Carbon nanotube electronics

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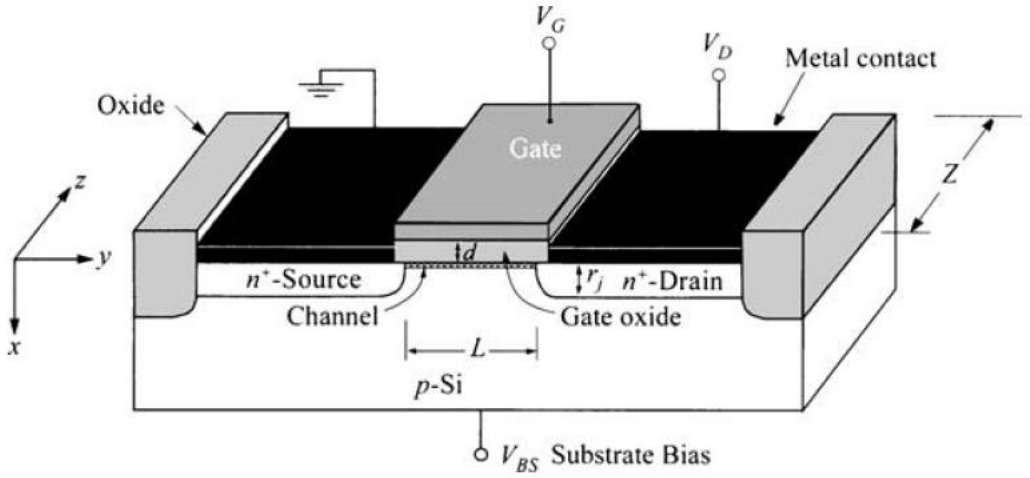
MOLECULAR AND CARBON-BASED ELECTRONIC SYSTEMS
2017-05-31

Introduction

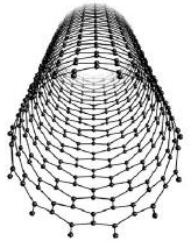
Why carbon nanotube electronics?

- Scaling of electronic devices
- Fundamental limits to the size of Si devices



New technology

Existing technology, new materials



Carbon nanotubes!

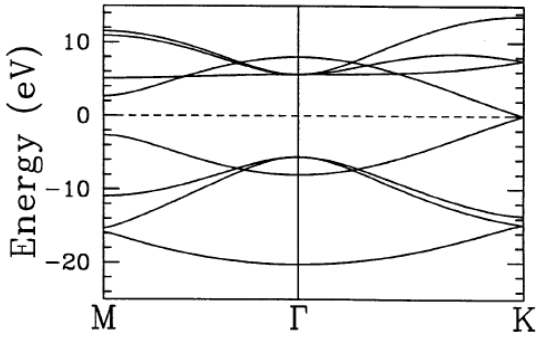
J-C. Charlier, Rev. Mod. Phys. **79**, 677-732 (2007)
P. Avouris and J. Chen, Materials Today **9**, 46-54 (2006)
Physics of Semiconductor Devices, 3rd ed., S.M. Sze and K.K. Ng (2006)

