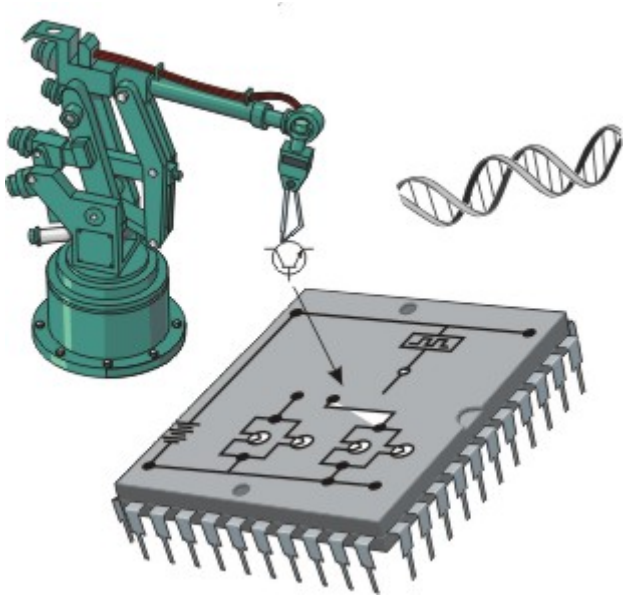
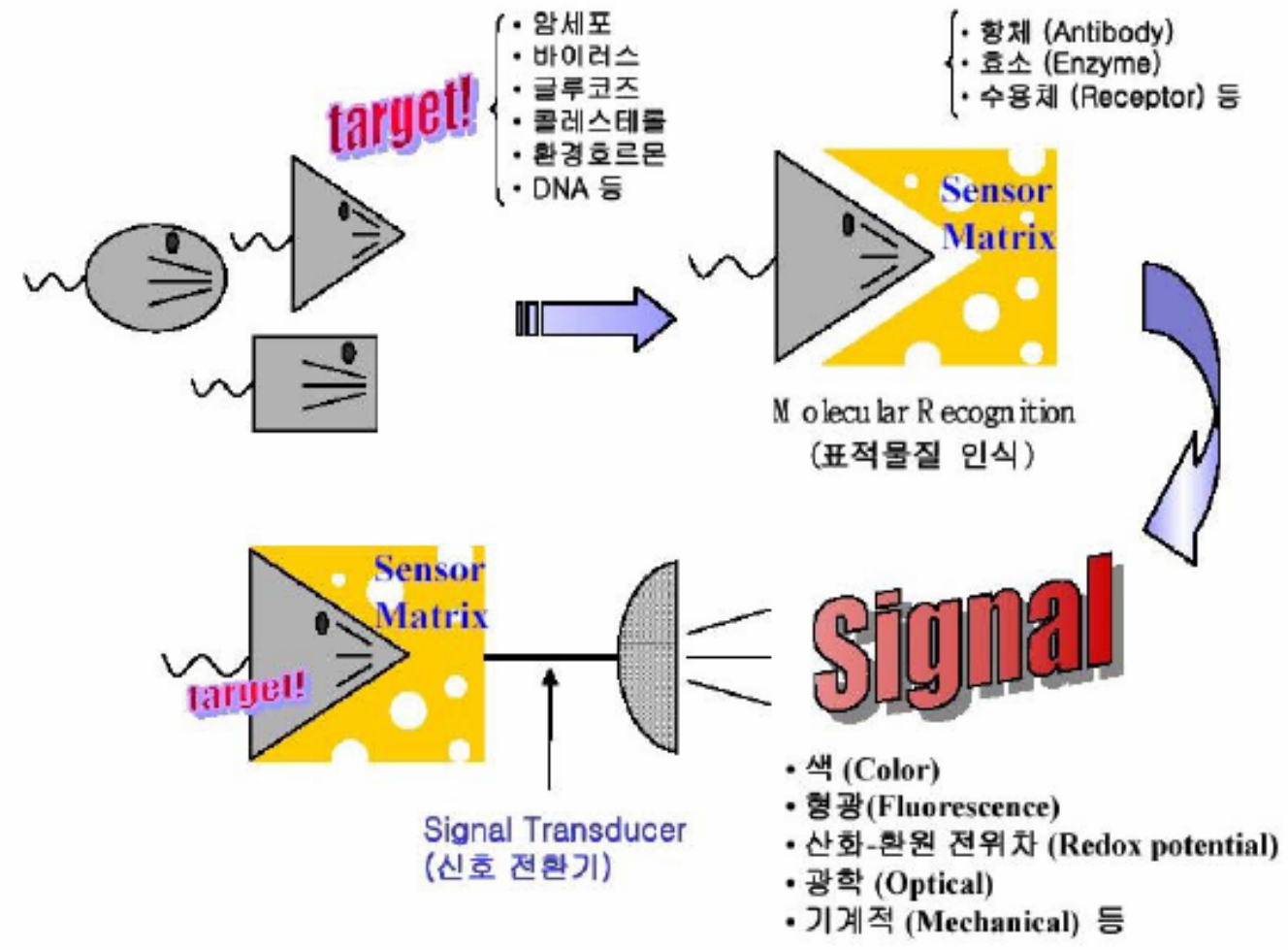
그린 바이오용 나노바이오 센서 대량 제작 기술



홍승훈

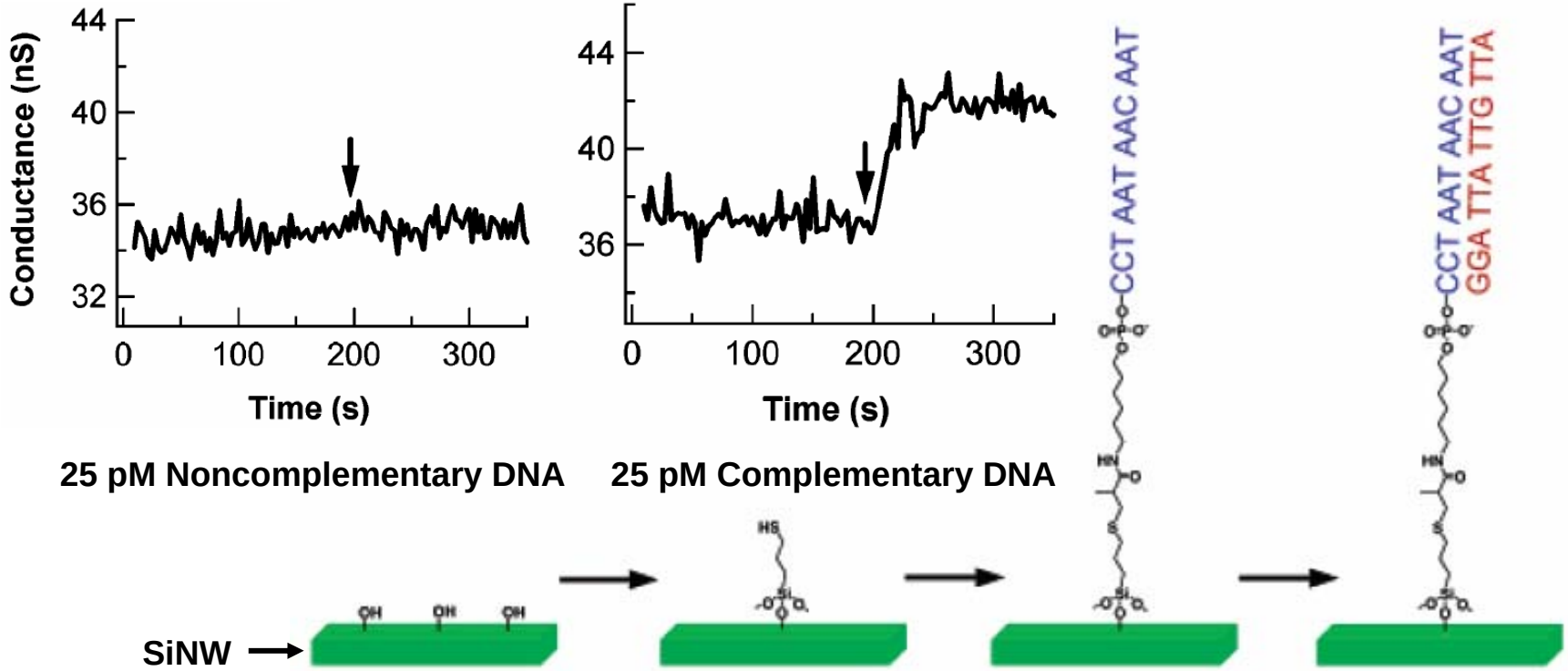
서울대학교 물리-천문학부

Biosensors


target!
• 암세포
• 바이러스
• 글루코즈
• 콜레스테롤
• 환경호르몬
• DNA 등
• 항체 (Antibody)
• 효소 (Enzyme)
• 수용체 (Receptor) 등
Sensor Matrix
Molecular Recognition
(표적물질 인식)
Signal
• 색 (Color)
• 형광(Fluorescence)
• 산화-환원 전위차 (Redox potential)
• 광학 (Optical)
• 기계적 (Mechanical) 등
Sensor Matrix
target!
Signal Transducer
(신호 전환기)

