高等研究院・インテックセンター
平成24年度成果報告会
Jan. 23, 2013

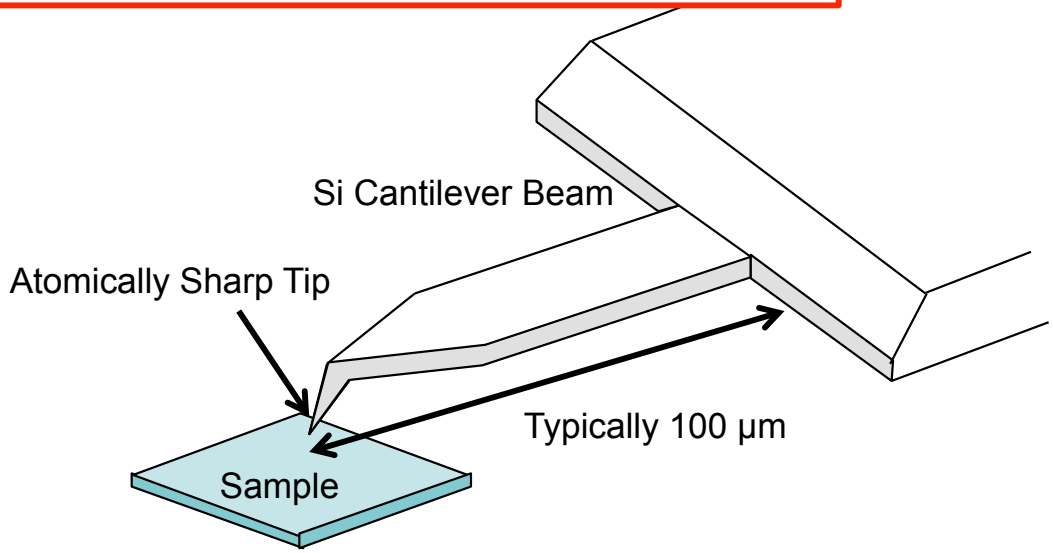
周波数変調原子間力顕微鏡による新規ナノ物性計測法の開発

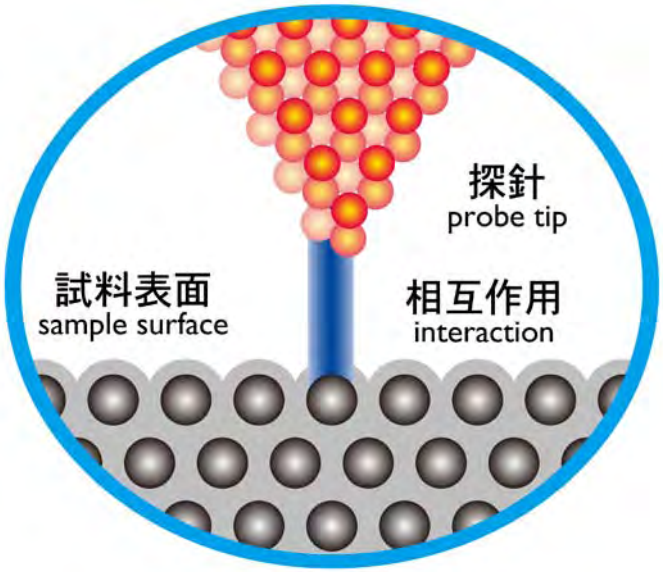
融合ナノ基盤工学研究部門

小林 圭 (産官学連携本部)
山田 啓文 (電子工学専攻)

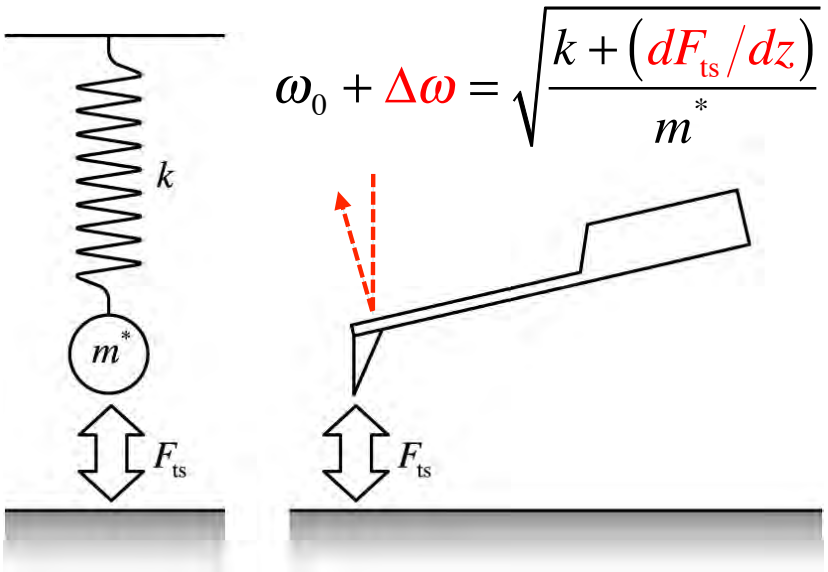
Key Technology: FM-AFM

Atomic Force Microscopy (AFM)