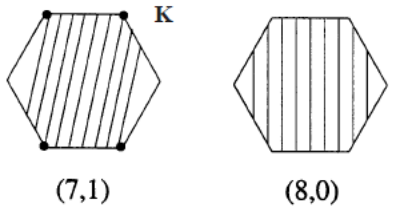
Background

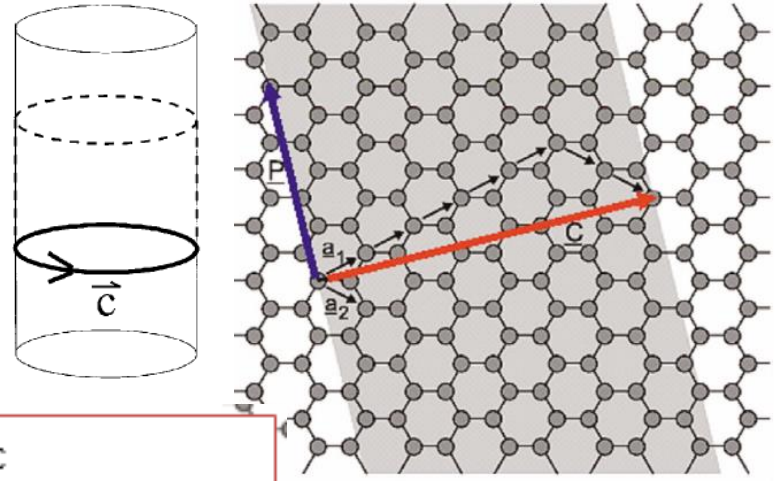
Electronic structure

- Chirality vector $\boldsymbol{C = na_1 + ma_2}$
- Circumferential component of wave vector

$$\boldsymbol{k_C \cdot C = 2p}$$







$n = m$: metallic
$n - m = 3i$: small gap
$n - m \neq 3i$: semiconductor

- Diameter-dependent bandgap

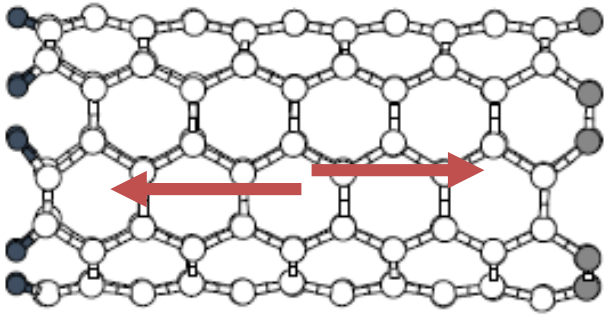
$$\mathrm{E}_g \propto 1/d_{CNT}$$

P. Avouris and J. Chen, Materials Today **9**, 46-54 (2006)
S.G. Louie, Topics in Applied Physics **80**, 113-145 (2001)

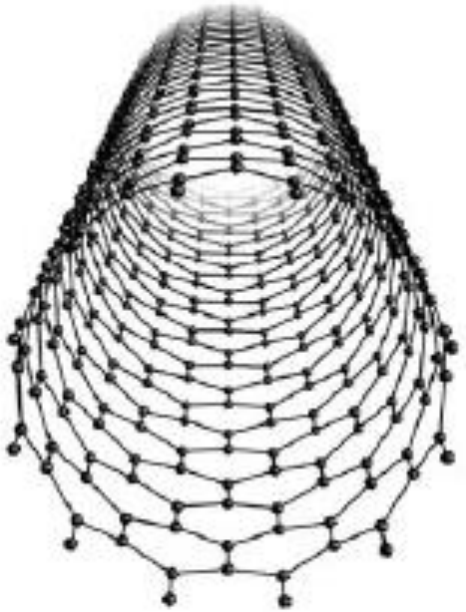
Background

Transport properties

- No boundary scattering



- Mean free paths ~ µm
- Mobilities ~ 100 000 cm^2/Vs



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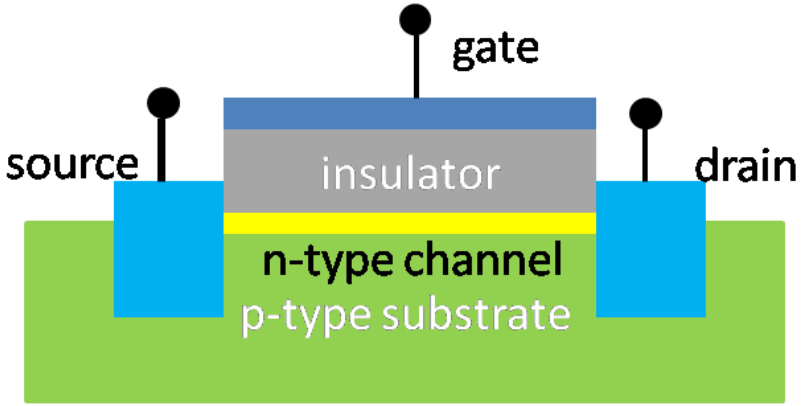
Carbon nanotube FETs

