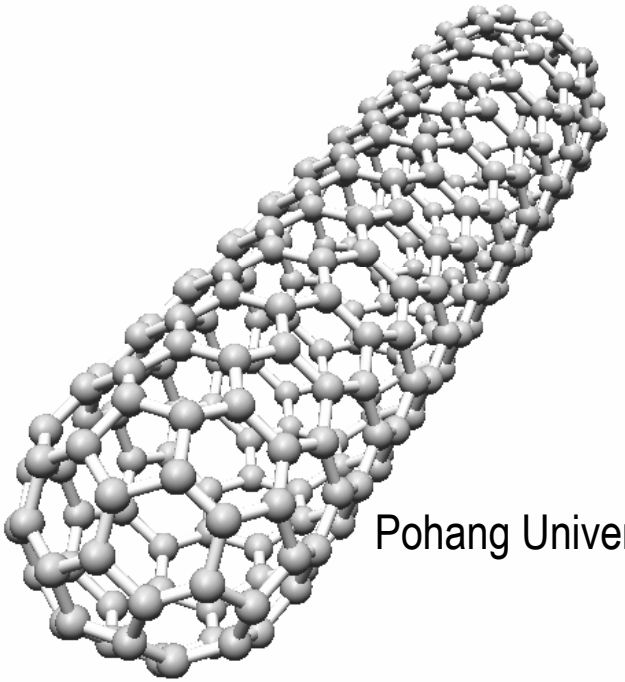
Carbon Nanotubes for Transistor Type-Biosensor and Therapeutic Applications



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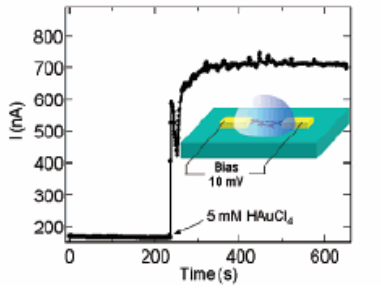
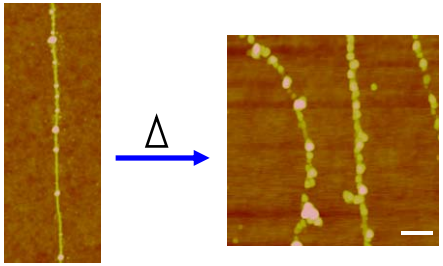
Pohang University of Science and Technology (POSTECH)
South Korea, 790-784

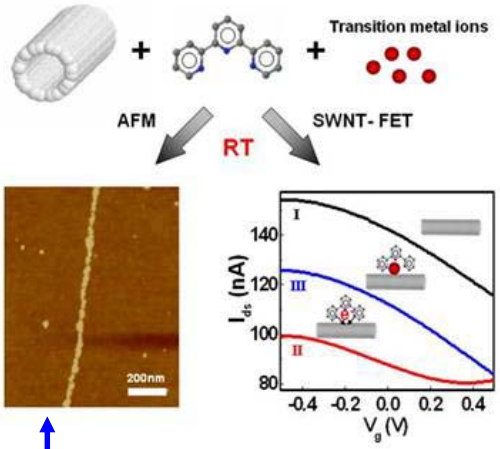
Surface Chemistry of Carbon nanotubes: Hybrid structures

Facile and spontaneous synthetic approaches





Choi, et al., ***JACS* 2002**, 124, 9059.

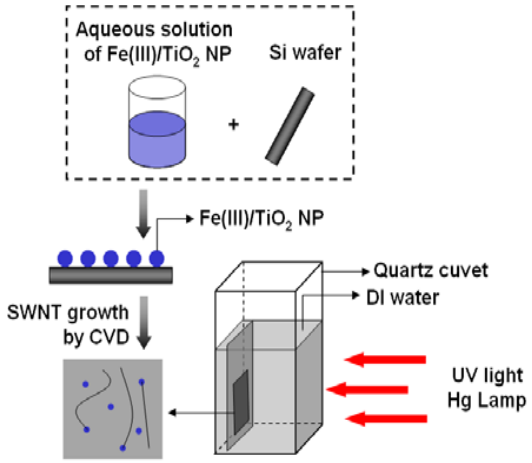


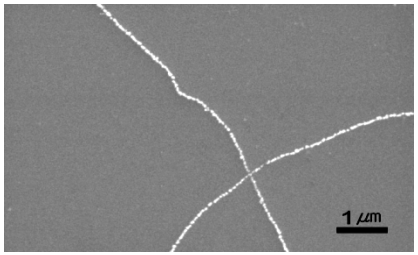
Lee and Choi, et al., ***Small* 2005**, 1, 975.

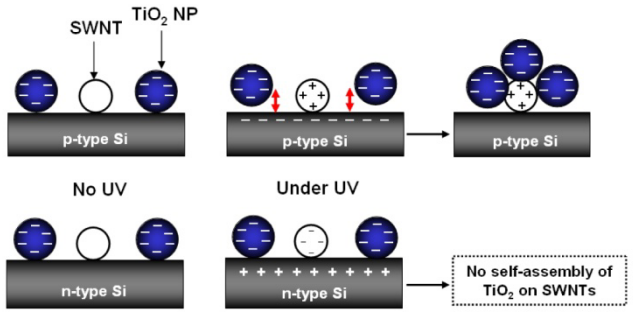
Noble metal-SWNT composites

Transition metal-SWNT

TiO_2-SWNT composites





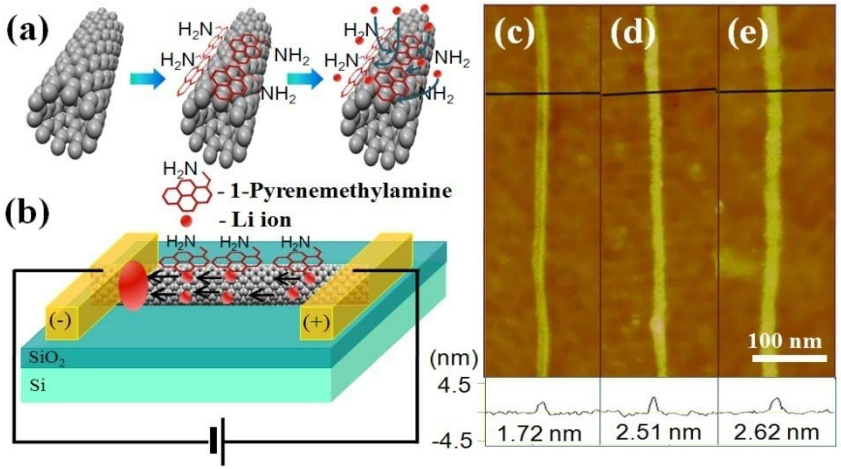


Mechanism

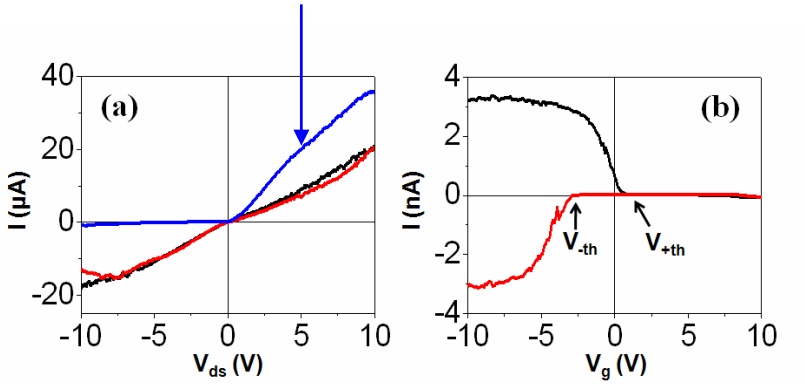
Shin and Choi, et al., ***Adv. Mater.* 2007**, *19*, 2873.