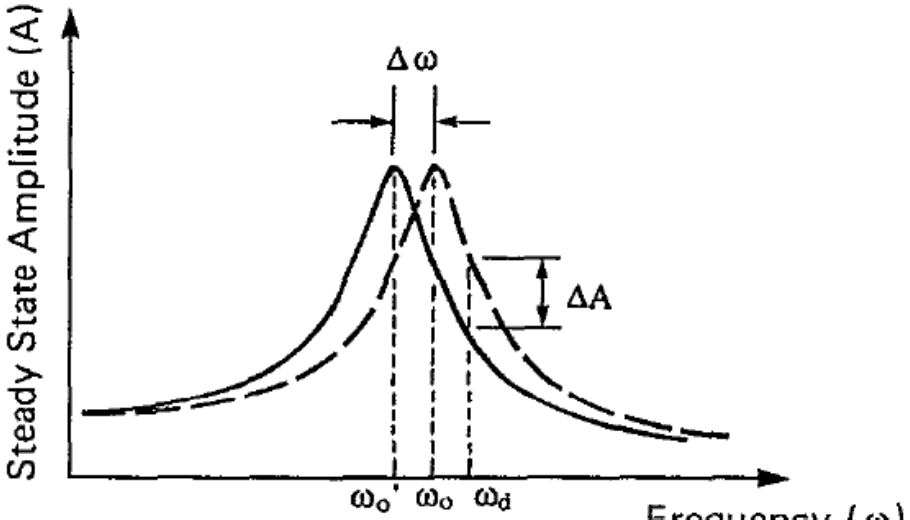




Frequency Modulation AFM

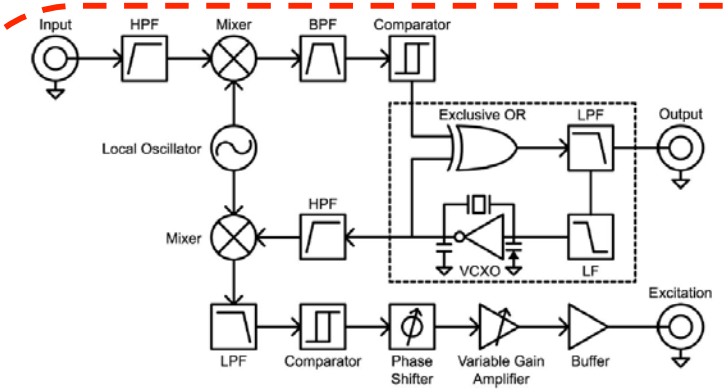


$$\omega_0 + \Delta\omega = \sqrt{\frac{k + \left(dF_{ts}/dz\right)}{m^*}}$$

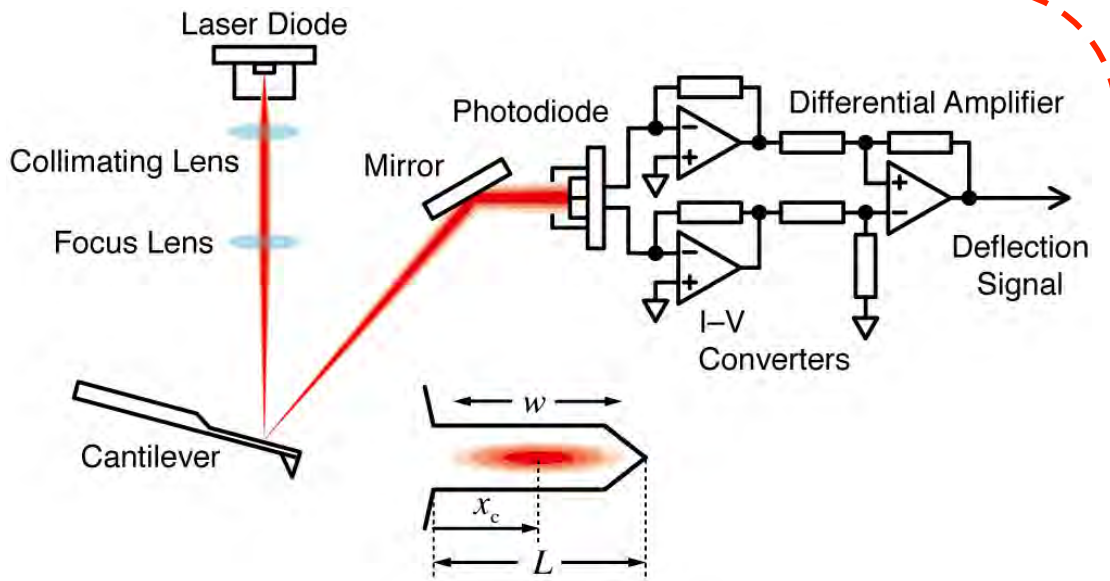


FM-AFM (T.R. Albrecht, 1991).

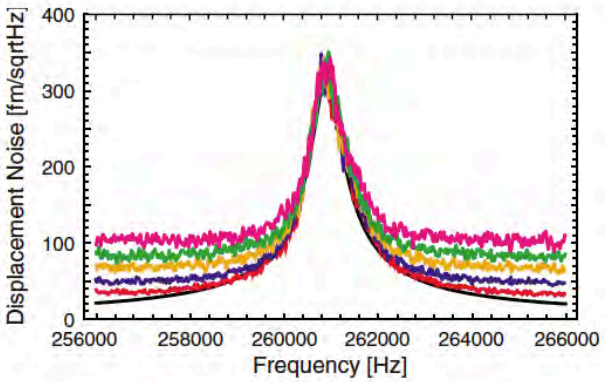
Key Technology: FM-AFM

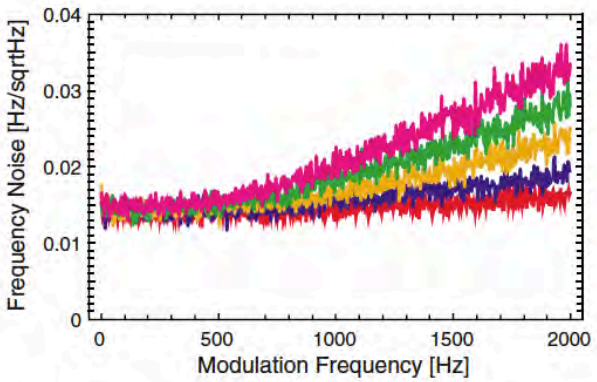


Highly Sensitive Frequency Detector
(Rev. Sci. Instrum. 2001).

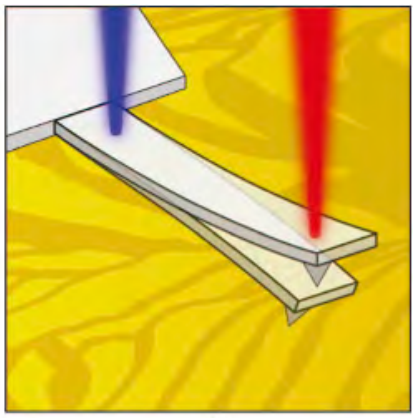


Low-Noise Displacement Sensor
(Rev. Sci. Instrum. 2005)





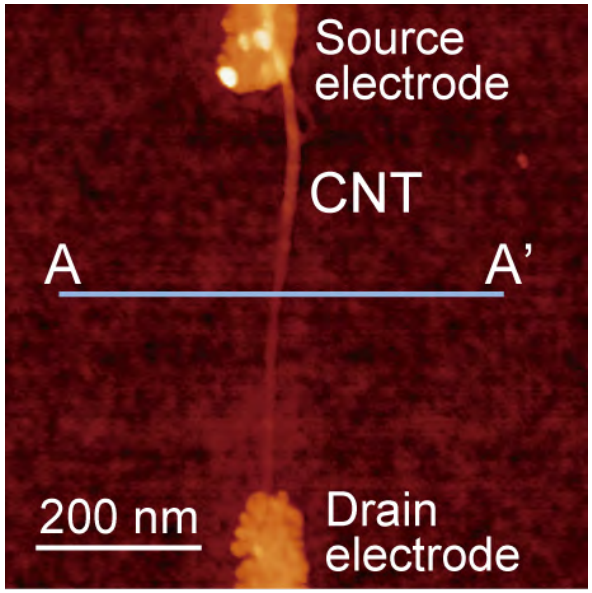
Noise Analysis of FM-AFM
(Rev. Sci. Instrum. 2009).



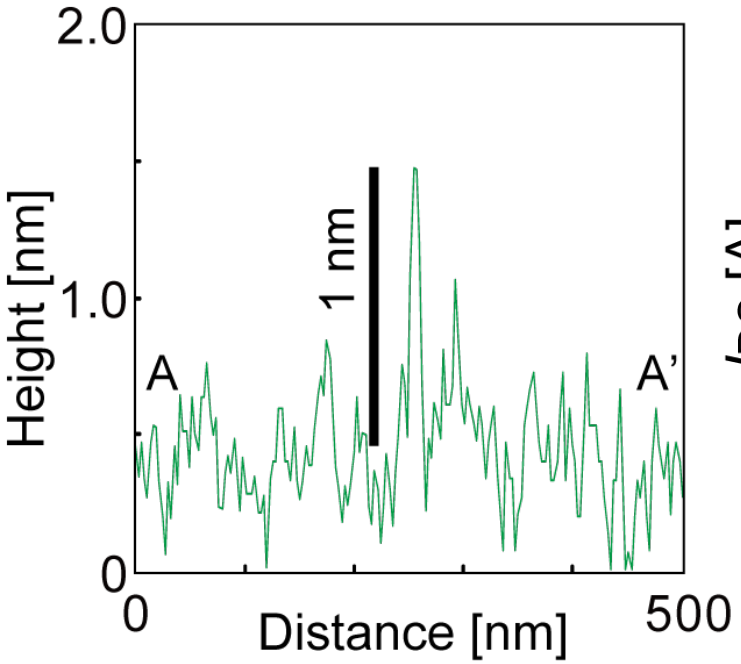
Photothermal Actuation
(Rev. Sci. Instrum. 2011).

