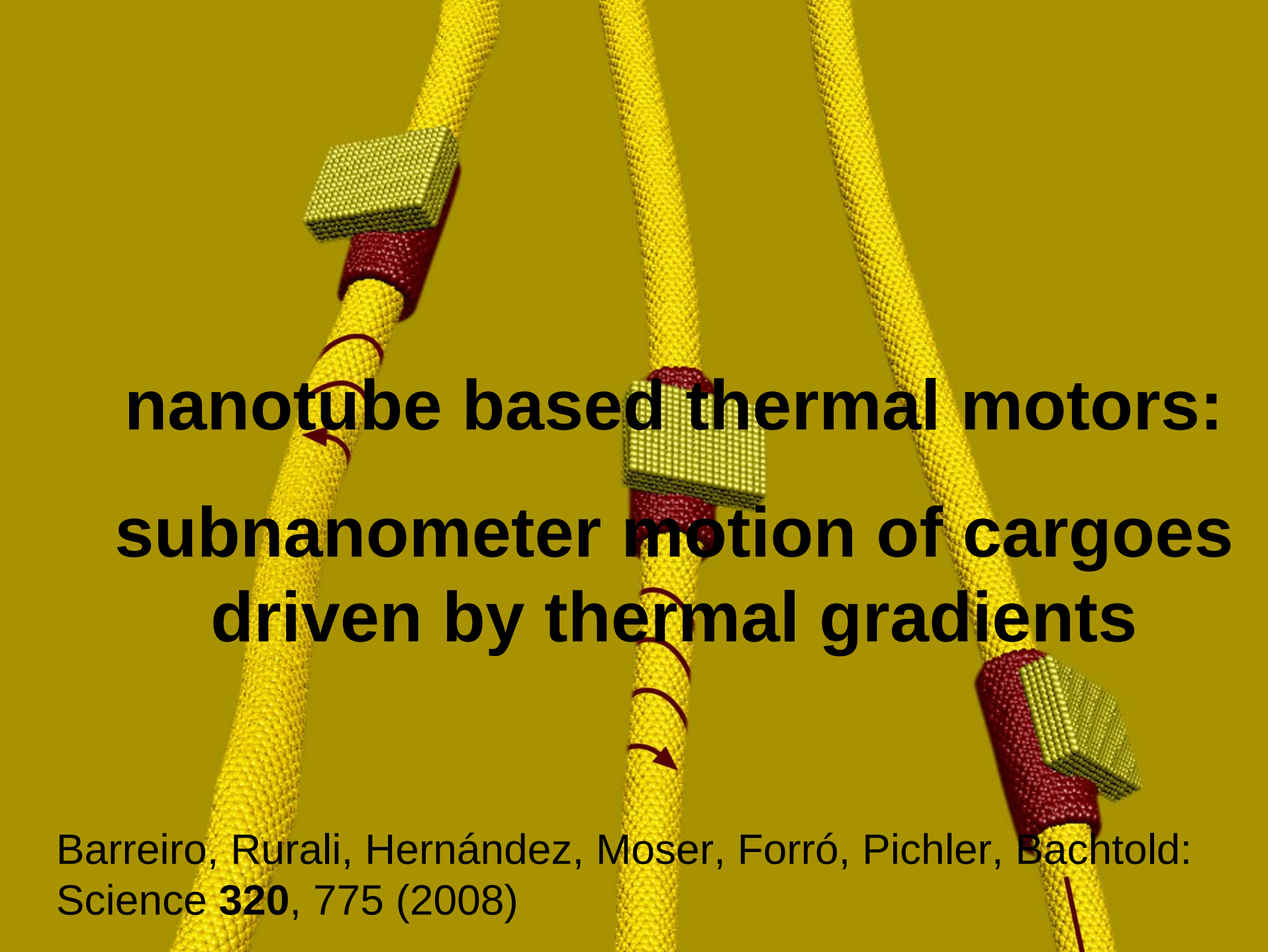
nanotube based thermal motors:

subnanometer motion of cargoes driven by thermal gradients

Barreiro, Rurali, Hernández, Moser, Forró, Pichler, Bachtold:
Science **320**, 775 (2008)

CIN2
CENTRE D'INVESTIGACIÓ EN
NANOCIÈNCIA I NANOTECNOLOGIA



nanotube based thermal motors:

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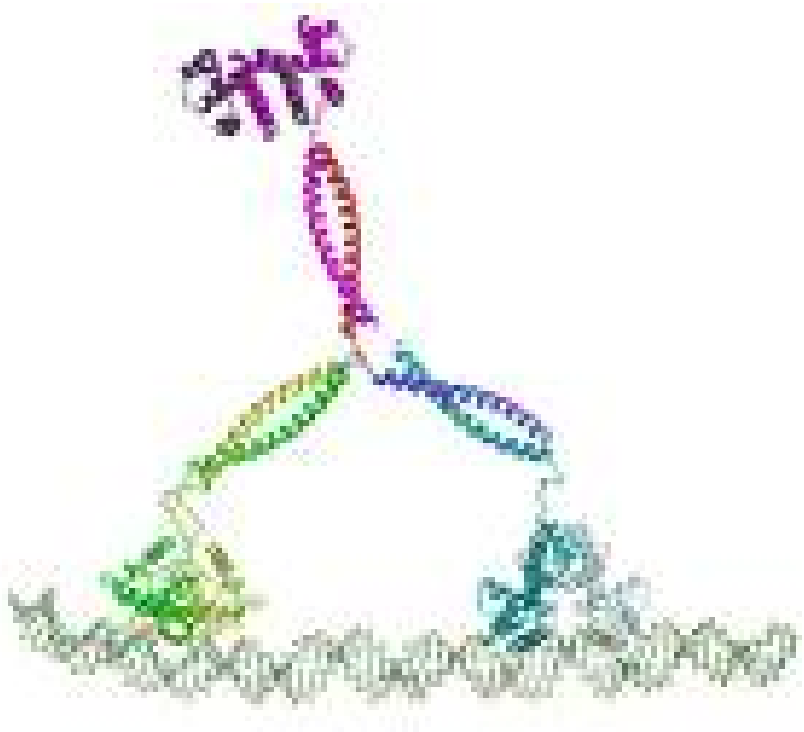
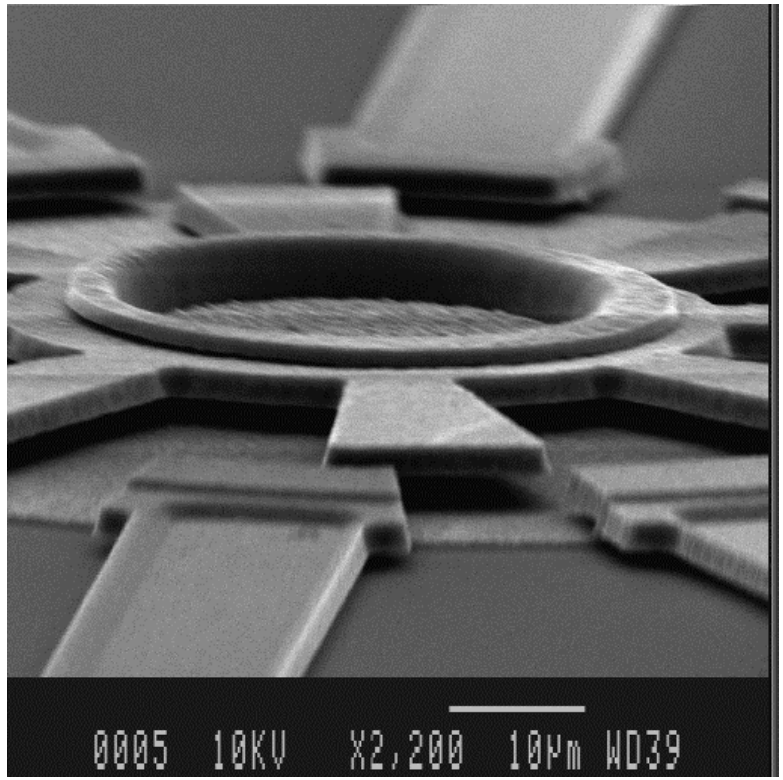
visionary concepts in nanoscience