Composition



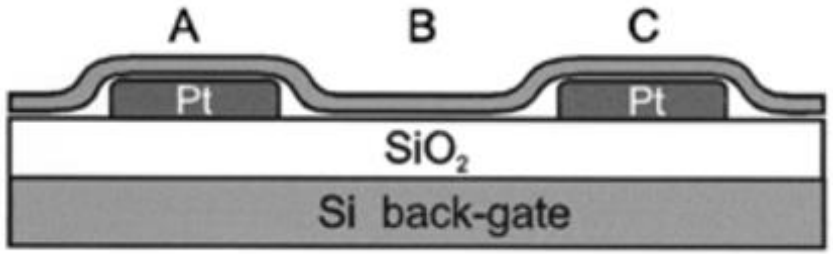
Field-effect transistor

Gate voltage controls shape and conductivity of channel

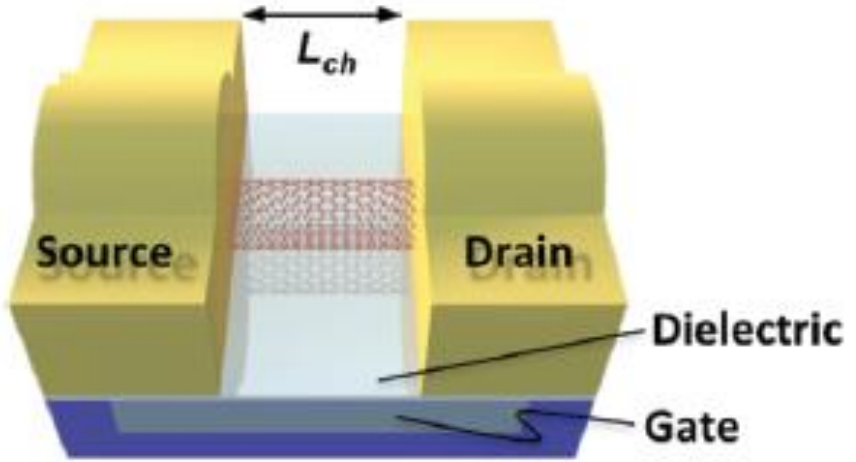
https://en.wikipedia.org/wiki/Organic_field-effect_transistor

Carbon nanotube FETs

Composition



CNT on top of electrodes
- high contact resistances…



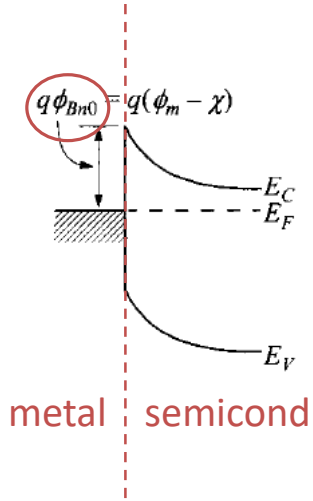
Electrodes on top of CNTs
I_{ON}/I_{OFF} up to 10^6