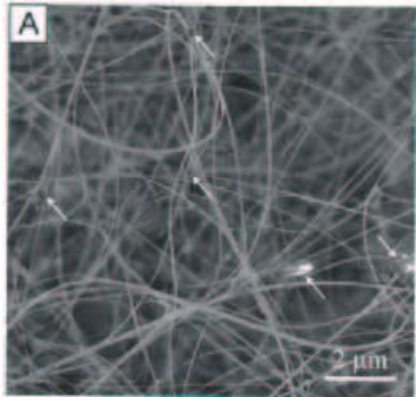
Example: DNA Sensor using Silicon Nanowire Circuits

(Other Group's Works)

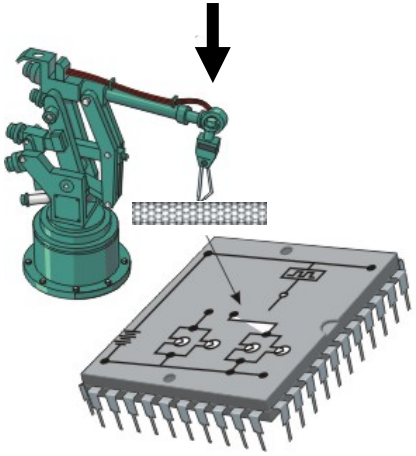


Z. Li etal., *Nano Lett.*, 2004, *4*, 245.

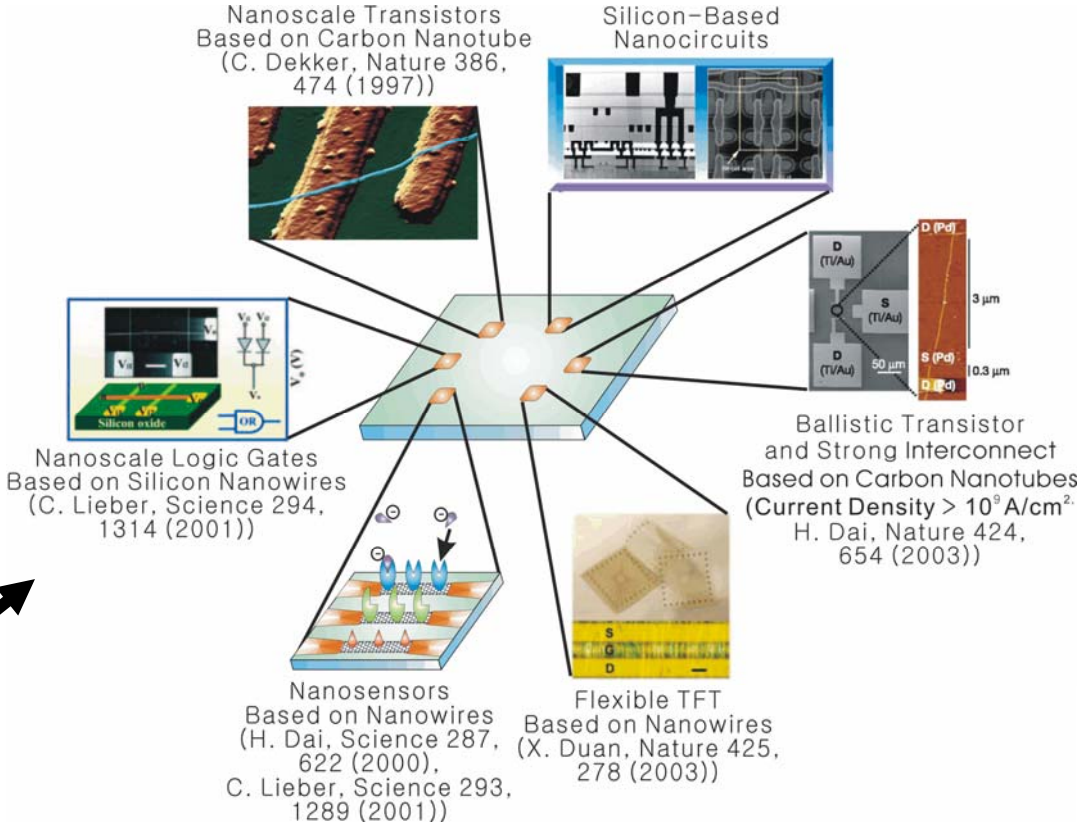
"Nano-Manufacturting" Problem of Nanowire-Based Devices



Nanostructure Synthesis



Assume it costs 1 second to assemble 1 nanowire.

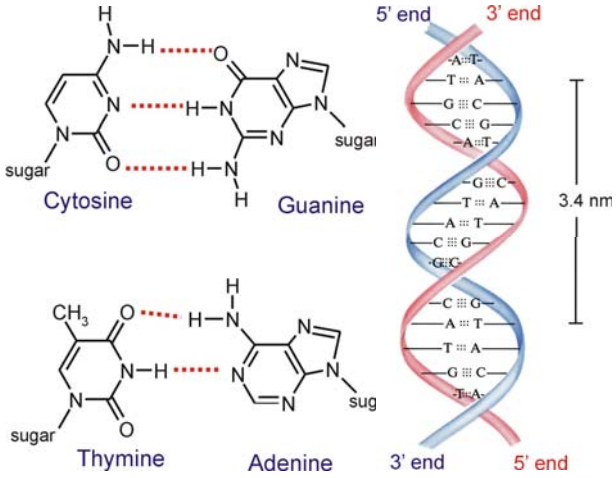


Common integrated circuits containing one billion wires: ~ 32 years for a single chip.

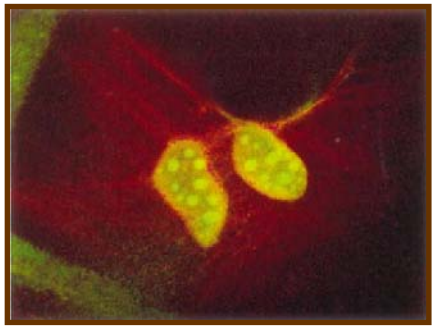
Commercial Application? You got to be kidding!

Self-Assembly: From *Nano* to *Macro*

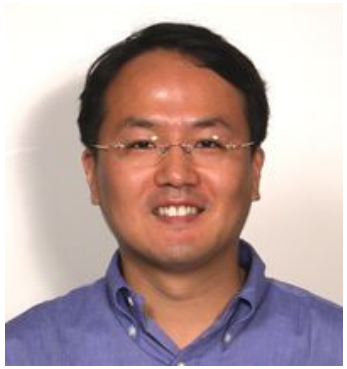
Nanoscale Self-Assembly via Biomolecular Recognition



Microscale Cells



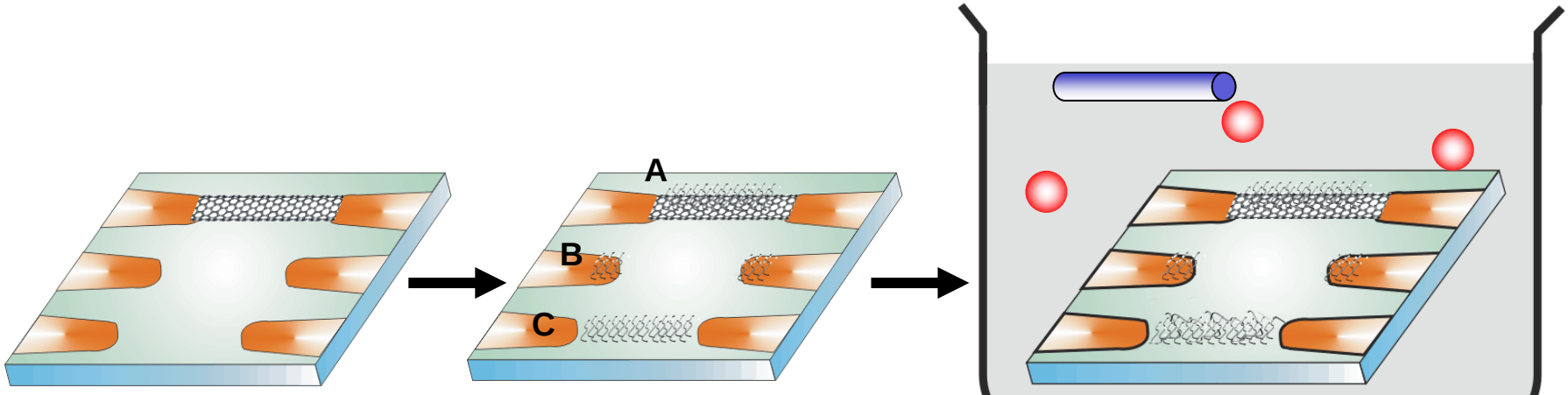
Macroscale Human Body



Everyone in this room is a *living evidence* proving, "self-assembly can be used to build macro-structures from nanostructures."