biological motors

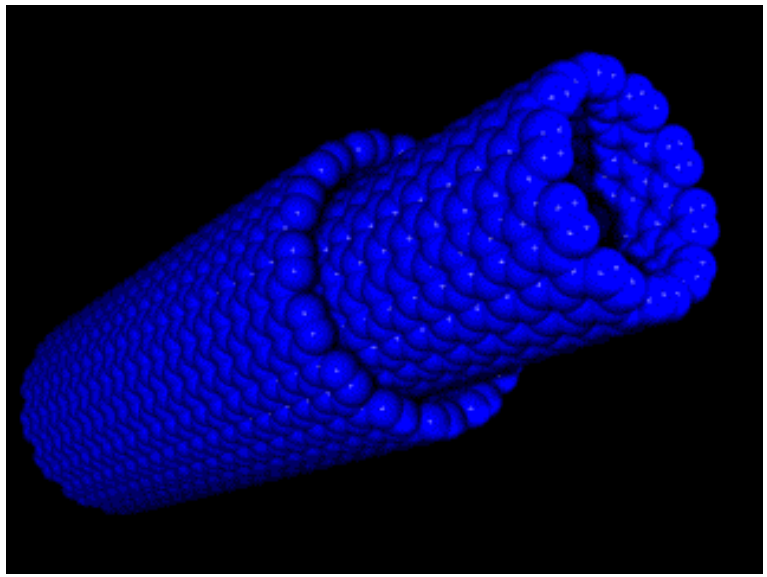
Lund University

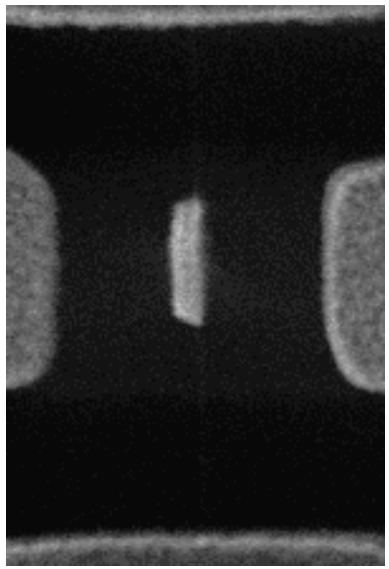


microfabricated motors

LAAS, Toulouse

molecular bearings

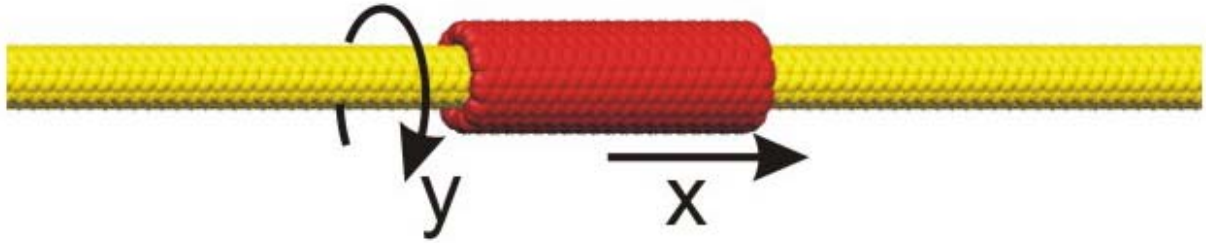


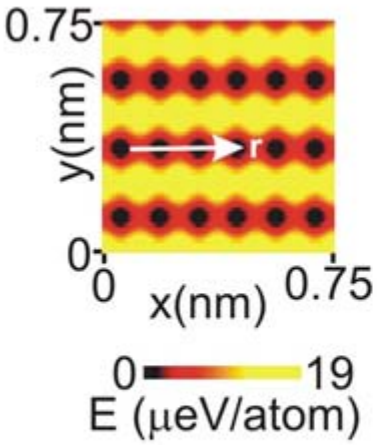


MWNTs ⇒ low friction

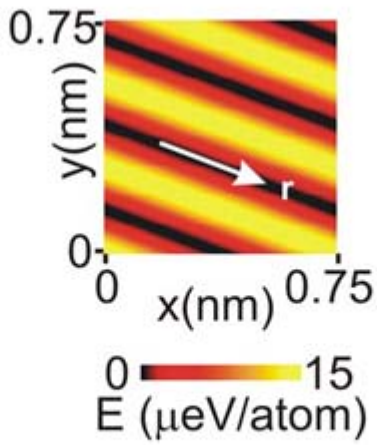
Cumings, Zettl, Science 2000
Yu, Yakobson, Ruoff, J. Phys. Chem B 2000
Kis et al., PRL 2006
Fennimore et al., Nature 2003
Bourlon et al., Nano Letters 2004

motion controlled by atomic arrangement

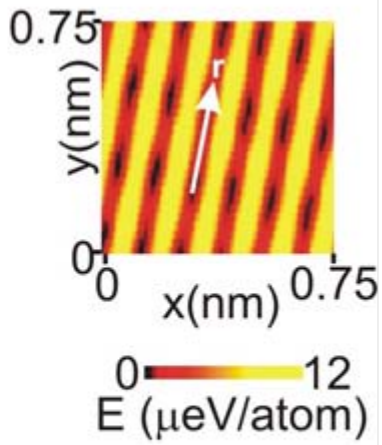




(5,5) - (10,10)



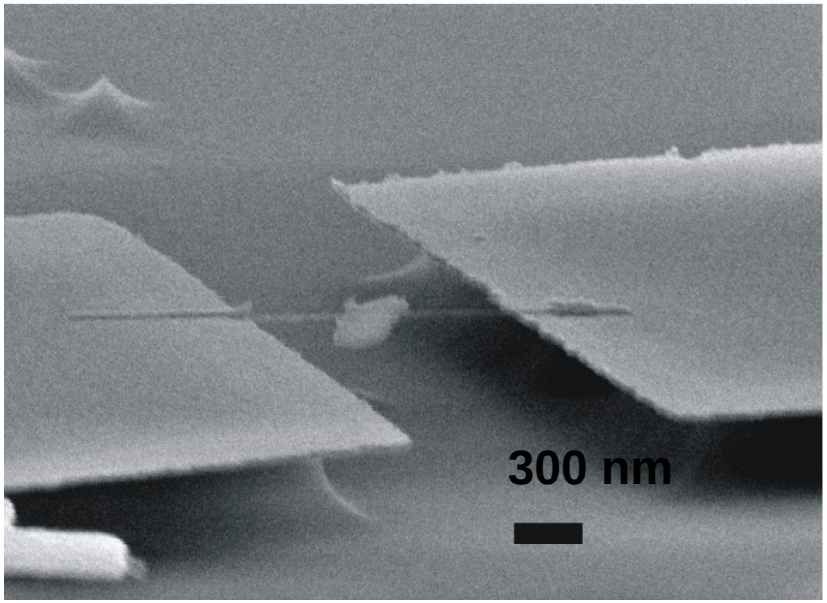
(29,9) - (38,8)

