Nanodevices: Nanotube and Nanogap Devices for Nanobio Aspects

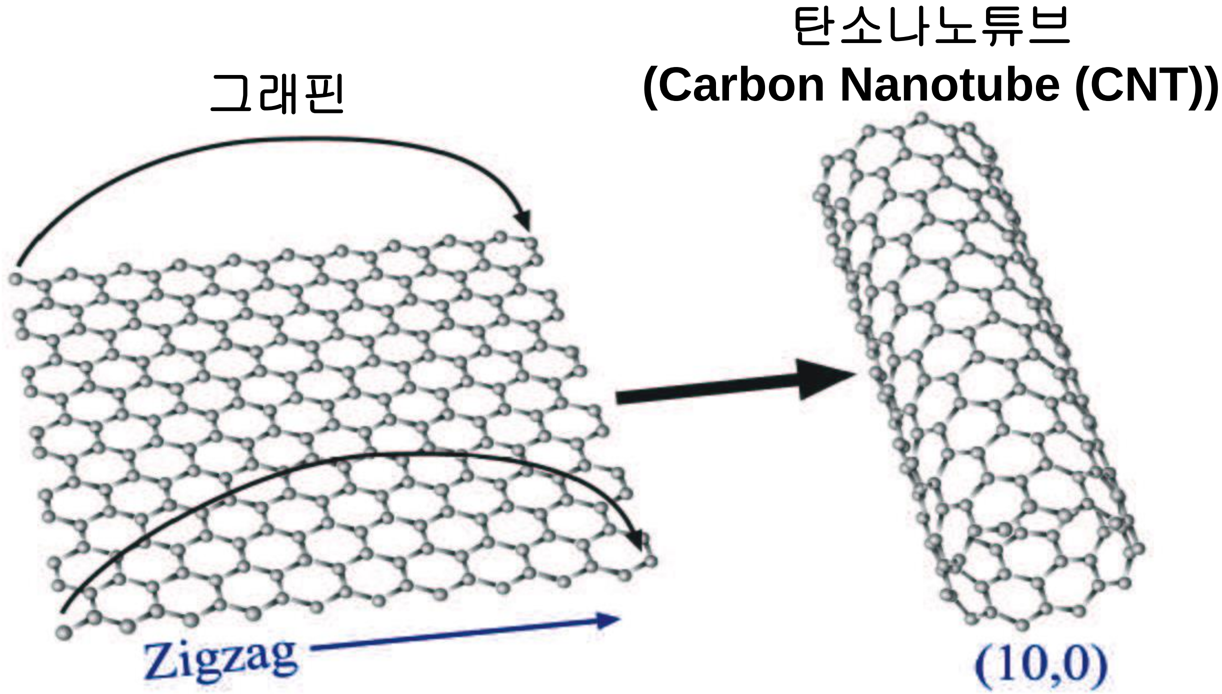
Summarized by
Prof. Dong June Ahn
Korea University

(Cited materials available in courtesy of
Prof. S.H. Hong @ SNU and Prof. W.S Yoon @ SKKU)

Nanotube Devices
For Nanobio Applications

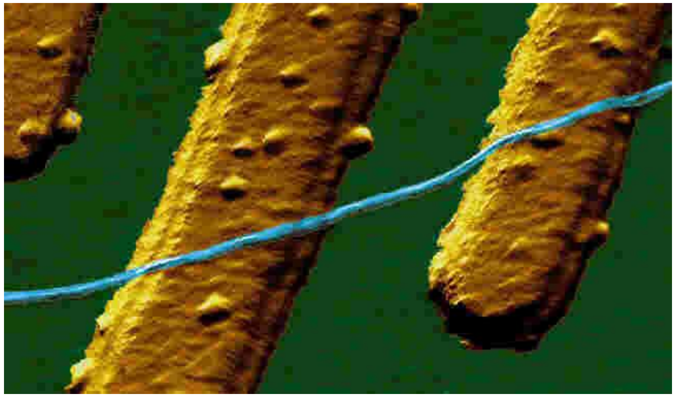
Mainly based on research by Prof. S.H. Hong @ SNU

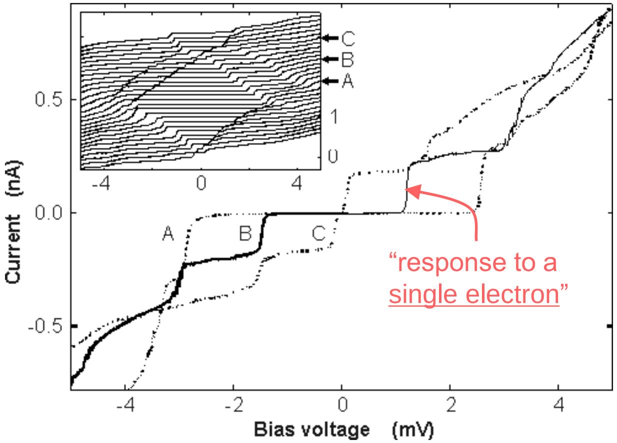
Graphene & Carbon Nanotubes



- 그래핀 : **hydrophobic** 표면, 투명, 유연성, <u>도체-> 투명 전극</u>
- **CNT : hydrophobic** 표면, 투명, 유연성, <u>도체/반도체 -> 투명전극 또는 센서</u>
- 탄소나노소재들은 유해한 이온이 나오지 않기때문에, 바이오인터페이스에 유리할 것으로 예상됨

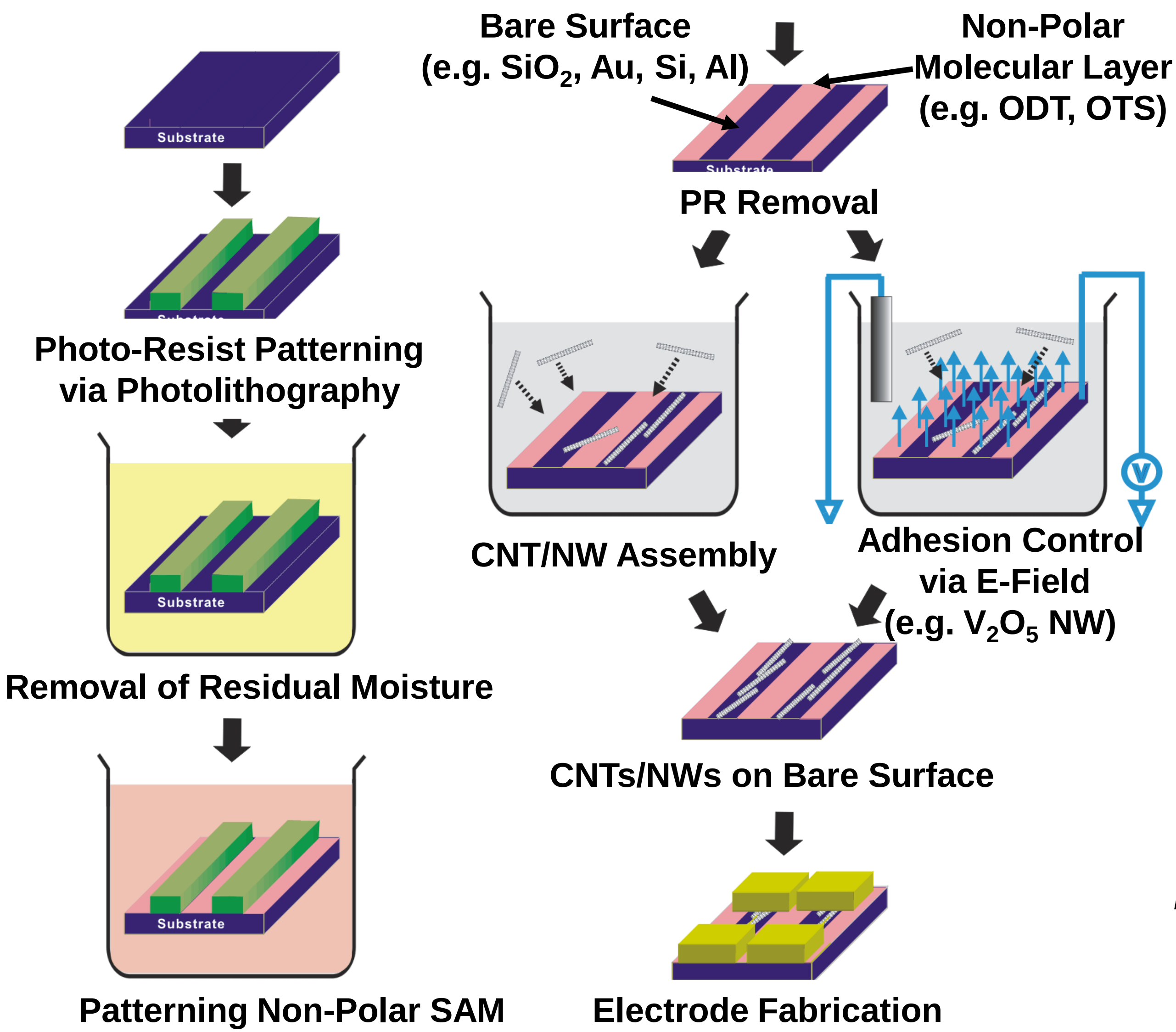
A famous example of a nano electronic device

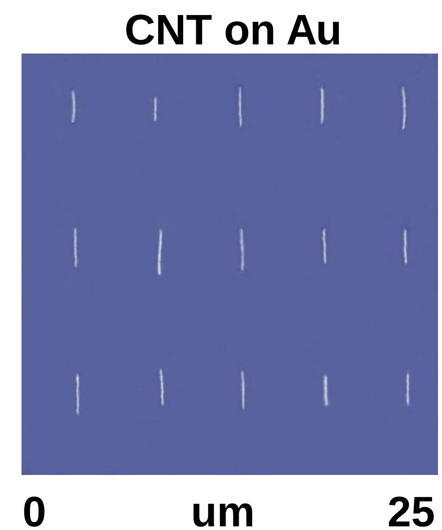




→ Extremely sensitive to outer environment!!

Mass-production Method of CNT/Nanowire-based Devices



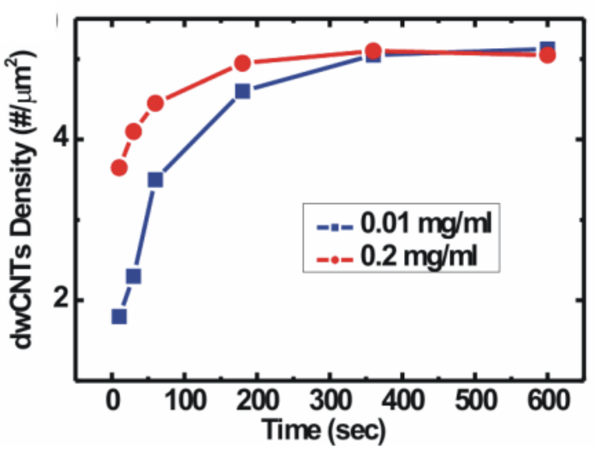


Nature 425, 36 (2003)

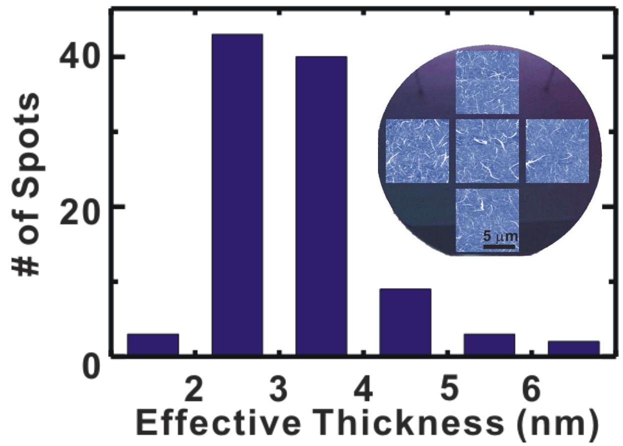
Nature Nanotech. 1, 66 (2006)