P. Avouris and J. Chen, Materials Today **9**, 46-54 (2006)

Carbon nanotube FETs

Characteristics

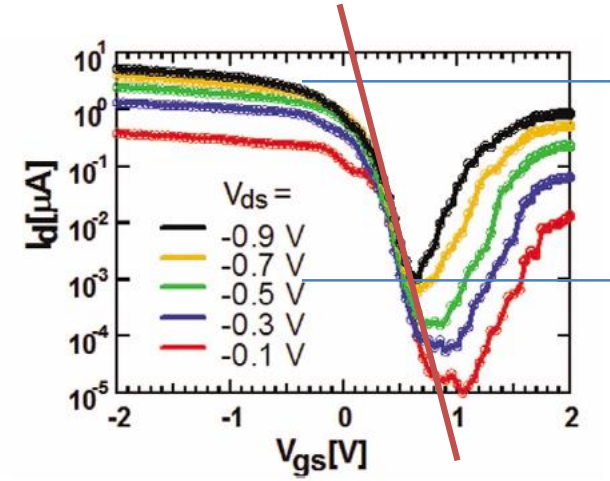
Schottky barrier



Smaller for larger CNT diameter

want as small as possible

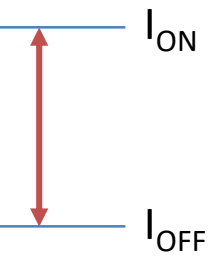
Subthreshold slope (SS)



$$SS = \frac{1}{d\log_{10} I_d / dV_{gs}}$$

want as high as possible

ON/OFF ratio (I_{ON}/I_{OFF})



High ON current and low OFF current (leakage current) important

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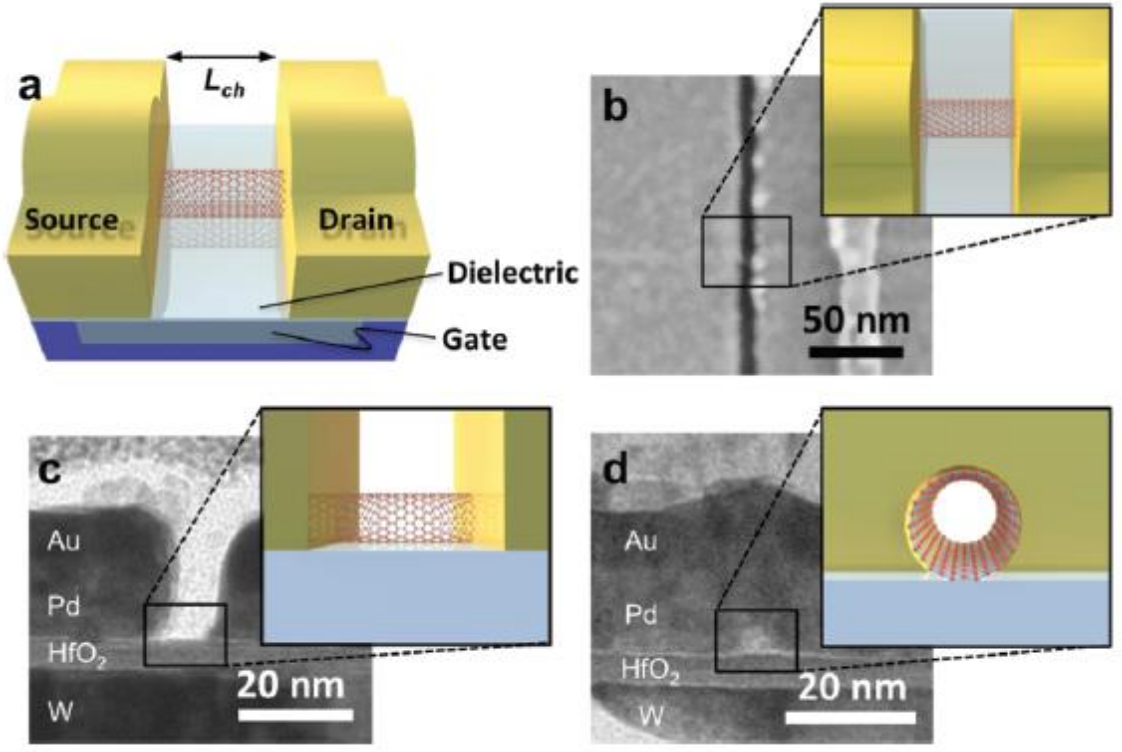
Physics of Semiconductor Devices, 3rd ed., S.M. Sze and K.K. Ng (2006)