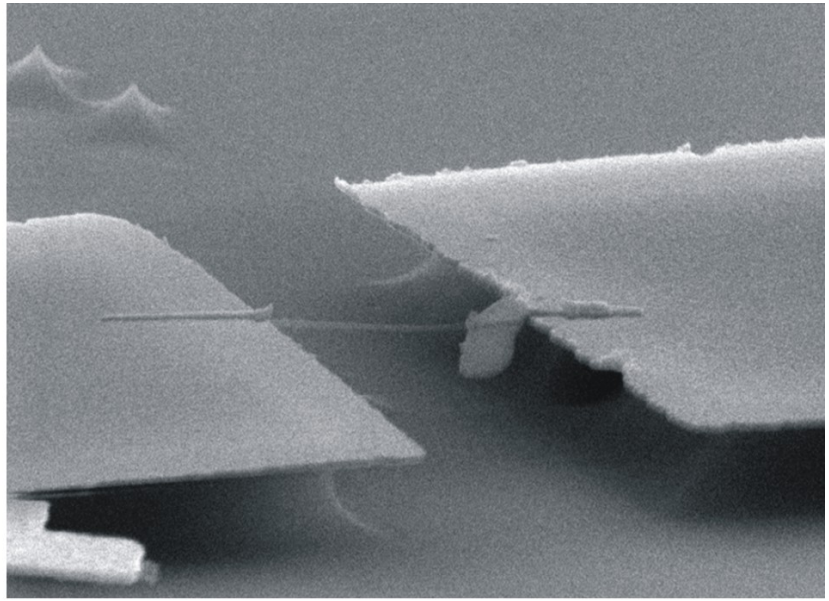


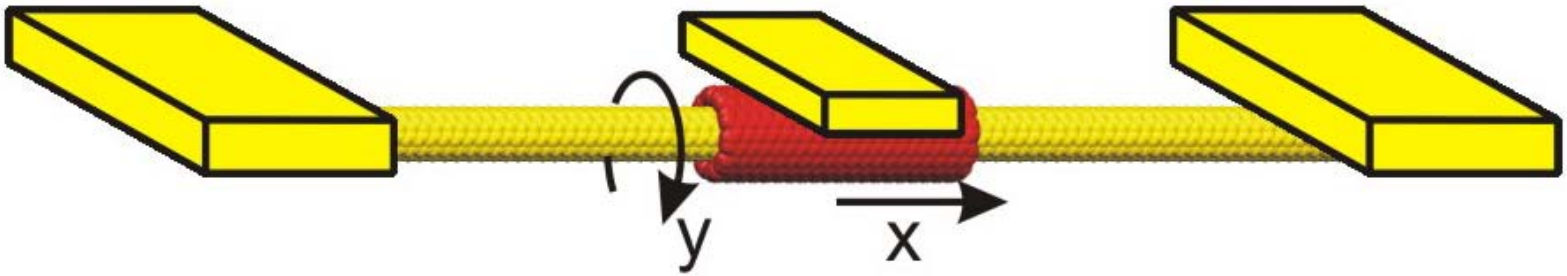
(27,12) - (32,17)