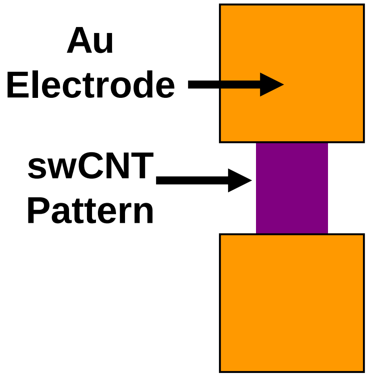
Uniform *Monolayer* Formation via Self-Limiting Mechanism

Self-Limiting Mechanism

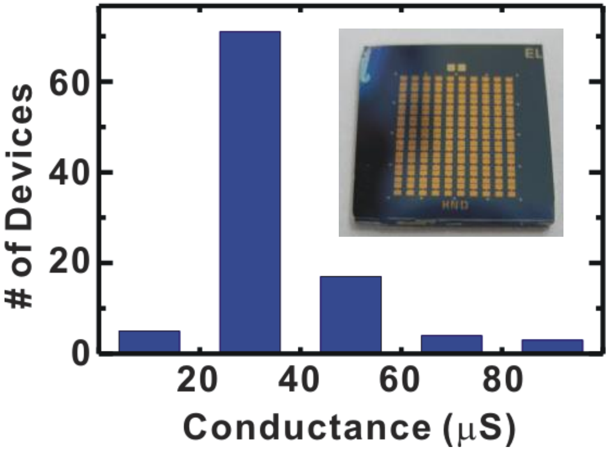


swCNT Film Thickness

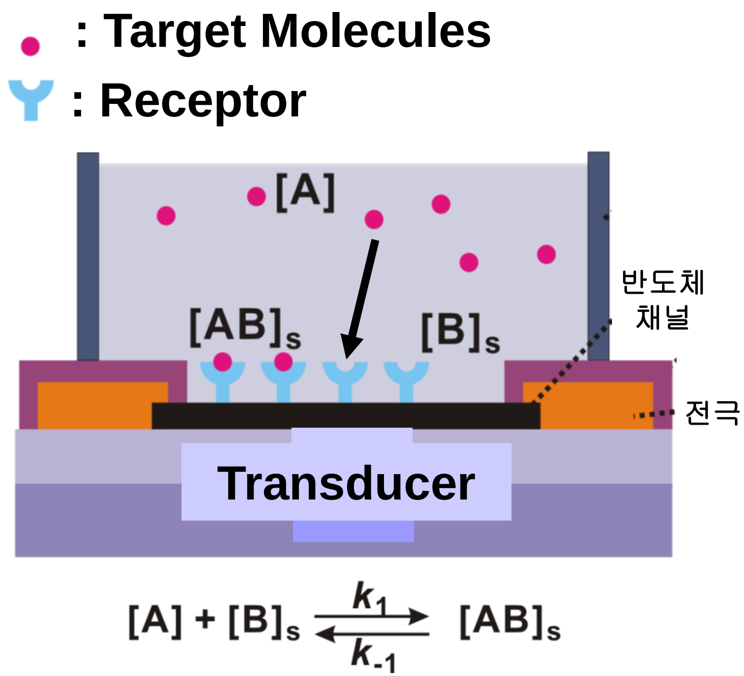


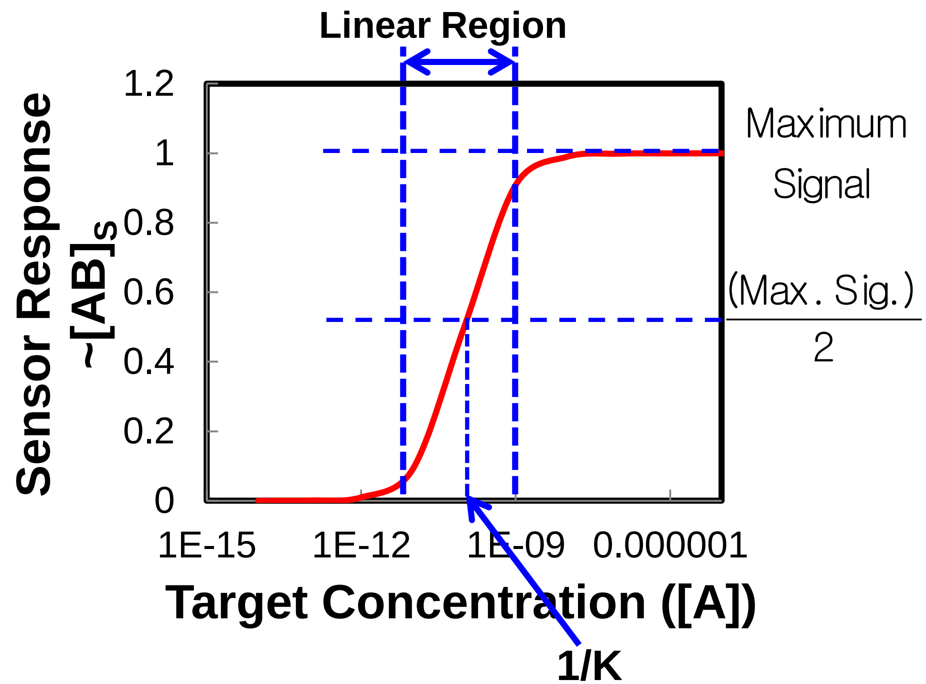


Conductance Distribution



반도체 채널 기반 선택적 센서





(Step 1) Adsorption of target molecules onto receptor: Langmuir isotherm

$$[AB]_s = [B]_s \cdot \frac{[A]}{[A] + 1/K} \quad (K = k_1/k_{-1} : \text{binding constant})$$

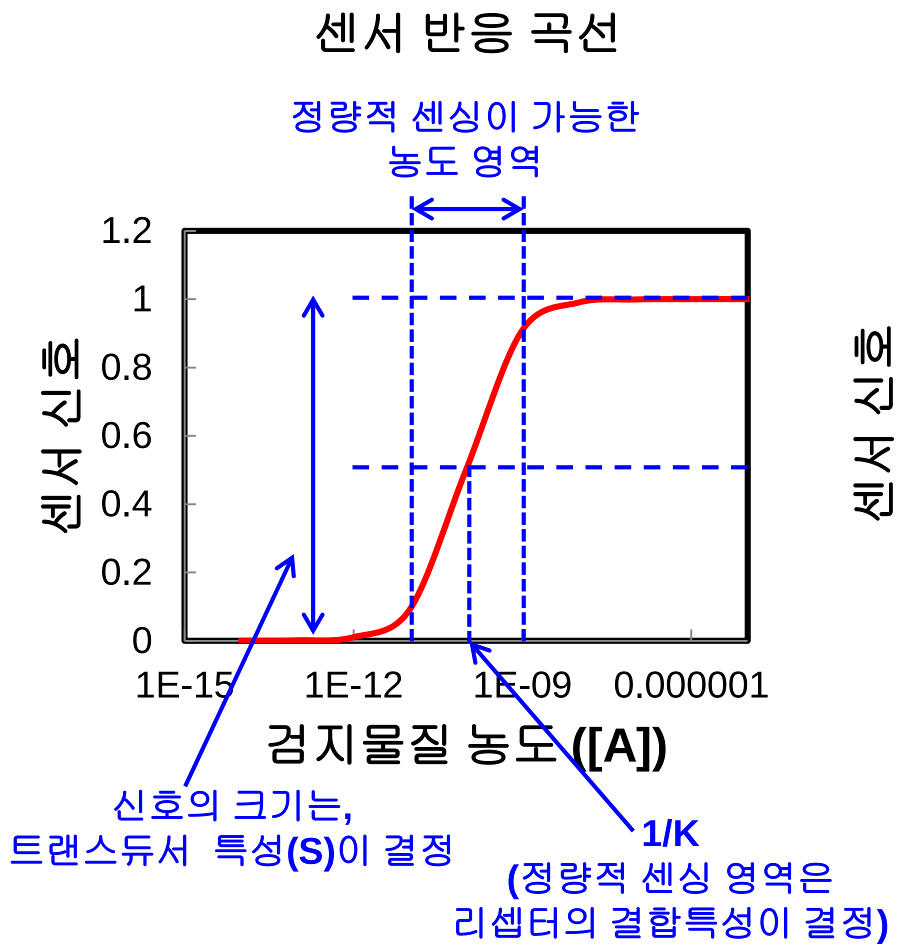
(Step 2) Sensor signal generated by adsorbed target molecules($[AB]_S$):

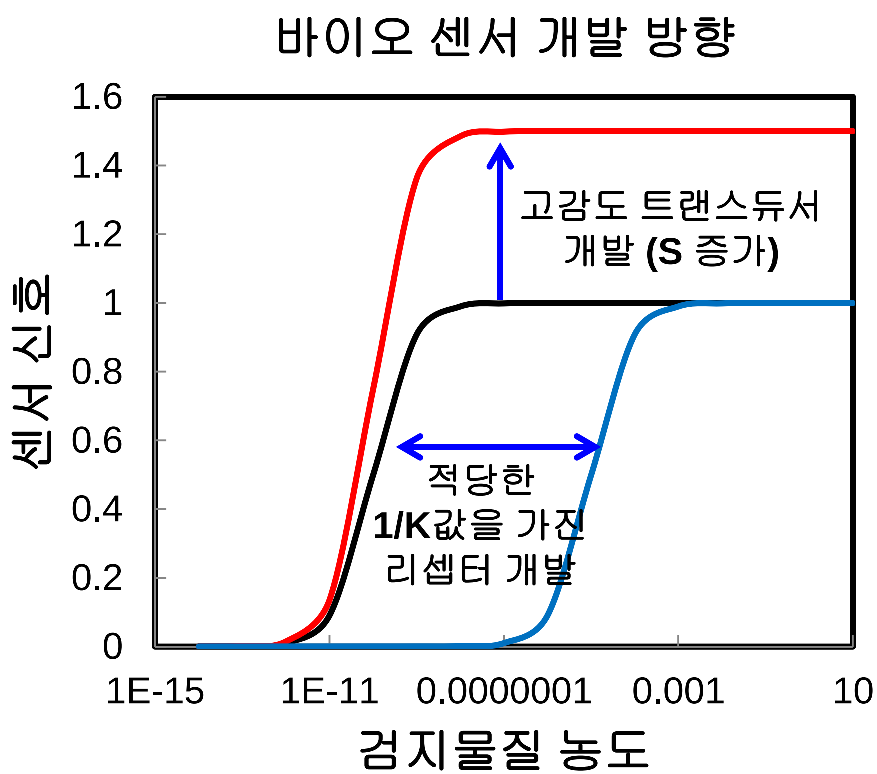
-> Linear Response Approximation

$$(\text{Sensor Signal}) \approx C \cdot [AB]_S = C \cdot [B]_S \cdot \frac{[A]}{[A] + 1/K} \equiv S \cdot \frac{[A]}{[A] + 1/K}$$