Surface Chemistry of Carbon nanotubes: Schottky diodes

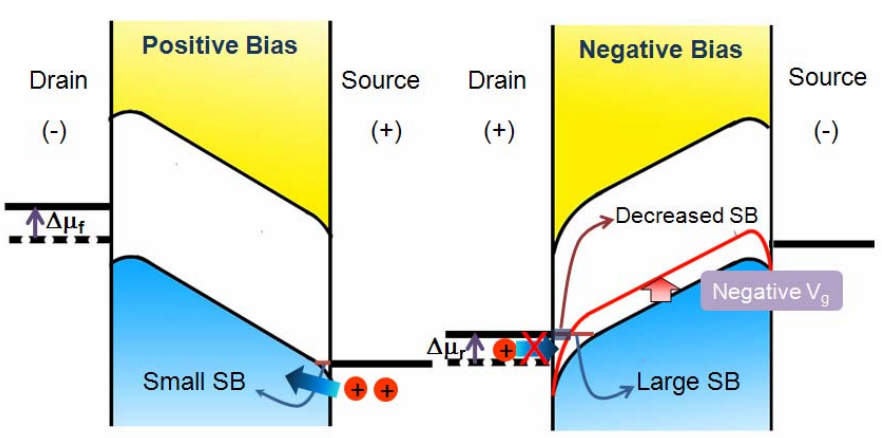
Intercalation of Li ions in pyrene-functionalized SWNT



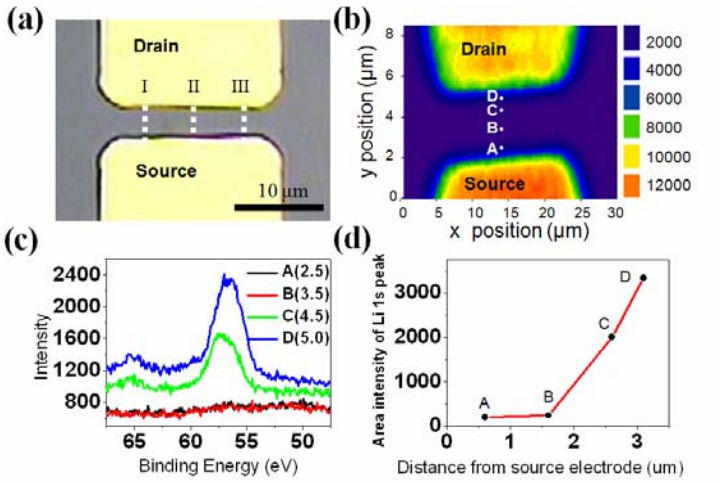
Schottky diode behavior



Modulation of band energy

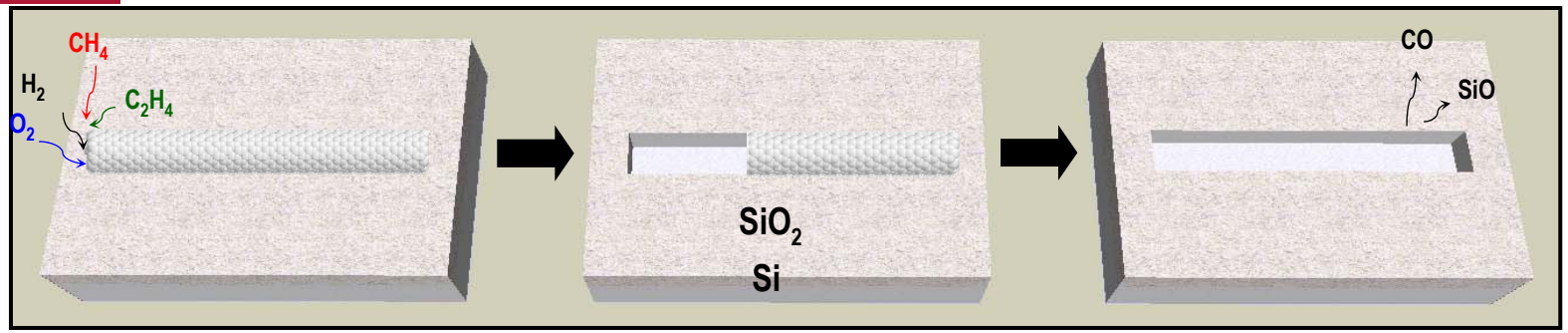


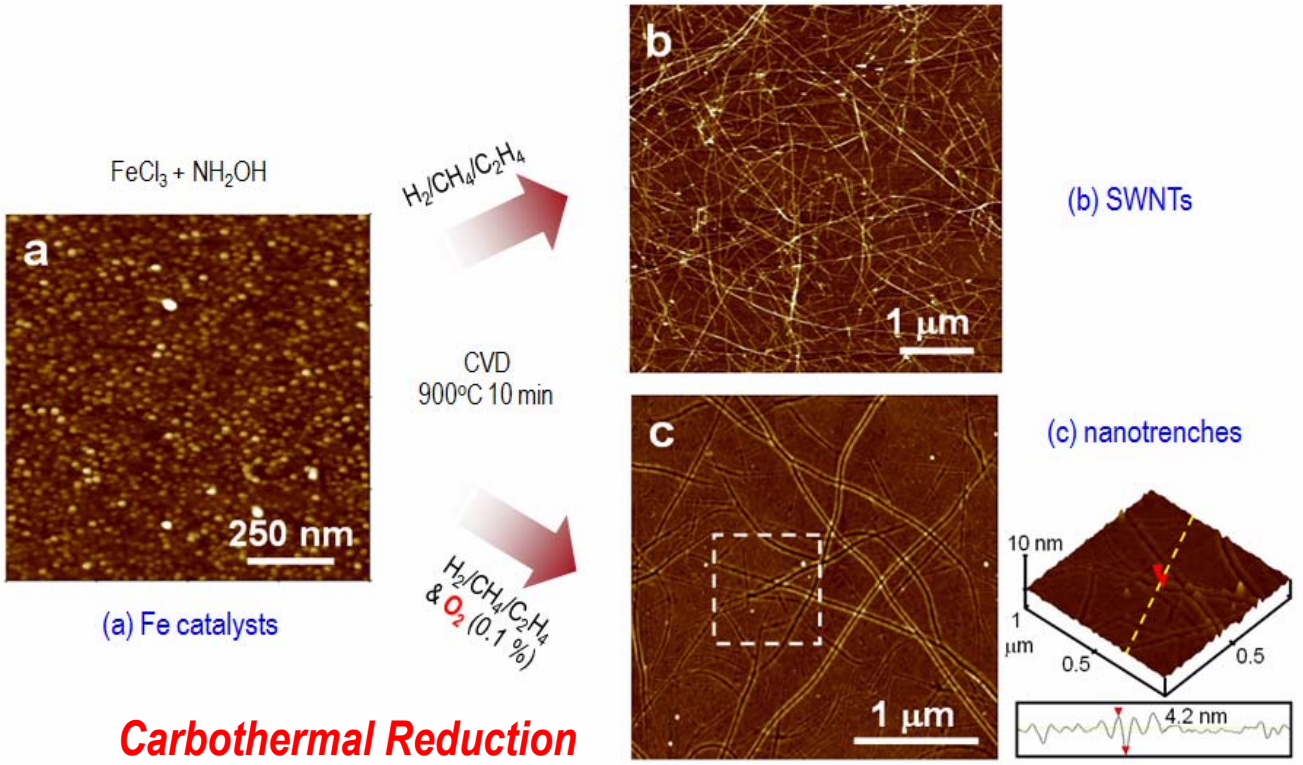
Lithium intensity distribution (SPEM, Li 1s)



Lim and Choi, et al., ***JACS* 2008**, 130, 2160.