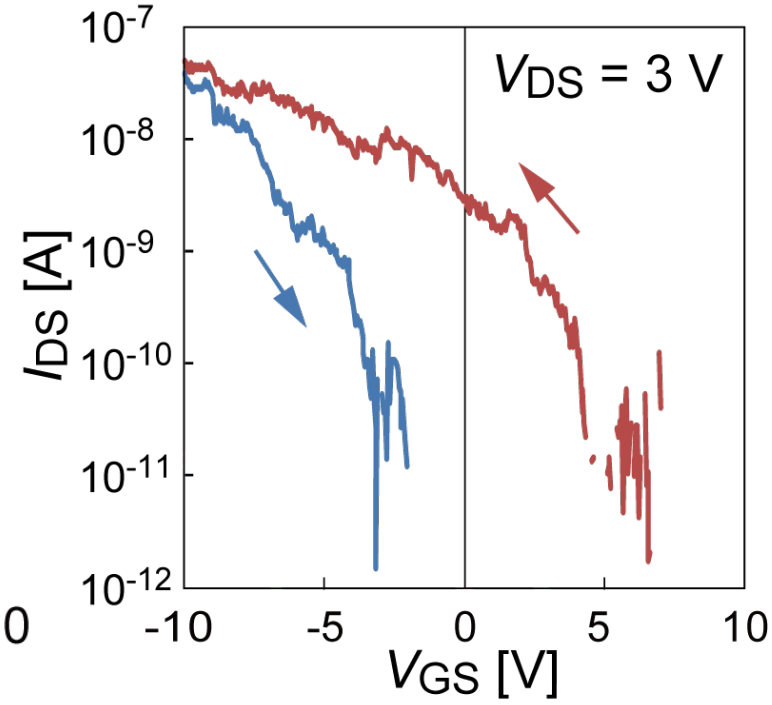
Electrostatic Force Microscopy on Carbon Nanotubes

CNT aligned between two electrodes by dielectrophoresis



Topographic image





The CNT showed p-type semiconducting characteristics.

Appl. Phys. Lett. 102, 013115 (2013).

Electrostatic Force Microscopy on Carbon Nanotubes

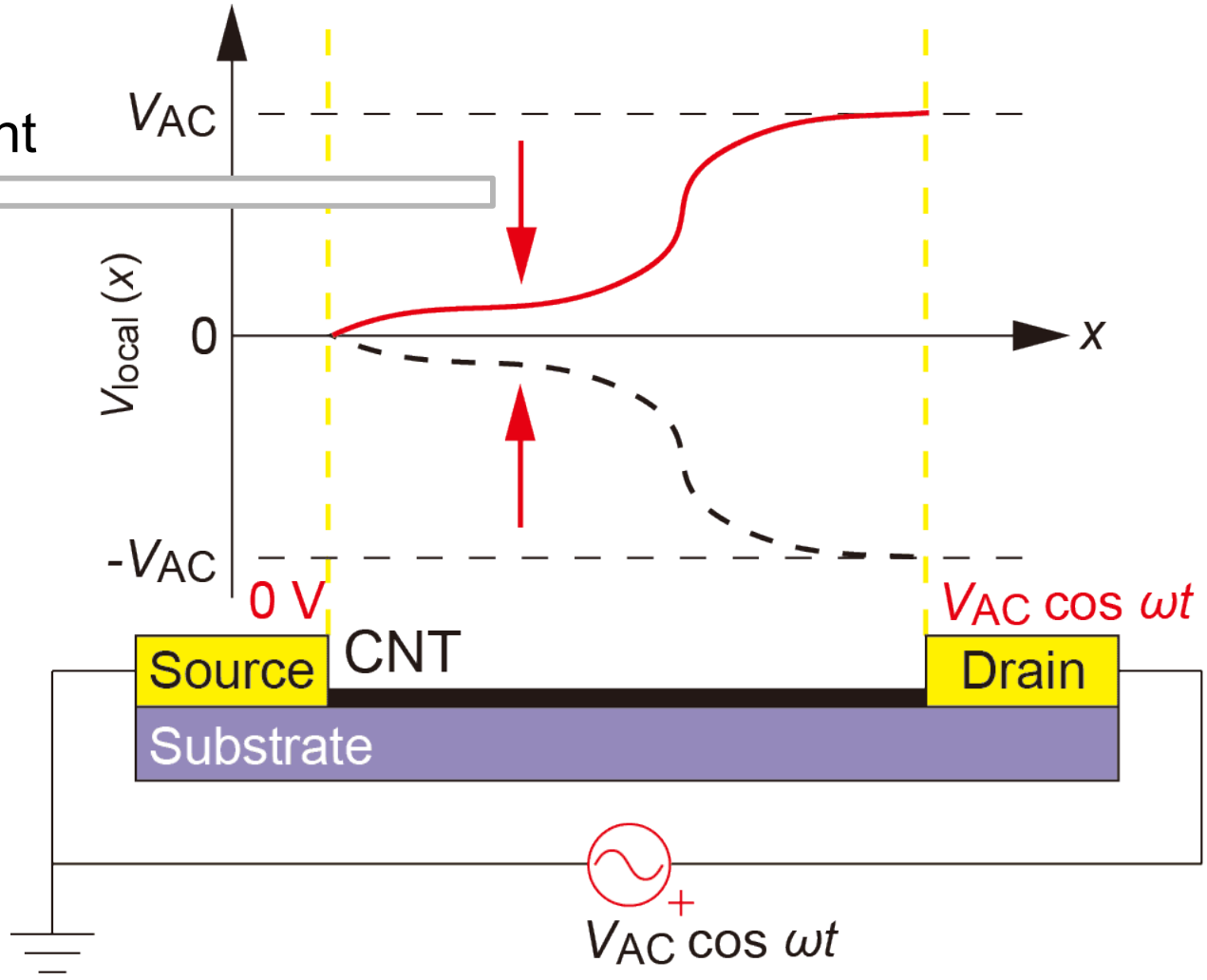
High-Frequency Electrostatic Force Microscopy (HF-EFM)