바이오 센서의 전형적인 반응 특성

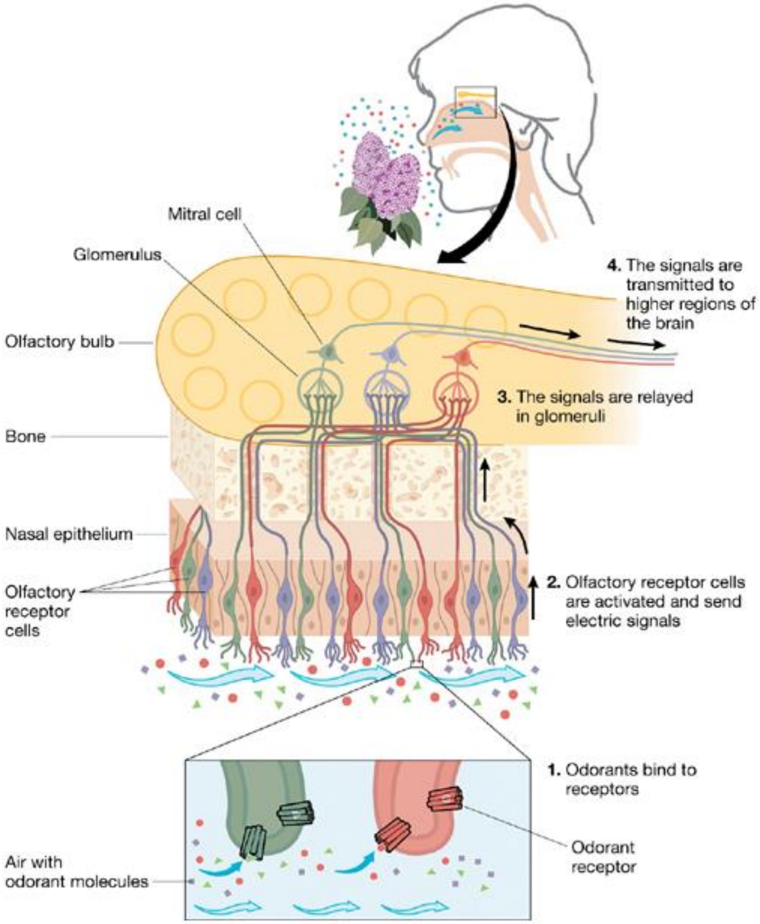
$$(\text{센서신호}) \approx S \cdot \frac{[A]}{[A] + 1/K}$$



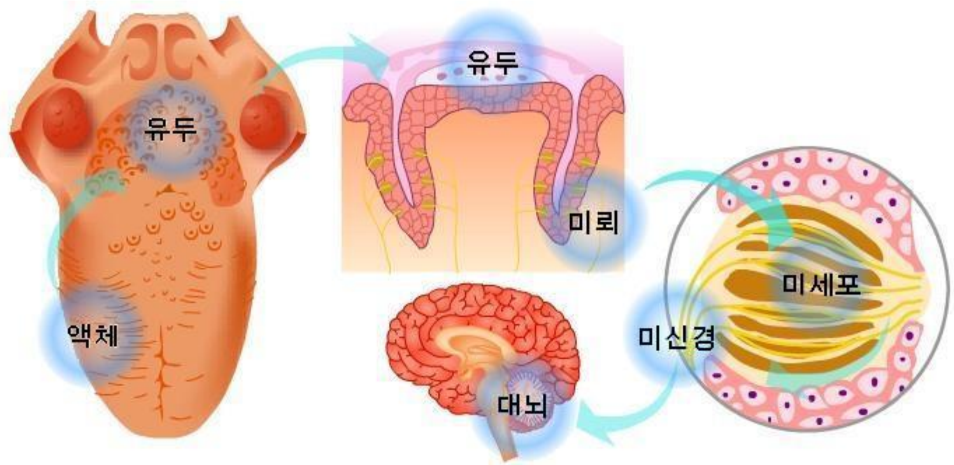


인간의 미각/후각 시스템

인간의 후각 시스템

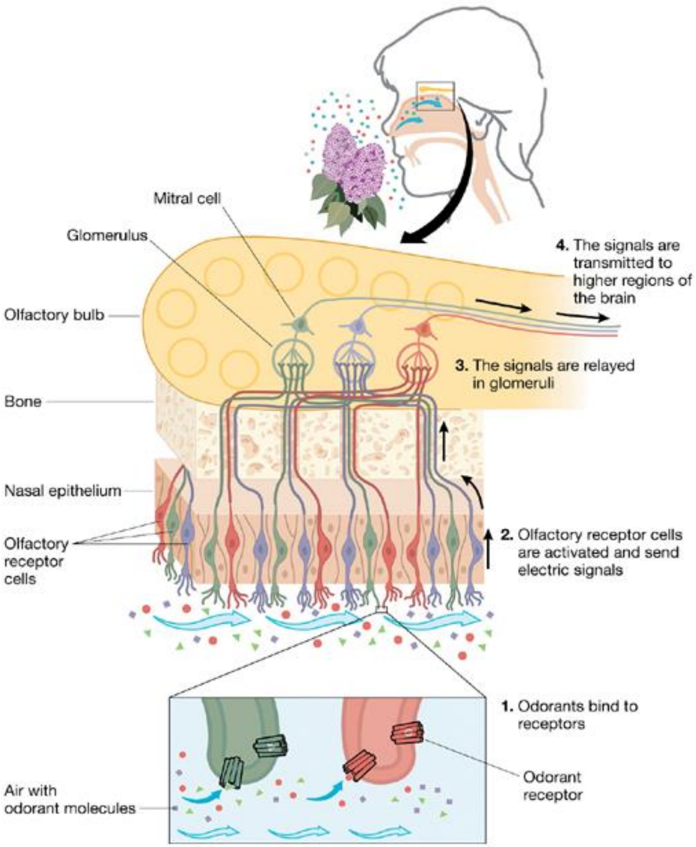


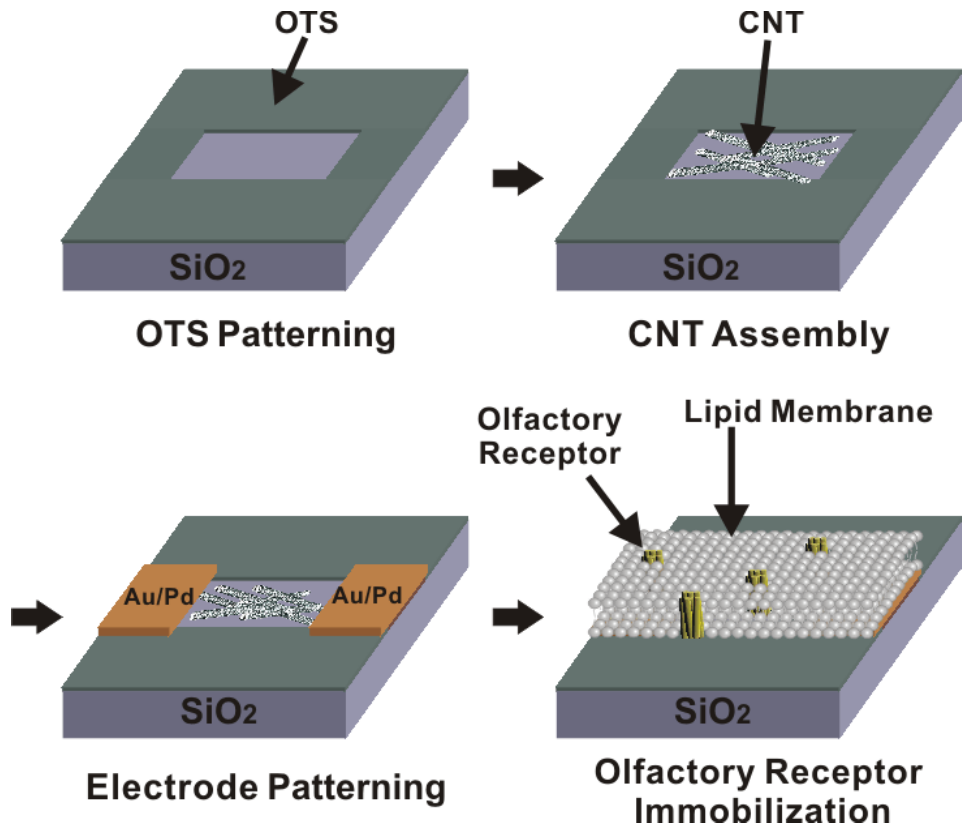
인간의 미각 시스템



- 미각/후각 시스템은 수용체 단백질을 이용한 방식으로 작동
- 다양한 종류의 후각/미각 수용체가 존재하기에, 이를 질병의 바이오 마커 검지에 활용 가능

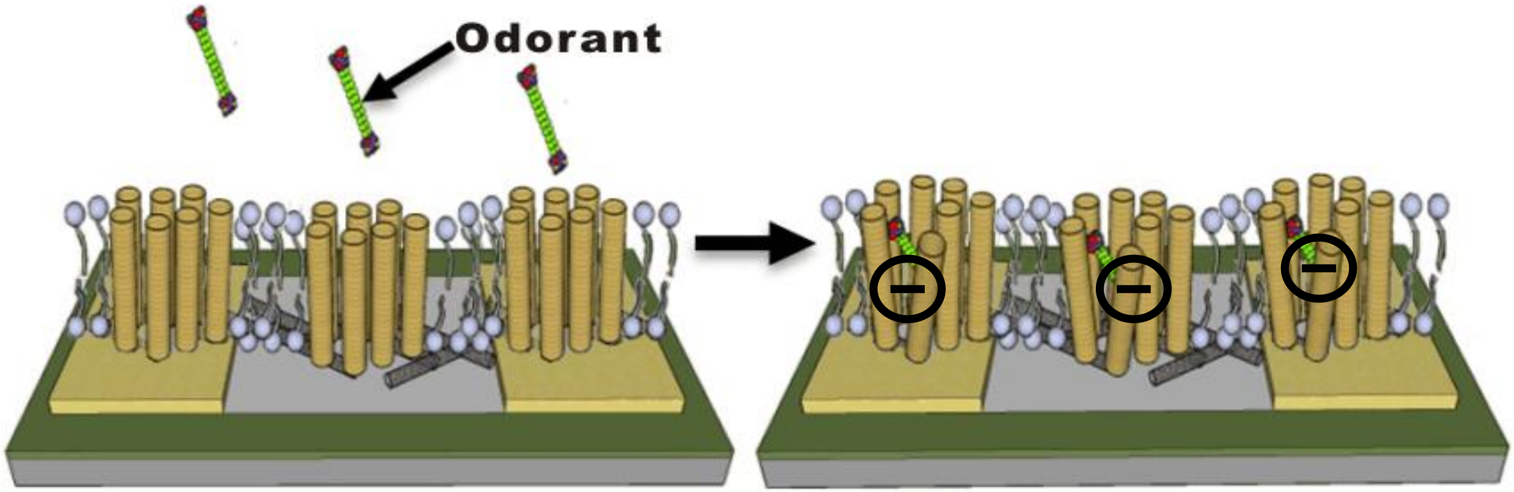
Bioelectronic Nose

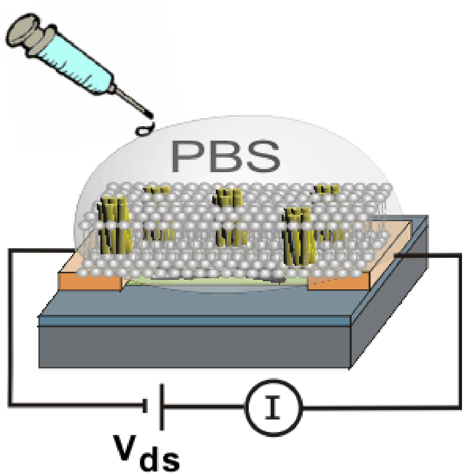




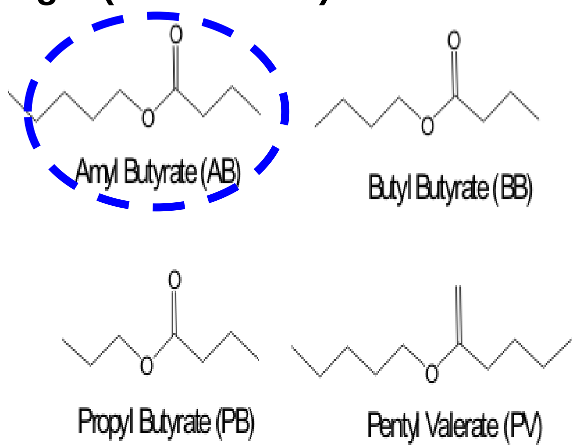
- Olfactory receptor protein: as a sensor receptor
  CNT-based channels: as a sensor transducer
- Olfactory receptors with lipid membrane were coated on CNT-channels.
  (Work with Prof. Tae-Hyun Park at Seoul National University)
  Advanced Materials **21**, 91 (2009); *Biosens. Bioelec.* (2012); *Analyst* (2012)