Very Successful Results in Various Aspects (e.g. IQ etc)

Our Solution: Surface-Programmed Assembly



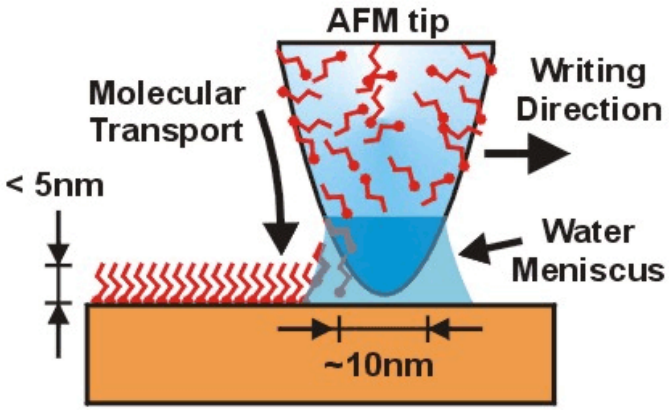
Microfabrication Process

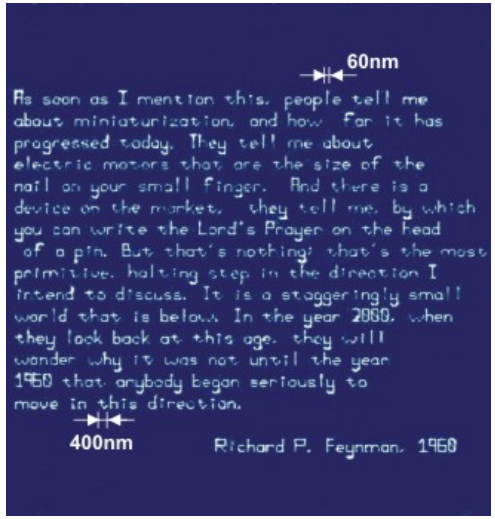
Molecular Patterning via DPN, Contact Printing, Photolithography, etc