Modulating only channel voltage

Amplitude at each point of the channel

Lock-in detection

Values related to local voltage



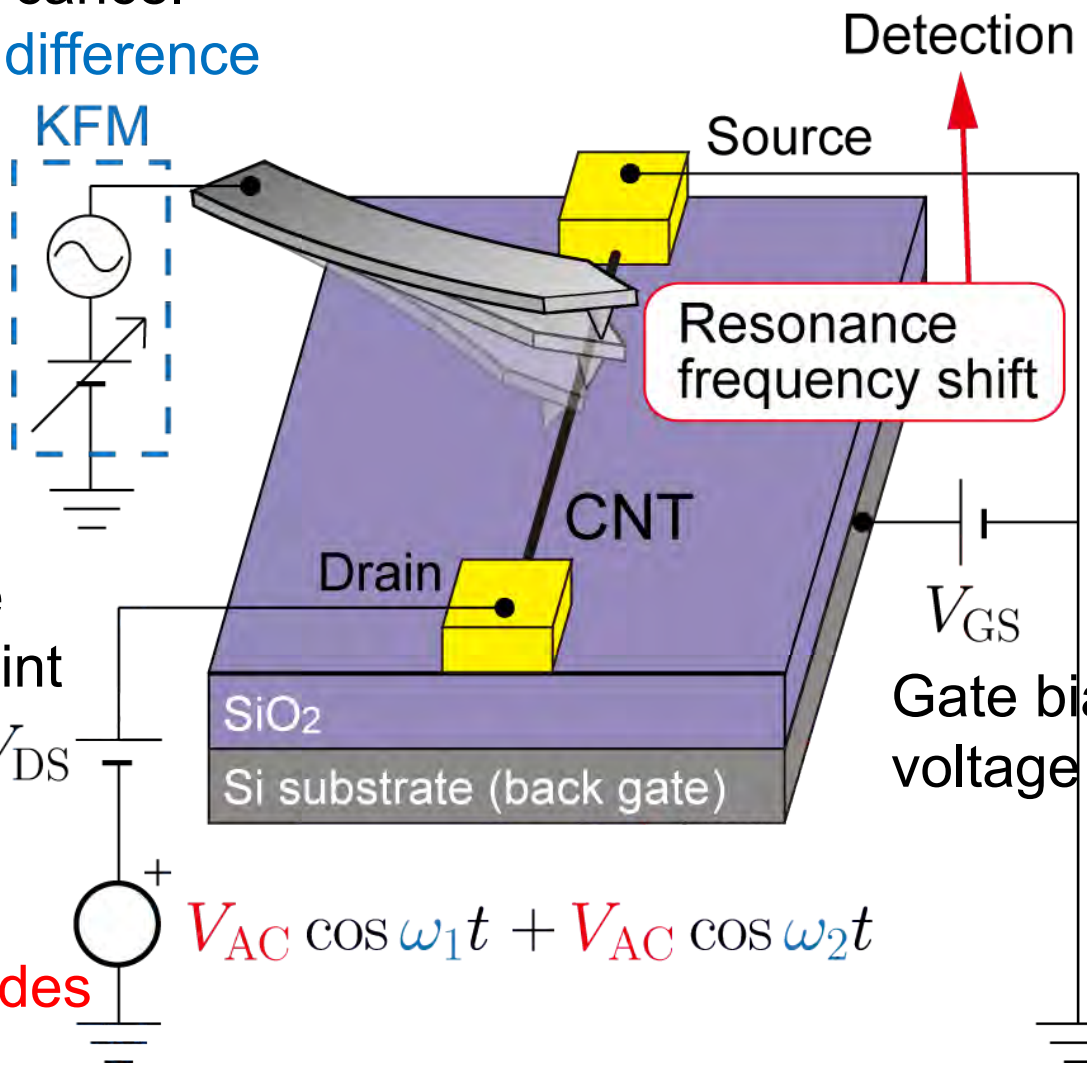
Assumption:
Potential profile is symmetric with respect to the polarity of the drain voltage.

Appl. Phys. Lett. 102, 013115 (2013).

Electrostatic Force Microscopy on Carbon Nanotubes

Setup for FM-HF-EFM

FM-KFM bias for cancel
contact potential difference



FM-HF-EFM
is based
on FM-AFM.

EFM signal is
detected using
FM method.

Drain bias voltage
to fix operating point
as a transistor

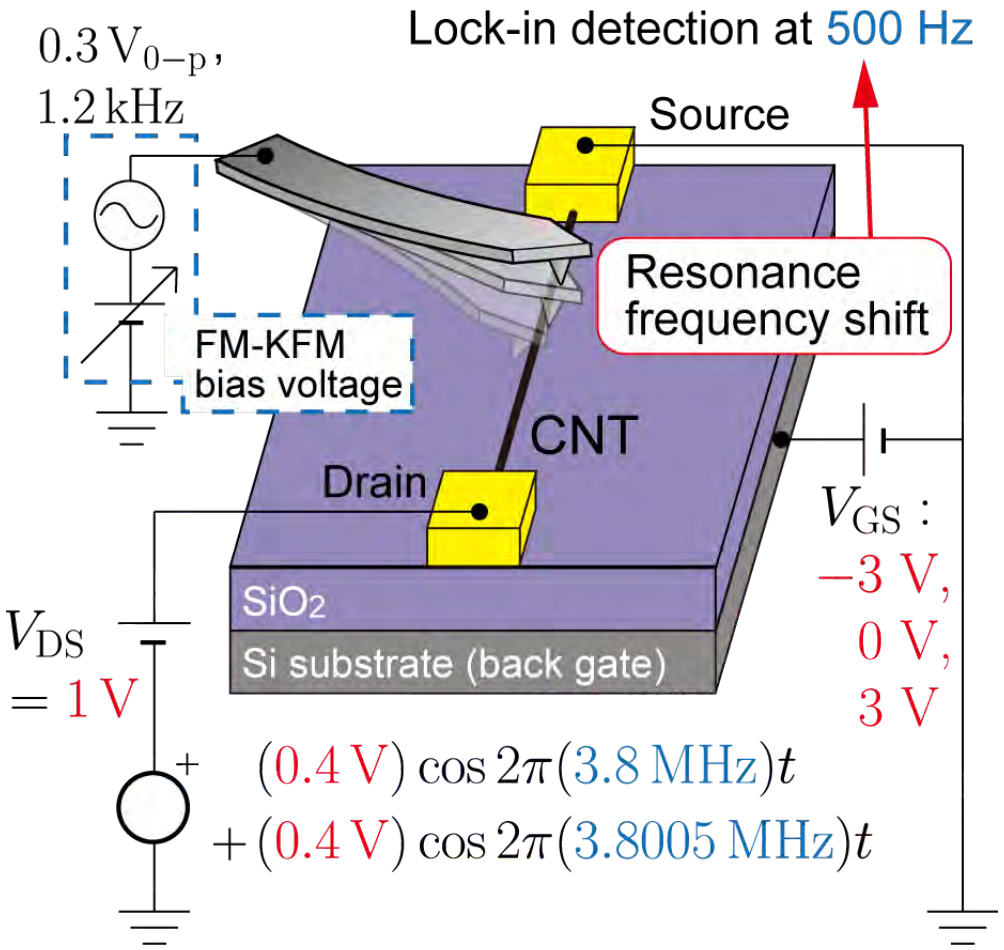
Gate bias
voltage

Modulation voltages
with the same amplitudes
and slightly different
frequencies from each other

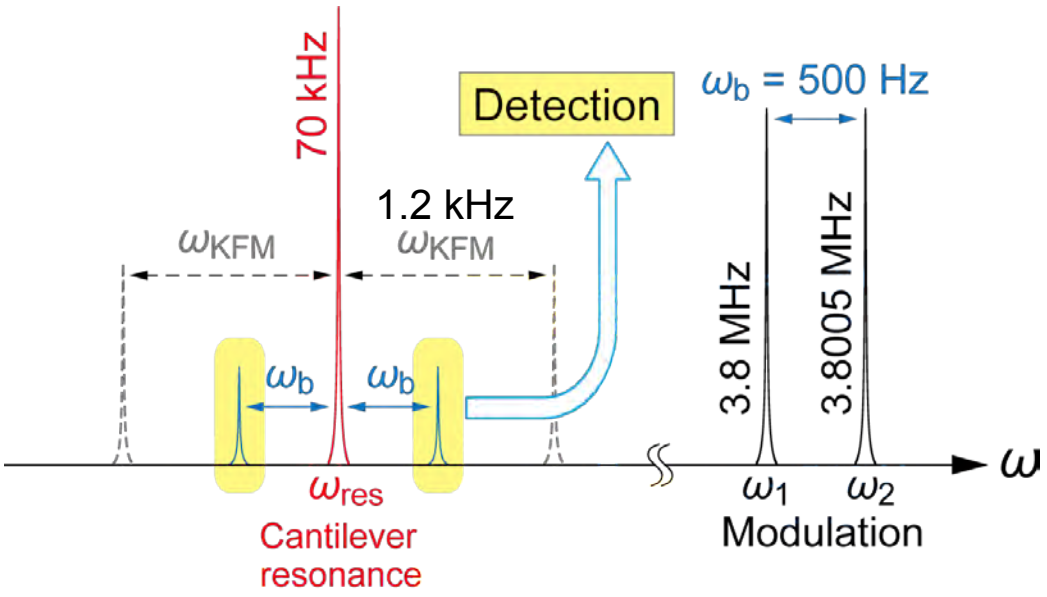
Appl. Phys. Lett. 102, 013115 (2013).