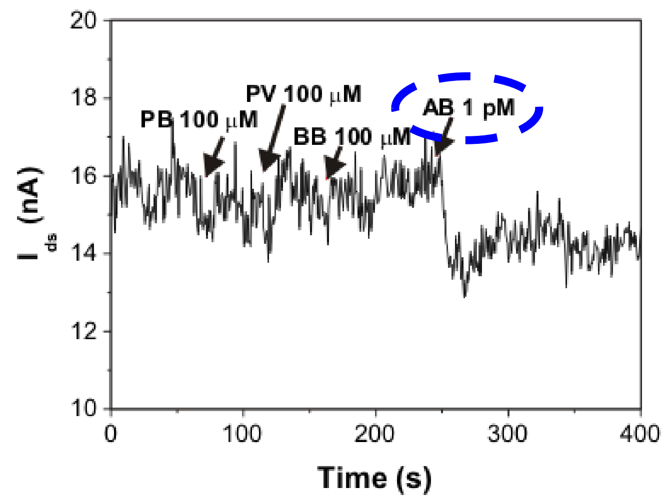
Differentiation of Single-Atomic Variation





Target (Fruit Flavor)

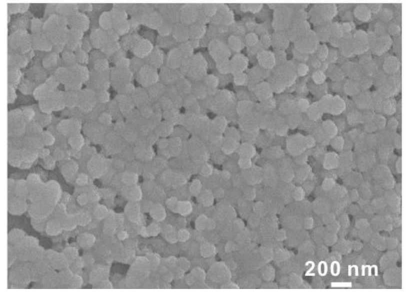


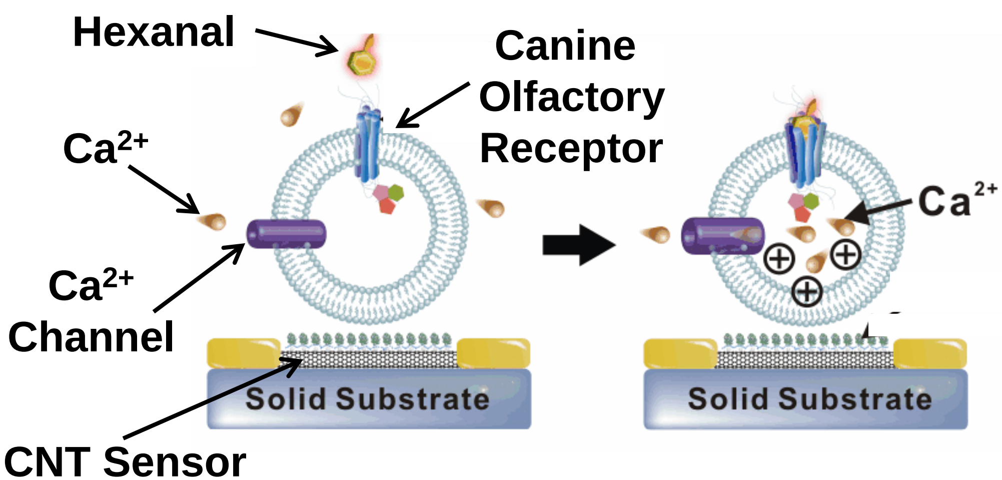


- The charge state change of olfactory receptor protein alters the electrical currents in the CNT channels.

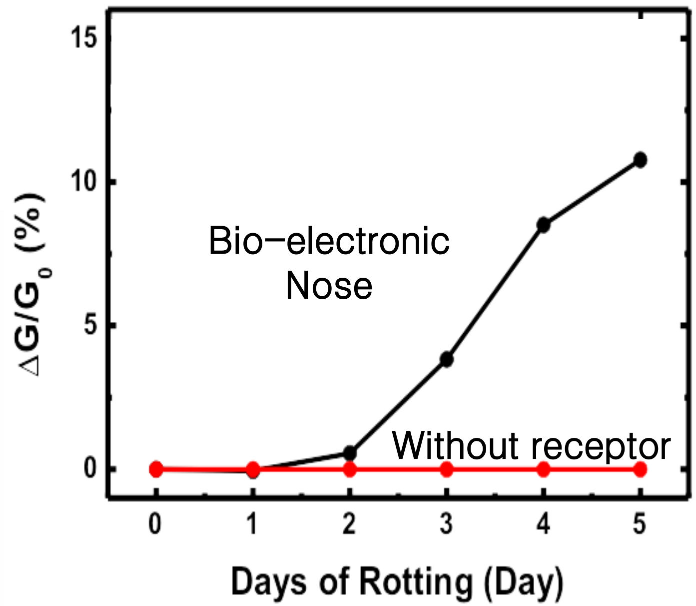
Canine-Olfactory Receptor-based Bioelectronic Nose

Nanovesicle





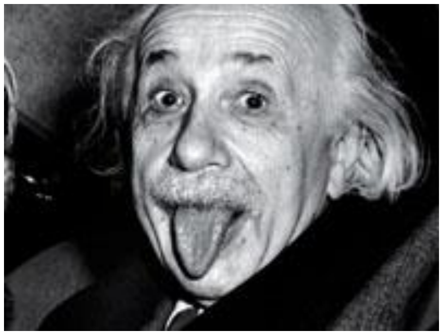
Evaluation of Rotten Milk

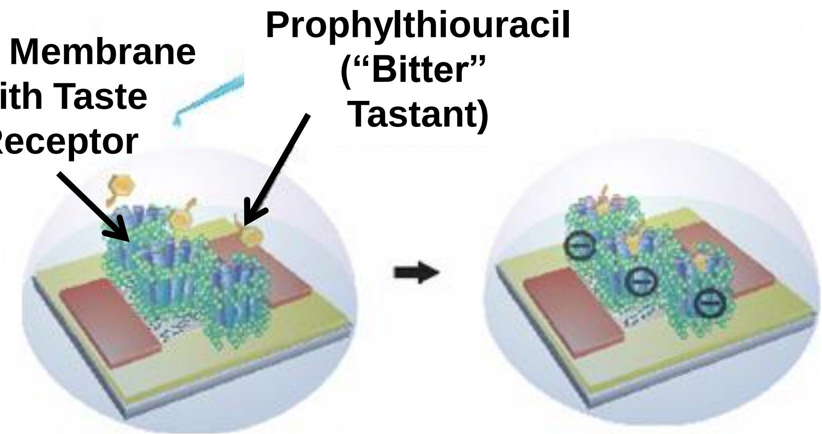


- Canine olfactory receptors were expressed in a HEK cell. Then, nanoscale vesicles were extracted from the cell and fixed on CNT channels to build the bioelectronic nose.
- Hexanal : odorant from rotten food, marker of lung cancer.

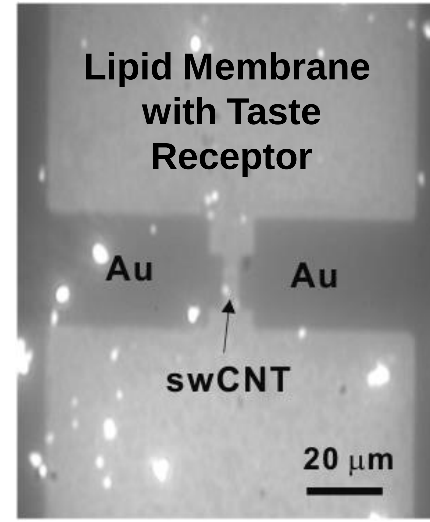
(Work with Prof. Tae-Hyun Park at Seoul National University)

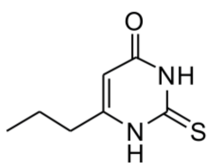
Bioelectronic Tongue



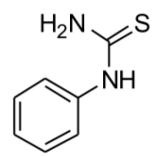


CNT Junction

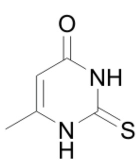




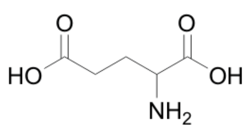
Propylthiouracil
(PROP, bitter taste)



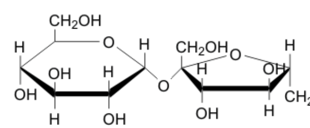
Phenylthiocarbamide
(PTC, bitter taste)



Methylthiouracil
(MTU, no bitter taste)

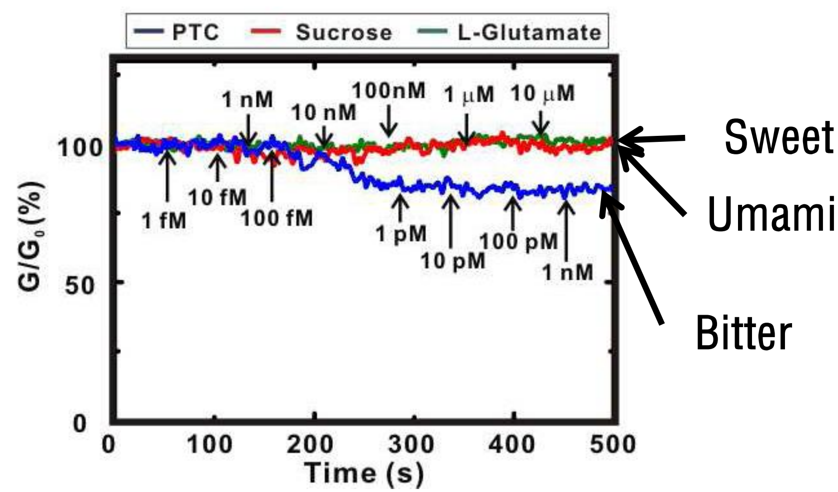


L-Glutamic acid
(umami taste)



Sucrose
(sweet taste)

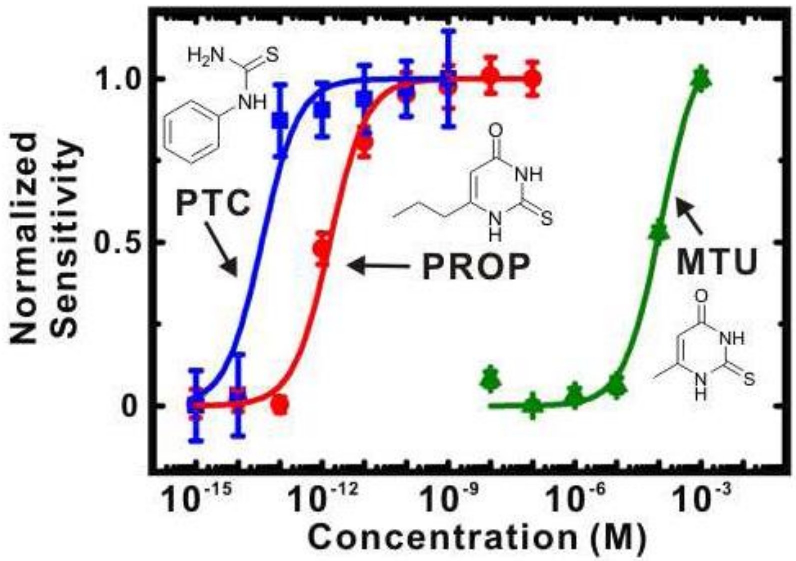
It responds only to bitter tastant.



