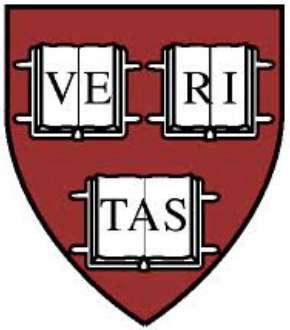


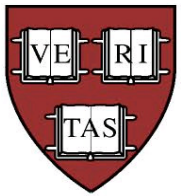
Harvard University
Department of Chemistry and Chemical Biology
Lieber Group

Silicon nanowire based sensors for life-science applications

Steffen Strehle

Outline

- Why are nanowires interesting?
- Lieber Group research
- Nanowire VLS synthesis and device fabrication
- Basics of silicon nanowire sensors
- Sensing of the neurotransmitter dopamine
- Summary/Acknowledgment



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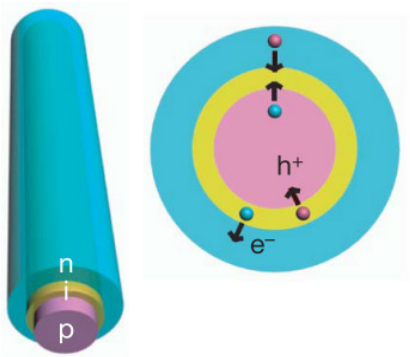
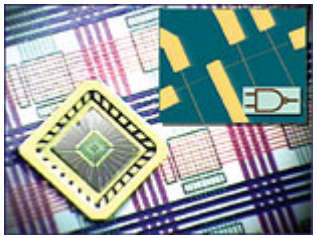
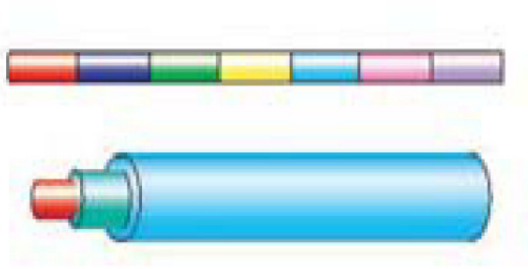
- similar to current electronic devices (i.g. FET) but potentially revolutionary concepts will emerge (i.g. quantum properties)
- nanoscale building blocks with precisely controlled and tunable properties
- best defined and controlled classes of nanoscale building blocks compared to, for example, carbon nanotubes
- serve as a one-dimensional platforms for nanodevices
- demonstrated nanometer-scale applications:



- field-effect transistors (FETs)
- p-n diodes
- light-emitting diodes (LEDs)
- bipolar junction transistors
- complementary inverters
- nano-scale lasers
- complex logic gates
- basic computational circuits
- gas & bio-chemical sensors
- solar cells / thermoelectric devices





Tian, Nature 449 (2007) 885; Lieber, MRS Bulletin,32 (2007) 99

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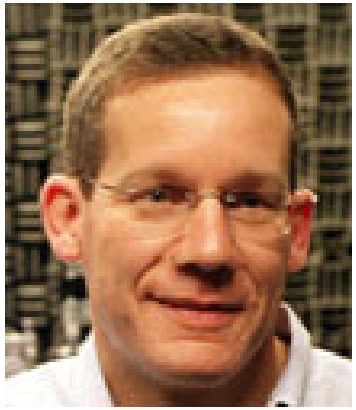
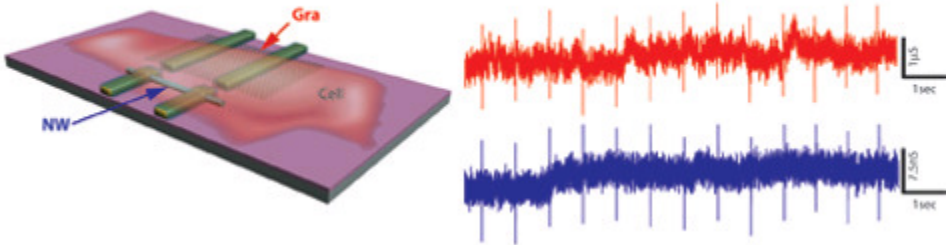


Charles M. Lieber

over 300 papers & 35 patents

- focused on the "bottom-up" paradigm for nanotechnology
- design and synthesis of nanoscale building blocks, elucidation of the fundamental properties
- methods for complex integrated assembly of nanostructures

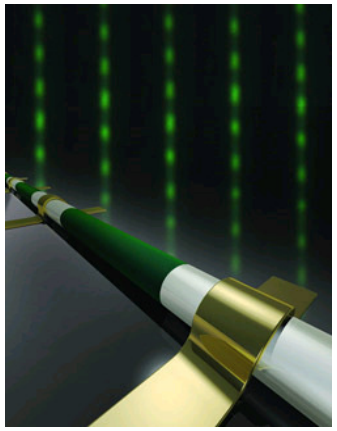
11 grad students
11 PostDocs



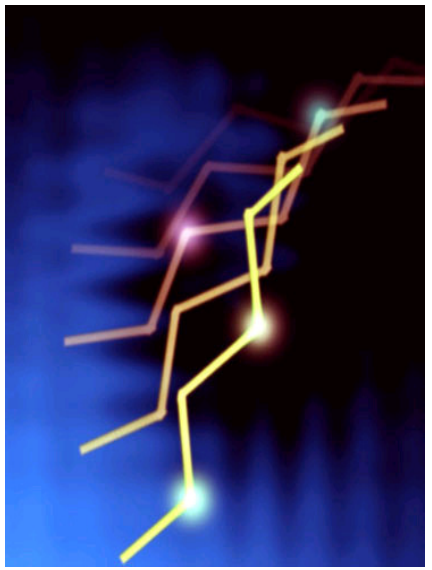
Current fields of research:

- bio-chemical sensors
- cell-nanowire interfaces
- nanowire based solar cells
- logic nanowires circuits
- synthesis principles

http://cmliris.harvard.edu



Nature 430, 61 (2004)]



Nature Nanotechnol. 4, 824-829 (2009) (cover)