Carbon nanotube FETs

Sub-10 nm transistor

Schematic



Top

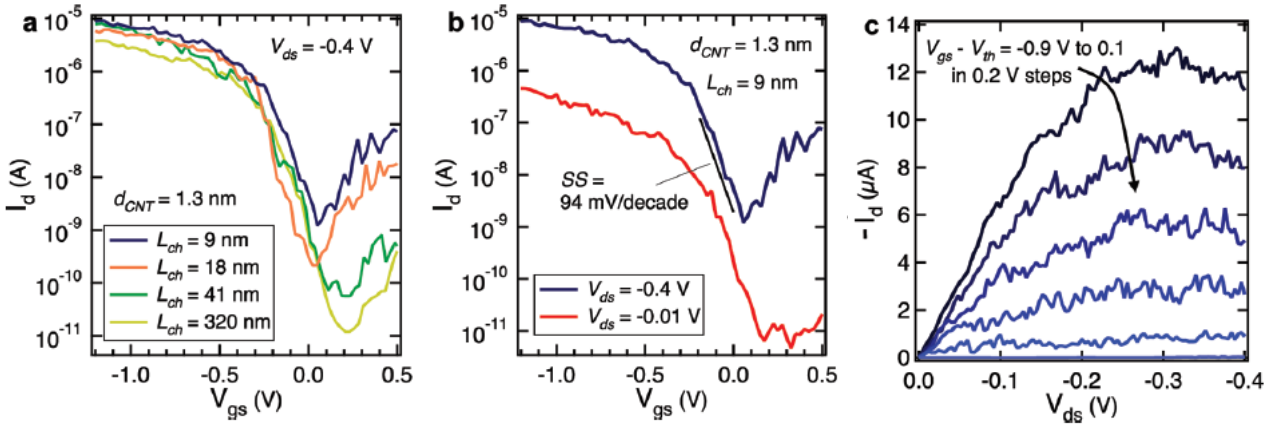
Cross section

Cross section

A.D. Franklin *et al.*, Nano Letters **12**, 758-762 (2012)

Carbon nanotube FETs

Sub-10 nm transistor



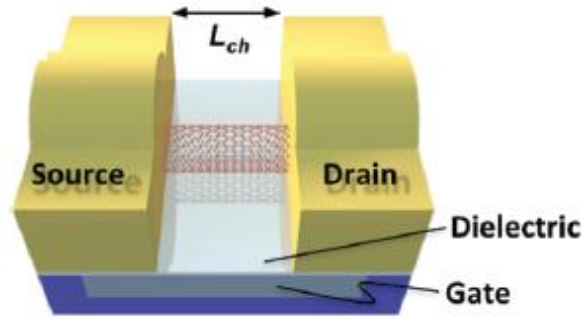
I_d for different L_{ch}

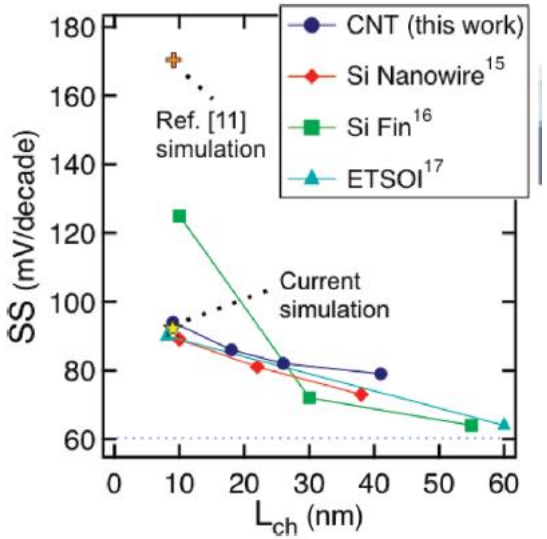
SS in off-state (L_{ch}= 9 nm)

On-state char. (L_{ch}= 9 nm)

→ Better SS than expected + current saturation

A.D. Franklin *et al.*, Nano Letters **12**, 758-762 (2012)