Electrostatic Force Microscopy on Carbon Nanotubes

Experimental Conditions



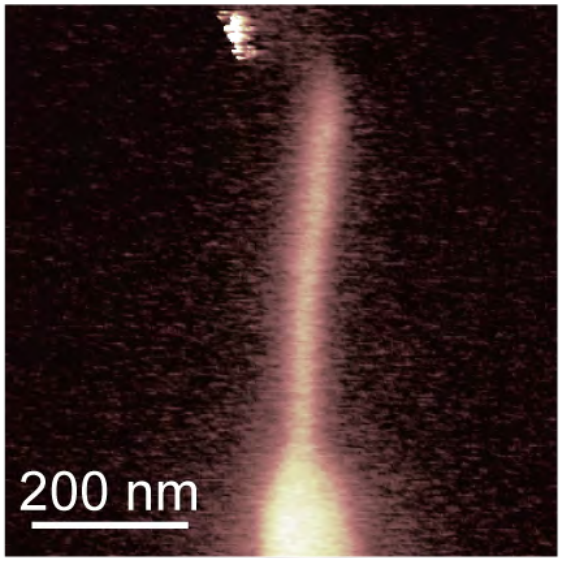
- Cantilever
  - Spring constant: 2 N/m
  - Resonance frequency: 70 kHz
  - Oscillation amplitude: 15 nm_{p-p}
  - Pt-coated
- In vacuum (~10^{-4} Pa)
- Acquisition time per image: 45 min



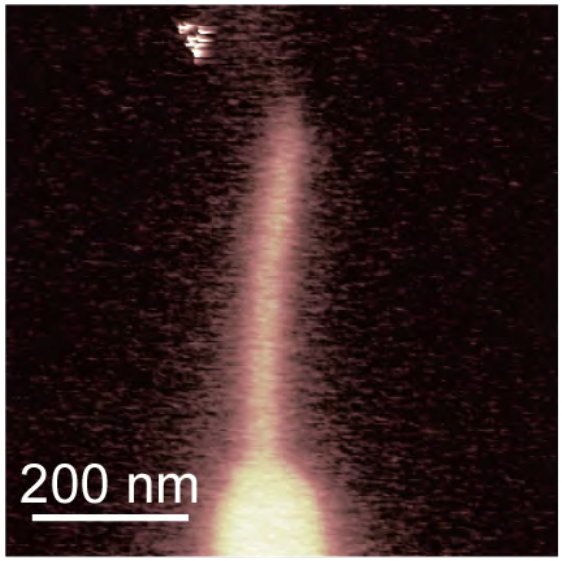
Appl. Phys. Lett. 102, 013115 (2013).

Electrostatic Force Microscopy on Carbon Nanotubes

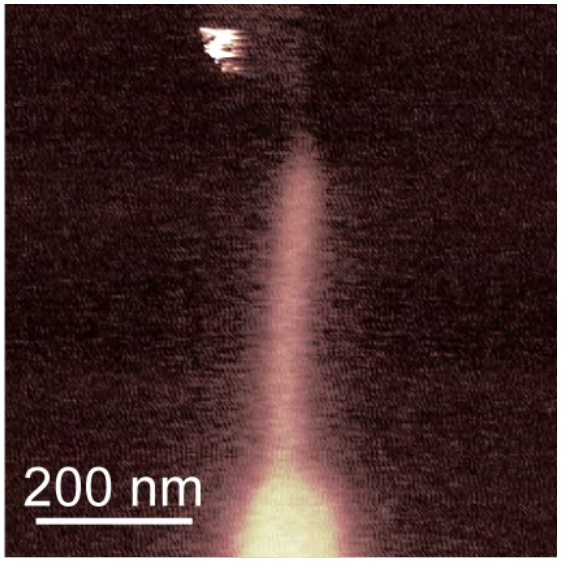
FM-HF-EFM image



V_{GS} = -3 V

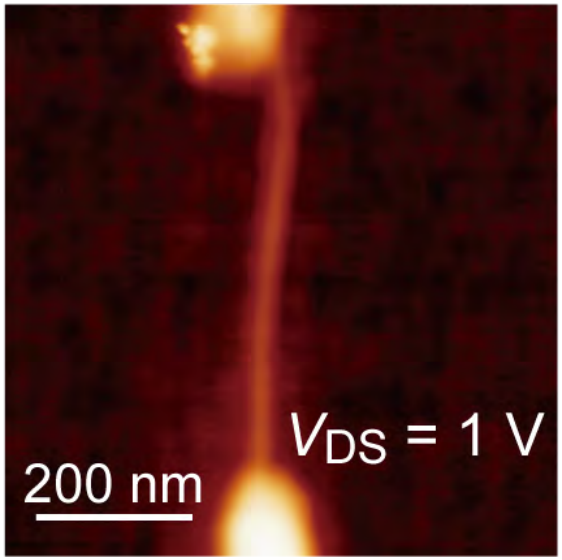


V_{GS} = 0 V

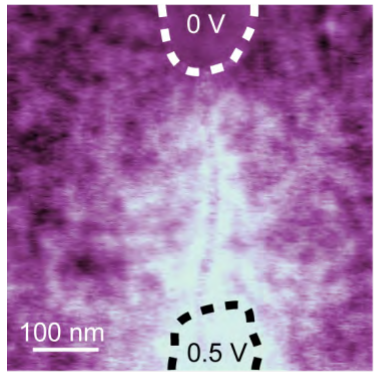


V_{GS} = 3 V

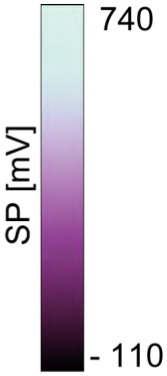
Topographic image



- FM-HF-EFM images were less affected by background trapped charges.