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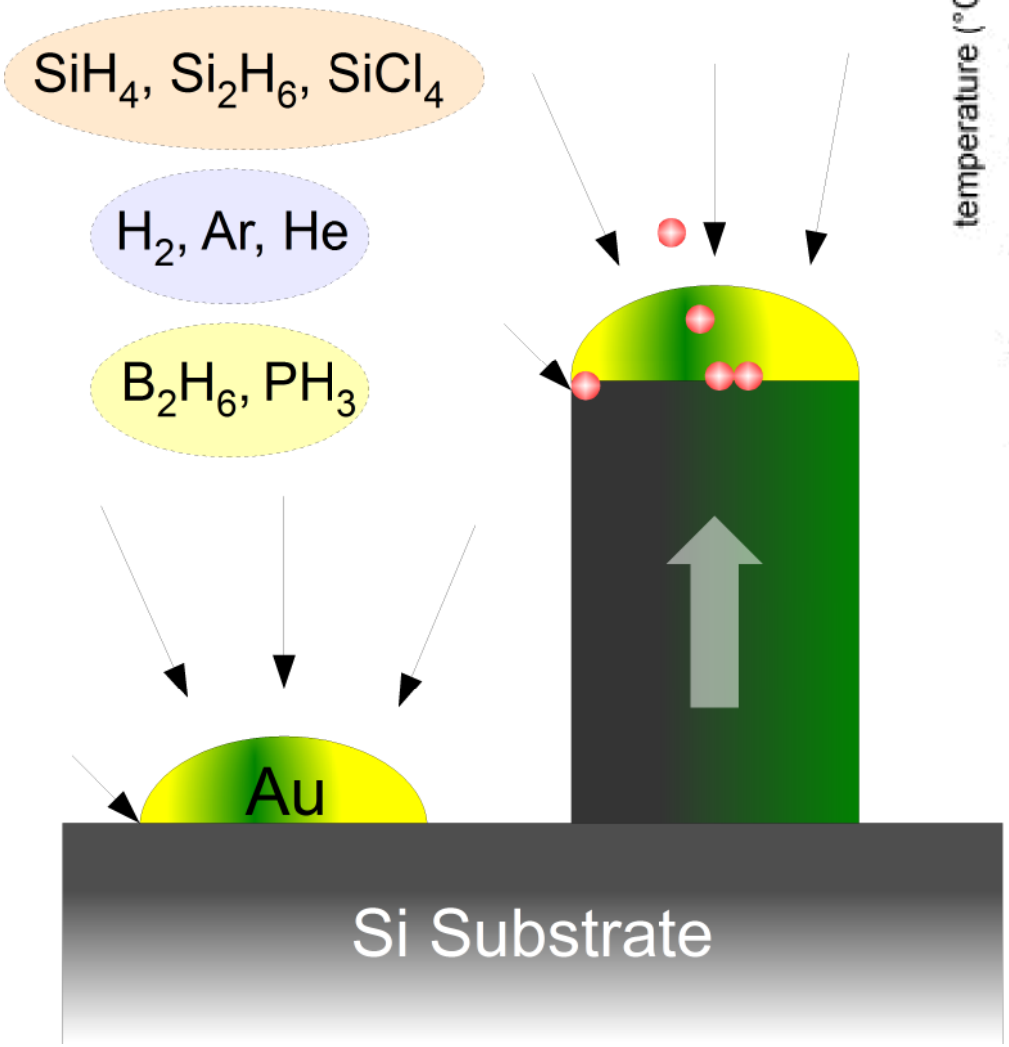
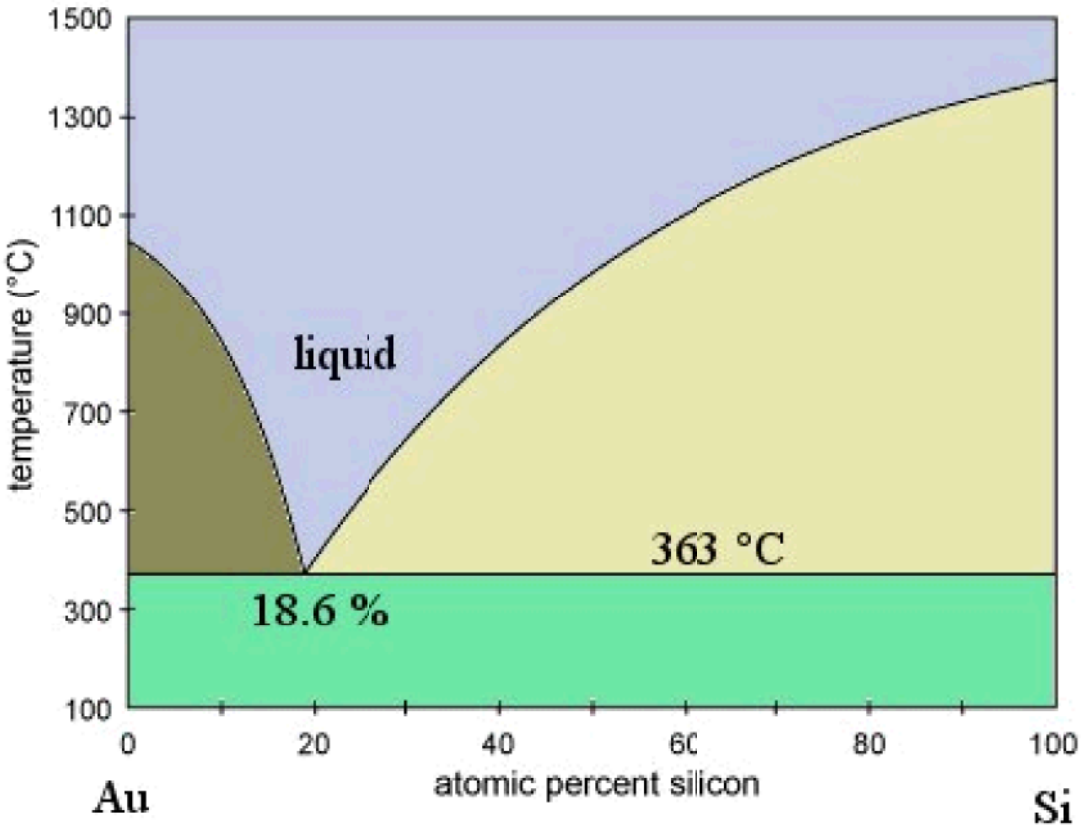
VLS: Vapor-Liquid-Solid