Saito, Matsuo, Kimura, Dresselhaus, Dresselhaus
Chemical Physics Letters 2001

1. device



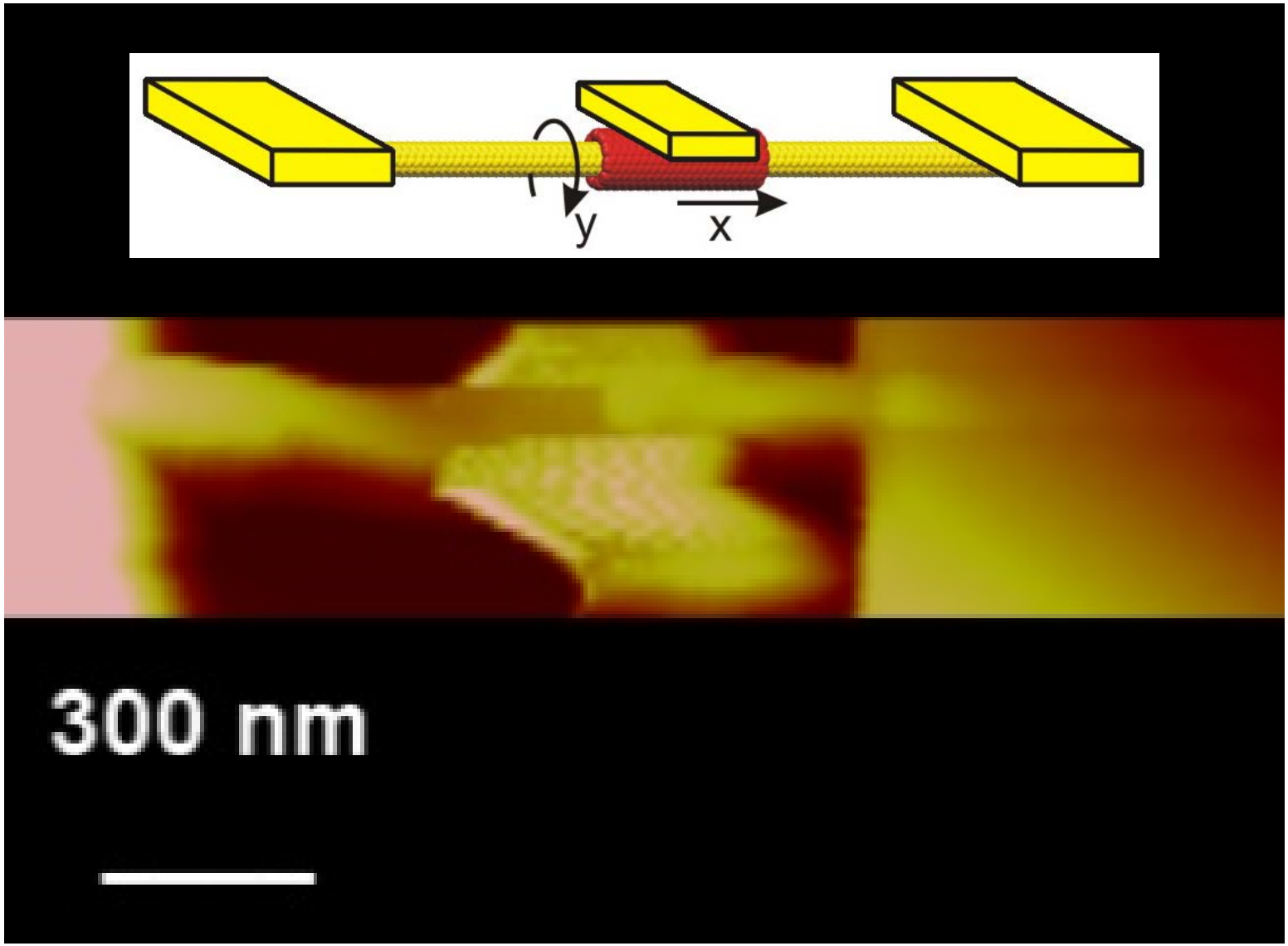




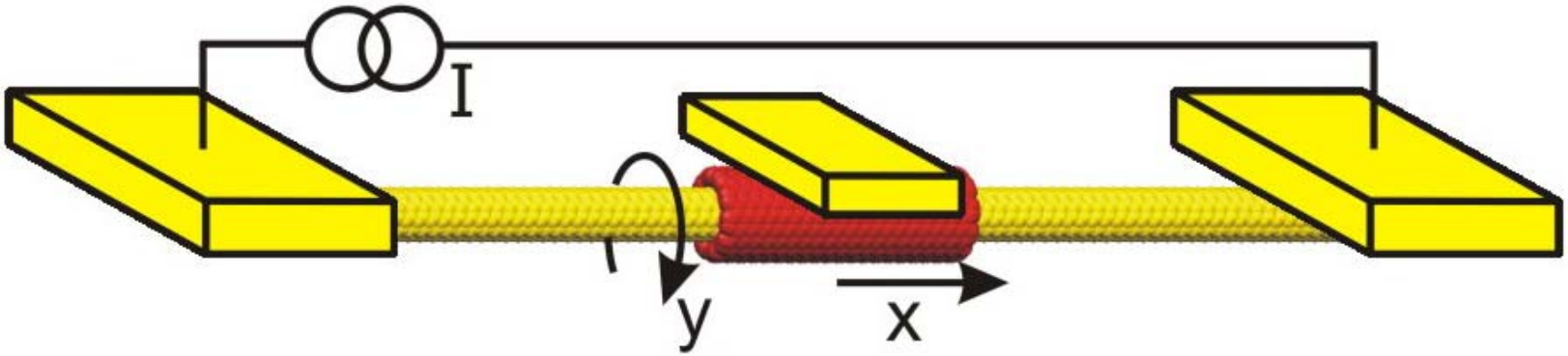
verification of the device layout

move the plate with an AFM tip

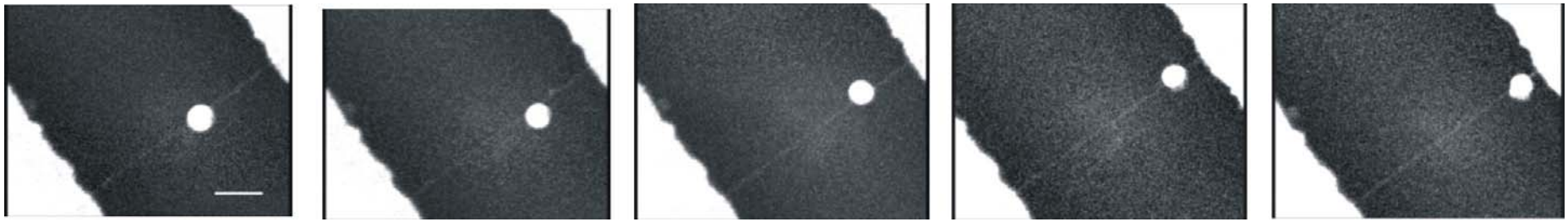
AFM actuation

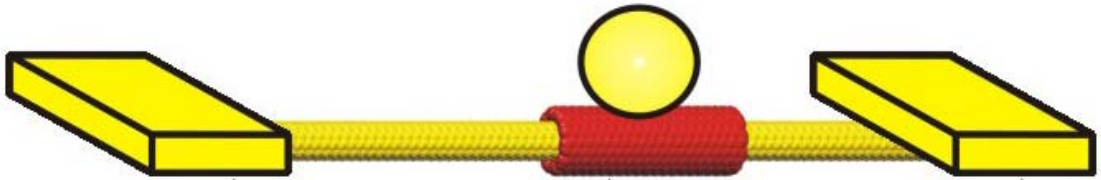


2. motion upon passing a large current