Work with Prof. Tae-Hyun Park at Seoul National University
Lab on a Chip **11**, 2262 (2011)

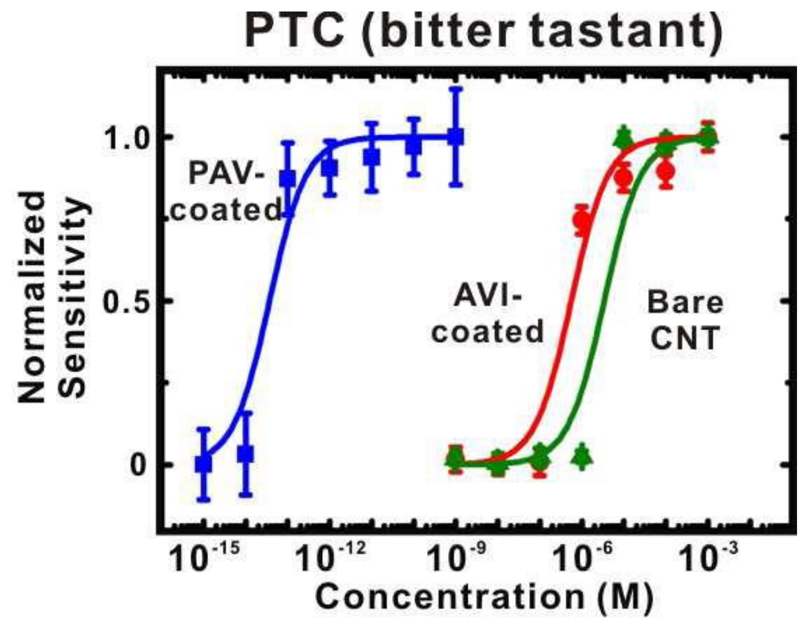
Response Curves of Artifical Tongue

Different Bitter Tastants



PTC, PROP : 사용된 수용체에 흡착하는 쓴맛 물질
MTU : 사용된 수용체에 반응 안하는 유사 물질

Artificial Tongue with Different Bitter Taste Receptors

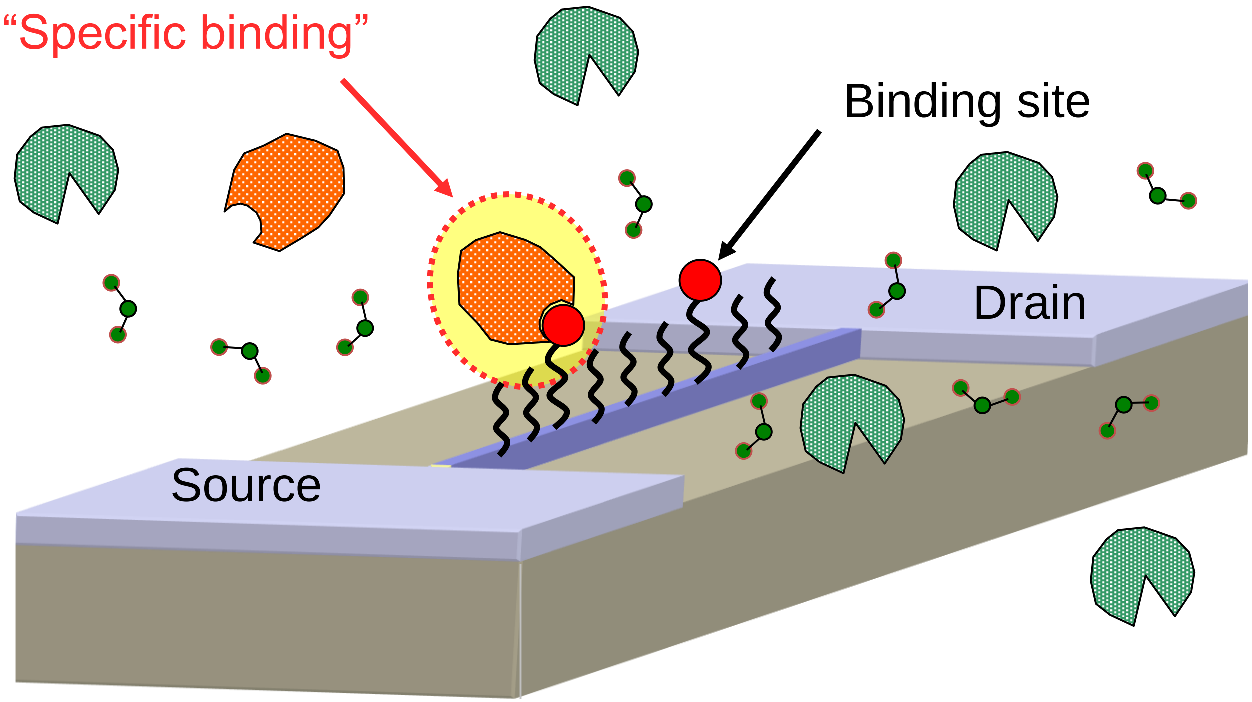


AVI: 미맹인 사람의 미각수용체
PAV: 정상인의 미각수용체

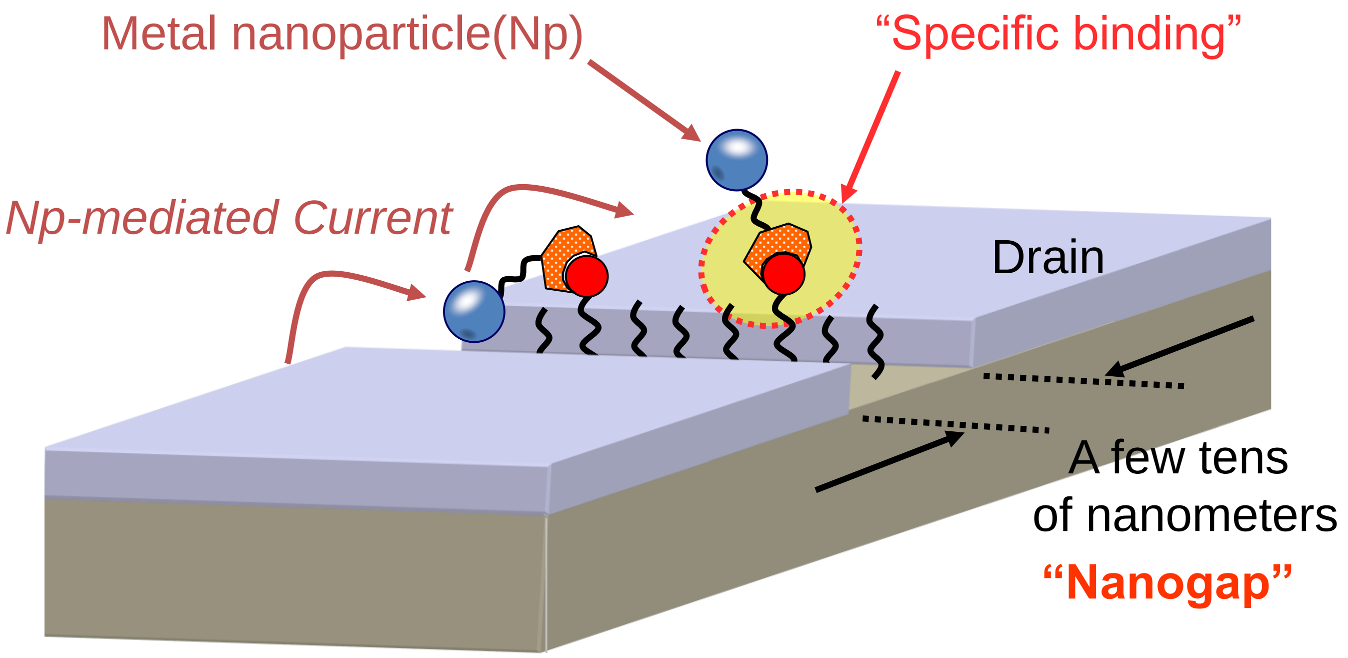
Nanogap Devices for Nanobio Applications

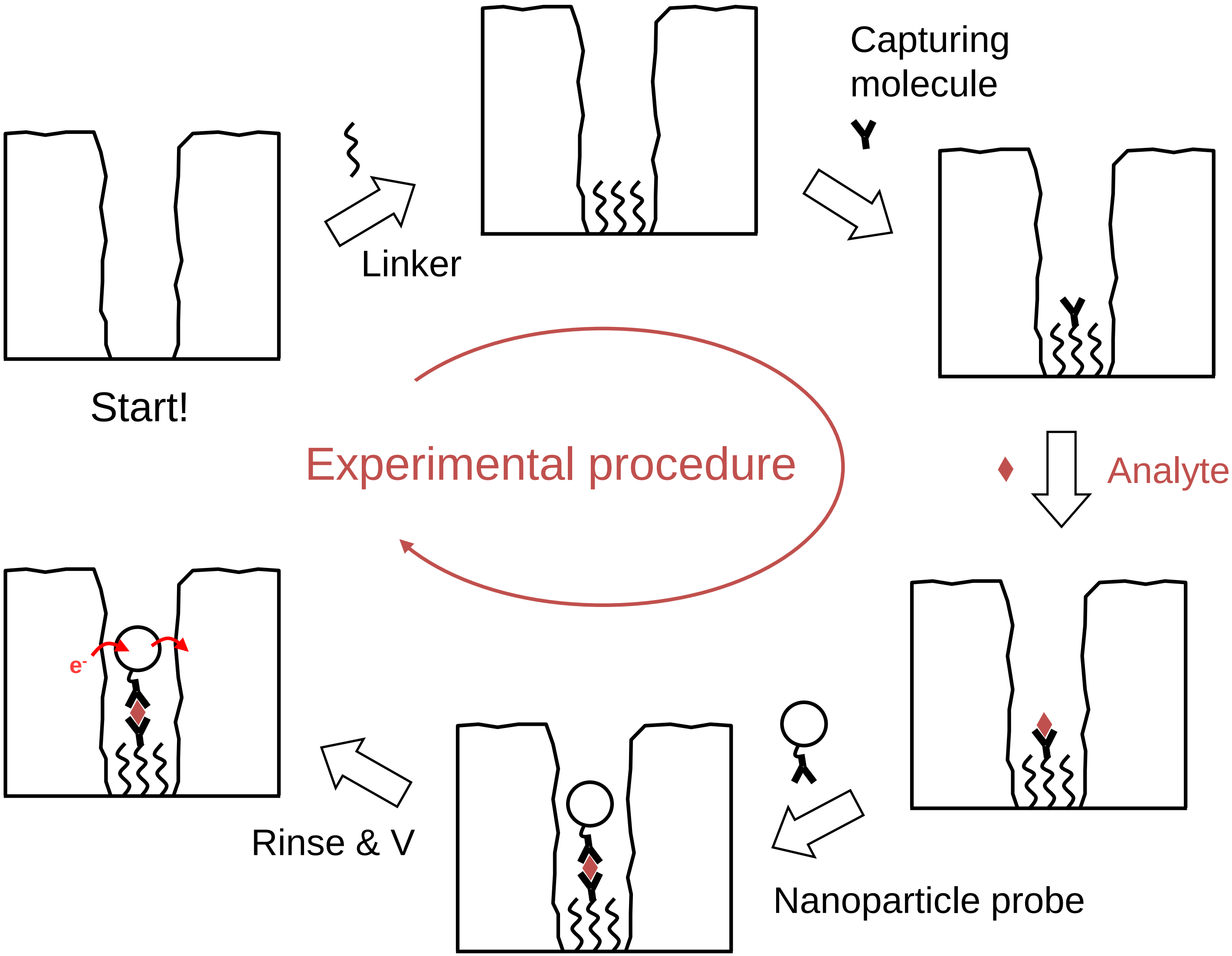
Mainly based on research by Prof. W.S. Yoon @ SKKU