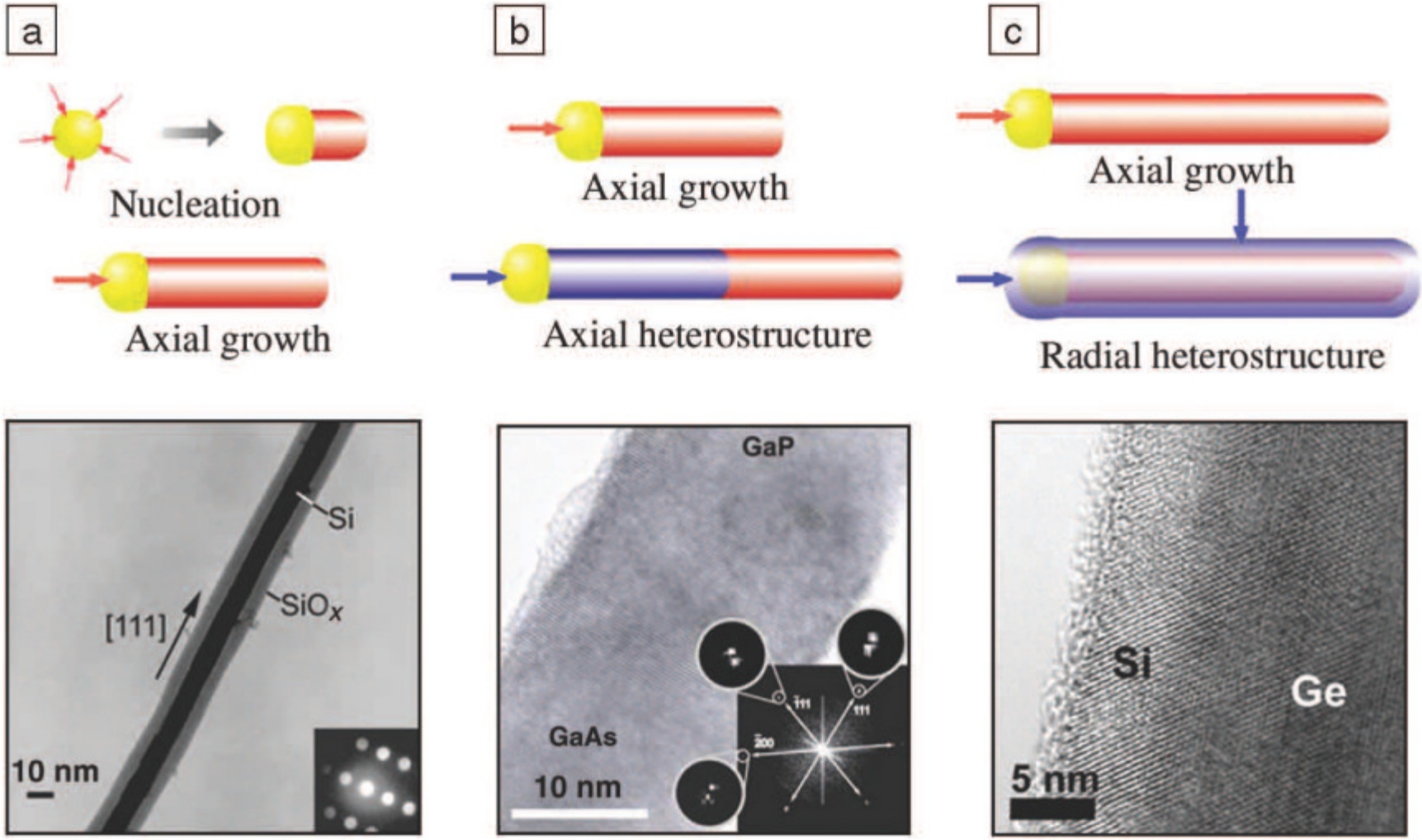
→ metal catalyzed nanowire growth



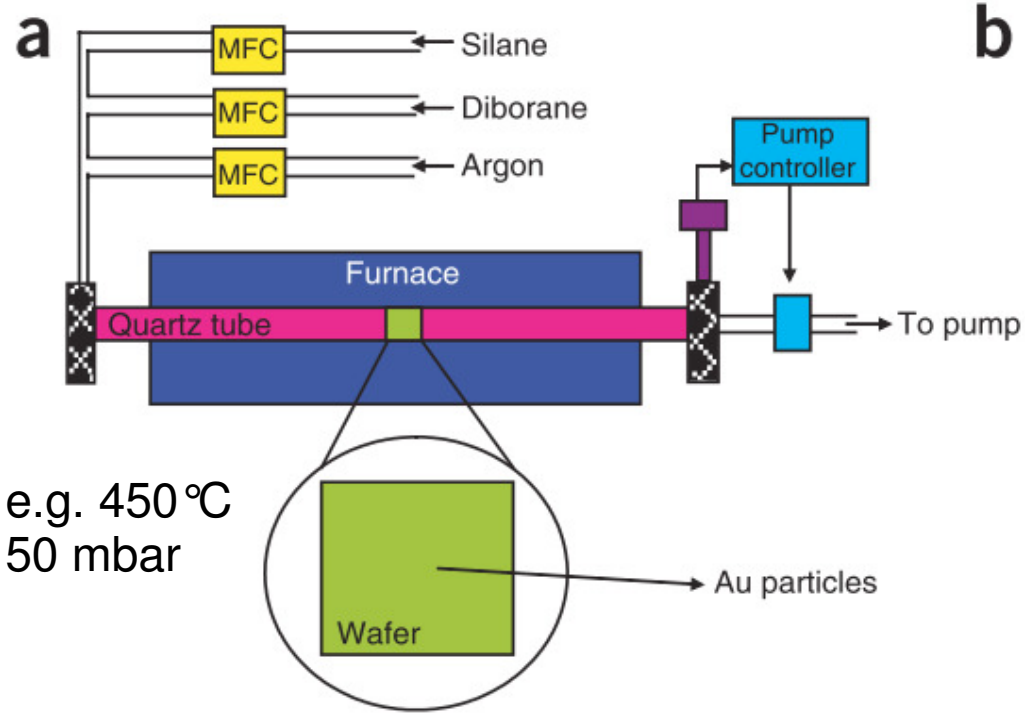


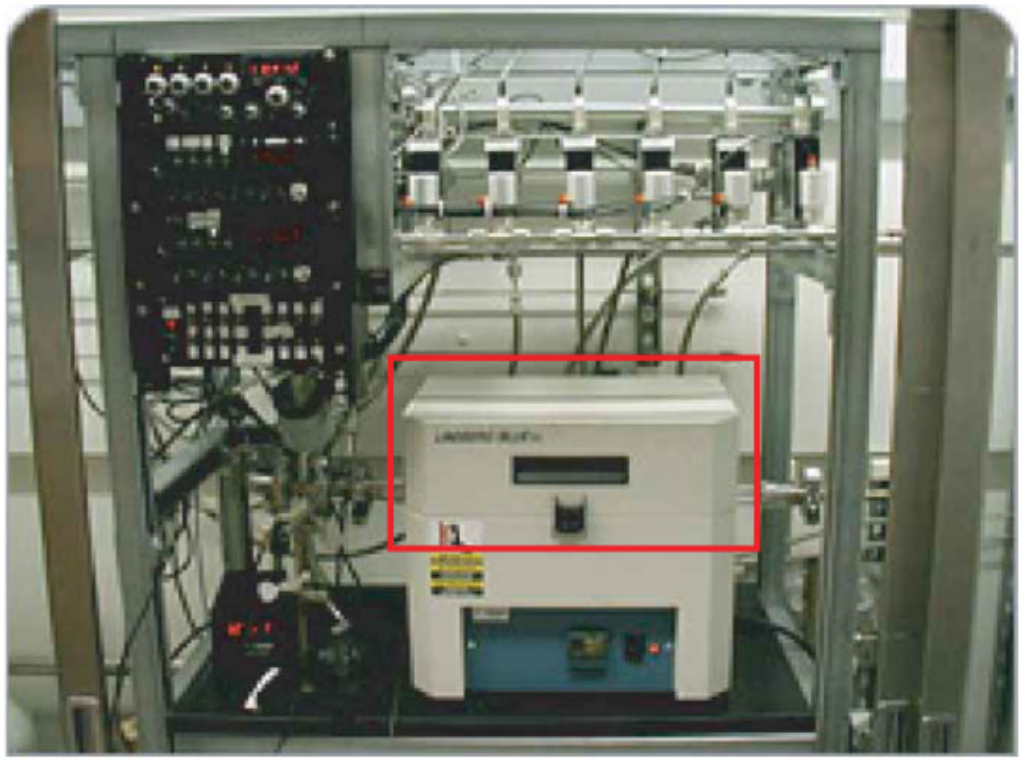
- metal evaporation/colloids
- Au particle size determines wire diameter
- singe crystal wires epitaxial/non-epitaxial
- overcoating leads to tapering
- doping by second gas