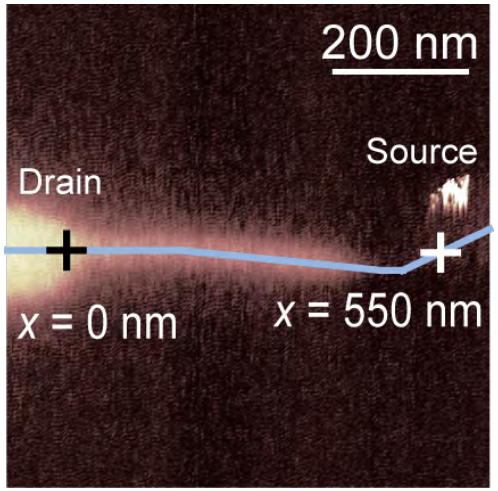
FM-KFM image



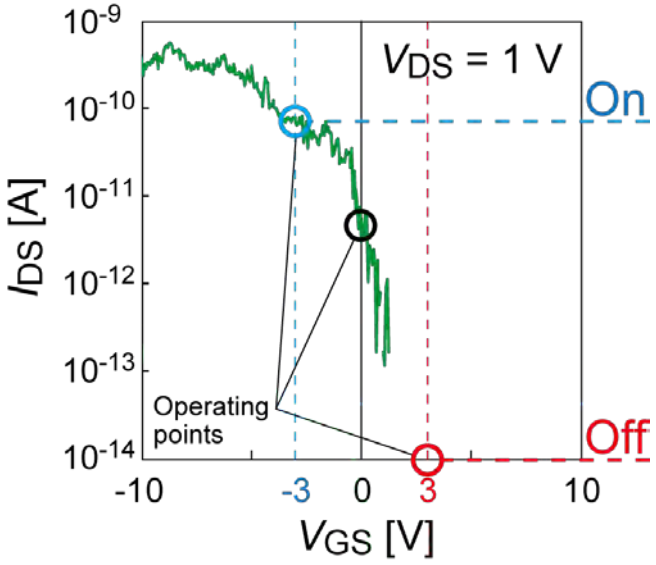
Appl. Phys. Lett. 102, 013115 (2013).

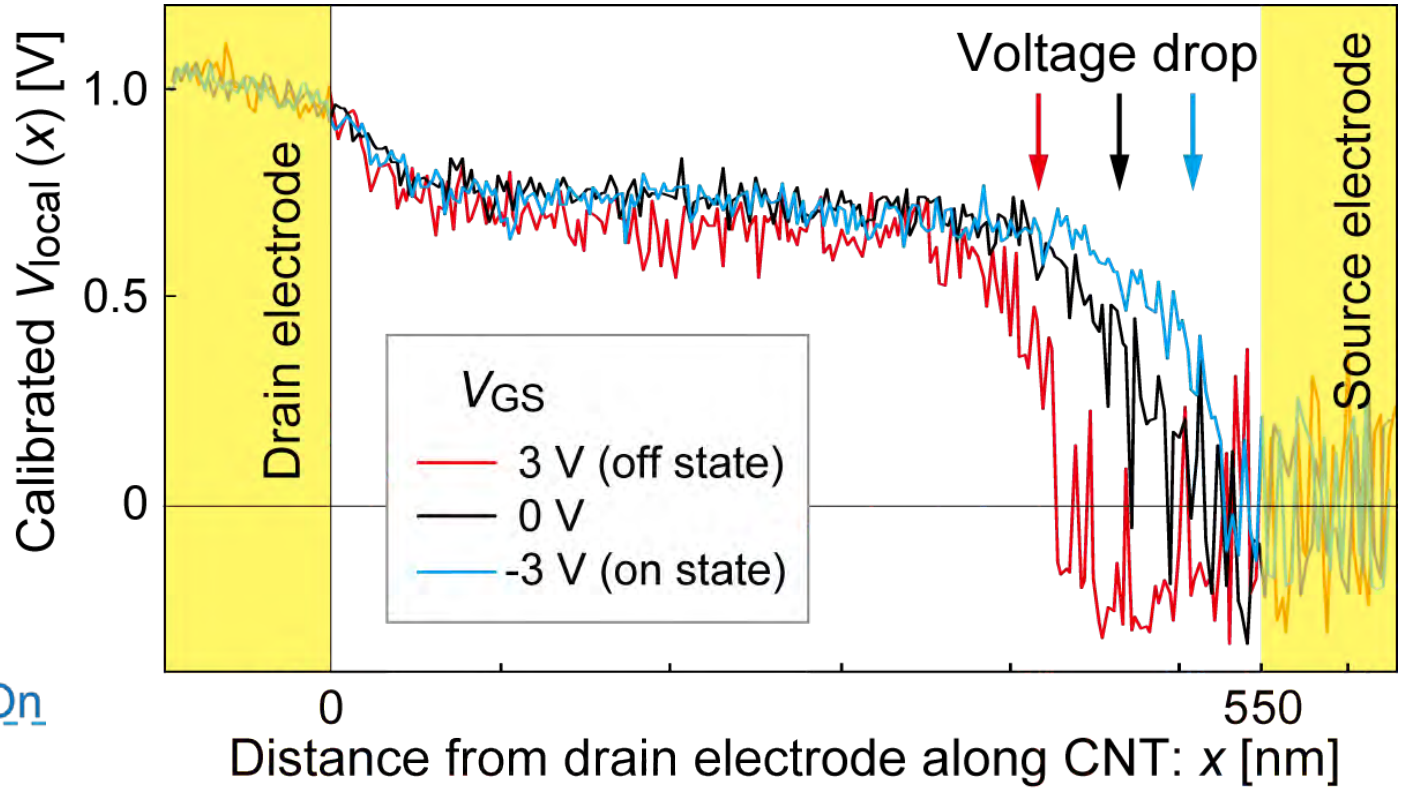
Electrostatic Force Microscopy on Carbon Nanotubes

- Cross-sectional profiles of FM-HF-EFM along CNT channel



FM-HF-EFM



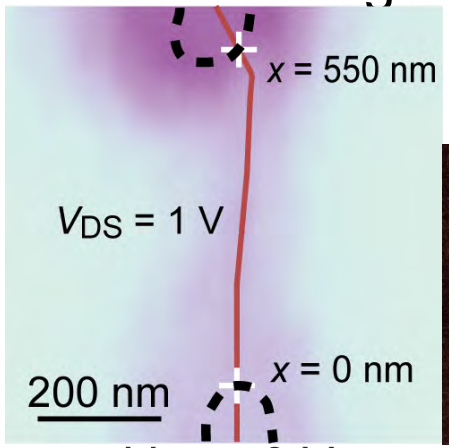


Electrical characterization of (quasi)-one-dimensional nanomaterials

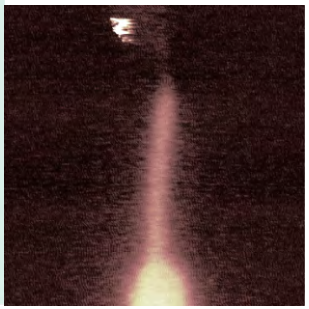
Appl. Phys. Lett. 102, 013115 (2013).

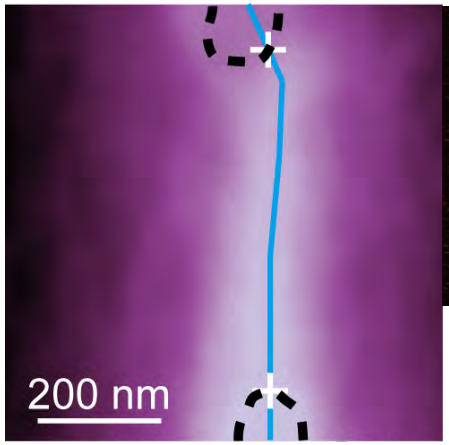
Electrostatic Force Microscopy on Carbon Nanotubes