Nw-FET biosensor



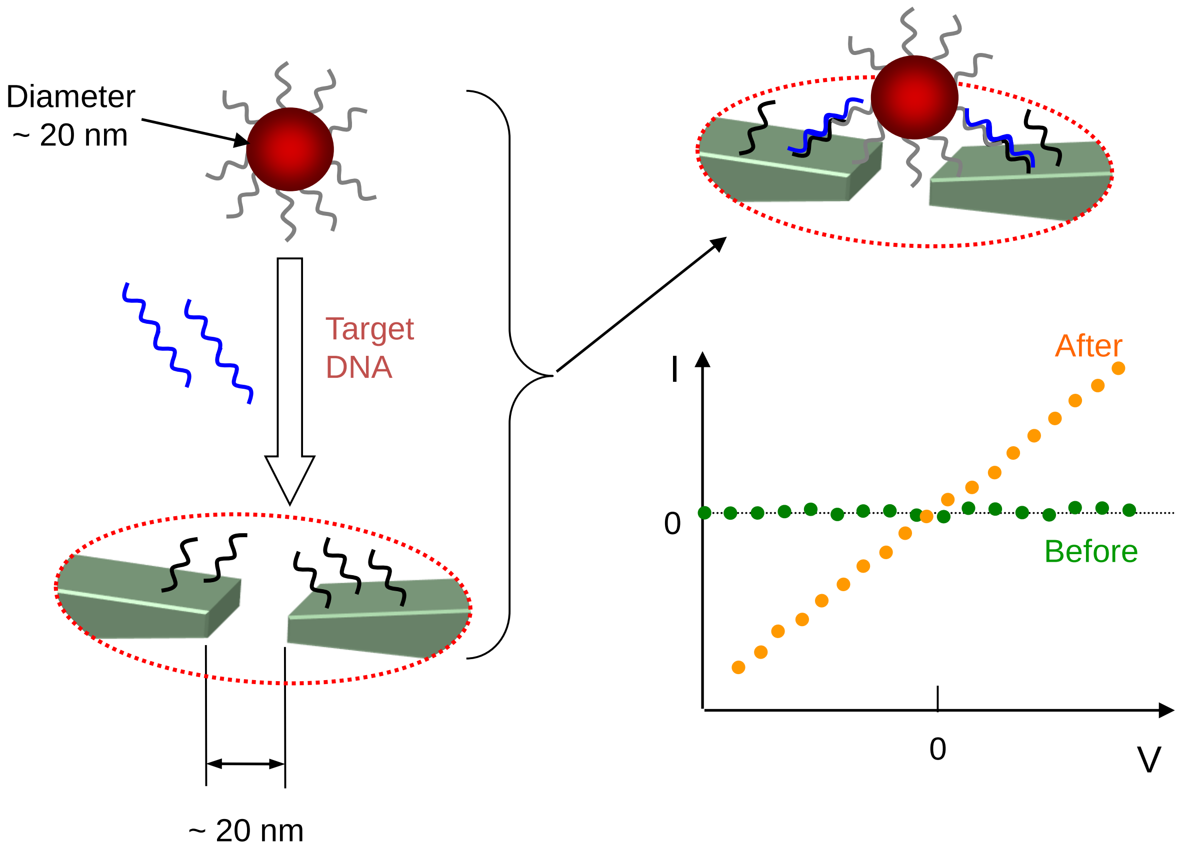
Nanogap biosensor



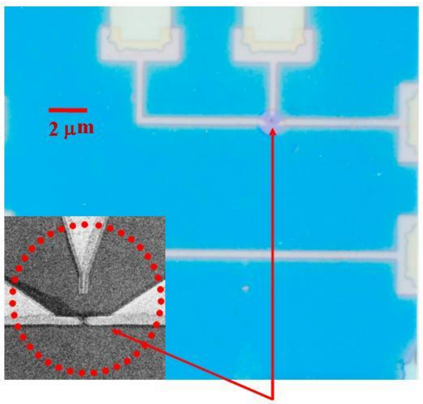


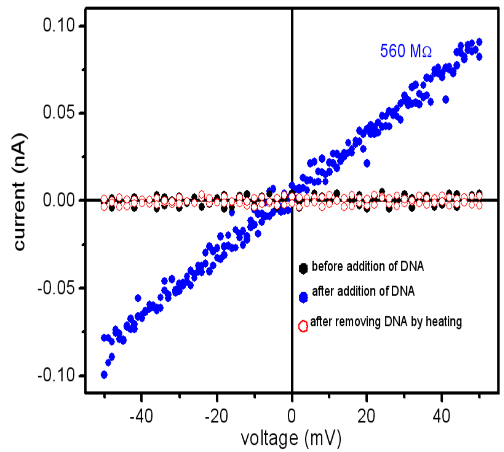
Linker
Capturing
molecule
Start!
Experimental procedure
Analyte
e-
Rinse & V
Nanoparticle probe

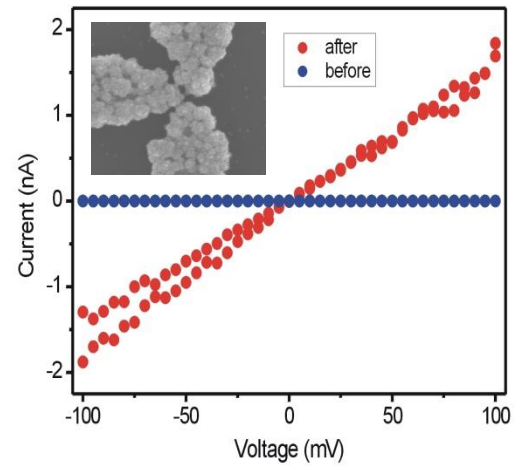
Biosensing with a nanogap device



Detection of DNA by nanogap sensor



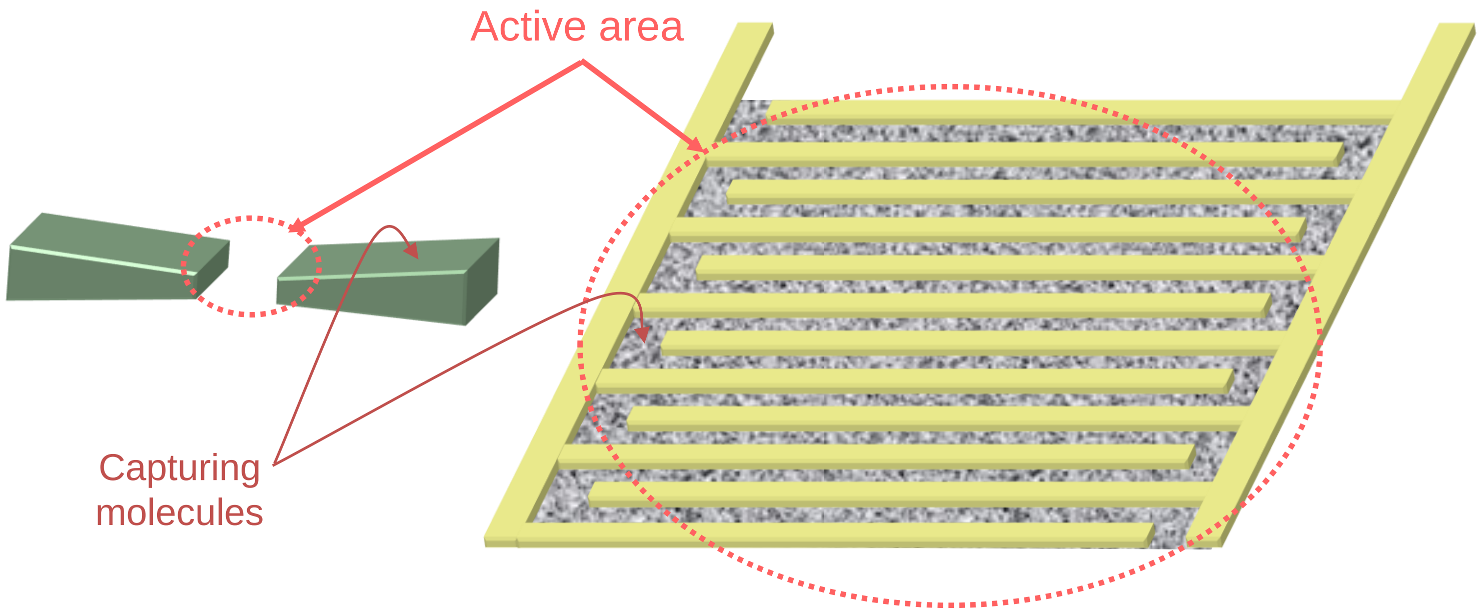




but, 2 out of "too many" devices.

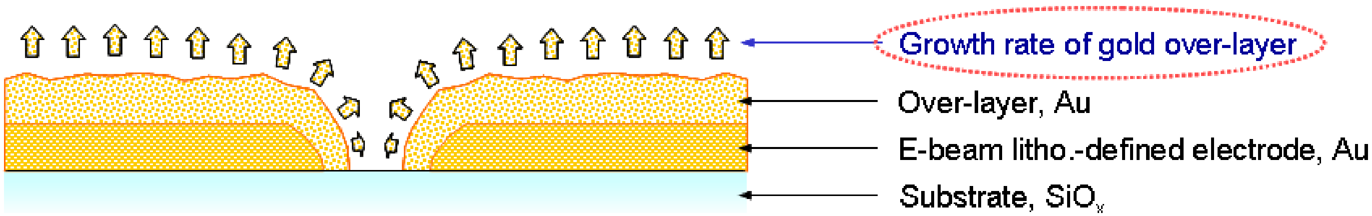
New design of the gap sensor

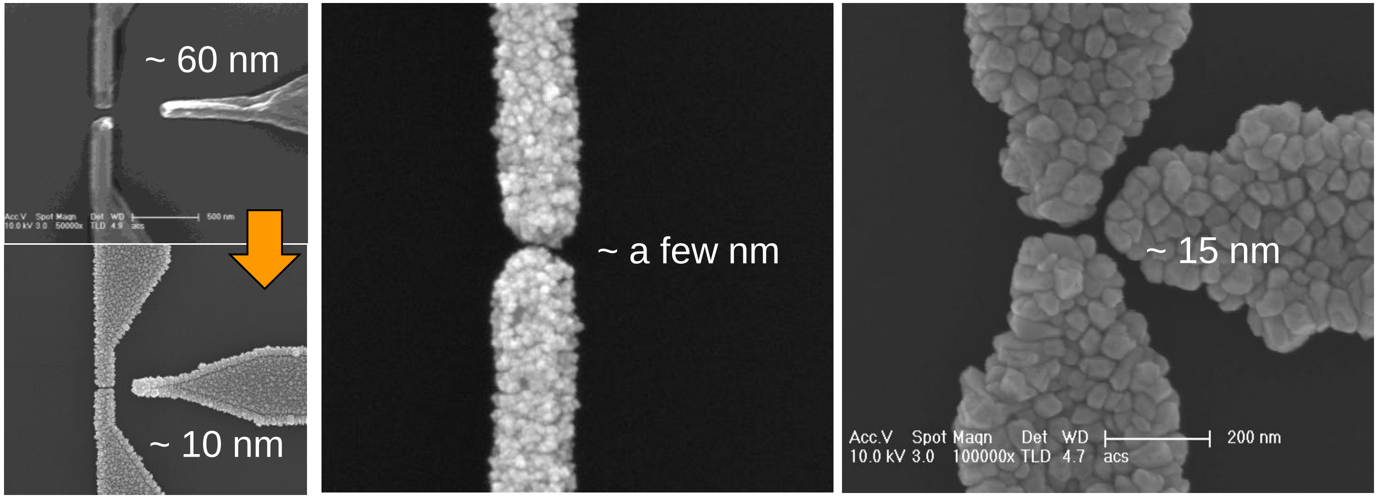
→ (1) Increased active area, (2) chemistry “in” the gap region