- Radial and axial homo- or heterostructures possible

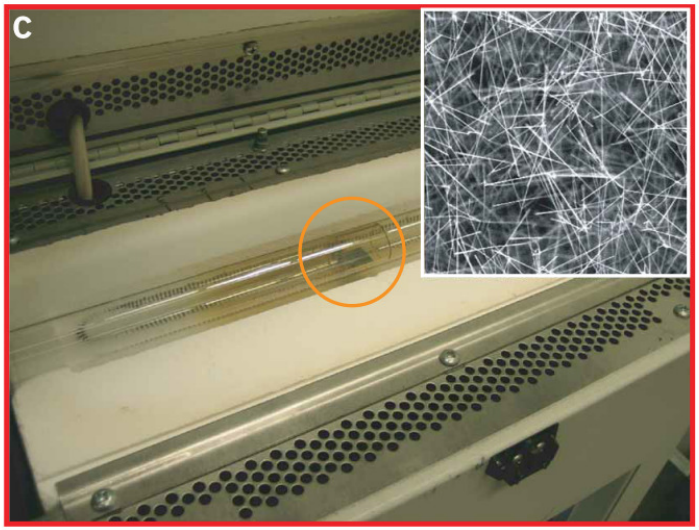


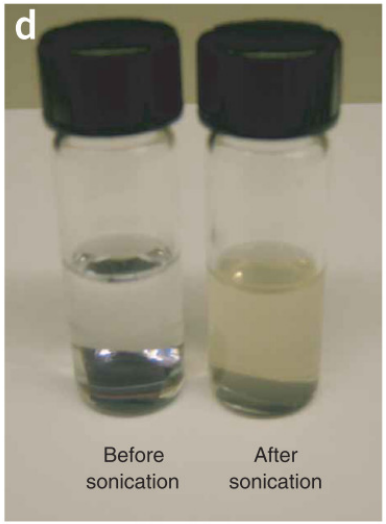
MRS Bulletin, 2003, July, 486





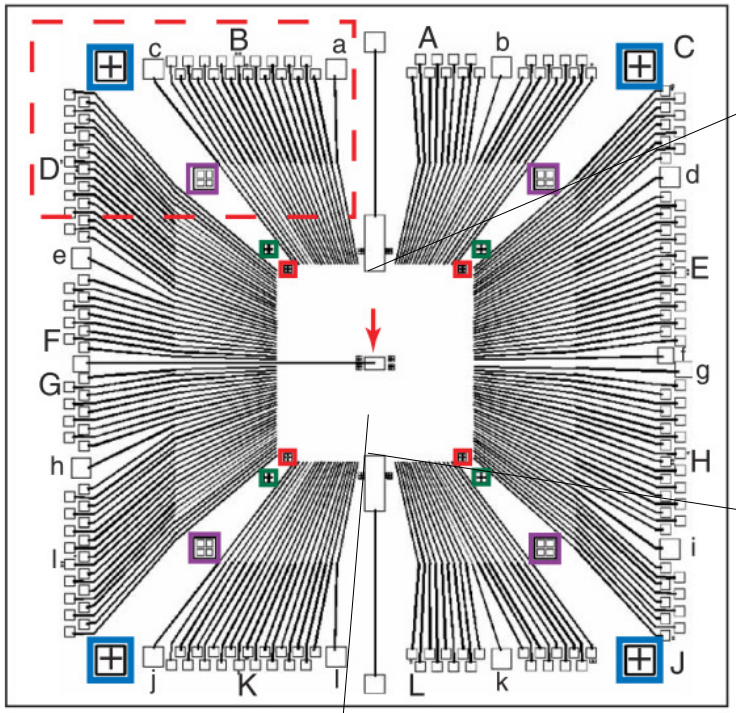
- poly-L-lysine adsorption on substrate
- gold nanoparticle adsorption
- SiNWs CVD growth step
- sonication of growth substrate
- or other transfer techniques

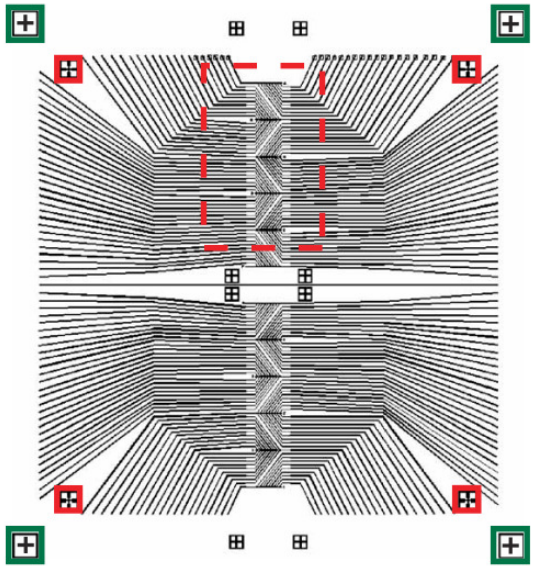


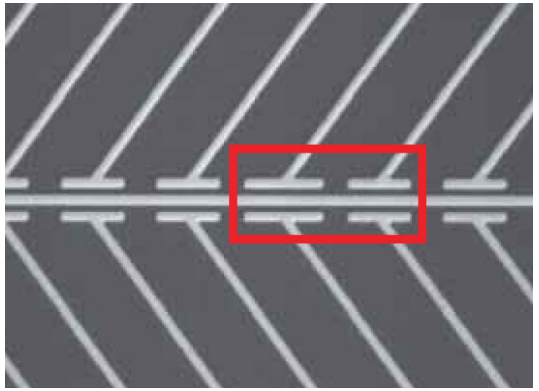


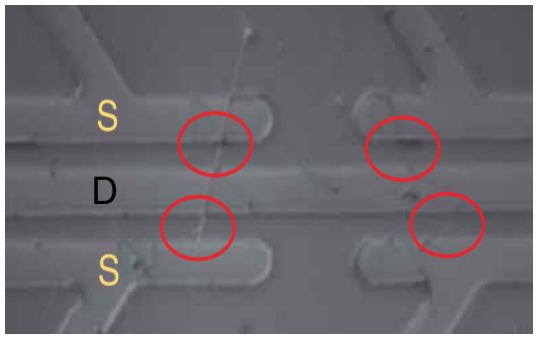
NATURE PROTOCOLS 1 (2006) 1713

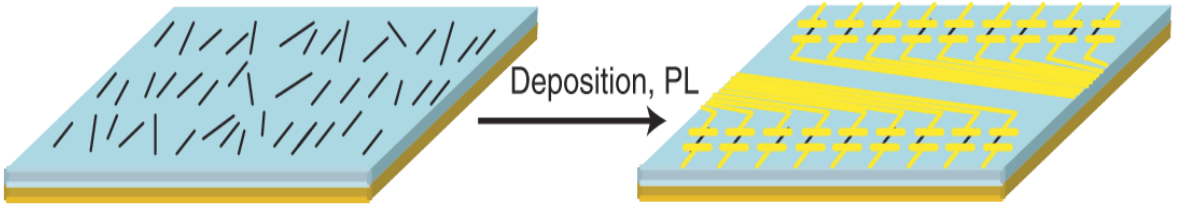
→ device fabrication by micro-technological technologies