- FM-KFM images



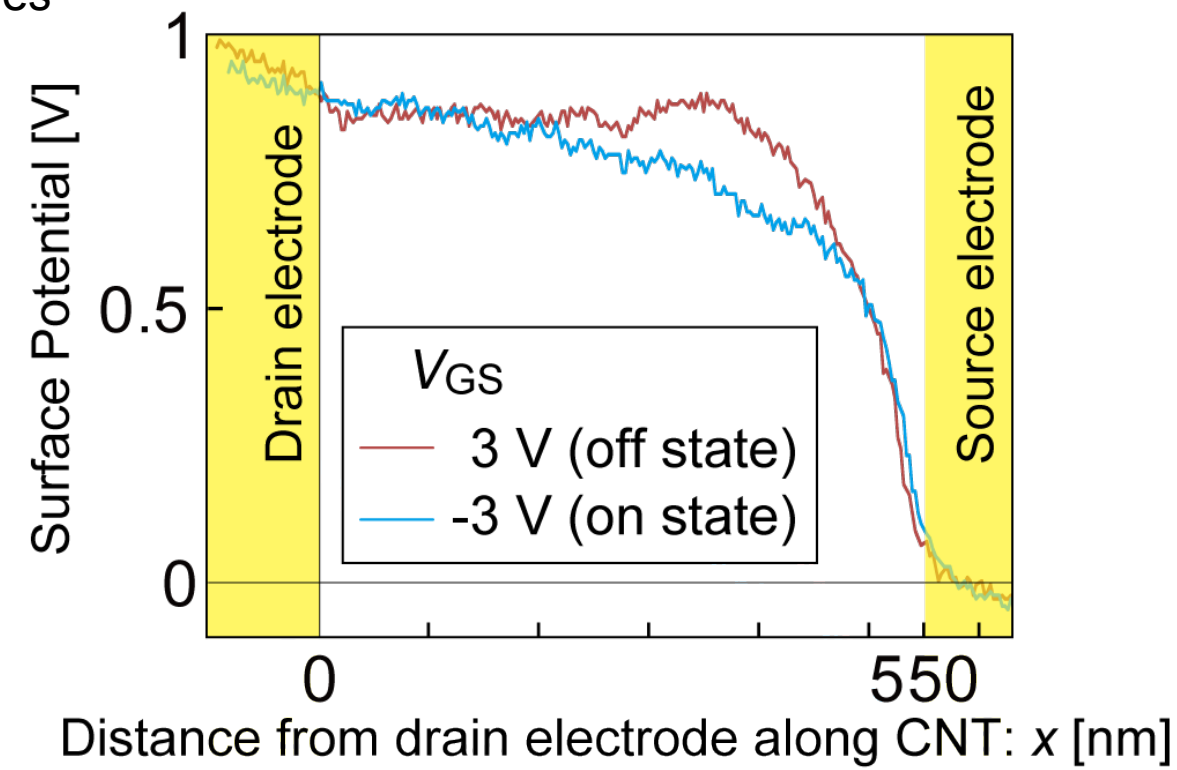
- FM-HF-EFM images





Degradation of spatial resolution

- Cross-sectional profiles of FM-KFM along CNT channel

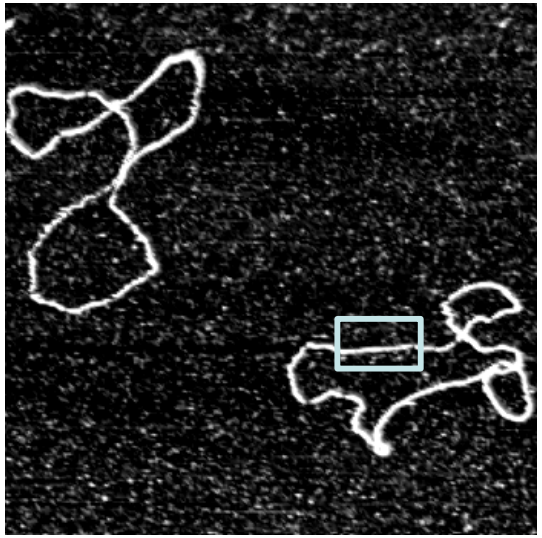


The dependence of the location of potential drop on gate voltage was not clearly observed.

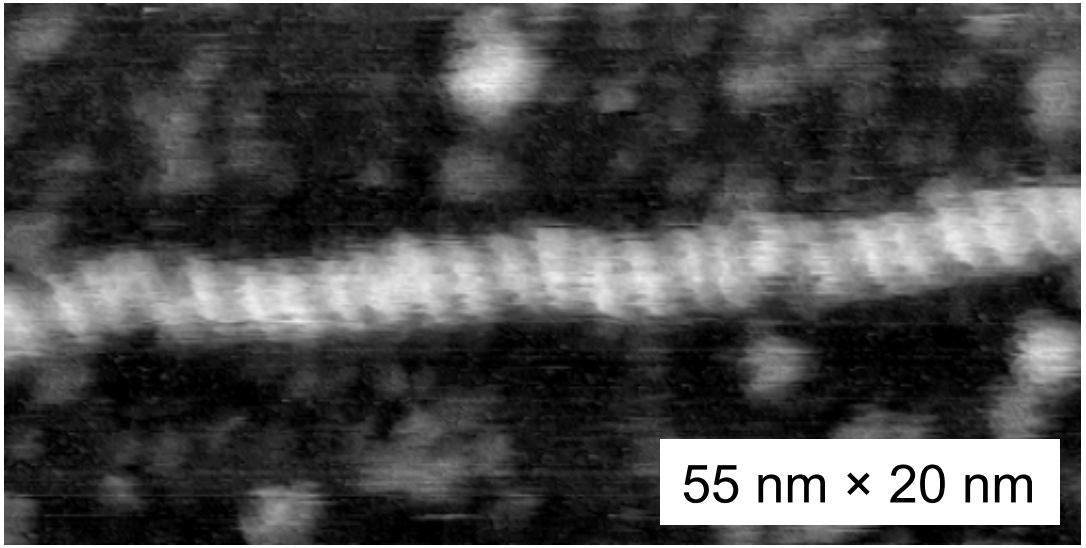
Appl. Phys. Lett. 102, 013115 (2013).

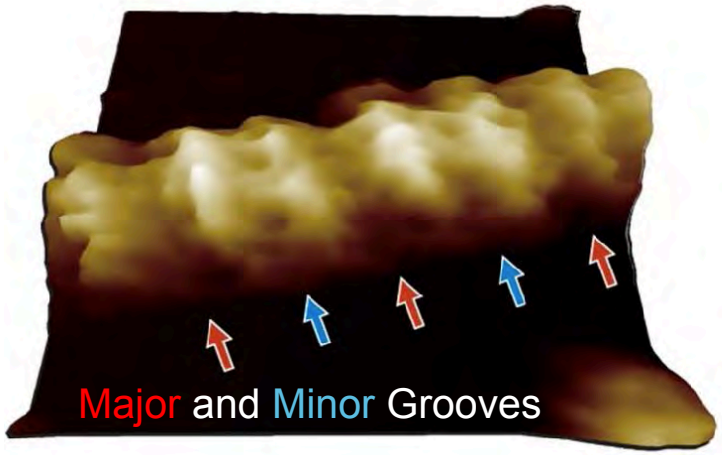
FM-AFM Imaging of DNA on Mica

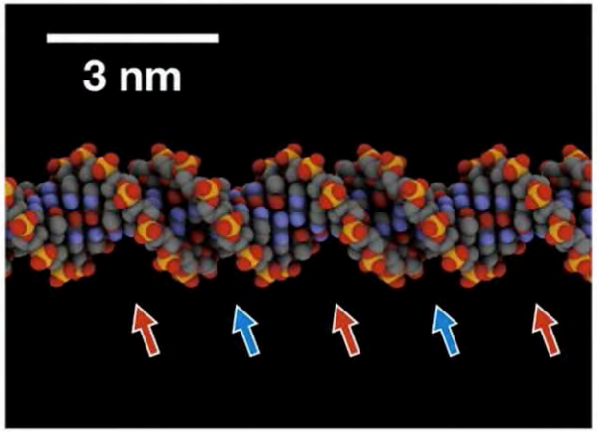
DNA on Mica imaged in 50 mM $NiCl_2$ Plasmid (pUC18, 2686 bp), Total length: ~1um