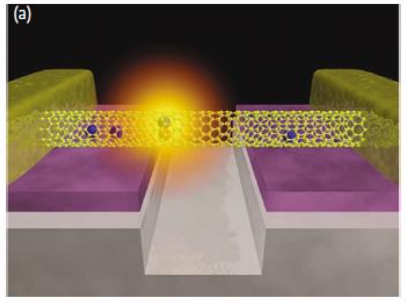




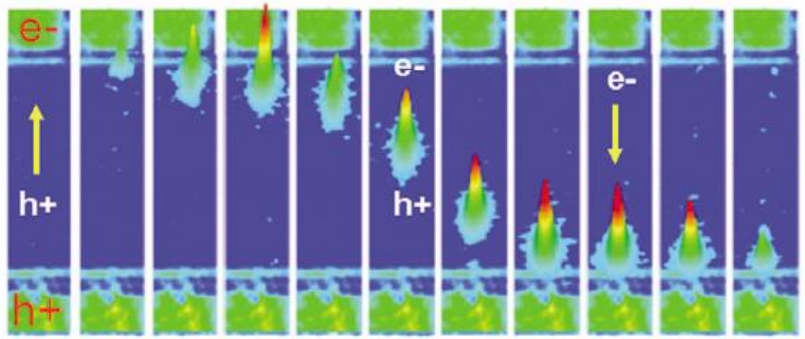
Performance and scaling compared to Si devices

Other applications

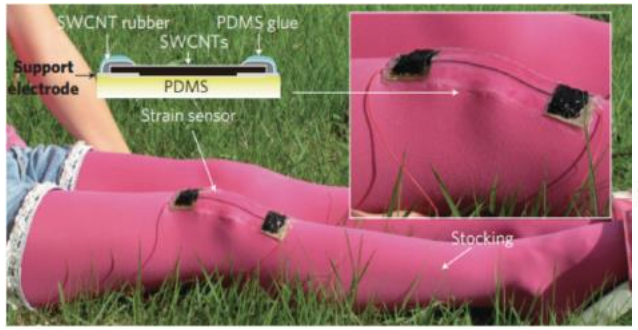
Optoelectronic devices and stretchable electronics

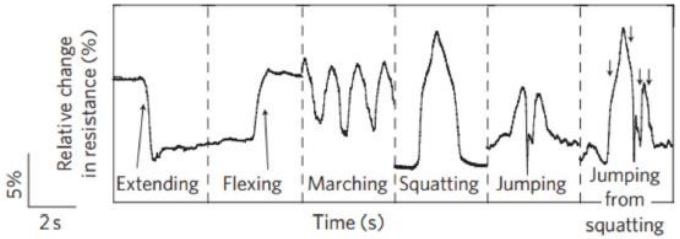


Place of recombination of electrons and holes controlled by V_g

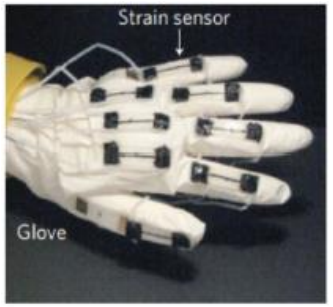


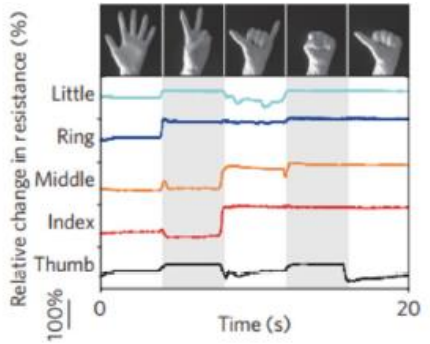
Movable light source!