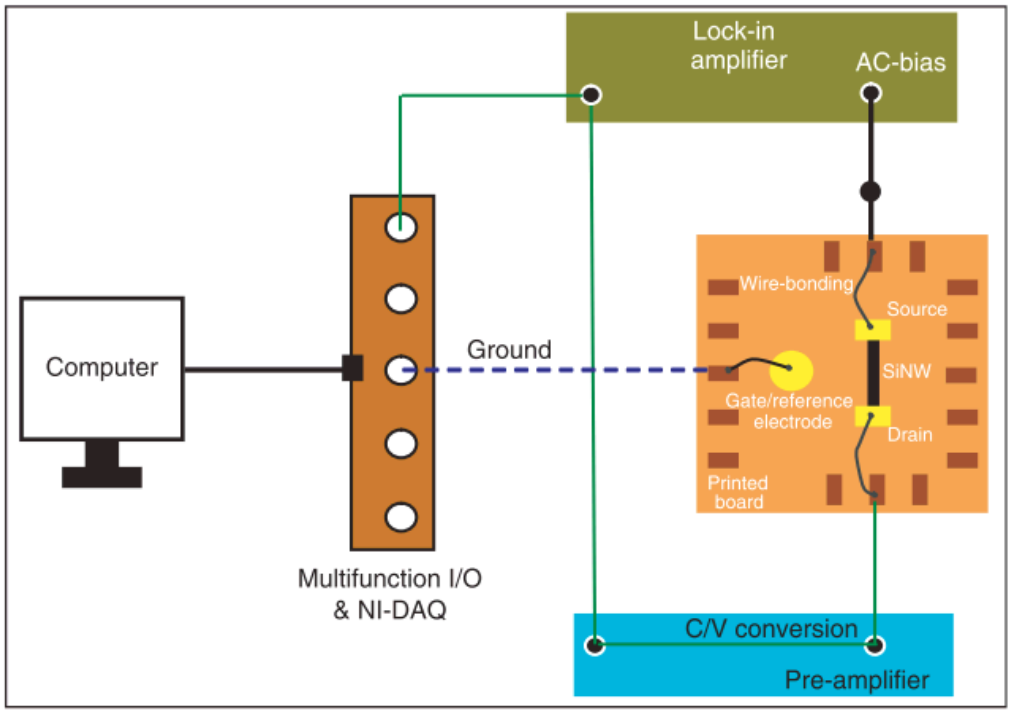


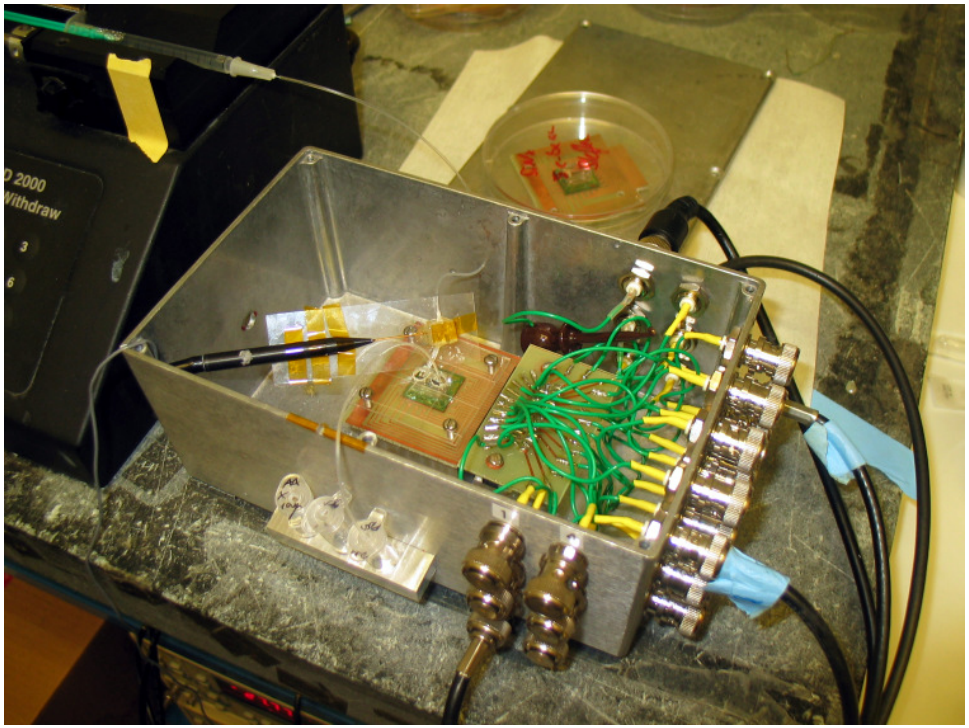


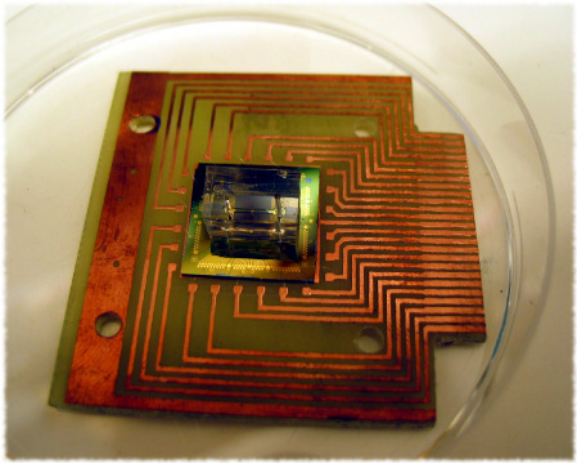


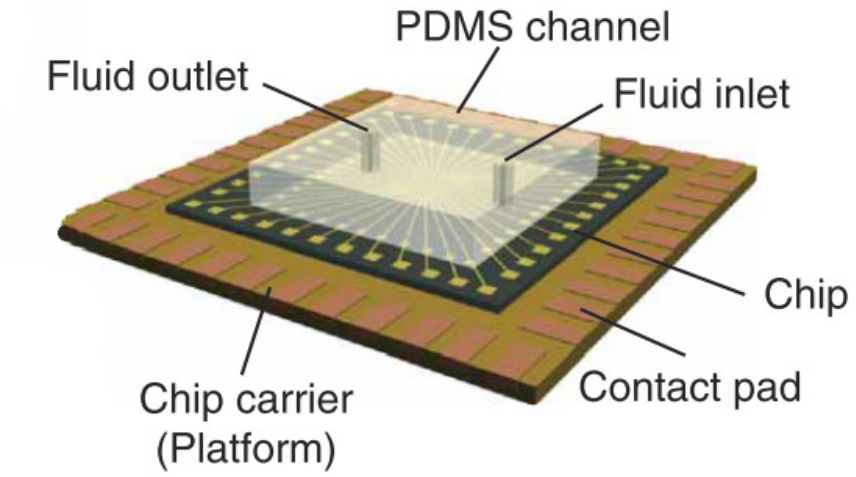
Contacts are made by photo- or e-beam lithography and subsequent metal evaporation

NATURE PROTOCOLS 1 (2006) 1713









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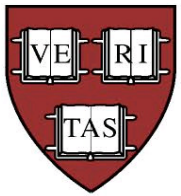

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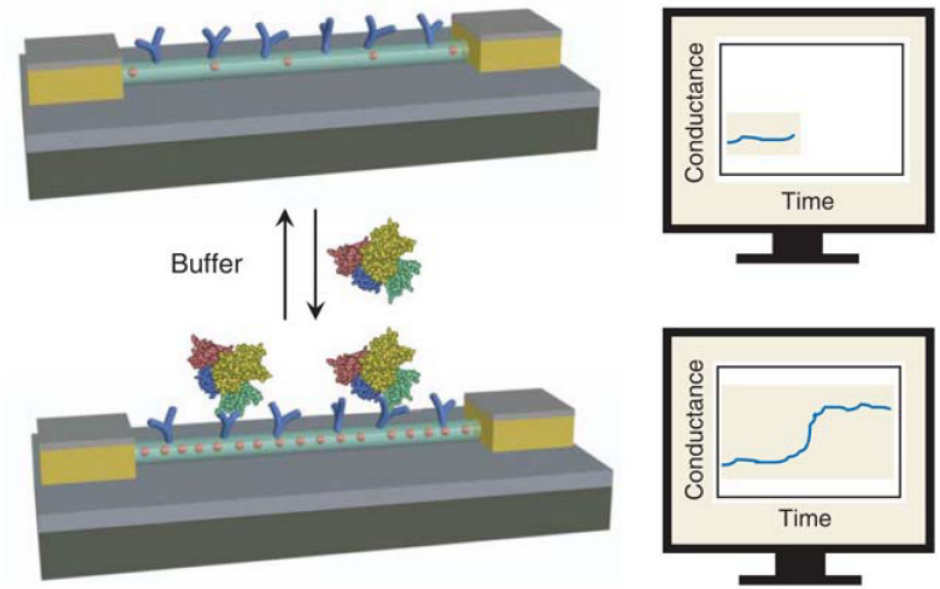
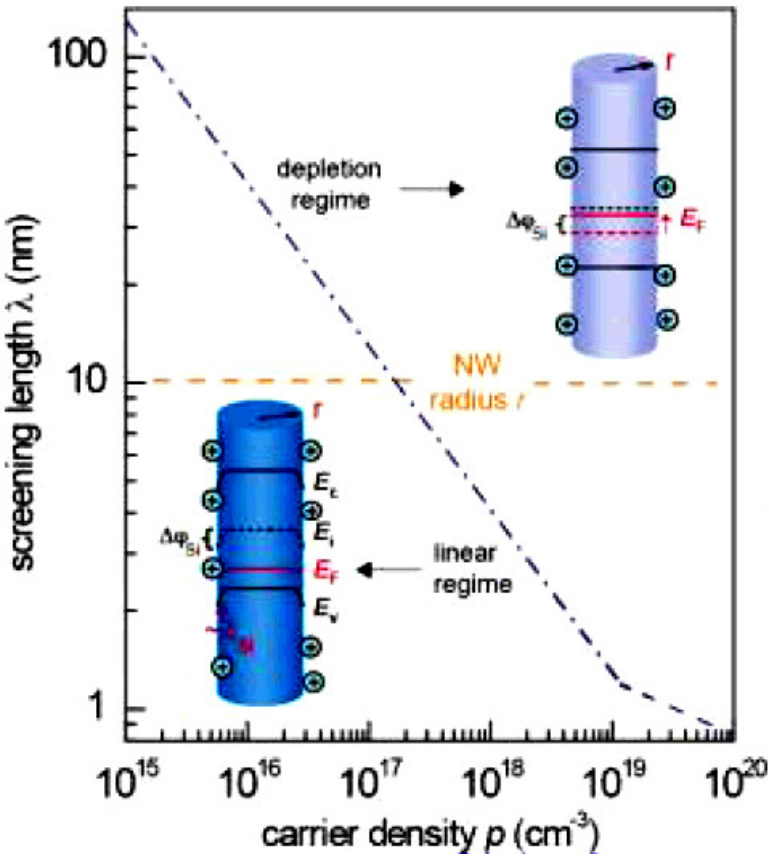
- nanoscale FETs can overcome limitations of planar semiconductor devices
- binding to the NW surface can lead to depletion or accumulation of carriers in the "bulk" of the nanometer diameter structure and increase sensitivity to the point of single-molecule detection