Surface Chemistry of Carbon nanotubes: Carbothermal Reduction – ***Etching SiO_2***

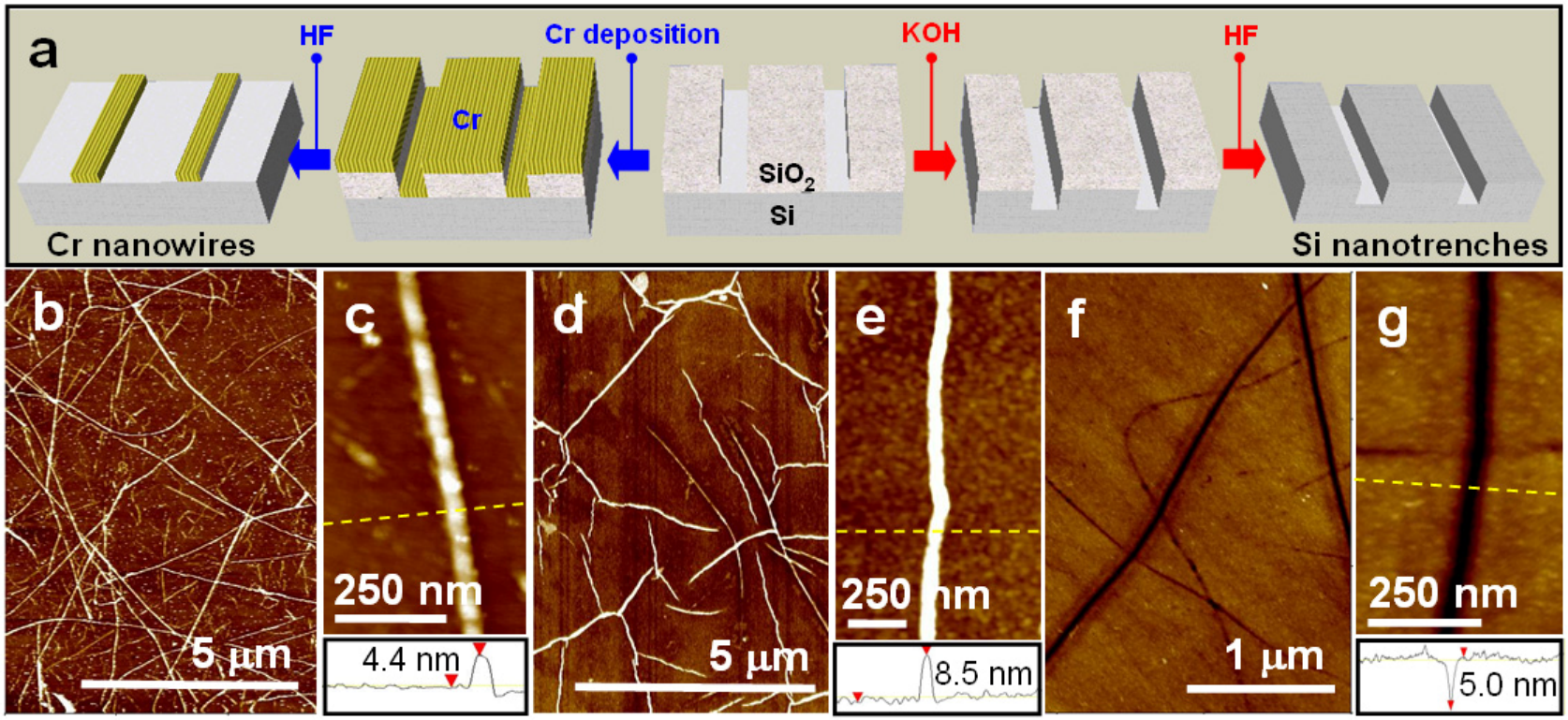




Carbothermal Reduction

Byon and Choi, ***Nature Nanotech* 2007**, 2, 162.
Byon and Choi, ***Nano Lett. 2008***, 8, 178.

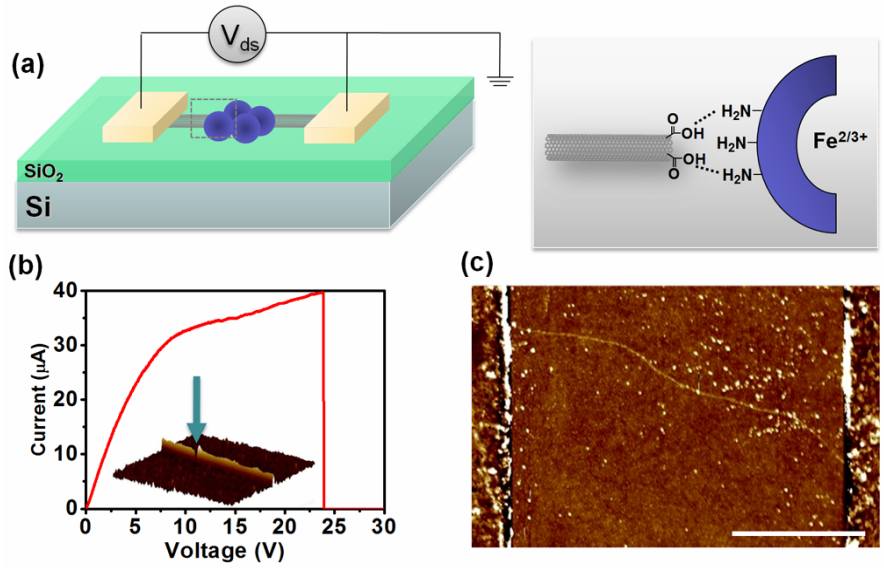
Sub-10 nm scale Lithography using Nanotrenches

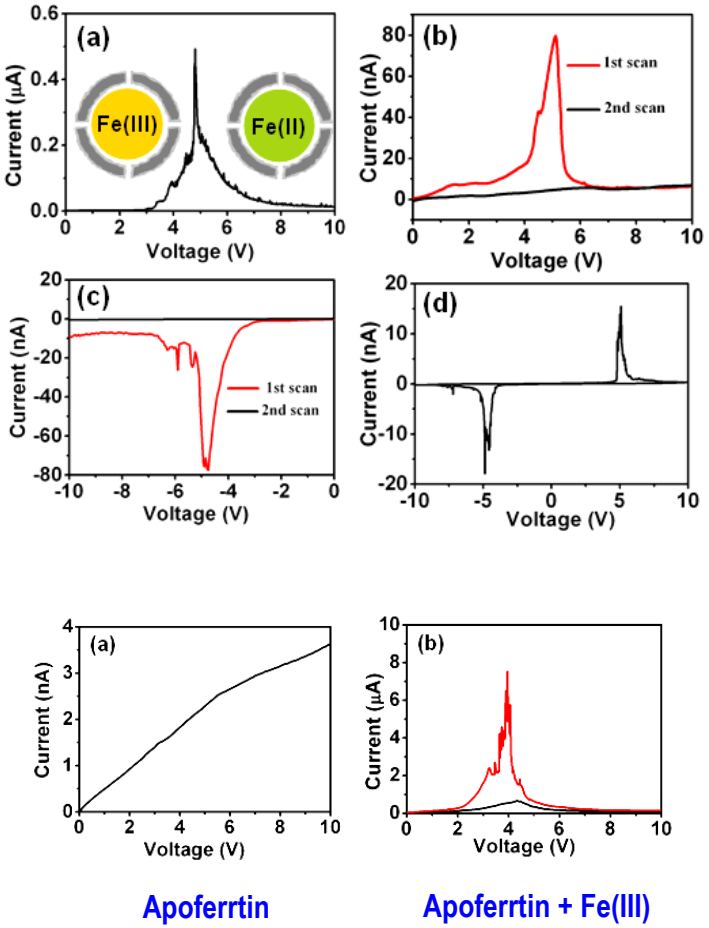


Byon and Choi, ***Nature Nanotech* 2007**, 2, 162.