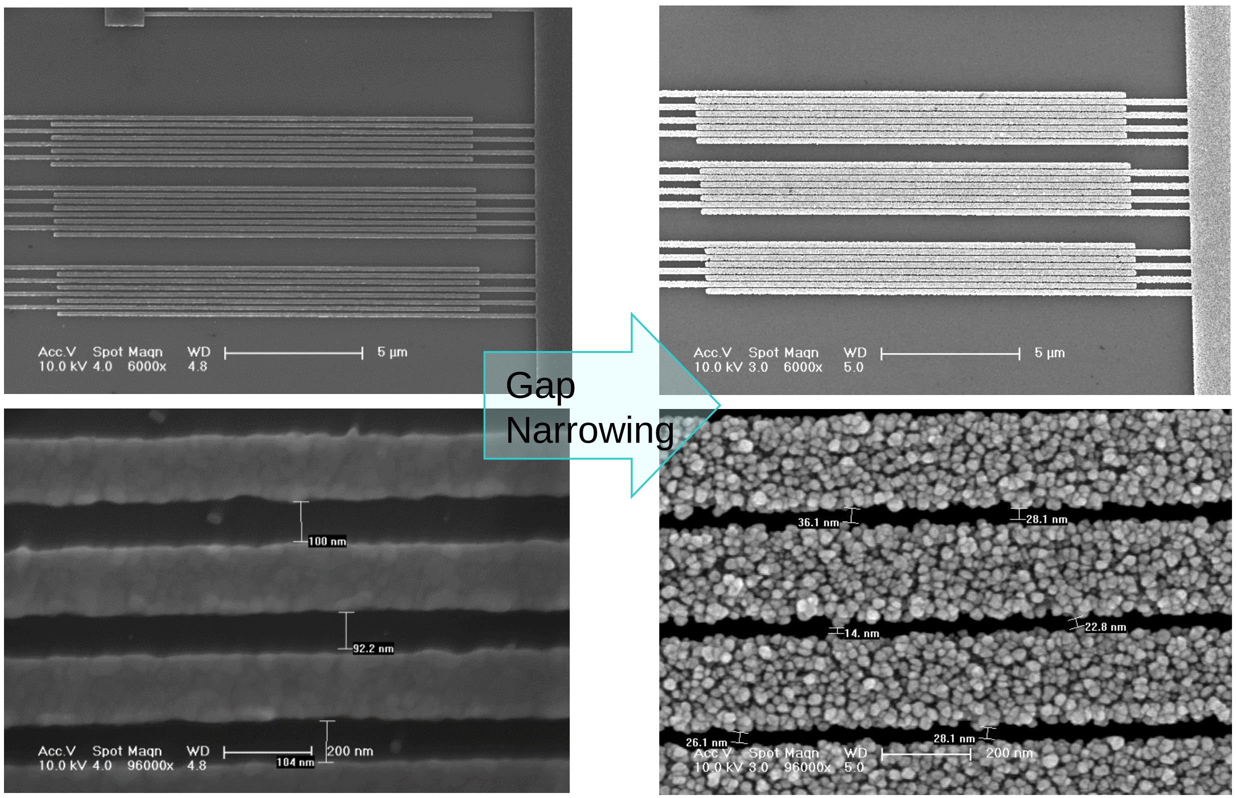
Nanogap by surface-catalyzed chemical deposition

: Narrowing the gap by selective growth of metallic over-layer

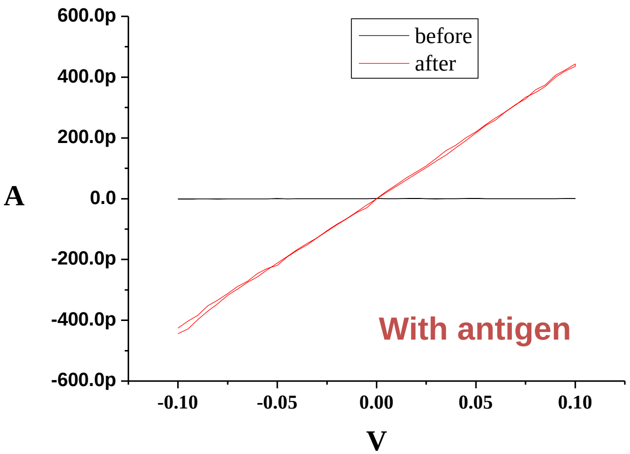


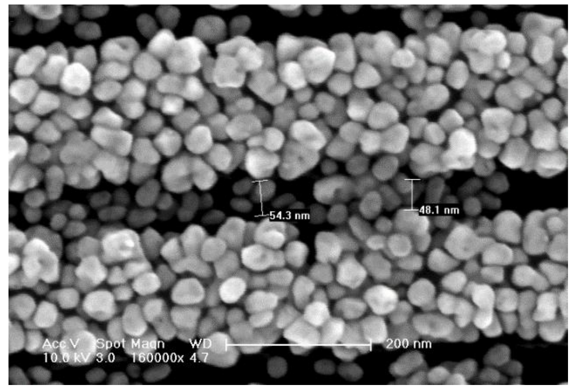


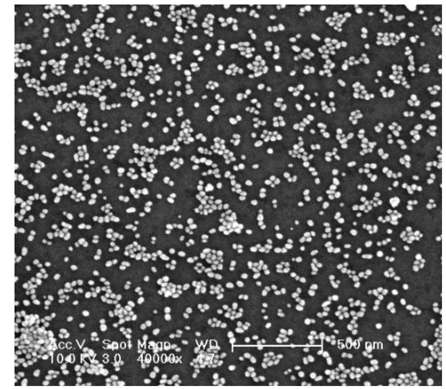
Narrowed-gap IDE

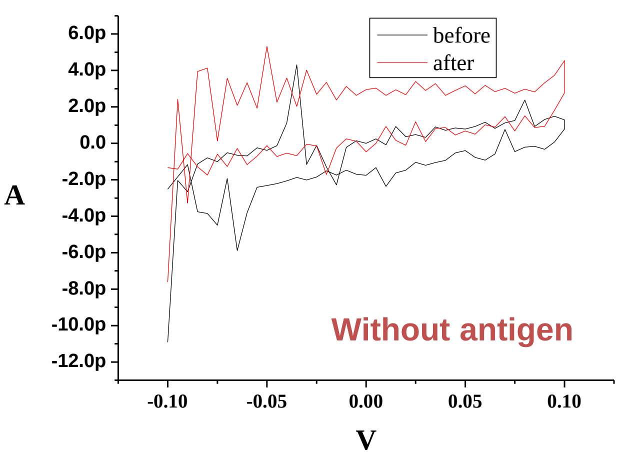


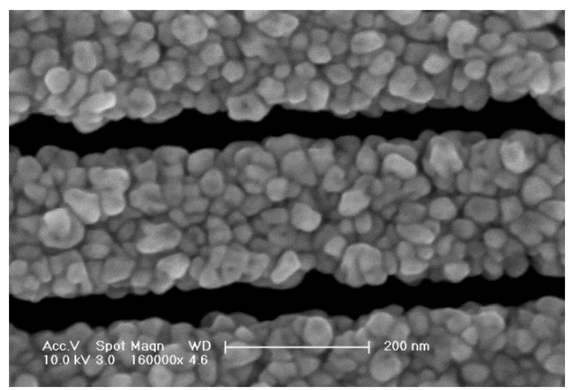
Detection of PSA by narrowed-gap IDE

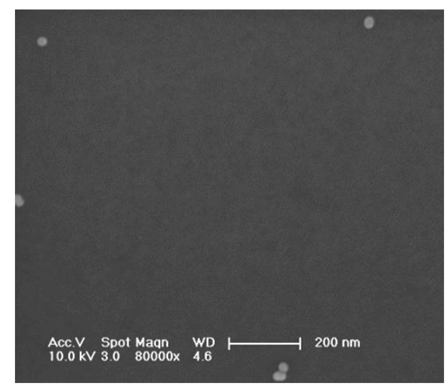




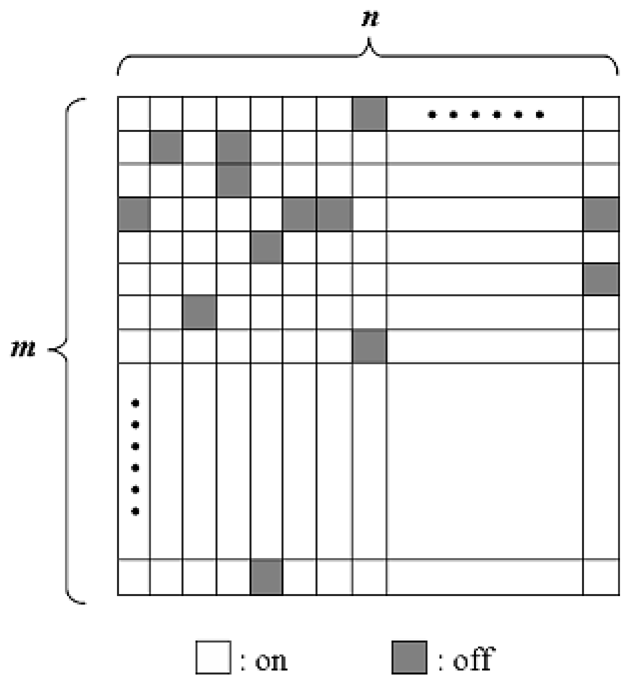




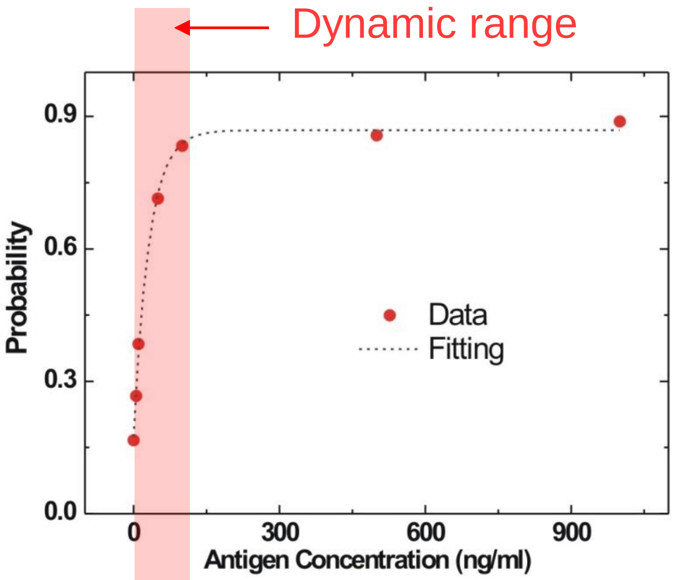




P-C curve from an integrated on/off sensor



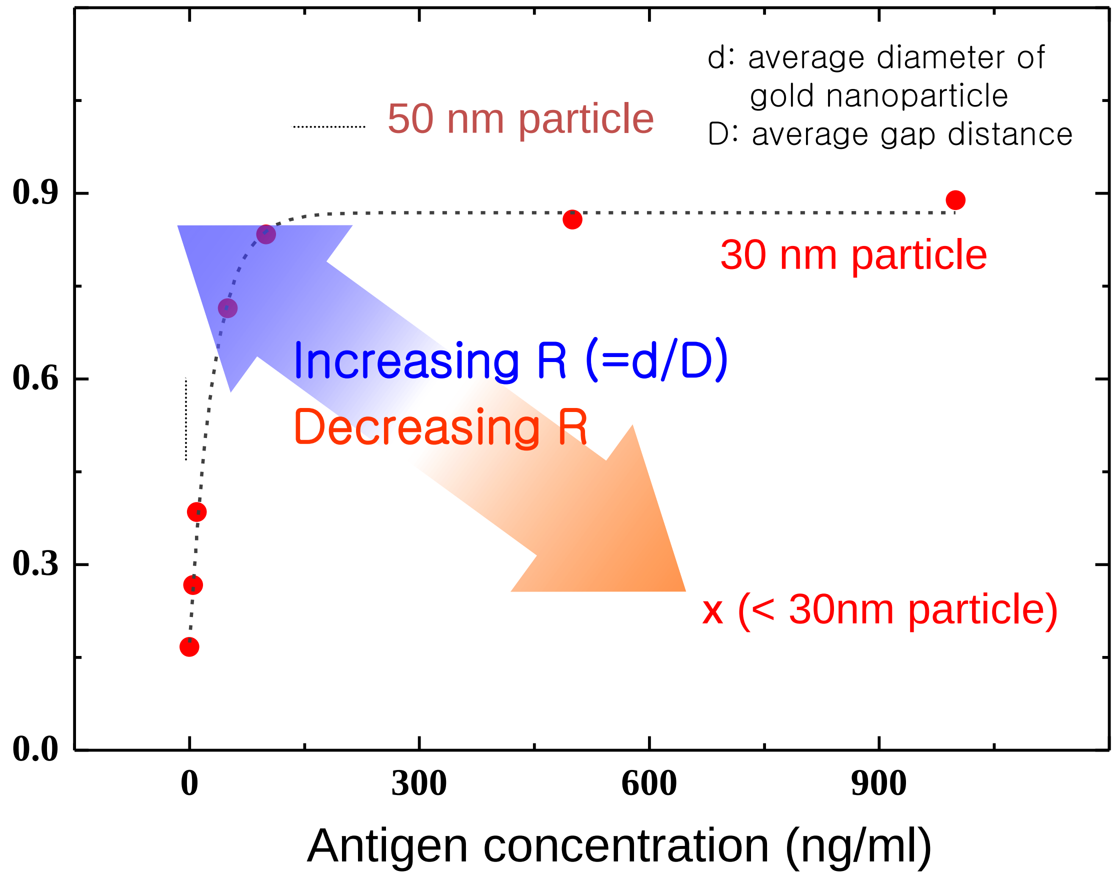
$$Concentration = f\left(\frac{N_{on}}{N_{tot}}\right) = f\left(\frac{N_{on}}{m \times n}\right)$$