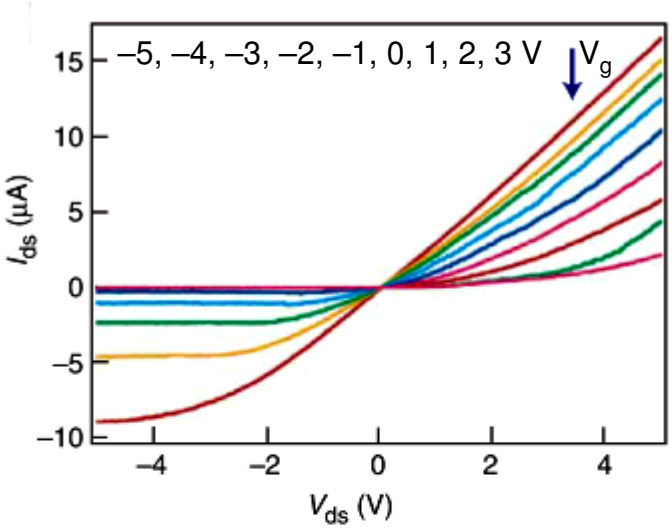
- silicon is always semiconducting compared to CNTs and Si technology is established
- doping type and level controls the sensitivity of SiNW
- massive knowledge about oxide surface modifications available

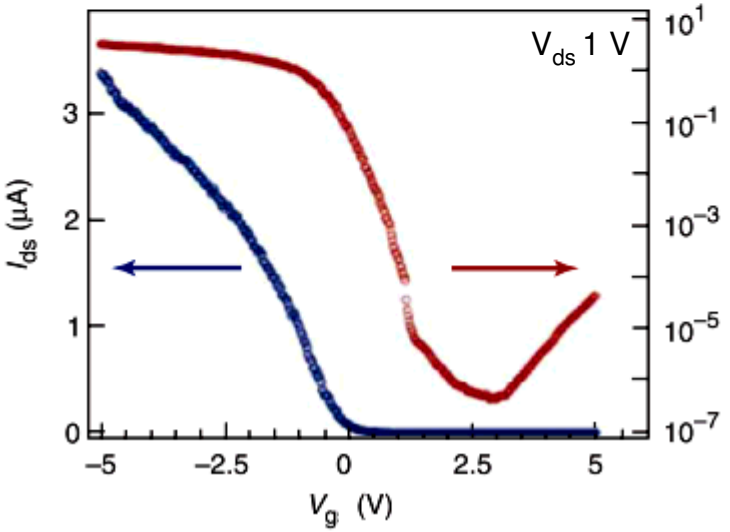
MRS Bulletin, 2007, 32, 142

- the sensitivity is highest in the so-called sub-threshold regime near carrier depletion (i.e., λ_{Si} >> r) but non-linear



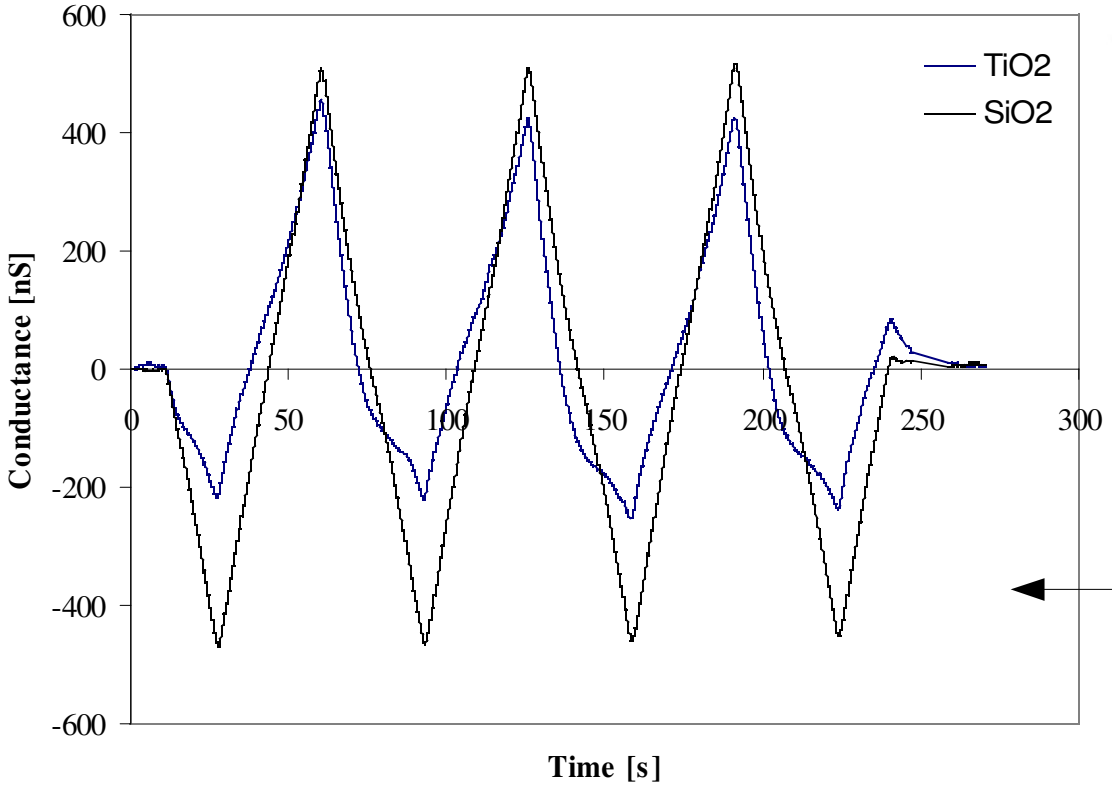
Nano Lett. 10 (2010) 547

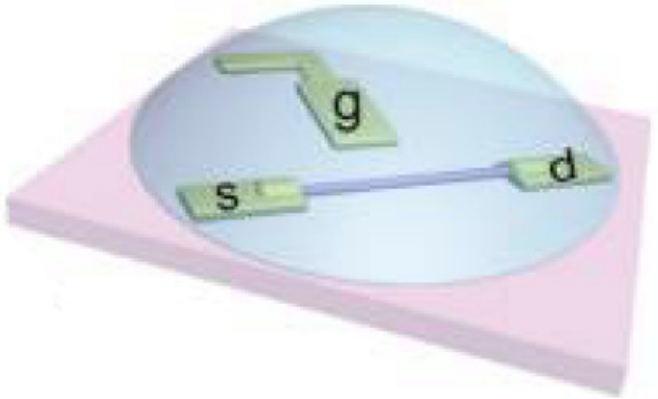




NATURE PROTOCOLS 1 (2006) 1713

- nanowire sensors need to be calibrated in terms of device-to-device variation
- strong correlation between the bio-sensor gate dependence (dI_{ds}/dV_g) and the absolute response (absolute change in current, ΔI)