Carbon nanotube electronics:
Carbon nanotube/protein-based memory device

Negative Differential Resistance (NDR) device
- Ferritin captured in metallic SWNT nanogap electrodes





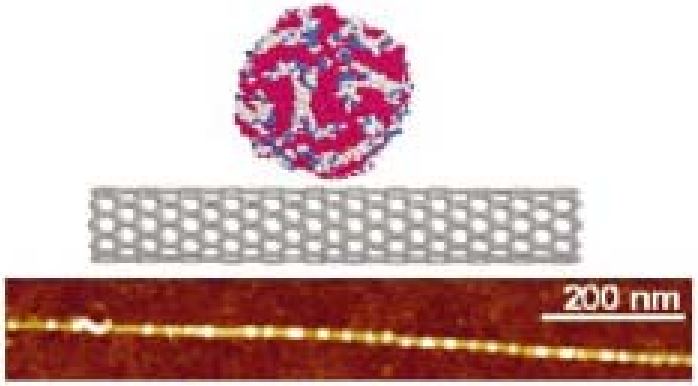
- Electrically cut m-SWNT (gap = ca. 20 nm)
- Electrostatically captured Ferritins
- Peak current density: 4.0 x 10^6 A cm^{-2} (record)
- Peak-to-Valley Ratio (PVR): ~ 40 (@ scan rate of 26 mV/s)
- NDR is 1.2 μohm cm^2

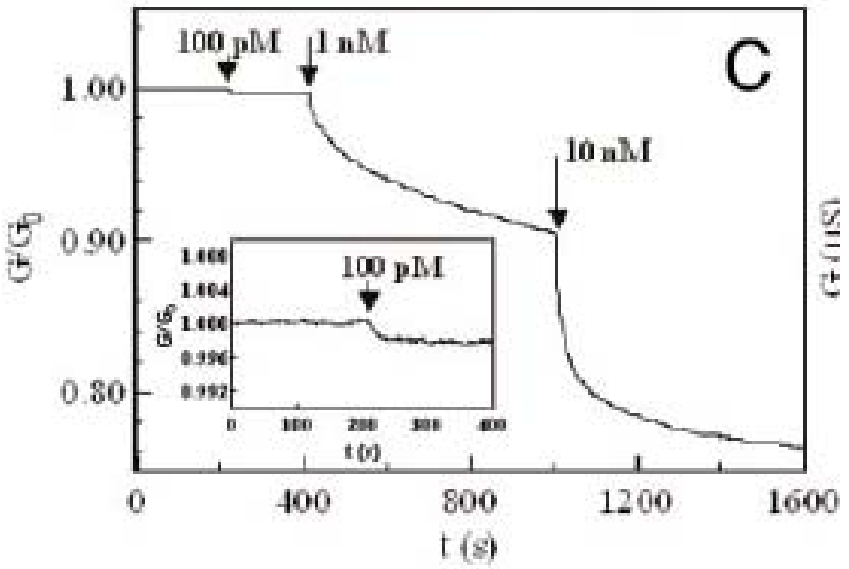
Apoferrtin **Apoferrtin + Fe(III)**

Tang and Choi, et al., ***JACS* 2007**, 129, 11018.

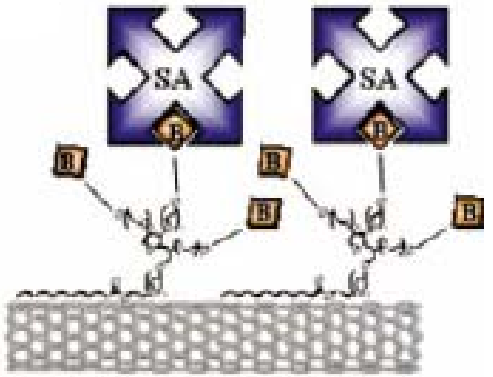
Electronic sensing of biomolecular recognitions using SWNTs-FETs

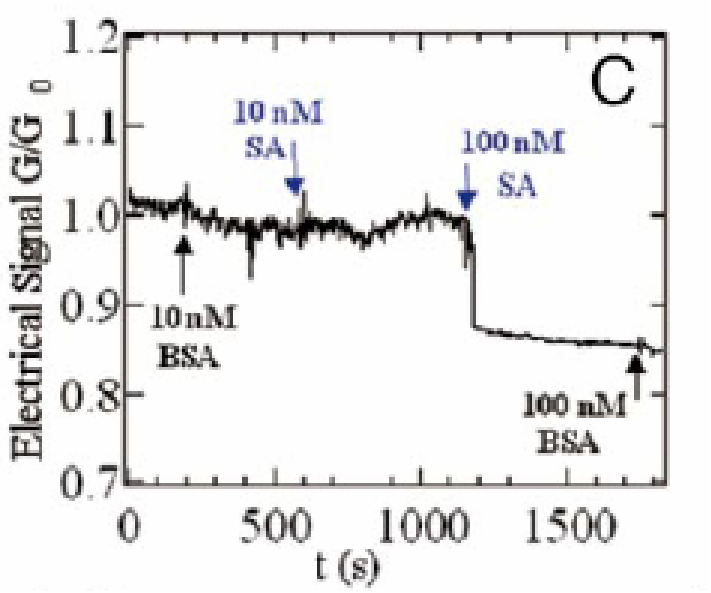
- Nonspecific Binding



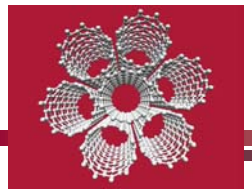


- Specific Binding (*using CDI-Tween20*)





Robert J. Chen *et al*,. *PNAS*. **2003**, *100*, 4984



Hurdles to overcome

Sensitivity

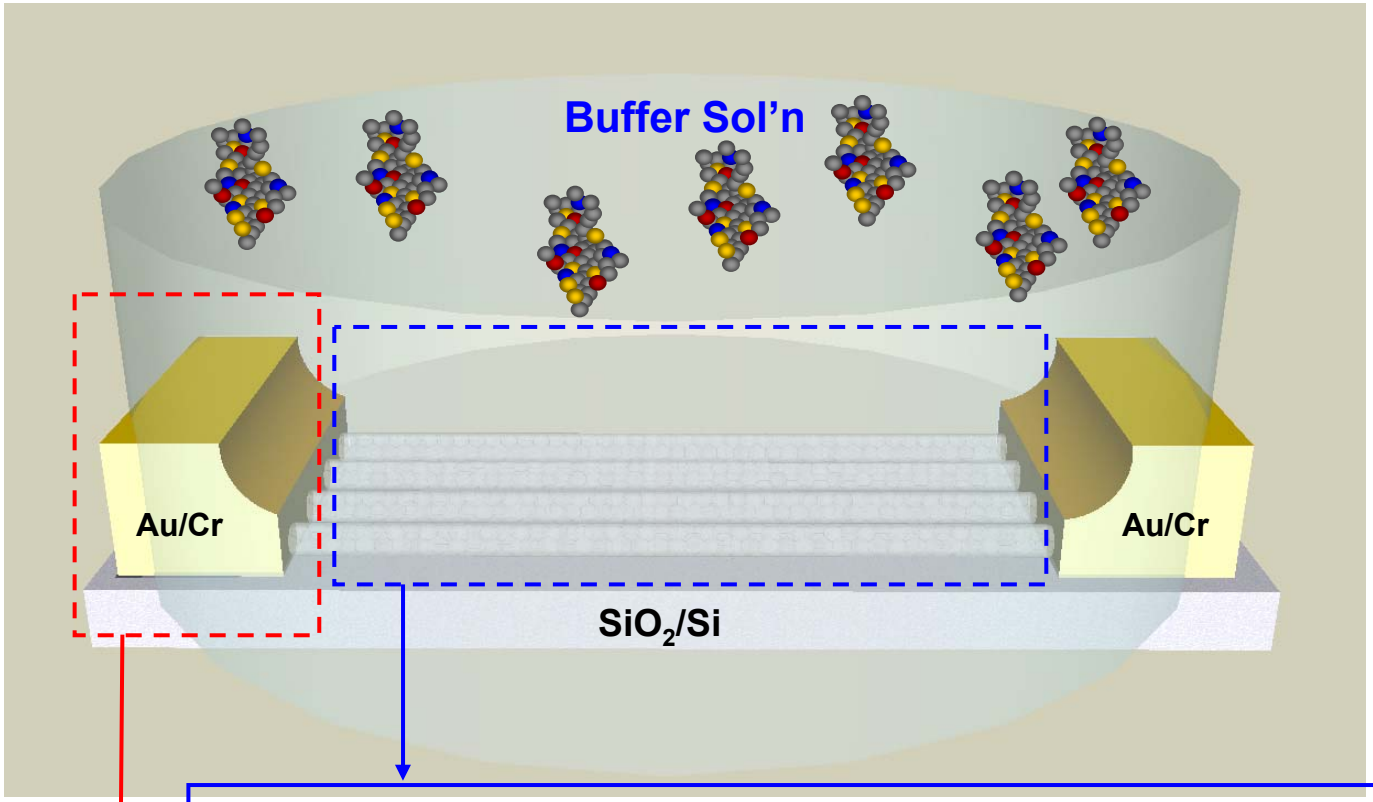
- At least ~ pM, grateful if it can go lower.
- Protein detection limit of SWNT-FET: >10 nM

  (c.f. Lieber group: ~ 10 fM detection limit of proteins using SiNW devices-*Nat. Biotechol*. **2005**, *23*, 1294.)