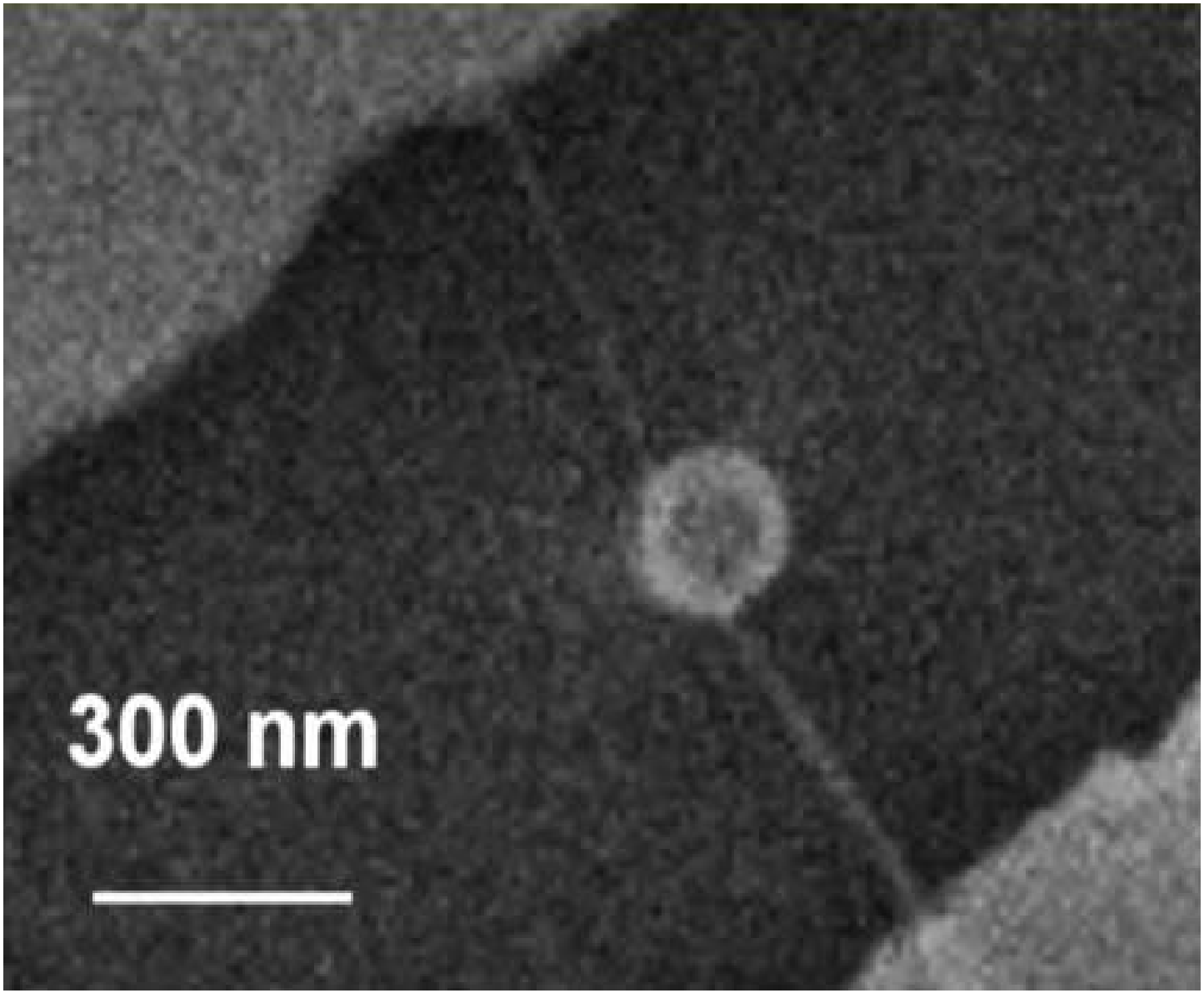


translation

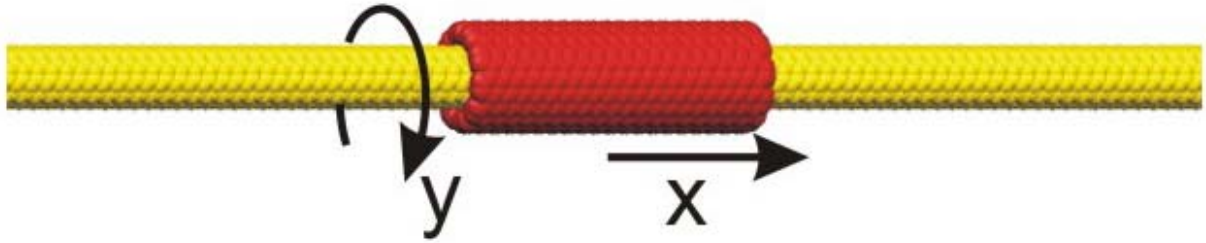


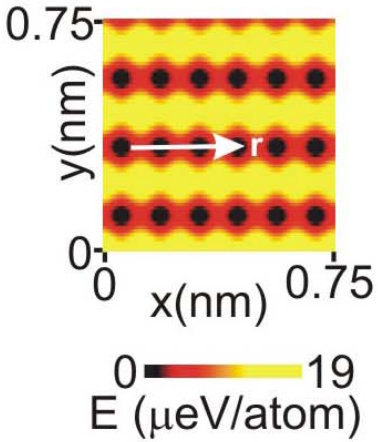


rotation

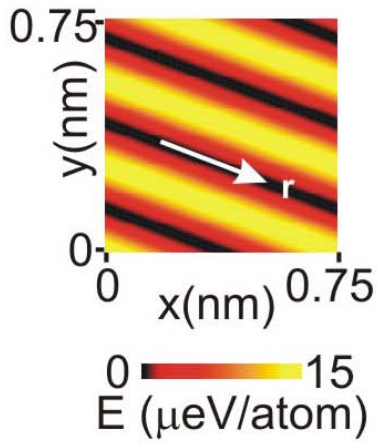


motion controlled by atomic arrangement

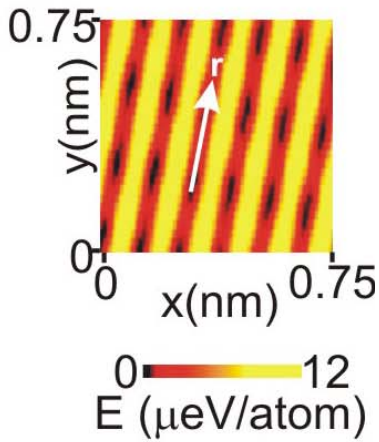




(5,5)-(10,10)



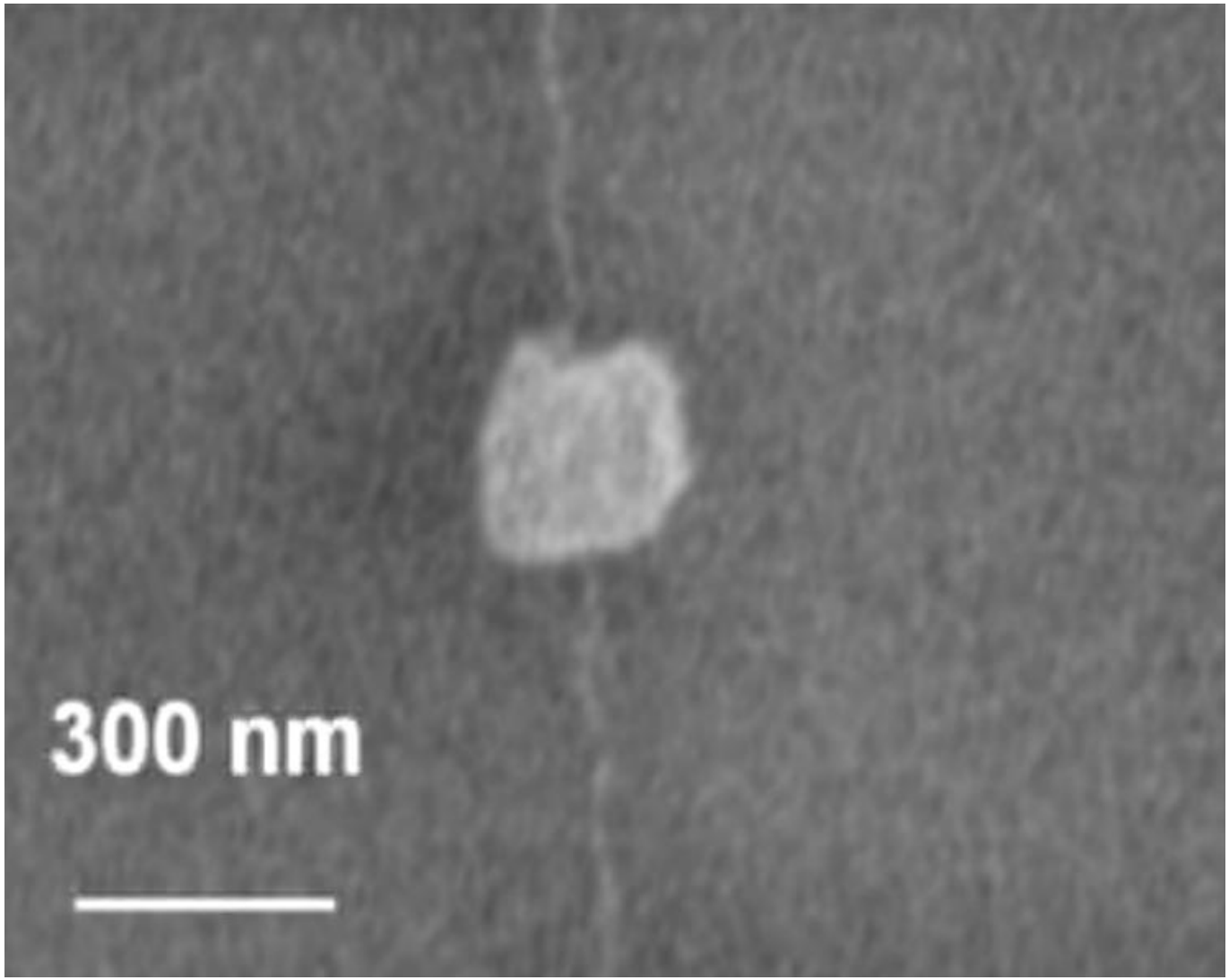
(29,9)-(38,8)