- "water gate" measurements can be used for calibration

WG sweep: +/- 0.1 V

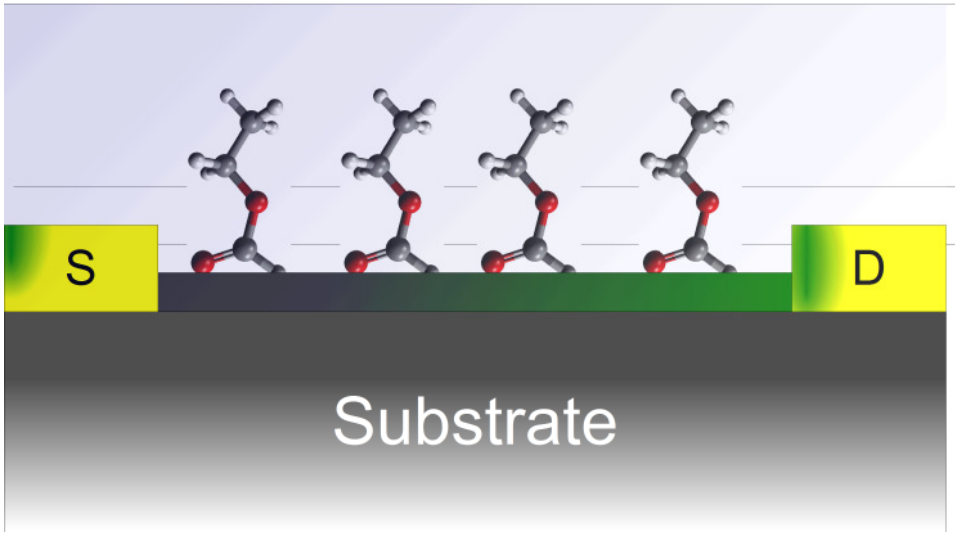
Nano Lett. 10 (2010) 547

Debye screening length

- scale over which mobile charge carriers (e.g. electrons) screen out electric fields

$$\kappa^{-1} = \sqrt{\frac{\epsilon_r \epsilon_0 k_b T}{2 N_A e^2 I}} = C \cdot \sqrt{\frac{\epsilon_r}{I}} \qquad \rightarrow \text{water, RT} \qquad \kappa^{-1}[nm] \approx \frac{0.304}{\sqrt{I(M)}}$$

I is the ionic strength of the electrolyte ε_0 is the permittivity of free space ε_r is the dielectric constant
k_B is the Boltzmann constant T is the absolute temperature in kelvins N_A is the Avogadro number
e is the elementary charge