Feasibility

- Prompt use: currently too long stabilization time
- Nonspecific binding: perfect protection of devices with efficient chemical blocking is mandatory.

The two regions effecting to a biosensor sensitivity



Nanotube aspect: Direct charge communication between proteins and nanotubes

Metal-nanotube contact aspect: Schottky barrier modulation by protein adsorptions on metal surfaces

The origin of conductance changes: Schottky Barrier

- Nanotube aspects:

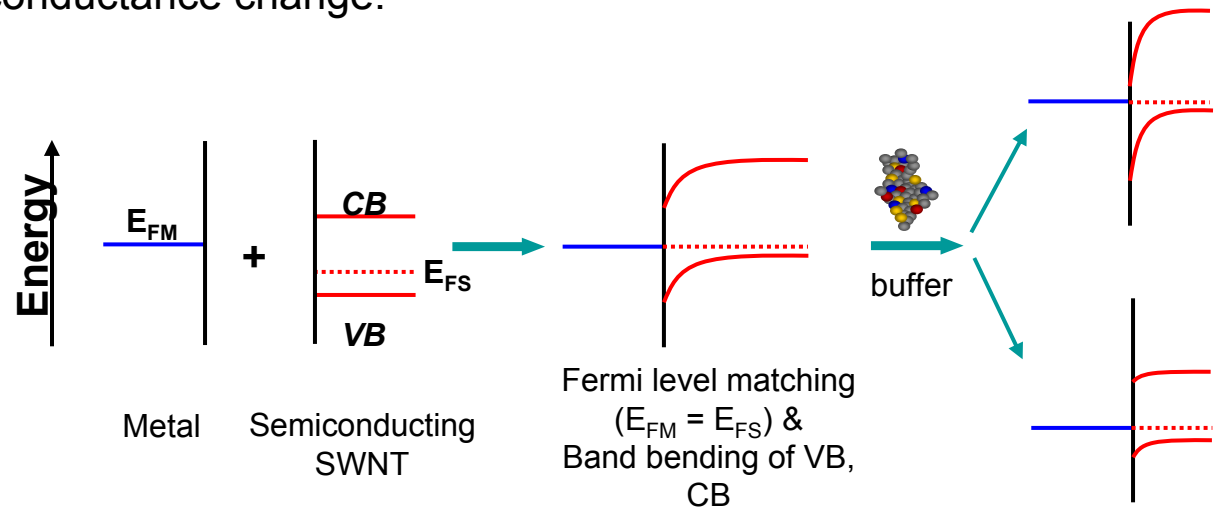
  Charge injection from biomolecules

  Electric double layer field modulation caused by biomolecules

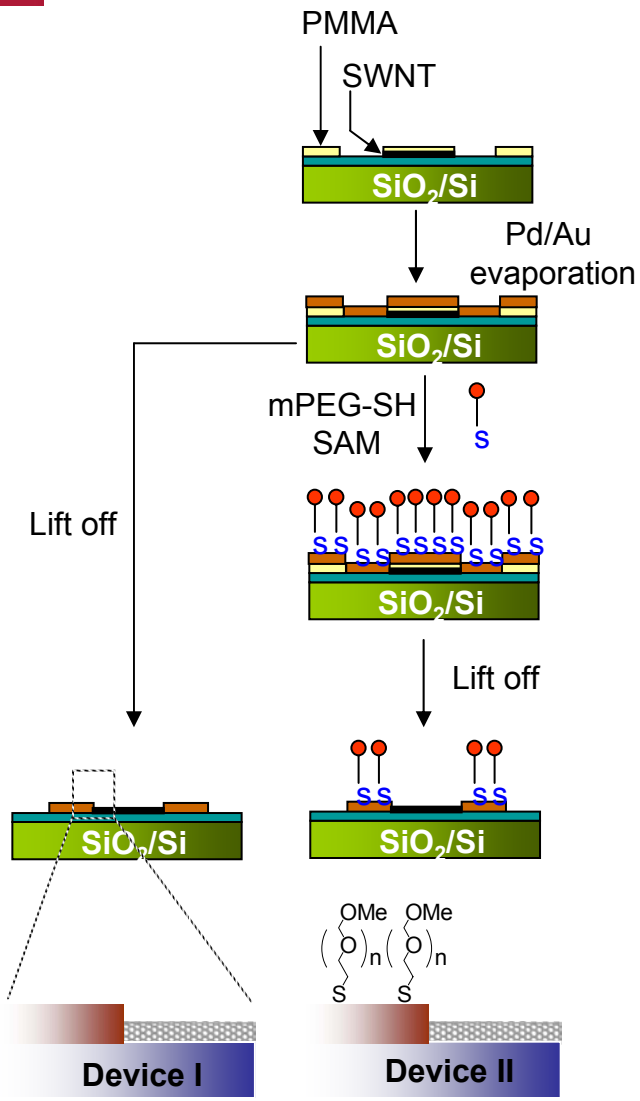
  → **Strongly depending on the pI (isoelectric point) values of proteins**

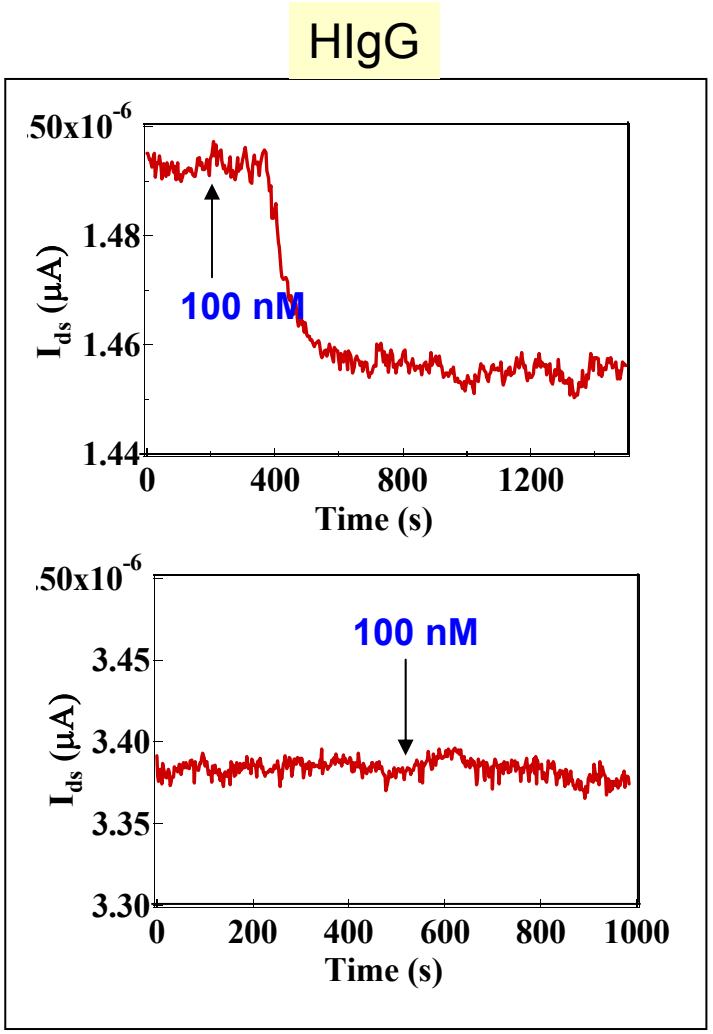
- Metal-nanotube contact aspect:

  Adsorbed chemical species may modulate *work function level of contact metals*, which consequently change the *Schottky barrier height* resulting in the conductance change.