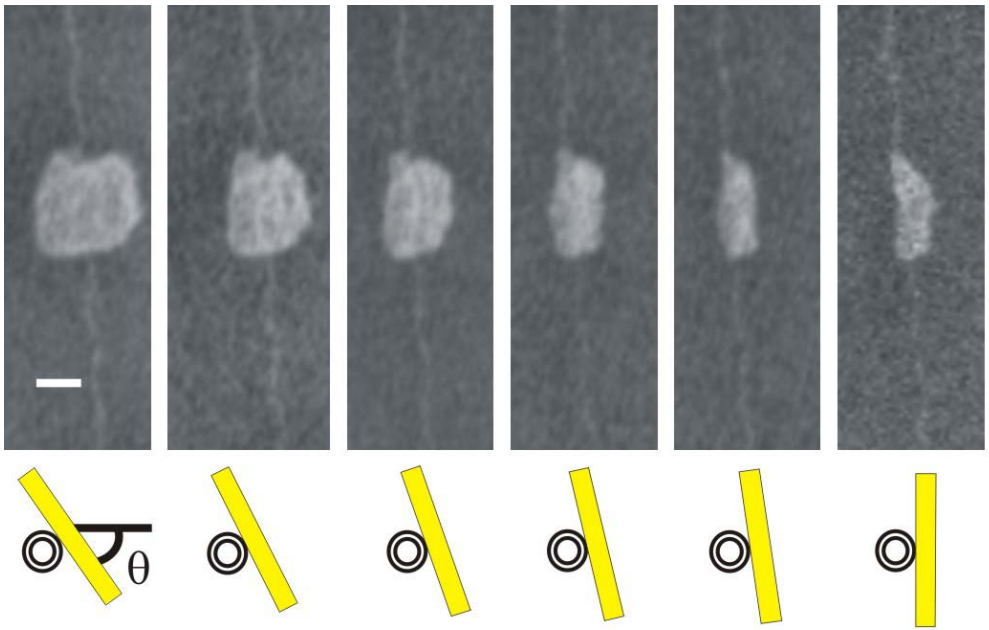
(27,12)-(32,17)

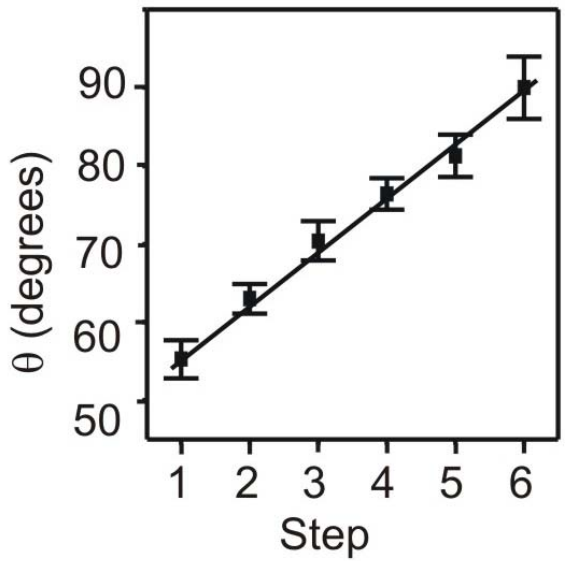
Saito, Matsuo, Kimura, Dresselhaus, Dresselhaus
Chemical Physics Letters 2001

stepwise rotation



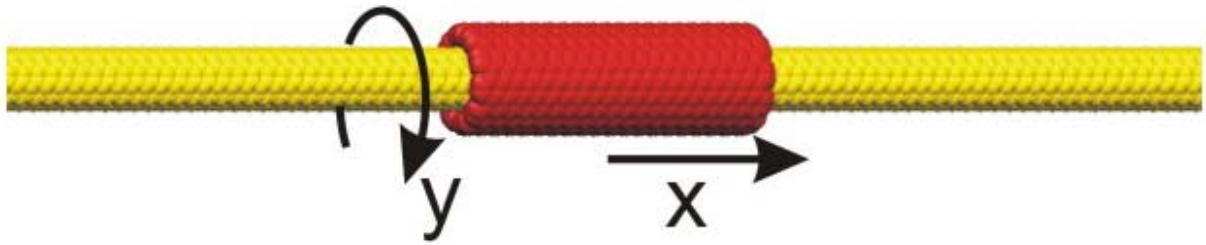
stepwise rotation

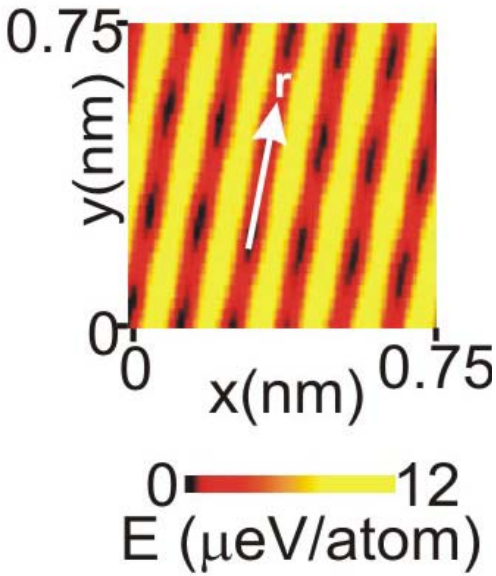




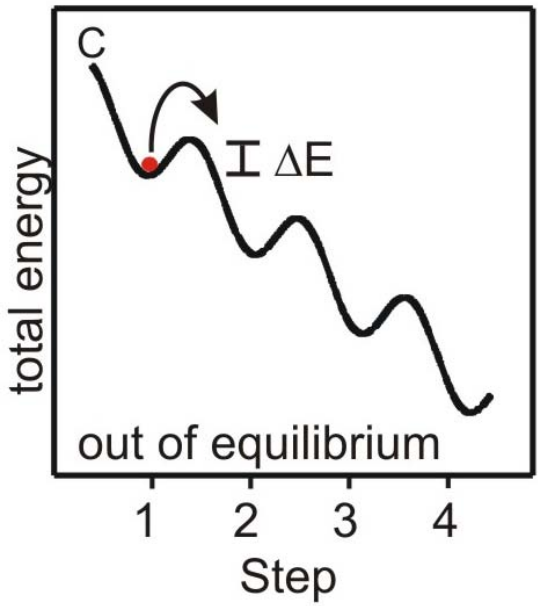
7º corresponds to about 0.4 nm displacement

motion controlled by atomic arrangement





(27,12)-(32,17)



Saito, Matsuo, Kimura, Dresselhaus, Dresselhaus
Chemical Physics Letters 2001

periodic barriers

ΔE ~ 10 μeV/atom

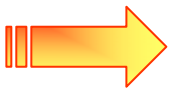
thermally enhanced process

$$\Gamma = \frac{\omega}{2\pi} e^{-\frac{\Delta E}{k_B \cdot T}}$$

approximation of linear harmonic oscillator:

$$\omega = \sqrt{\frac{k}{m}}, \qquad k = \frac{\partial^2 E}{\partial r^2} \approx \frac{\Delta E}{a_0^2}$$

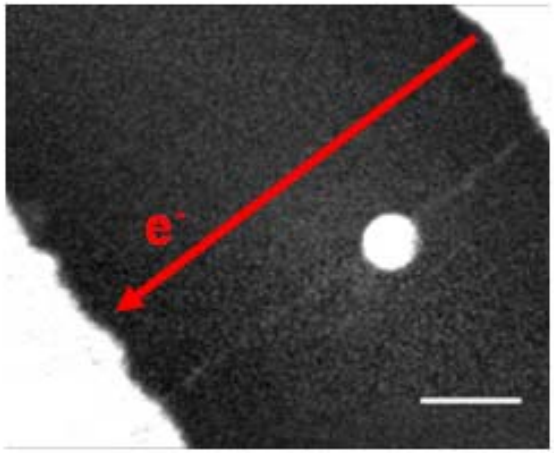
diffusion rate Γ~ 1 Hz, a_0=1 nm,
m mass of gold plate