Surface-Pattern Induced Assembly

Molecular Patterning Methods

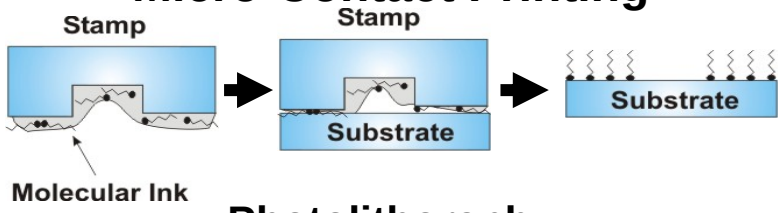
Dip-Pen Nanolithography



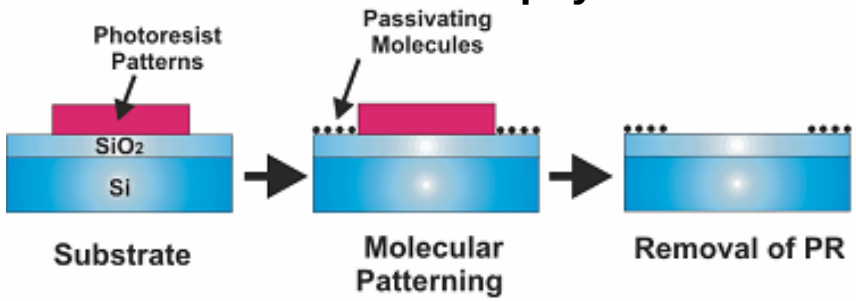


***Science* 288, 1808 (2000), *Science* 286, 523 (1999), *Science* 283, 661 (1999).**

Micro-Contact Printing

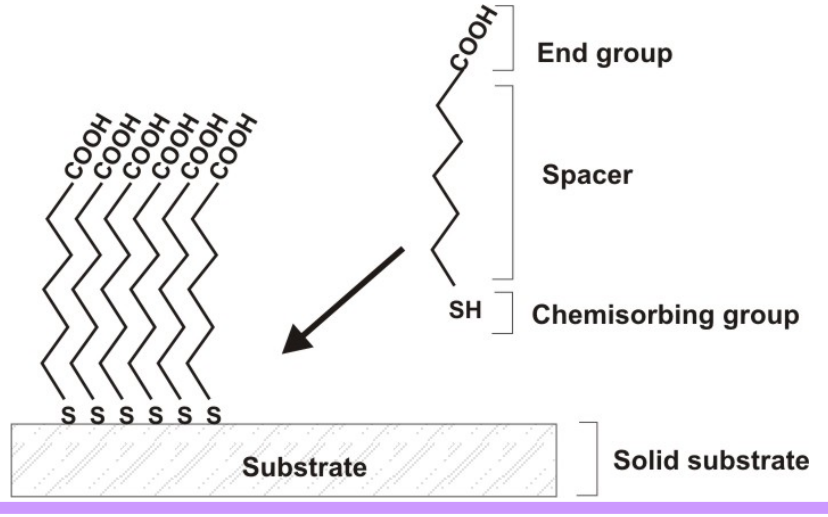


Photolithoraphy

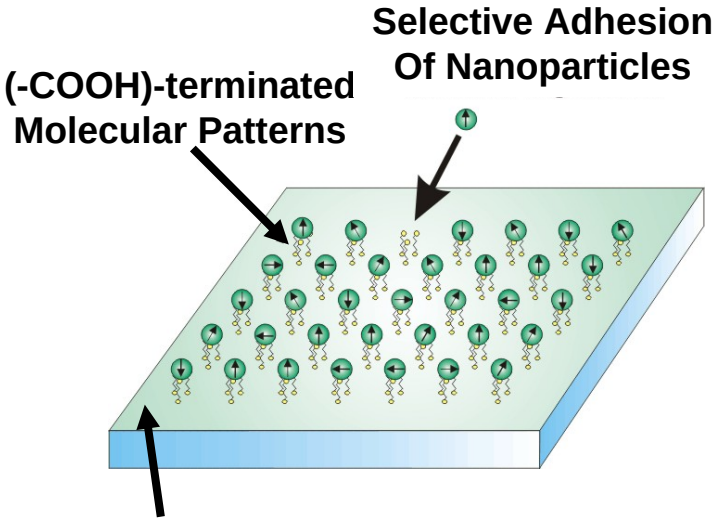


***Nature Nanotechnology* 1, 66 (2006)**

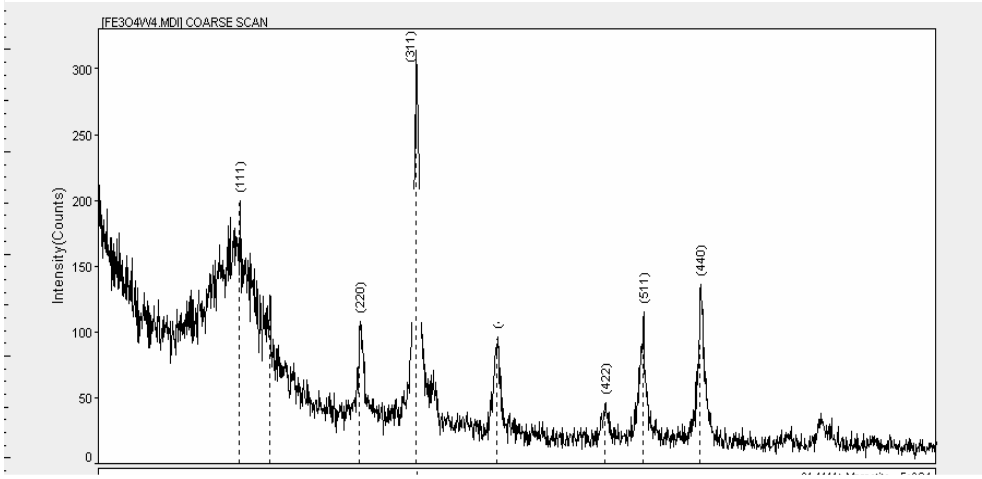
Self-Assembled Monolayers

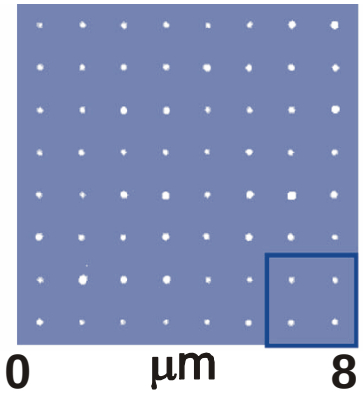


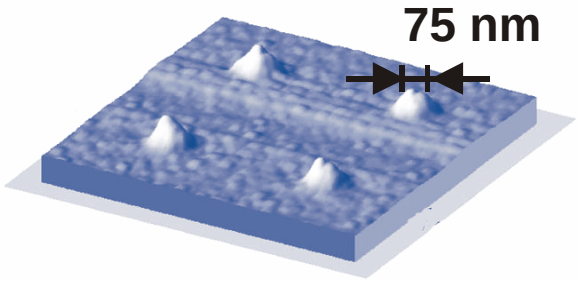
Assembly of Magnetic Nanoparticle Array



X-ray diffraction showing Fe_3O_4 Structures

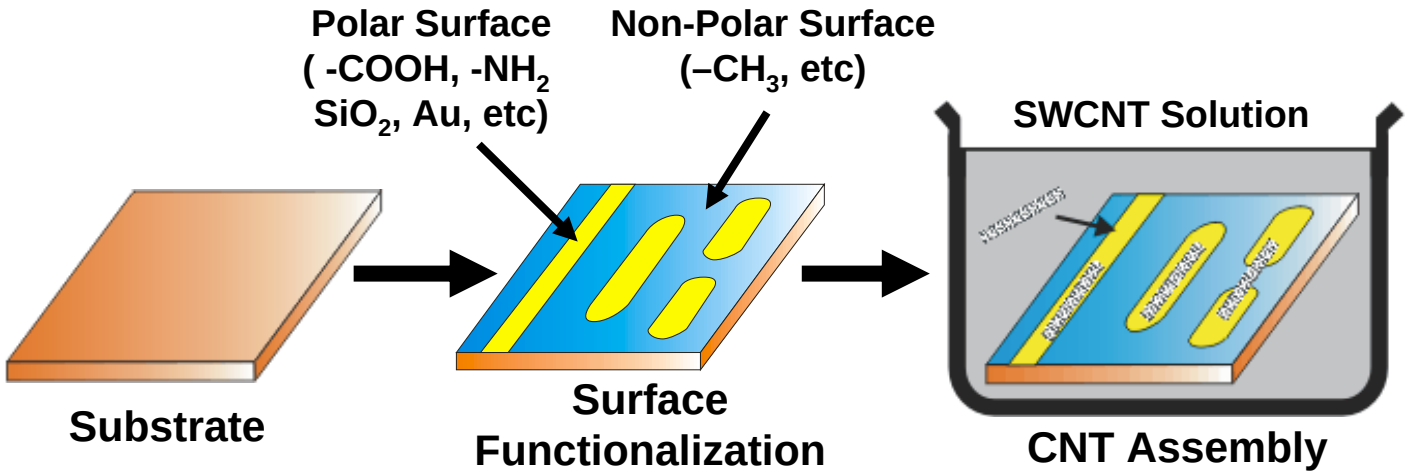






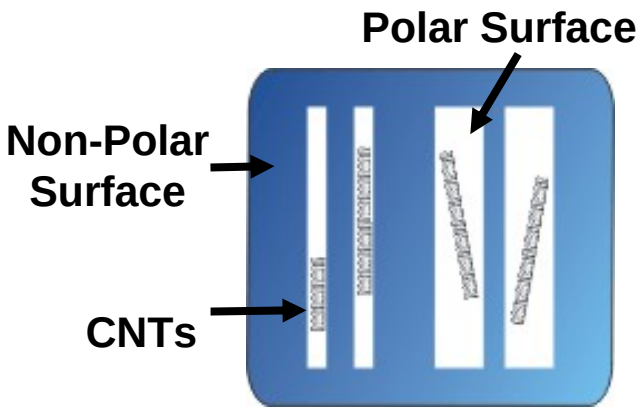
Advanced Materials **14, 231 (2002)**

Massive Assembly of Carbon Nanotubes

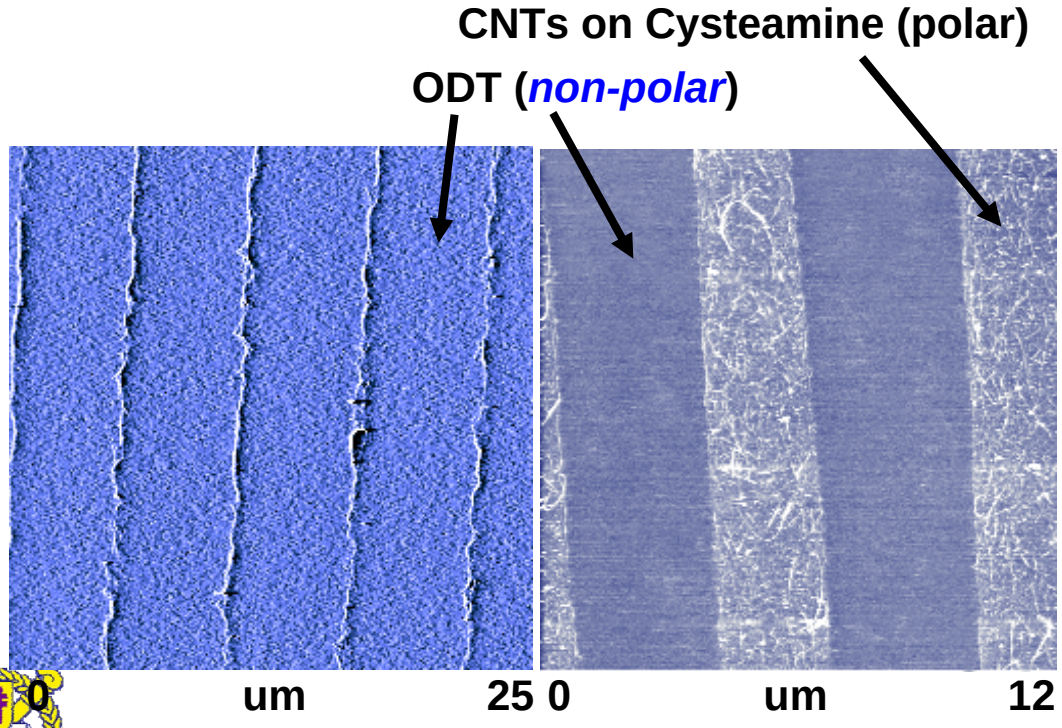


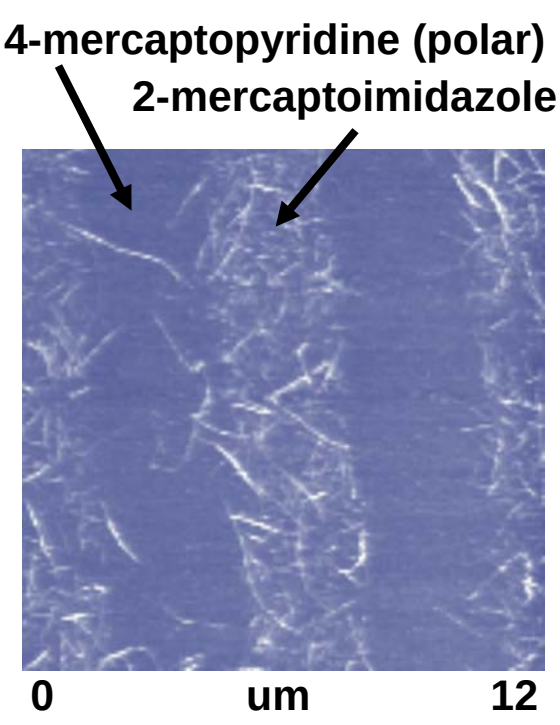
- ***WHAT YOU SEE IS WHAT WE DO***: **NO functionalization on CNT, NO flow cell, NO electric field, NO magnetic field, NO catalyst pattern, NO extra structures, NO…**
- ***No hydrophobic interaction*** **because CNTs are in non-polar solvent.**
- **Previous pioneering works about CNT and nanowire assembly: micromanipulation, electric or magnetic field alignment, assembly onto e-beam generated patterns (J. Liu and R. Smalley) flow cells (C. Lieber at Harvard), growth from catalysts (H. Dai at Stanford).**

