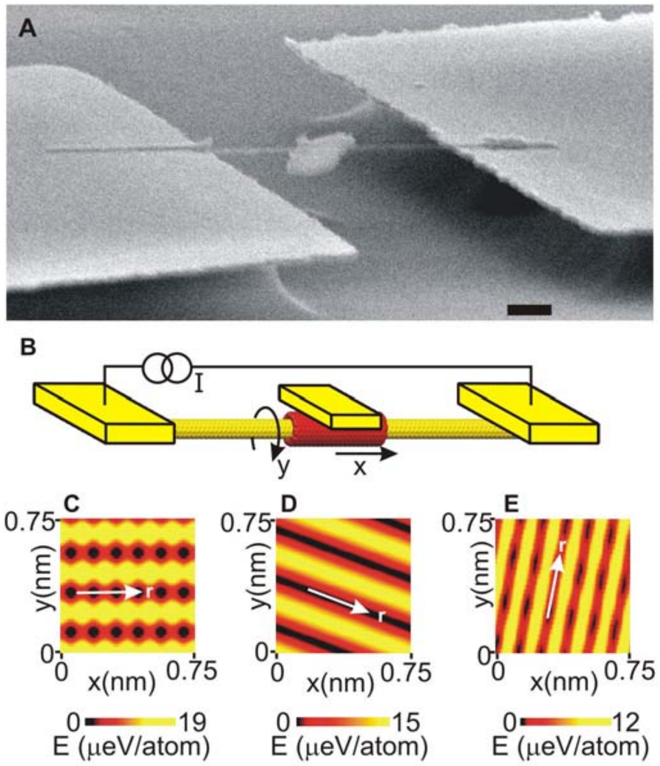

Fig. 1. Experimental setup. (A) Scanning electron microscope (SEM) image of one device. The scale bar is 300 nm. (B) Schematic of the nanotube motor and its degrees of freedom. The outer (red) nanotube moves with respect to the inner (yellow) nanotube. (C, D, E) Shape of the energy barrier for the relative motion between two coaxial nanotubes, namely (5,5)/(10,10), (29,9)/(38,8) and (27,12)/(32,17), respectively. The diameters of the inner tubes are 0.67, 2.7, and 2.7 nm, respectively. The white arrow indicates the easy axis of motion. The motion is modulated by a series of small periodic barriers in C and E, while vanishingly small friction is expected in D.

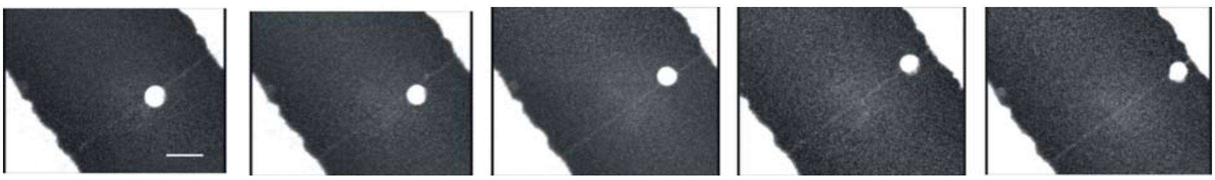

Fig. 2. Translational motion. Top down SEM images where the gold cargo is moving along the nanotube. The motion is actuated by passing a large electrical current through the nanotubes. Note that the driving mechanism for the motion is not due to electromigration, but comes from the thermal gradient along the nanotubes (induced by the electrical current). The metal plate, which initially had a rectangular shape, melted through Joule heating, and became a ball. The scale bar is 400 nm.