Experimental evidence for the detection mechanism



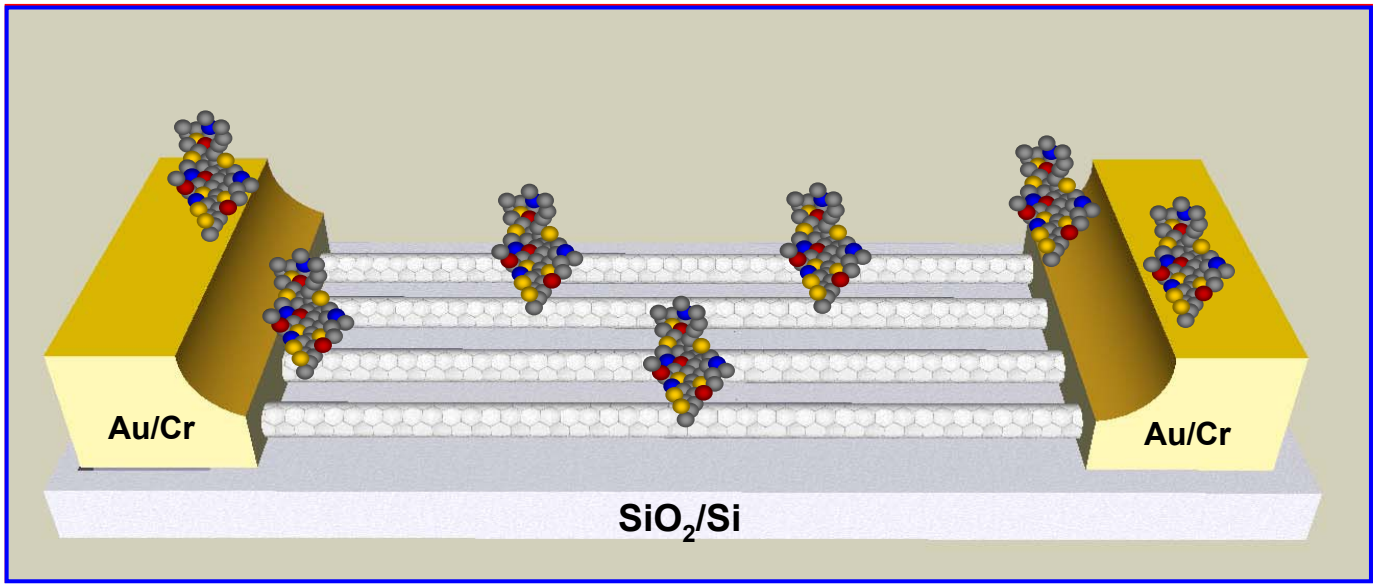


Device I

Device II

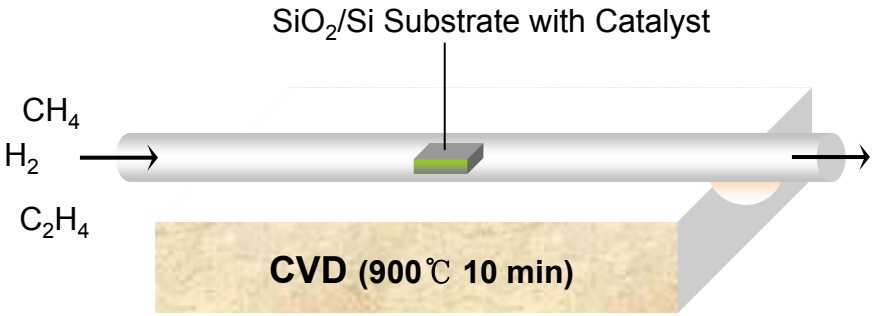
Chen, Choi, Dai et al, *J. Am. Chem. Soc.* **2004**, *126*, 1563

Increased Schottky contact area for high performance

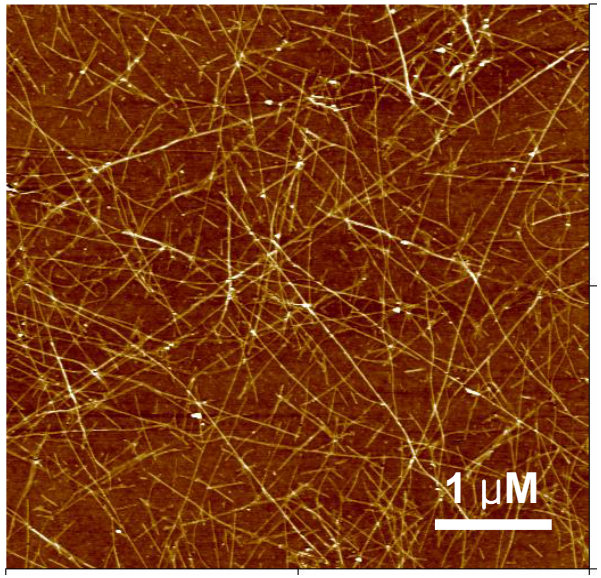


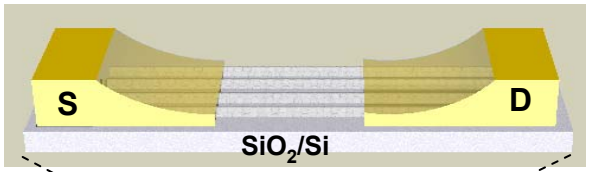
- Synthesis of network SWNTs
- Usage of the thin shadow mask
- Thermal evaporator with tilted angle stages

Fabrication of SWNT-FET having increased Schottky contact area

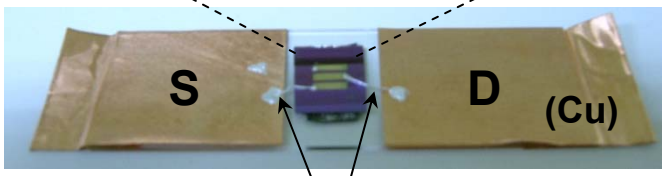


Growth SWNTs

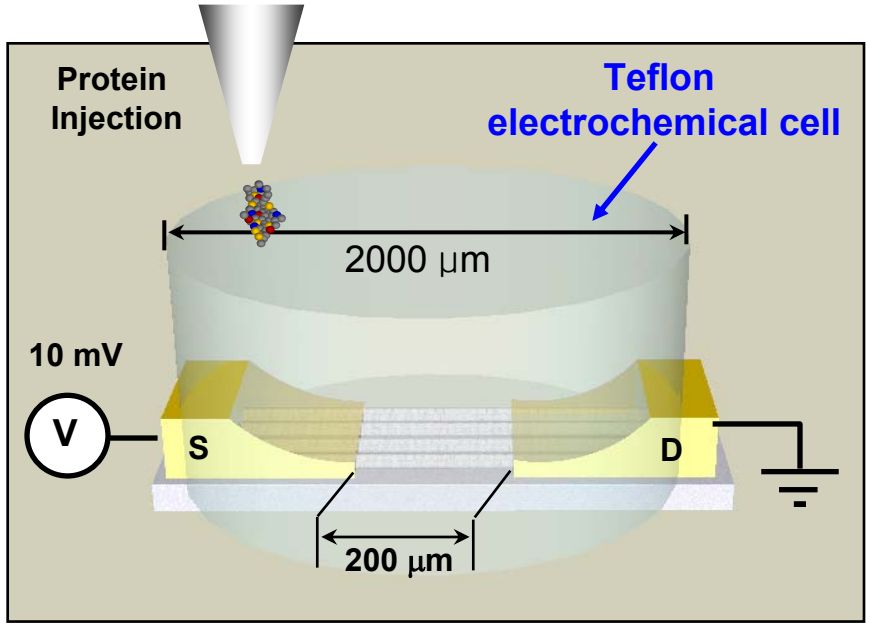




(R ~ 1 kΩ)