Alignment Problem in Carbon Nanotube Assembly



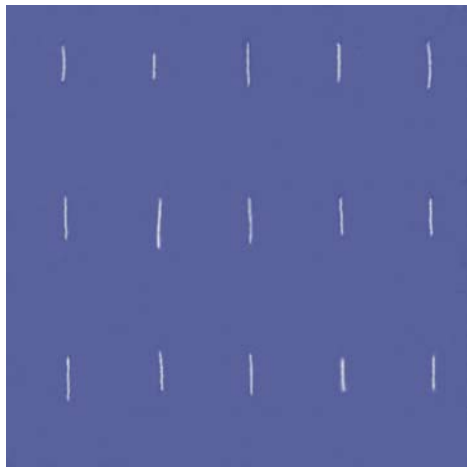
OR





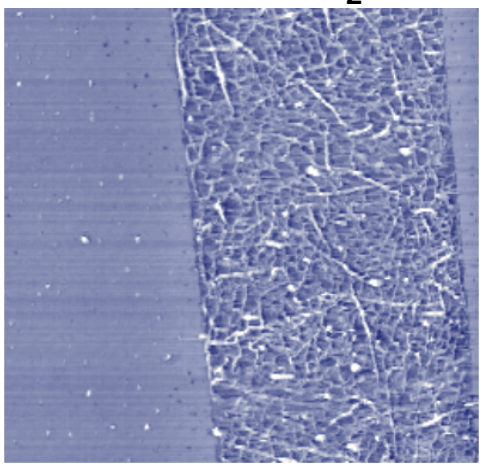
Massive Assembly of Nanotubes/Nanowires

CNT on Au



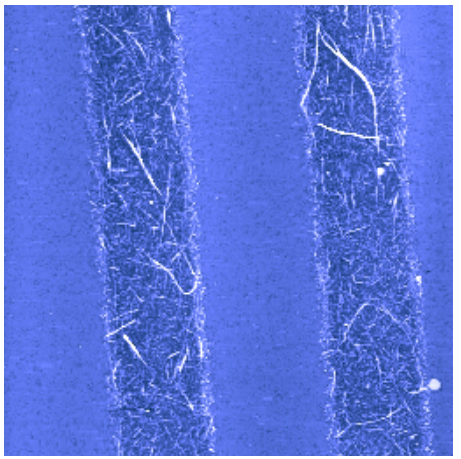
0 um 25

CNT on SiO_2



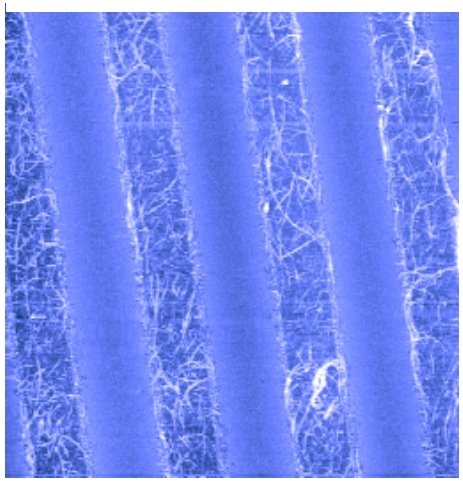
0 um 6

CNT on Si



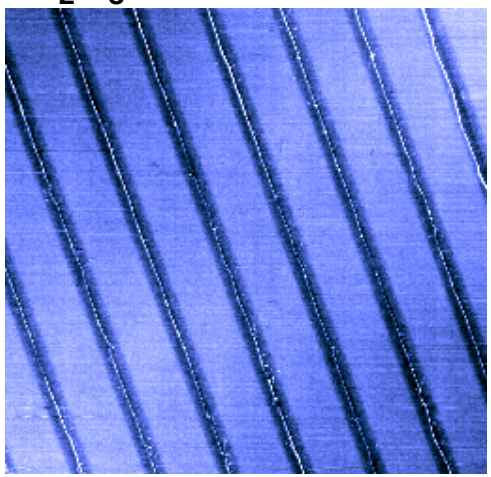
0 um 12

CNT on Al



0 um 20

V_2O_5 Nanowire on Au



0 um 40

CNT → polar

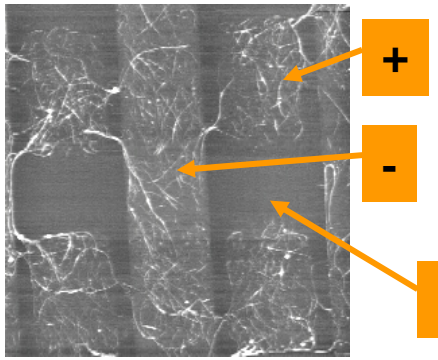
V_2O_5 NW (-) → (+)-surface

논문에 발표안된 일부 자료는
삭제되었음을 양해부탁드립니다.

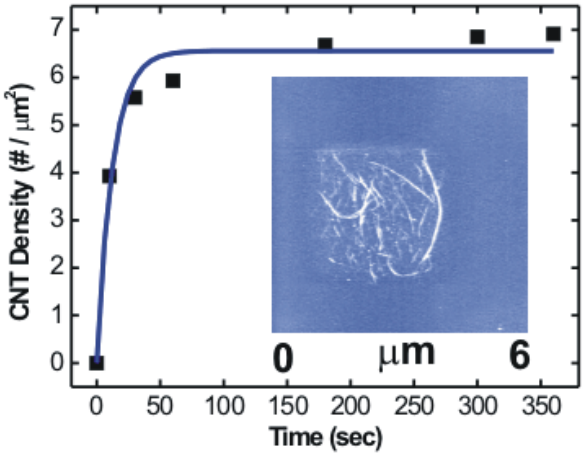
Mechanism of CNT/NW Assembly

1. Selective Adhesion:

- CNT → polar
- V_2O_5 NW (-) → (+)-surface
- ZnO NW (+) → (-)-surface
- …etc



2. "Self Limiting" Mechanism
→ 'Single' Layer Adsorption

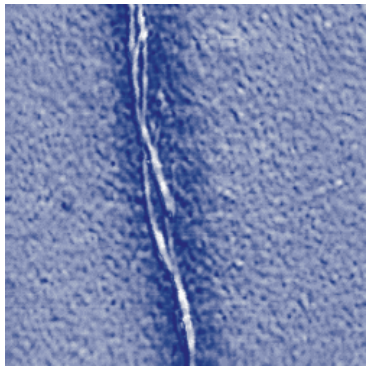


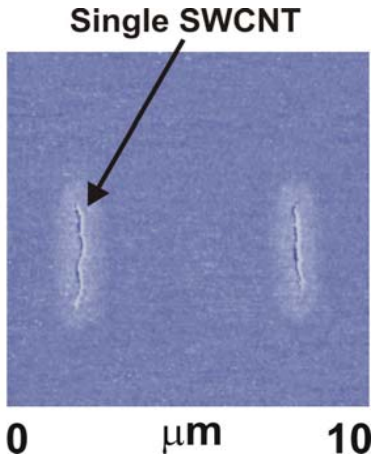
3. Energy Minimization
→ Alignment, "Lens" Effect

$$E_{tot} \cong \int_0^{l_p} \gamma_p ds + \frac{\kappa}{2} \int_0^{L} \left(\frac{d^2 r}{ds^2} \right)^2 ds$$