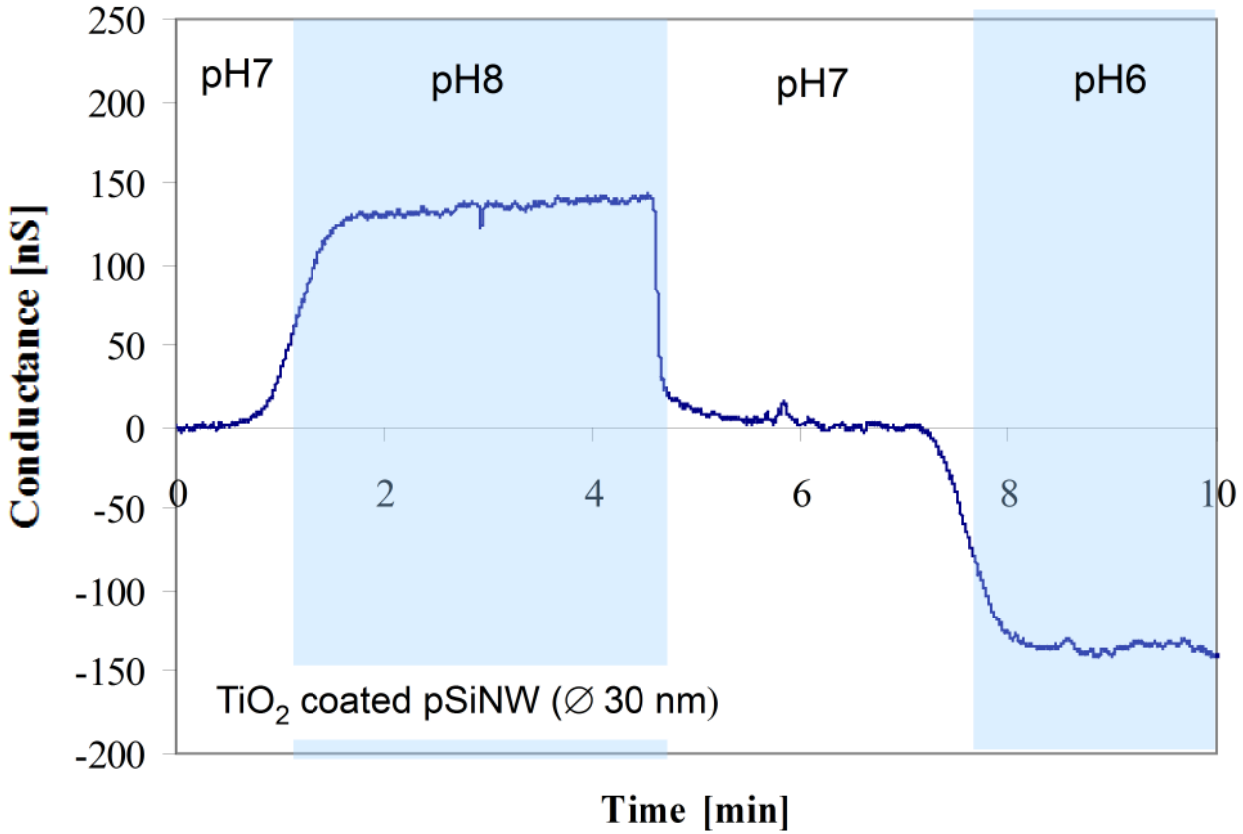


- 0.01xPBS: ~7 nm
- 0.1xPBS: ~2 nm
- 1xPBS: ~ 0.7 nm

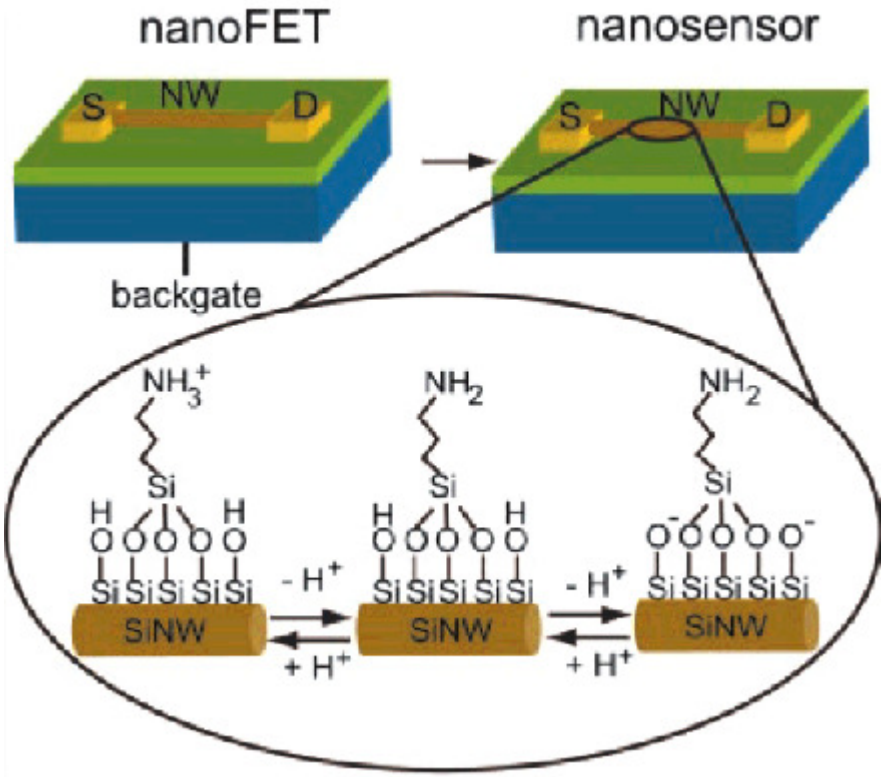
Nano Letters, 2007, 7, 3405

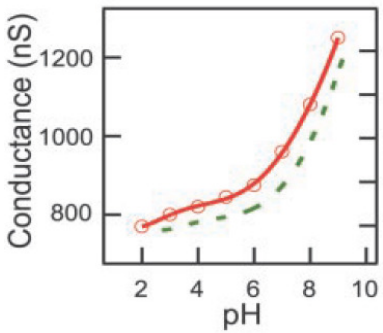
pH effect

- changing pH values (H_3O^+ / OH^-) cause a charge carrier depletion or accumulation in the NW due to the field effect
- can be exploited for pH sensing but interferes easily with other sensing experiments

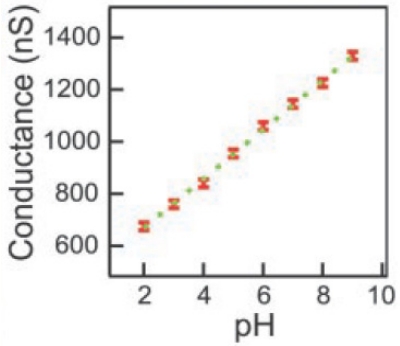


➢ pH sensor: 3-aminopropyltri-ethoxysilane (APTES) modifed pSiNW

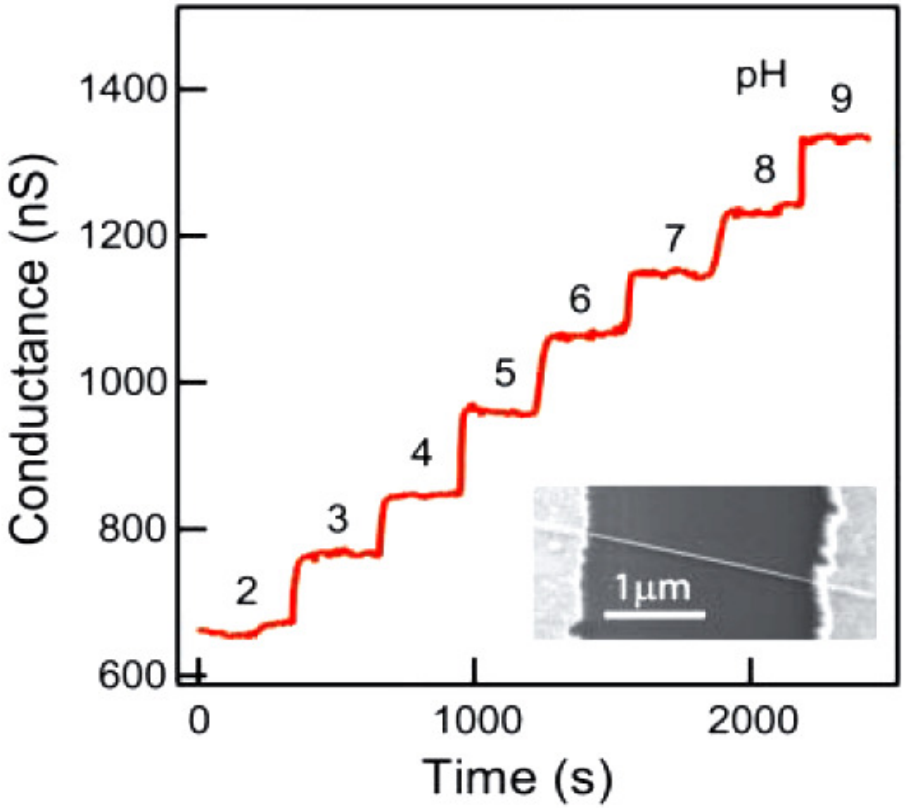




no APTES



with APTES



➢ *at low pH*: the -NH group is protonated to NH_3: positive gate

➢ *at high pH*: -SiOH is deprotonated to -SiO_2,

Science 293 (2001) 1289

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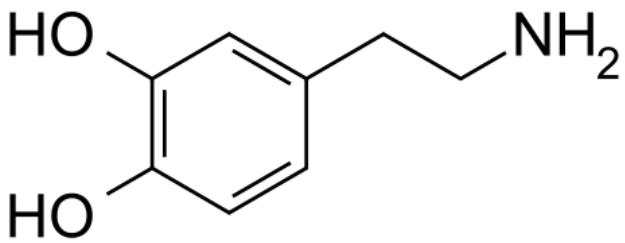
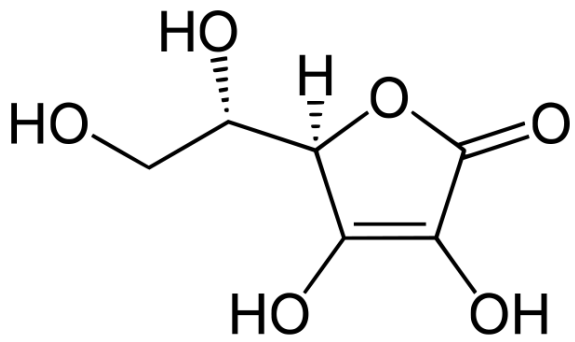
- imbalances in dopamine concentration can lead to neurological disorders like the Parkinson disorder
- controlled therapeutic delivery require rapid and accurate determination of neurotransmitter concentrations with high sensitivity
- label-free real-time measurement of catecholamines can be achieved electrochemically , yet limited in terms of bio-compatibility and spatial resolution
- phosphate modified TiO_2 should reacts with dopamine almost selectively → change of the TiO_2 charge is the gate voltage
- nanowire sensors can potentially provide spatial resolution and high sensitivity

Dopamine (DA)

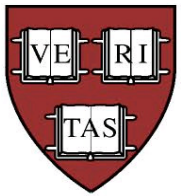


vs.

Ascorbic acid (AA)



Slides on request: s.strehle [at] gmx [dot] de



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- Aspects of silicon nanowire sensors
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- nanowires are a one-dimensional platforms for nanodevices
- nanowire based bio-/chemical-sensors allow a label free detection with high sensitivity
- screening length effects, pH sensitivity and device calibration were discussed
- the nanowires synthesis by VLS and device fabrication were briefly presented
- the sensing of dopamine using TiO_2 modified pSiNW was shown

Acknowledgement

- Prof. C.M. Lieber & the Lieber group
- German Research Foundation (DFG)
- Prof. G. Cuniberti
- Thank you for your attention!