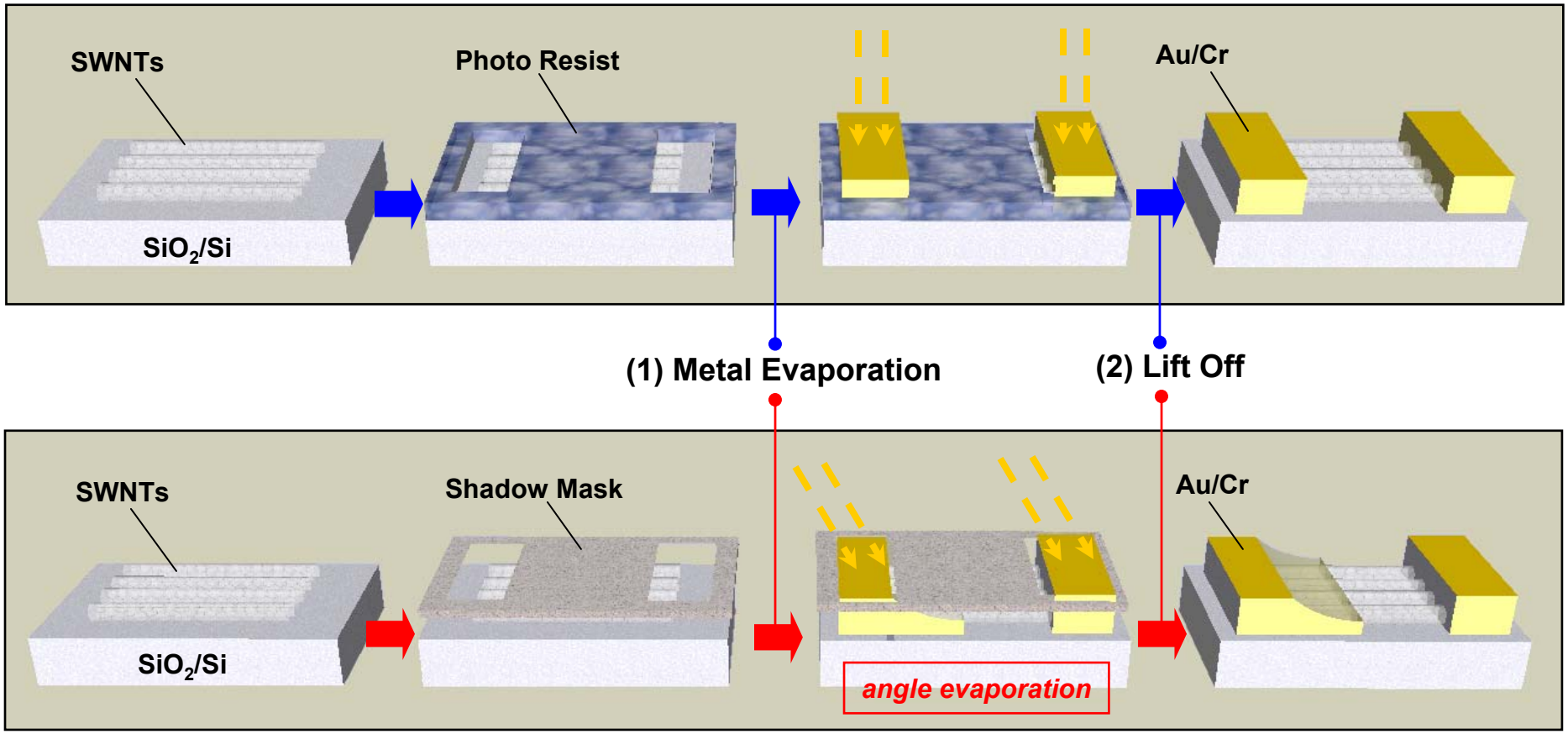
In wire



Choi and Dai et al. ***Nano Lett.*** **2003**, 3, 157.
Yang and Choi et al**.** ***Langmuir*** **2005**, 21, 9198.

Fabrication of SWNT-FET having increased Schottky contact area

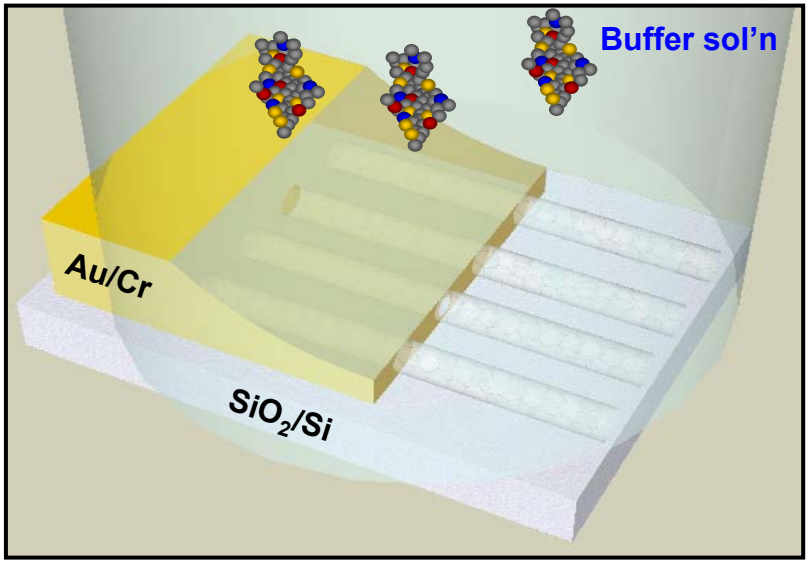
(a) SWNT FET device fabricated by a photolithography

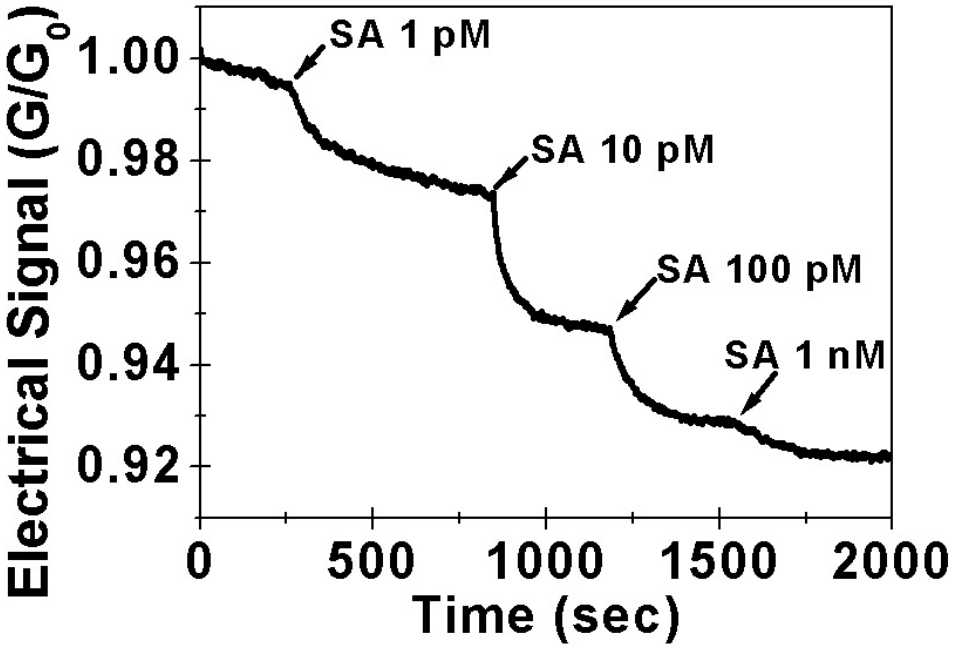


(b) SWNT-FET device fabricated by a shadow mask at tilted angle

Byon and Choi. ***J. Am. Chem. Soc.* 2006**, *128*, 2188.