Wearable piezoresistive sensor

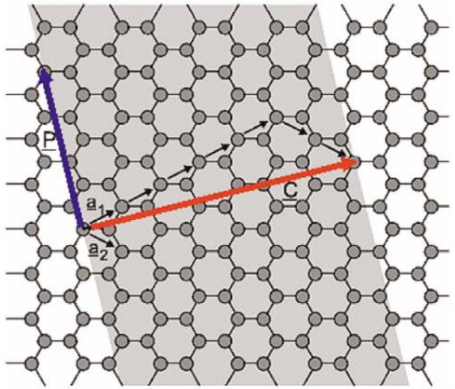




Y.S. Rim *et al*., Adv. Mat. **28**, 4415-4440 (2016)
P. Avouris and J. Chen, Materials Today **9**, 46-54 (2006)

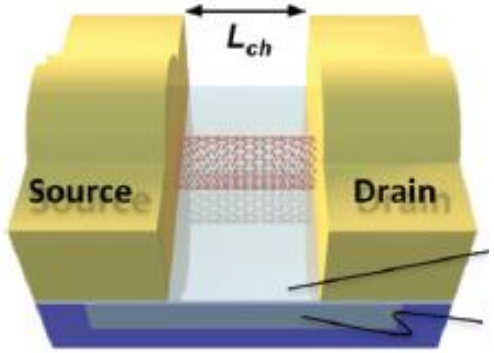
Summary

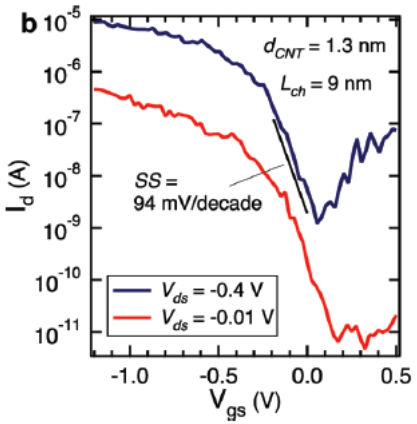
Carbon nanotube electronics



$$C = na_1 + ma_2$$

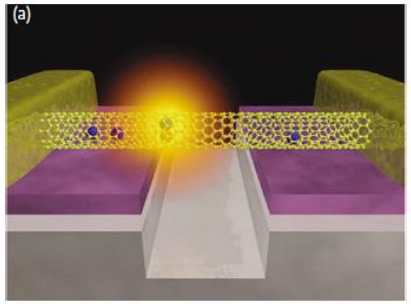
$$E_g \propto 1/d_{CNT}$$



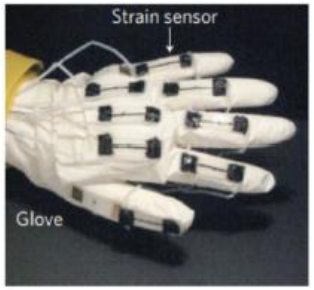


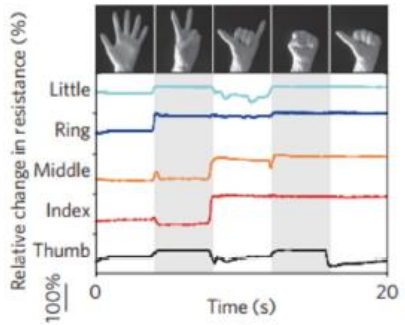
L_{ch} = 9 nm
I_{ON}/I_{OFF} ~10^4
SS = 94 mV/dec

V_g-dependent place of recombination



Resistance change in response to strain





Thank you.