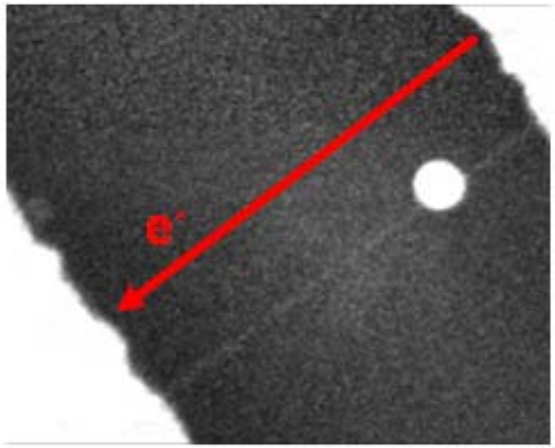


diffusion barrier ΔE ~ 17 μeV/atom

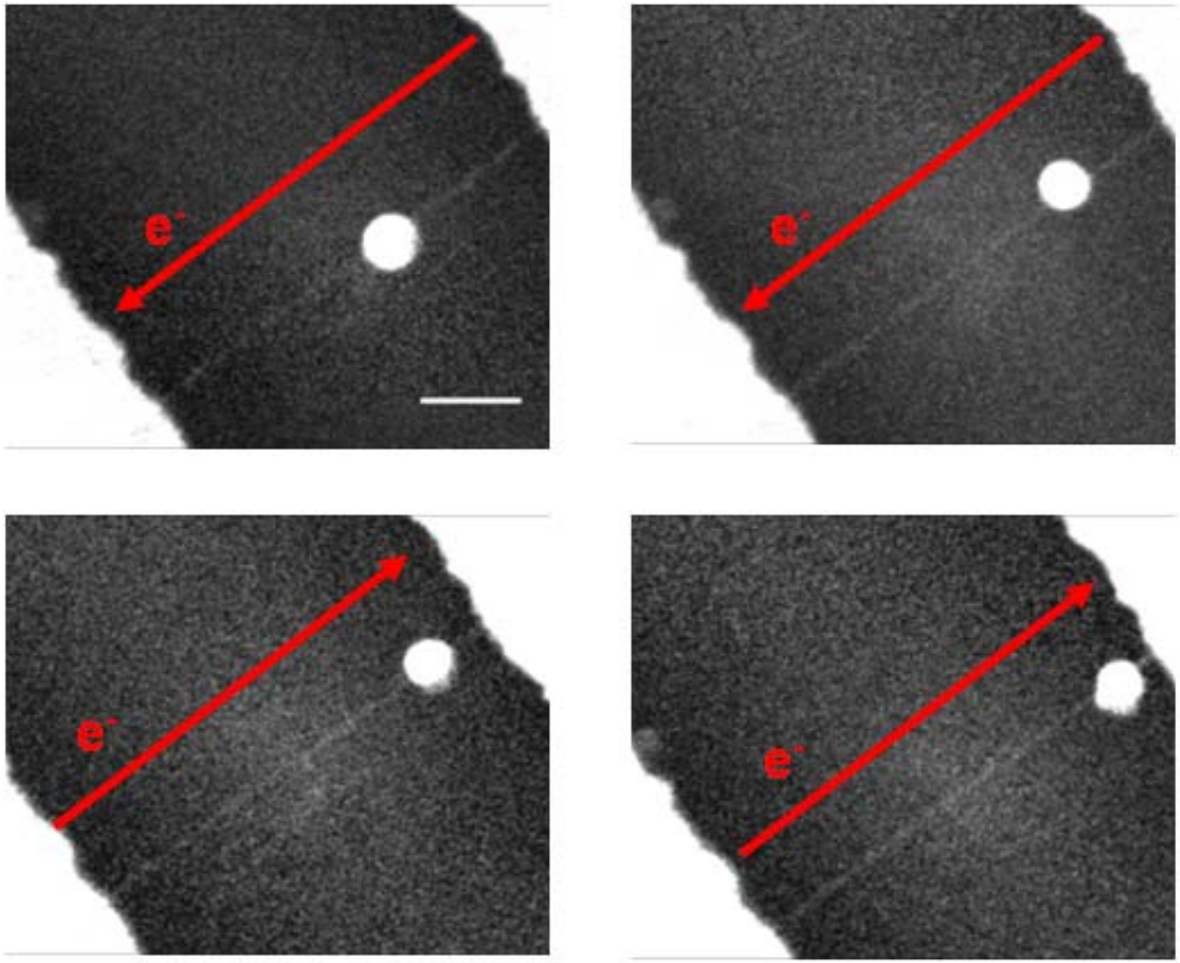
Saito et al. predict a potential barrier of 10 μeV/atom

3. driving mechanism



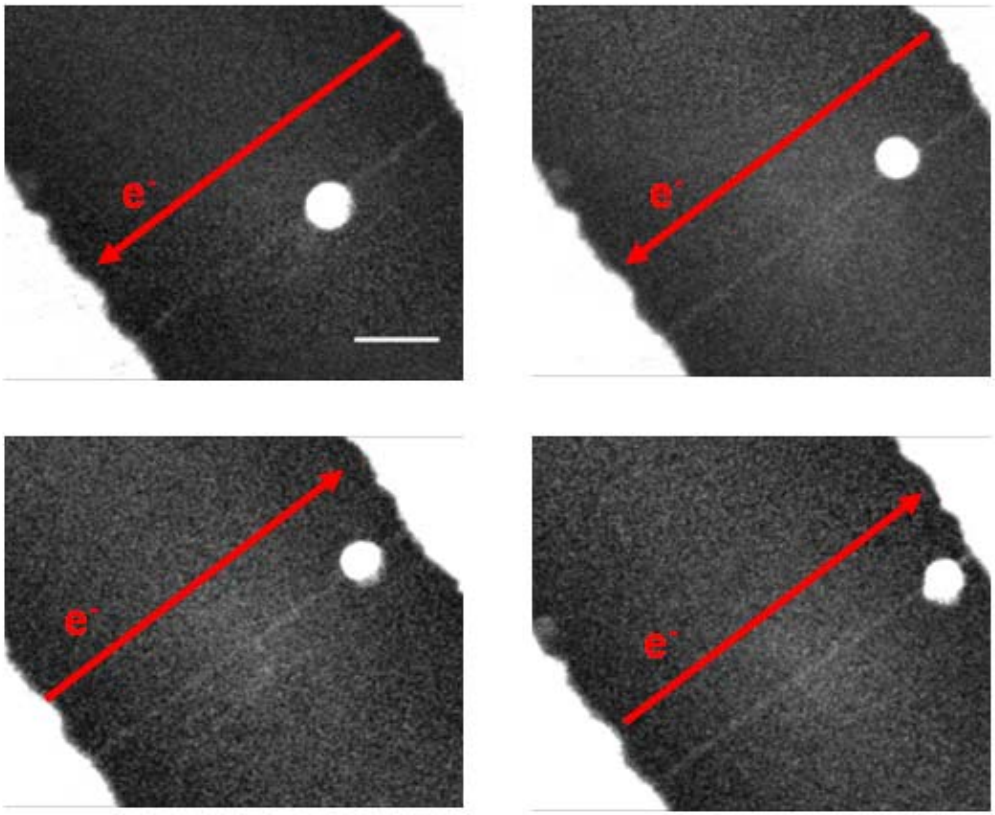


3. driving mechanism

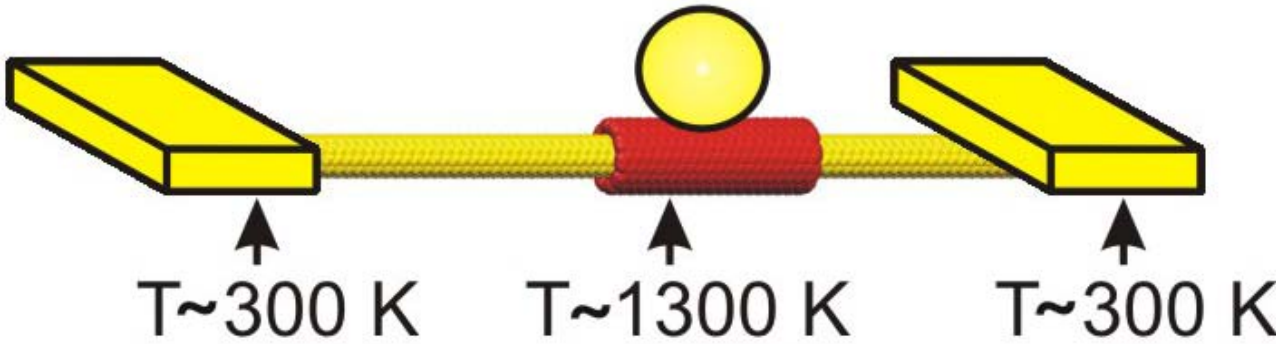


no electromigration!