CNT/NW-Surface Interface Energy

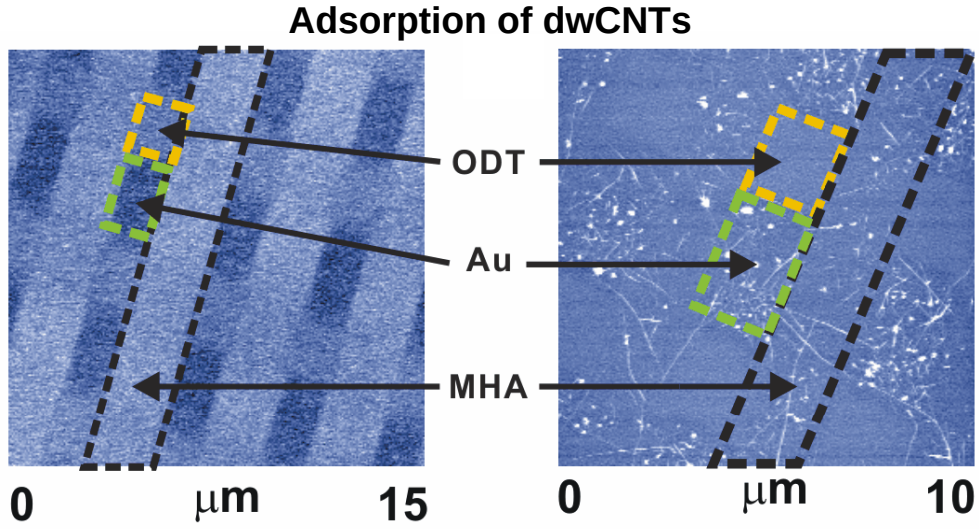
CNT/NW Bending Energy

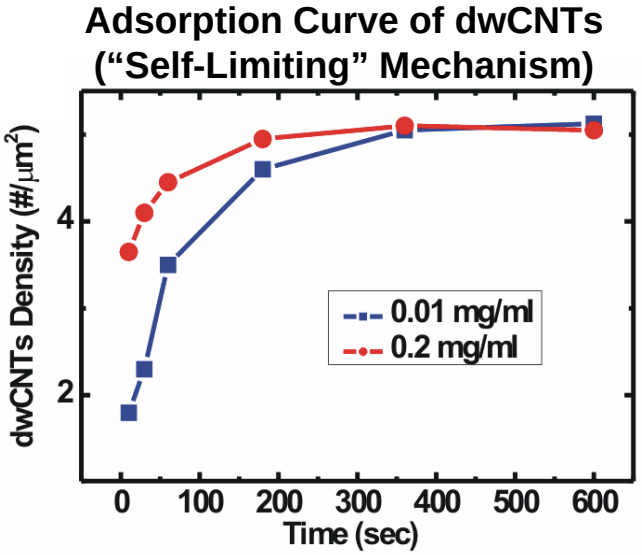


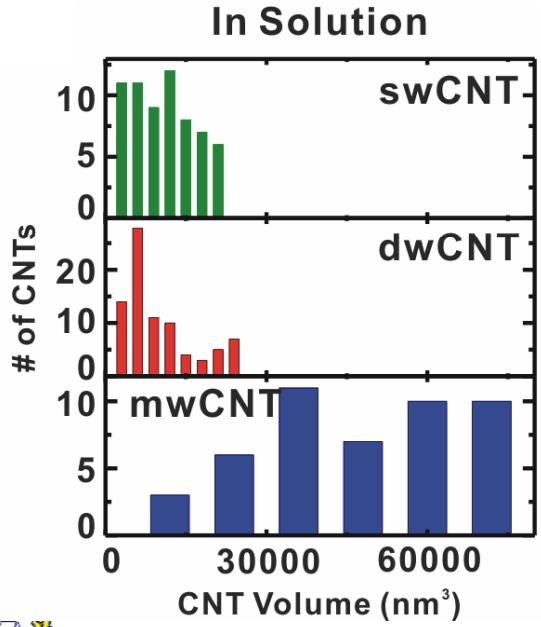


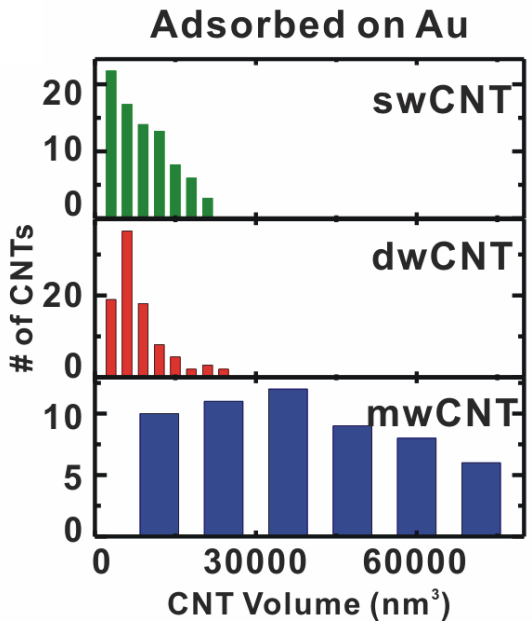
JCP 124, 224707 (2006); JPC-B Letters 110, 10217 (2006)