Highly sensitive SWNT-FET devices: Nonspecific bindings of proteins





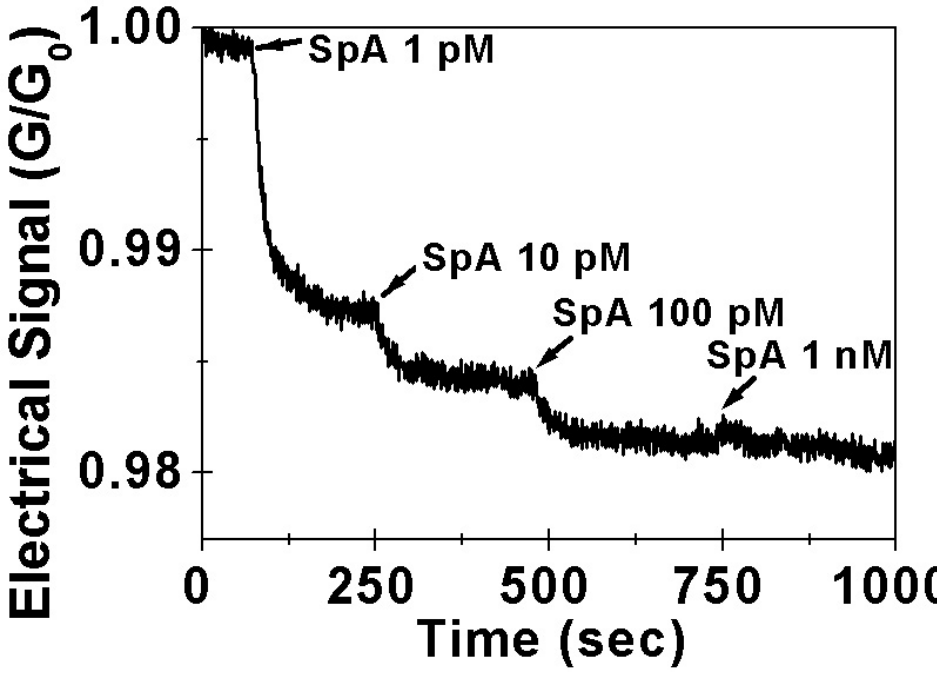
- SA
- SpA

a SWNT-FET fabricated by a shadow mask at tilted angle

→ *1 pM sensitivity*

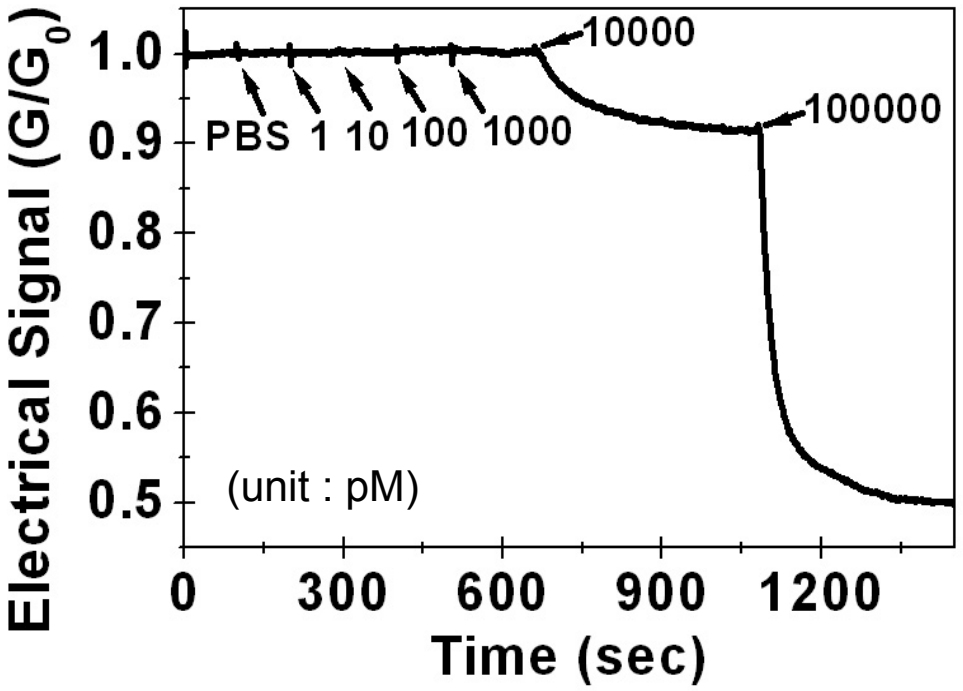
Byon and Choi. ***J. Am. Chem. Soc.* 2006**, *128*, 2188.

Highly sensitive SWNT-FET devices: Nonspecific bindings of proteins



a SWNT-FET fabricated by a **shadow mask** at tilted angle

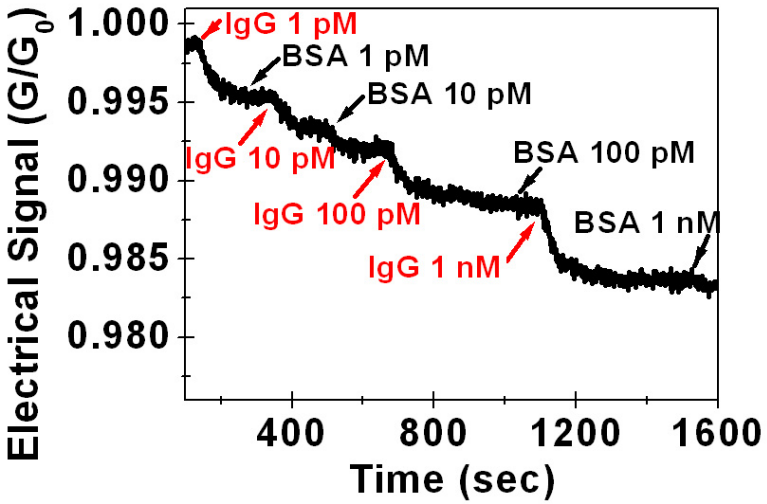
→ ***1 pM sensitivity***



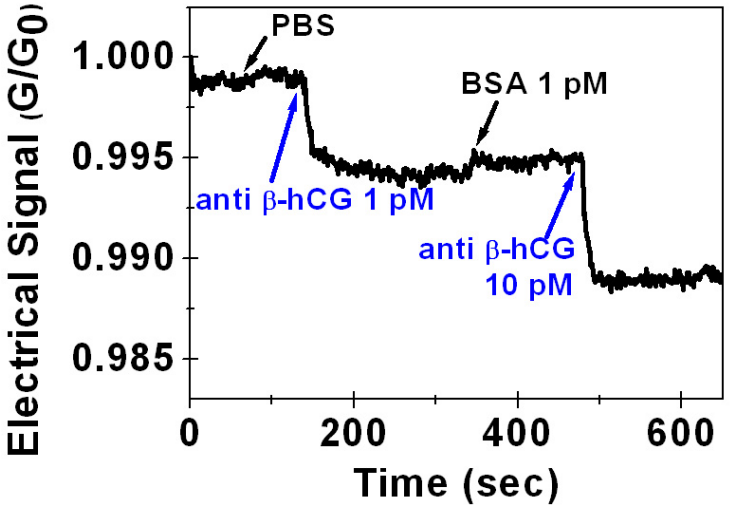
a SWNT-FET fabricated by a **shadow mask**
<Protein : SpA>

→ ***10 nM sensitivity***

Highly sensitive SWNT-FET devices: Specific bindings of proteins



- Probe protein: Protein A
- Target protein: rabbit IgG



- Probe protein: hCG
- Target protein: anti β-hCG

Treatment of 0.05% Tween20 after immobilizing probe proteins

→ ***1 pM sensitivity***

Acknowledgement

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