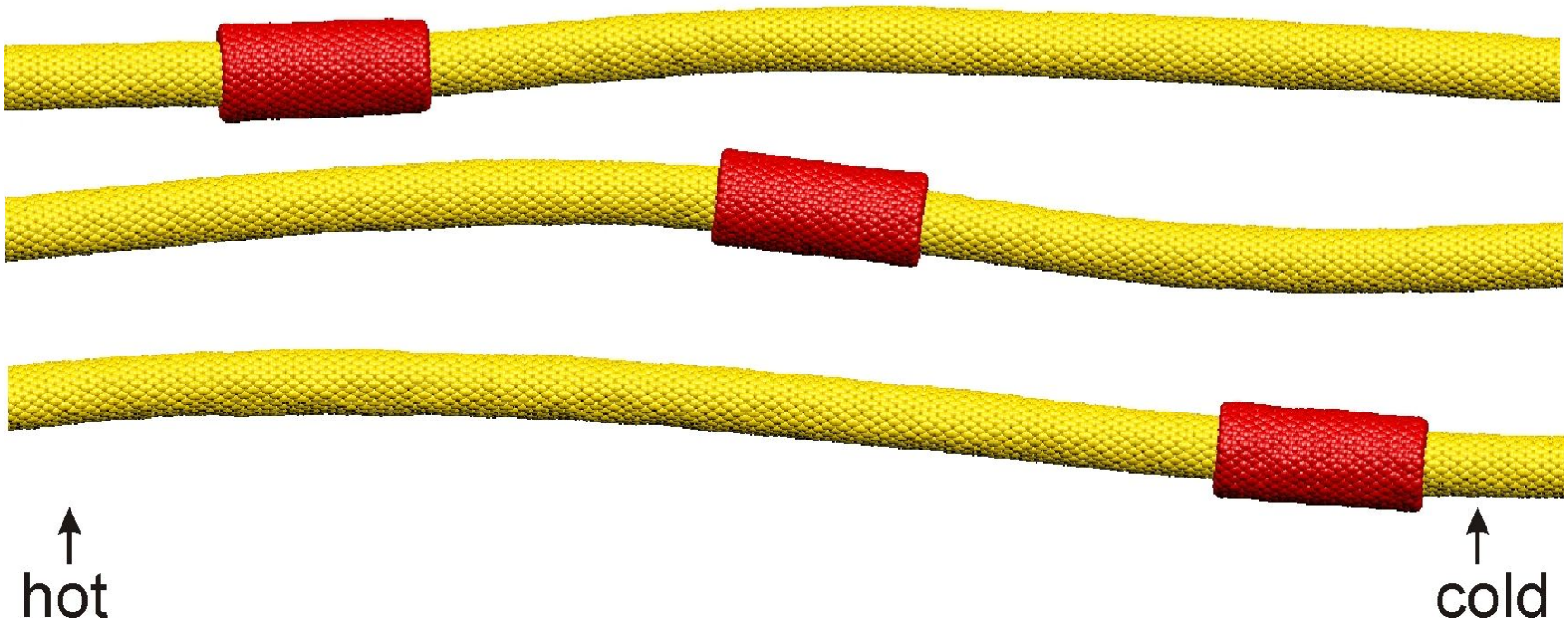
thermal actuation

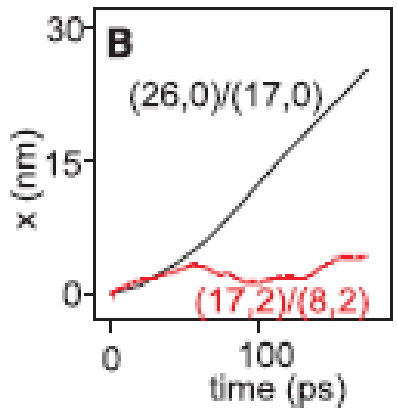


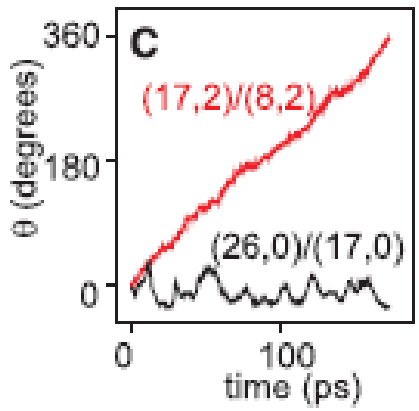
phonons drive the motion



4. molecular dynamics calculations



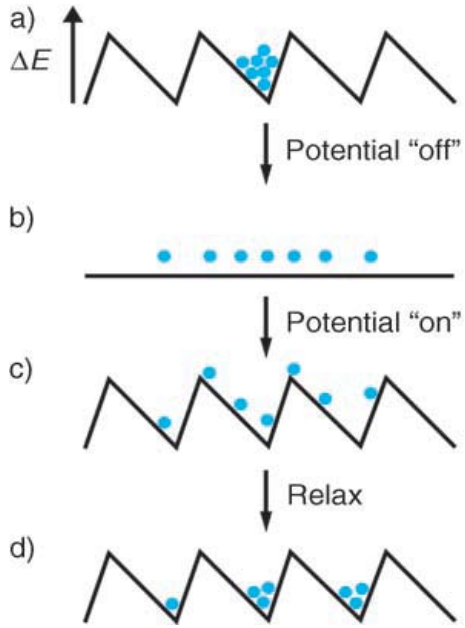




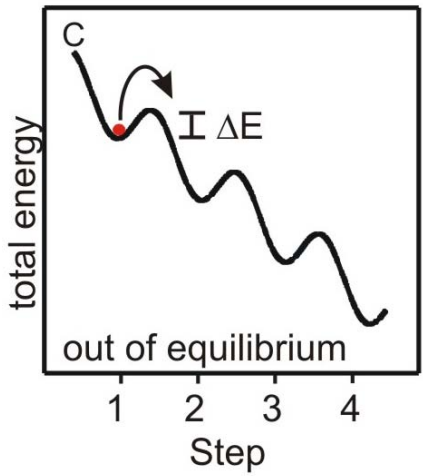
R. Rurali (UAB)
E. Hernández (ICMAB)

5. conclusion: new type of motion

our world



biological motors
ratchet effect



nanotube
thermal motors

acknowledgements

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Jordi Llobet, Xavier Borrisé

QNE, Joel Moser

Thomas Pichler

Laszlo Forró