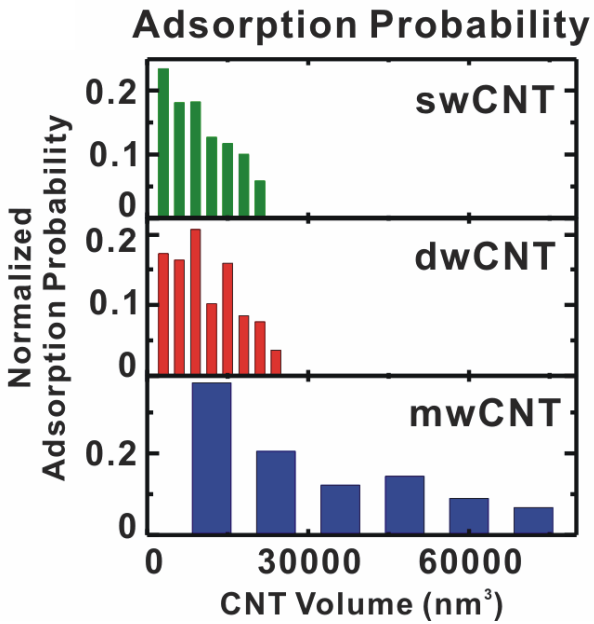
Adsorption Behavior of CNTs





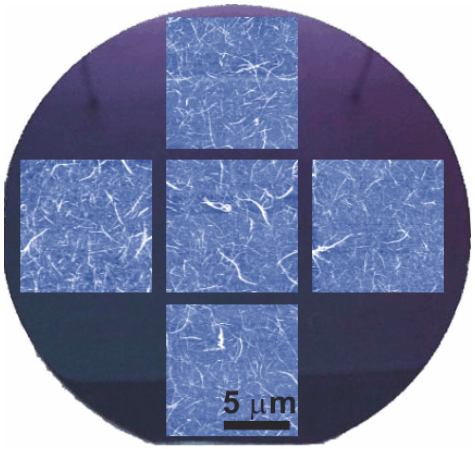




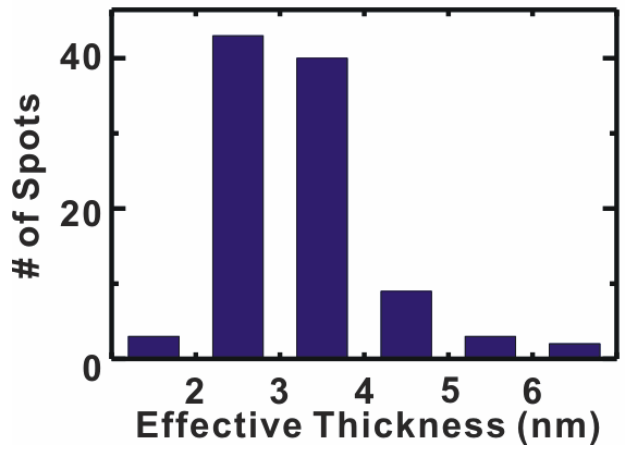


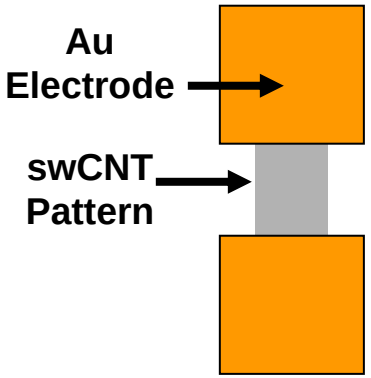
Uniformity of swCNT Circuits

Wafer Scale swCNT Assembly

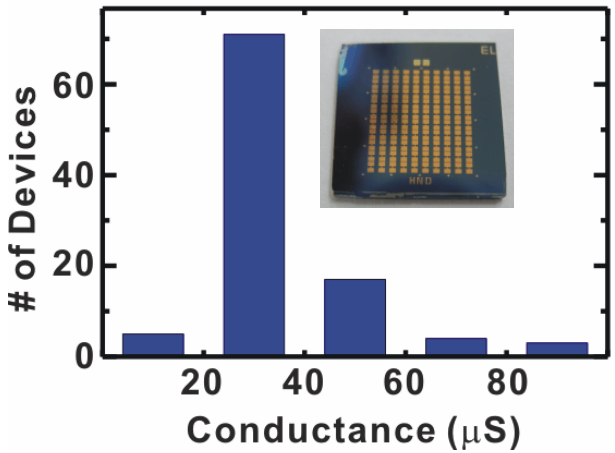


swCNT Film Thickness

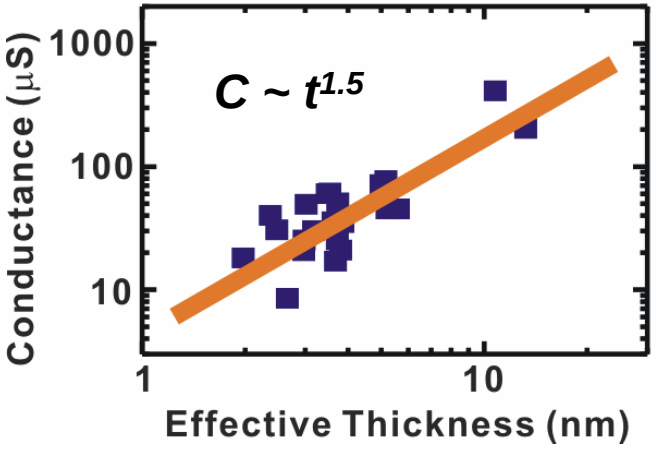




Conductance Distribution

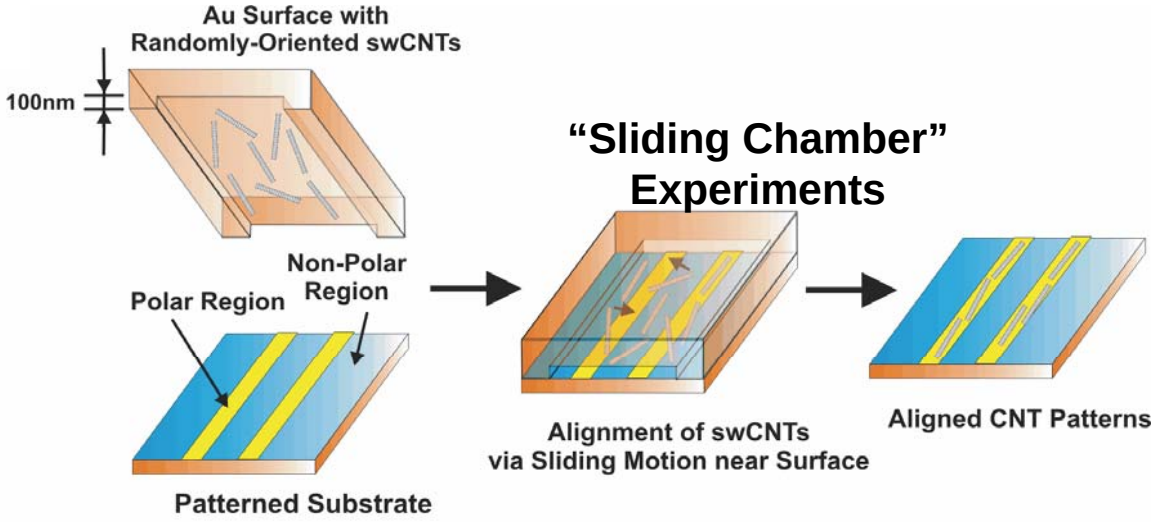


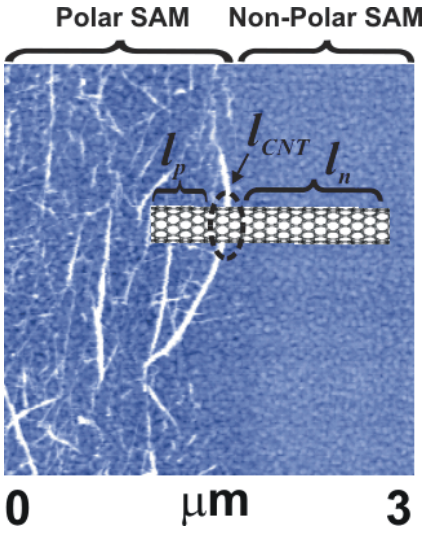
Conductance vs. Thickness

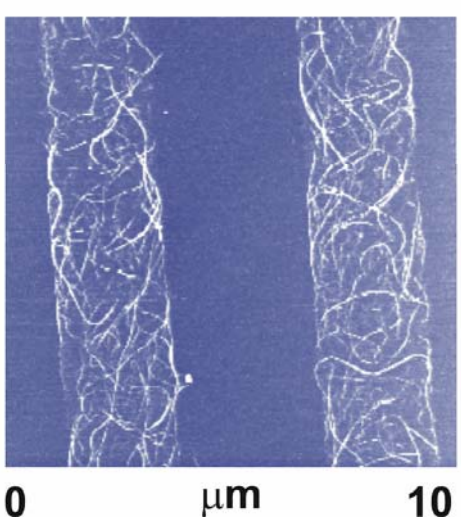


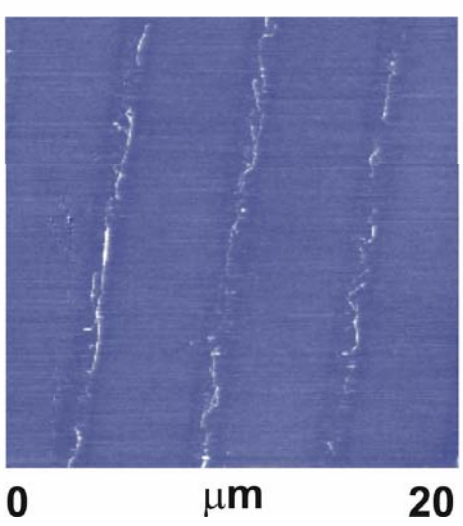
For Bulk Film : $C \sim t^{1.0}$

"Sliding Kinetics": Beyond Random Adsorption Kinetics









$$E_{tot} \cong \int_0^{l_p} \gamma_p ds + \frac{\kappa}{2} \int_0^{L} \left(\frac{d^2 r}{ds^2} \right)^2 ds$$

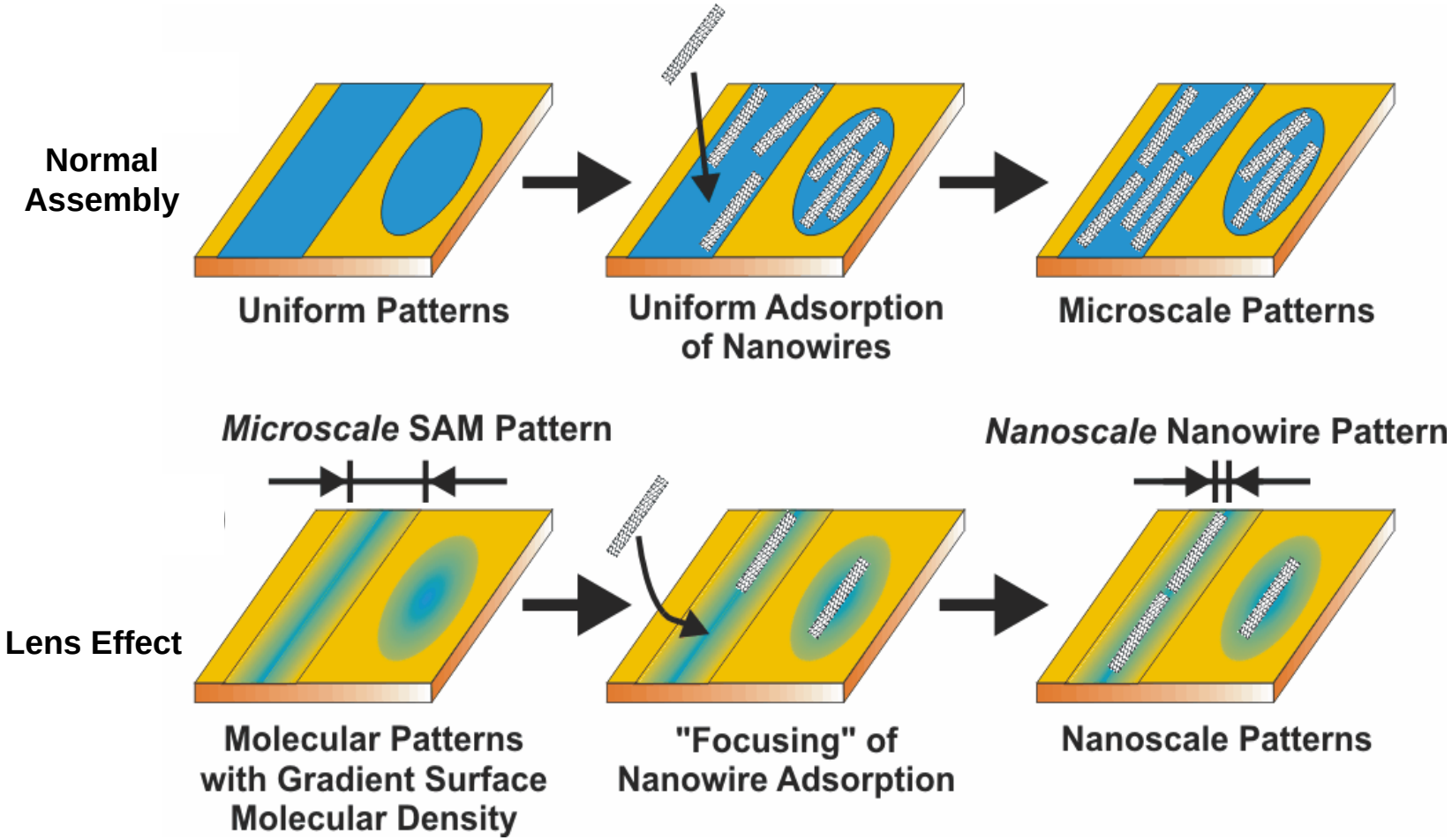
CNT-Surface Interface Energy

CNT Bending Energy

Adsorbed CNTs can "slide" to minimize the total energy, E_{tot}.

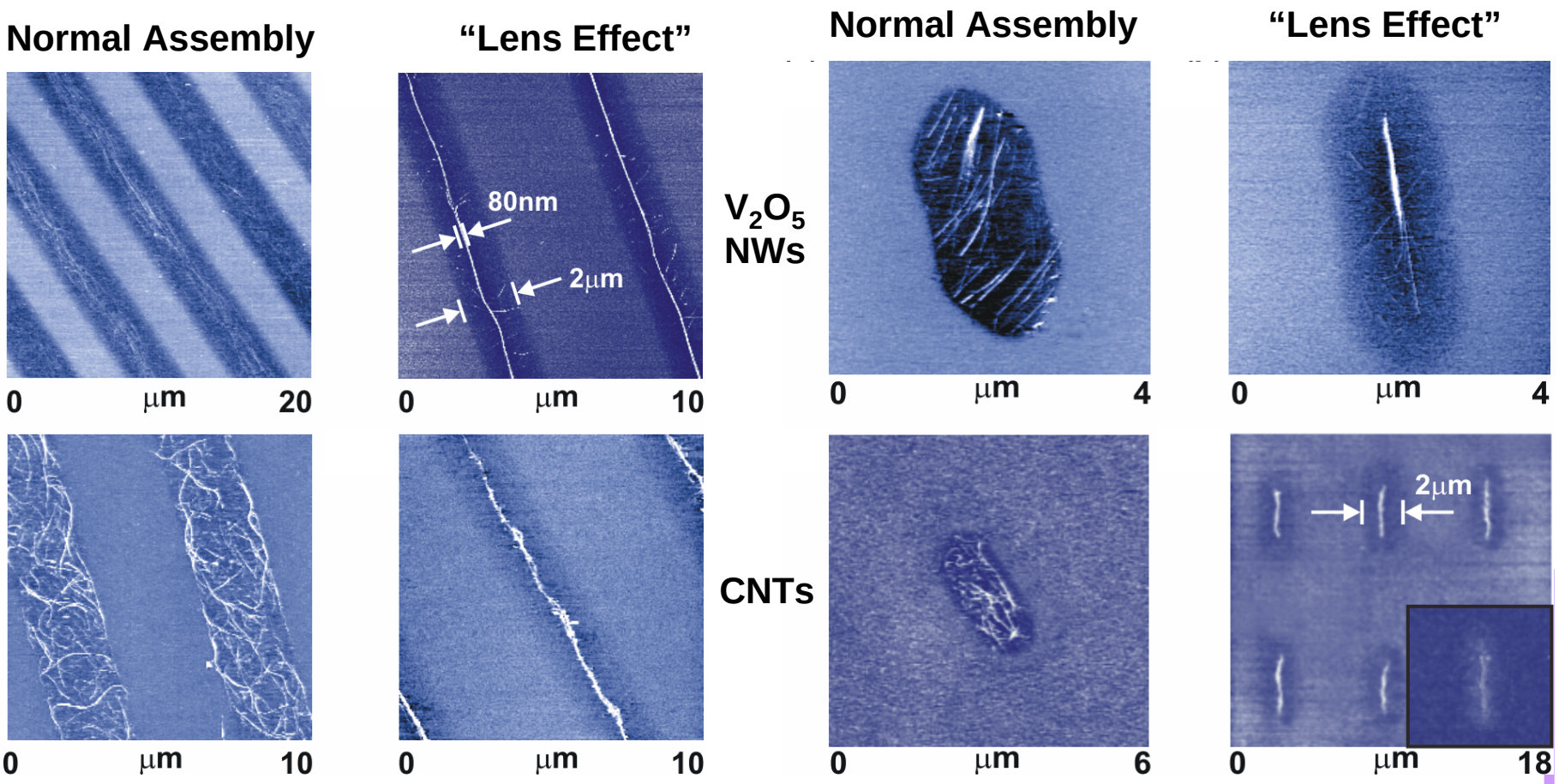
In collaboration with Prof. Nam-Kyung Lee at Sejong University, Korea (JCP 124, 224707 (2006))