$$P_{on} = A - B\,exp(-kC)$$

$$,\ from\ dP_{off} = -\,k\ .\ P_{off}\ .\ dC$$

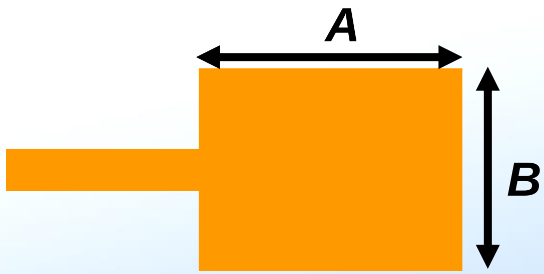
P-C curve of 50 nm gap sensor



Technological Comparison and Future …

다양한 트랜스듀서의 Scaling Behavior

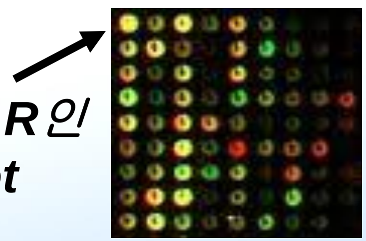
전극 기반 Electrochemical Sensor(혈당 센서 등)



- *(센서신호) =(전극과 용액간 전류)*
  ~ (전극 면적) ~ AB
- 만일 ***A, B*** *를 모두* ***1/s****로 줄이면,*
  (센서 신호) ~1/s^2 로 축소

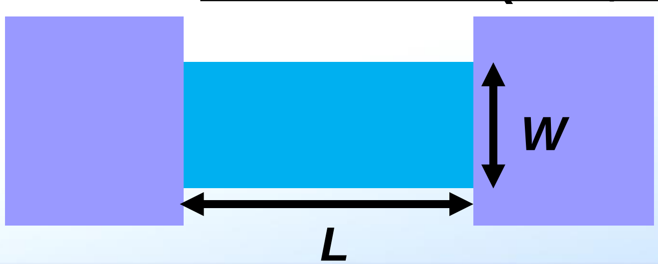
형광기반 바이오 칩(DNA 칩, 단백질 칩 등)

반지름 ***R*** *인*
spot



- *(센서신호) =(spot에서 오는 형광의 량)*
  ~ (spot 면적) ~ R^2
- *만일 **R** 를 **1/s**로 줄이면,*
  (센서 신호) ~1/s^2 로 축소

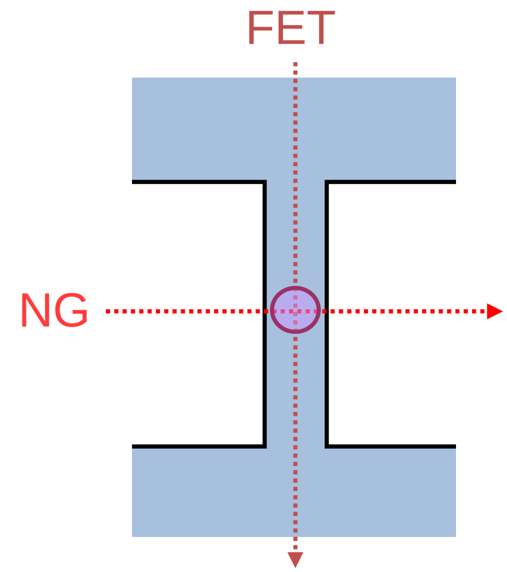
<u>반도체성 채널(CNT, 산화물 반도체 등) 기반 센서</u>

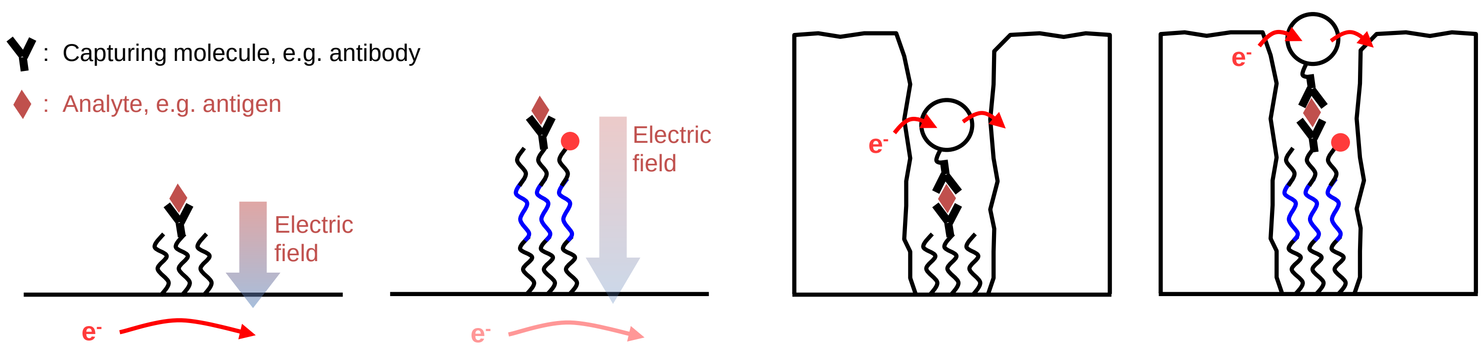


- *(센서신호) =(채널 전류) ~ W/L*
- 만일 ***W, L*** *를 모두* ***1/s****로 줄이면,*
  (센서 신호) ~ (W/L) ~그대로 유지
- 고집적화, 소형화에 유리

Comparisons between NG and FET

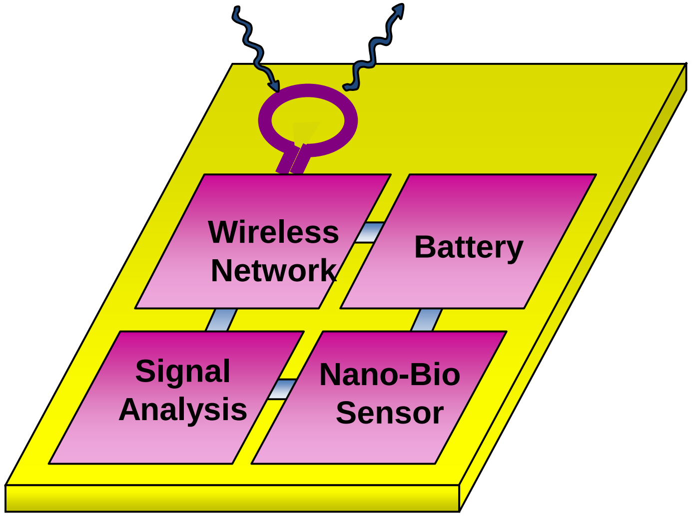
Detectivity (single molecule, in principle),
Chemical selectivity (molecular intrxn only),
SAM formation (insensitive to the thickness),
NSB (of known particles),
Measurement environment (dry possible),
On-off signal ratio (off current ~ ‘0’),
Protein stability (capillary wetting),
Cost (prep. & measurement),
……

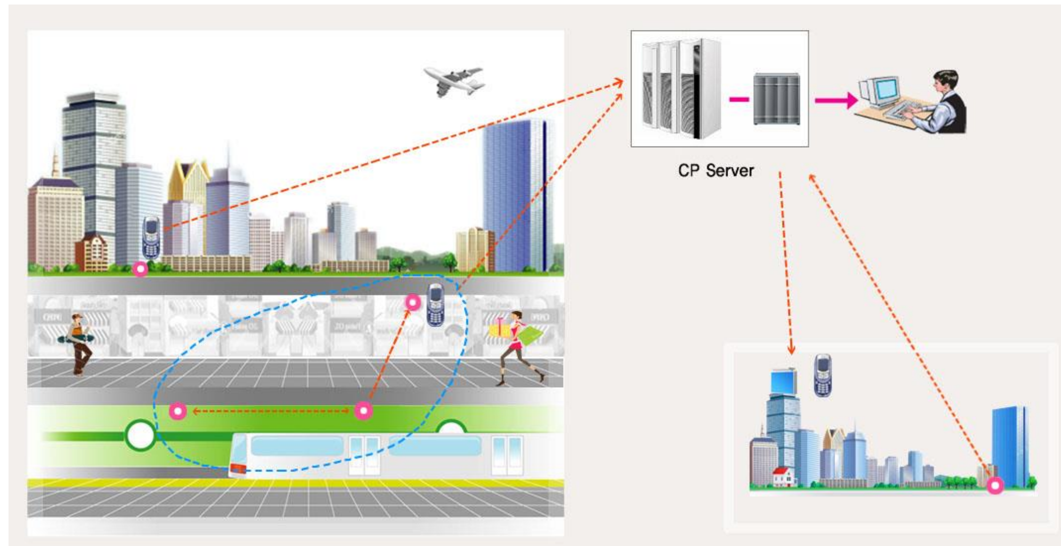




Ubiquitous Nano-Bio Sensor System

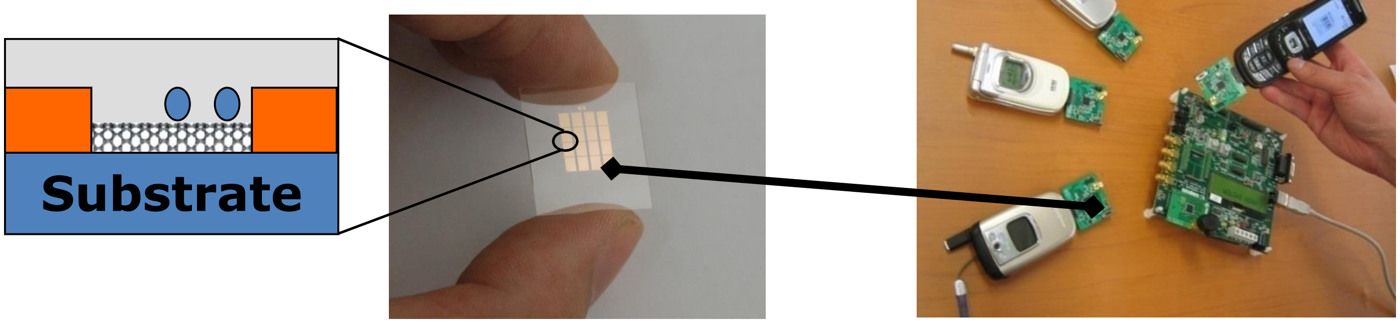
Environmental Safety Network (Gas, Bioterror, IoT, etc)





Portable Nano-Biosensor : Self-Diagnostics, etc

Ubiquitous Sensor Chip



- 무선 통신 기술 등은 이미 있으나, 초소형 실시간 검지 센서가 없어서 구현이 안되고 있음