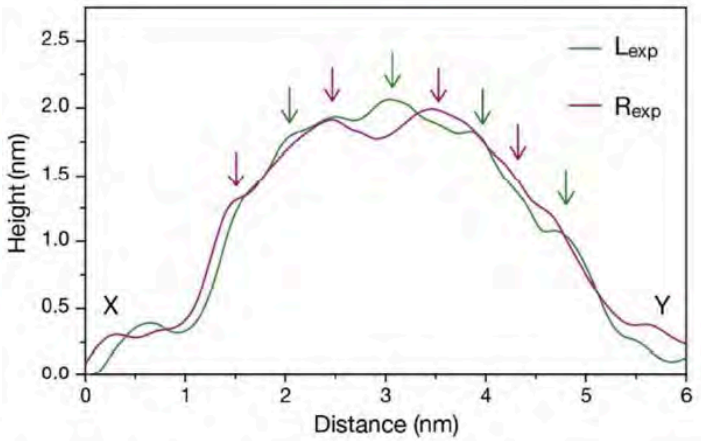


500 nm × 500 nm



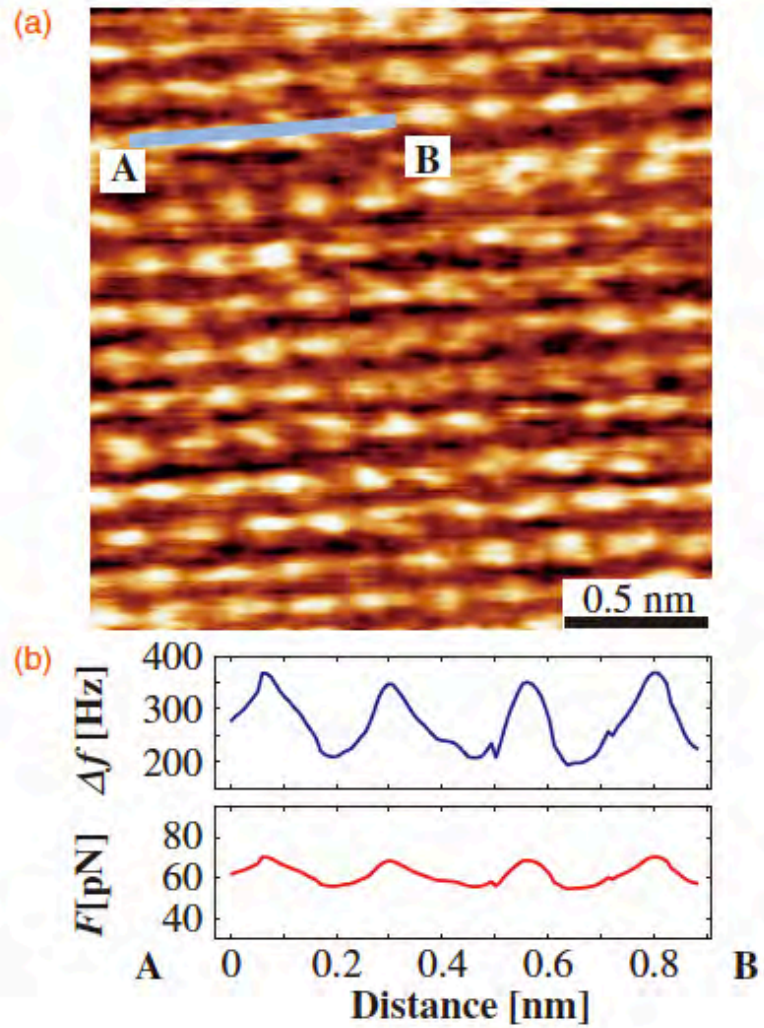


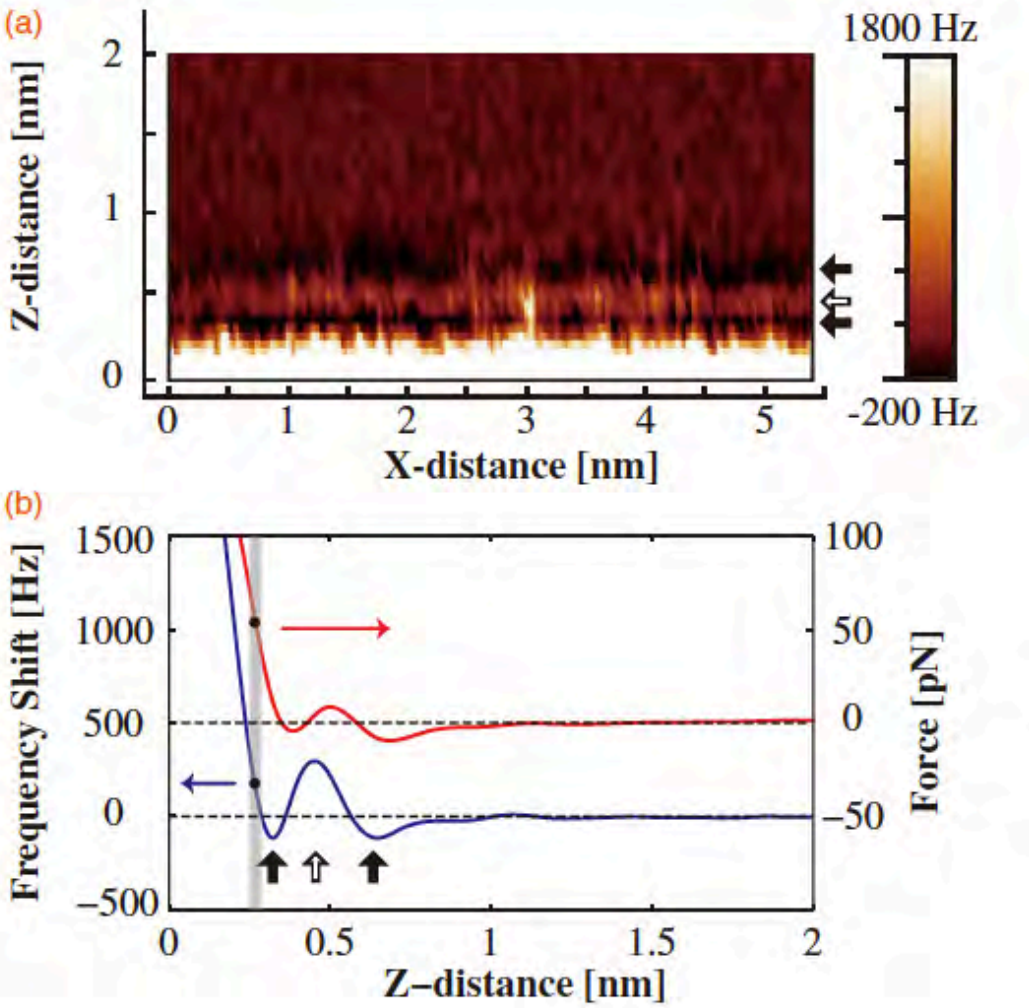




ACS Nano, *in press*.

2D Visualization of Hydration Structures on Graphite





Appl. Phys. Express 4, 125102 (2011).