Literature

Sub-10 nm Carbon Nanotube Transistor
A.D. Franklin *et al*., Nano Letters **12**, 758-762 (2012)

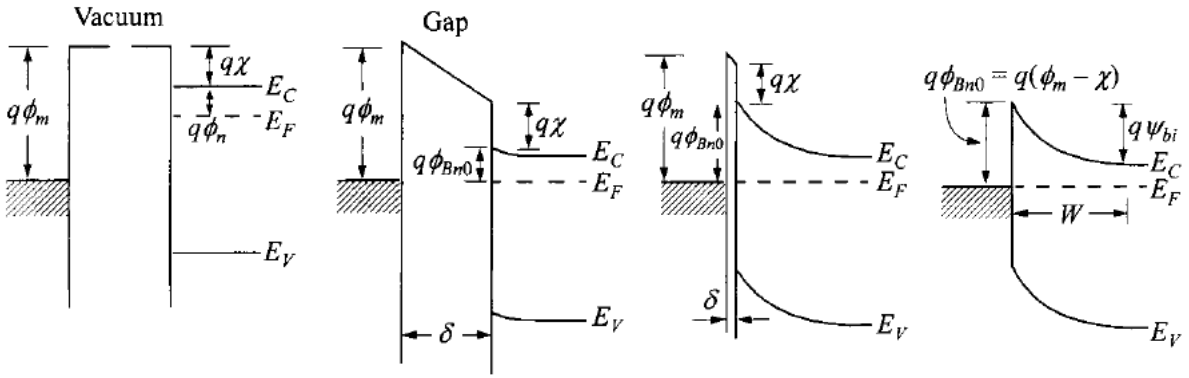
Nanotube electronics and optoelectronics
P. Avouris and J. Chen, Materials Today **9**, 46-54 (2006)

Physics of Semiconductor Devices
S.M. Sze and K.K. Ng, 3rd ed., Wiley (2006)

Electronic Properties, Junctions, and Defects of Carbon Nanotubes
S.G. Louie, Topics in Applied Physics **80**, 113-145 (2001)

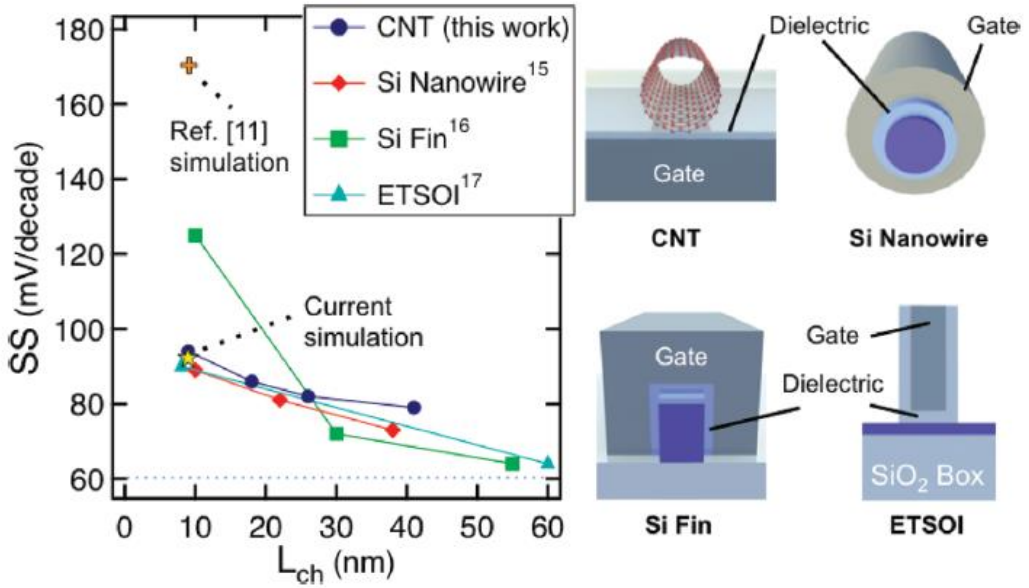
Electronic and transport properties of nanotubes
J-C. Charlier, X. Blase and S.Roche, Reviews of Modern Physics **79**, 677-732 (2007)

Recent Progress in Materials and Devices toward Printable and Flexible Sensors
Y.S. Rim *et al*., Advanced Materials **28**, 4415-4440 (2016)



Schottky barrier formation

Comparison with different Si device structures



A.D. Franklin *et al*., Nano Letters **2**, 758-762 (2012)
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