"Lens Effect" on *Gradient* Molecular Patterns



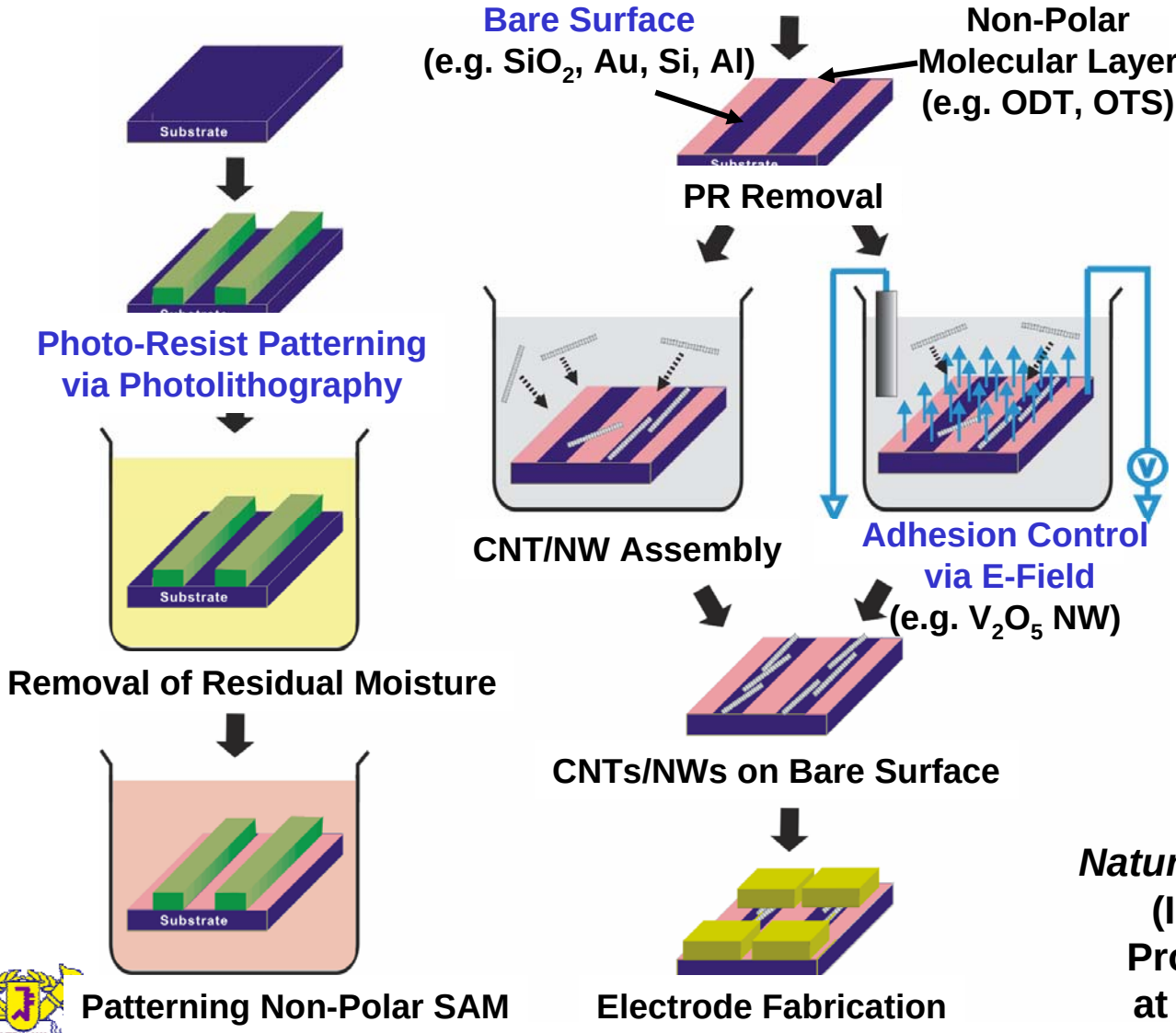
Nanotubes/nanowires slide to minimize the interface energy between surface and nanotubes/nanowires (*JPCB Letters 110, 10217 (2006)*).

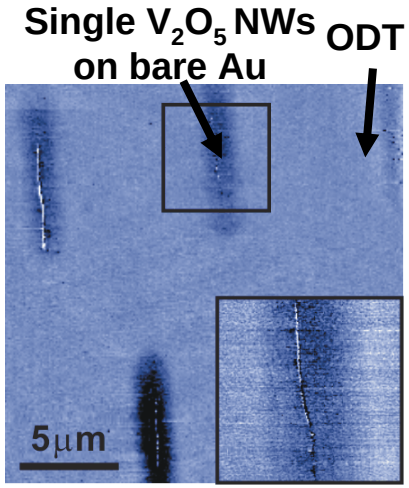
"Lens Effect"

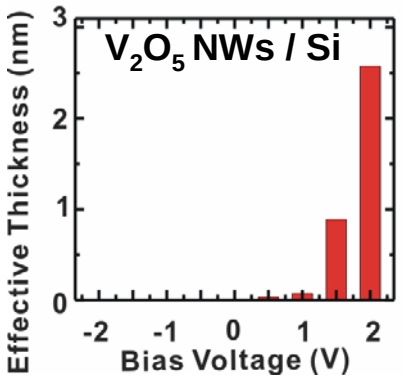


***JPCB Letters* 110, 10217 (2006)**

Fabrication of CNT/NW Circuits using only Conventional Microfabrication Facilities

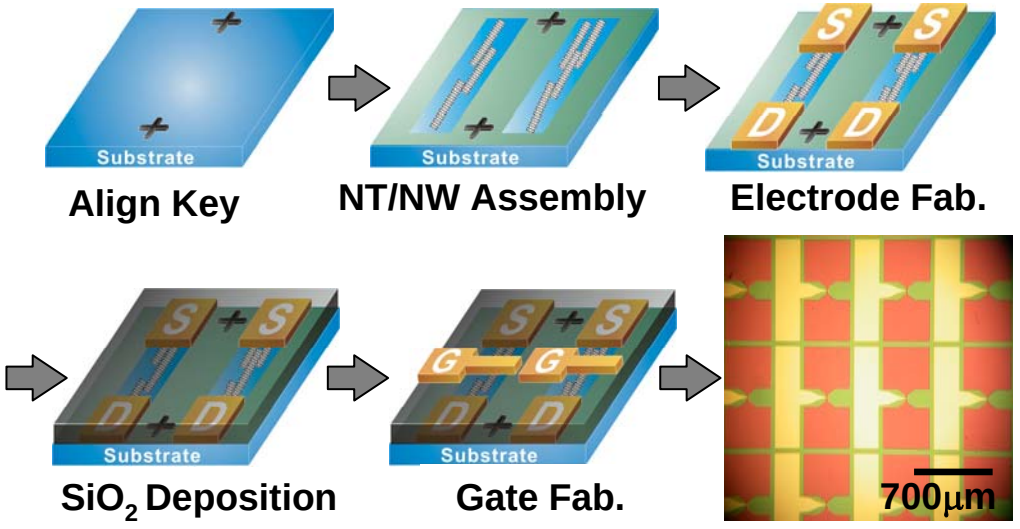


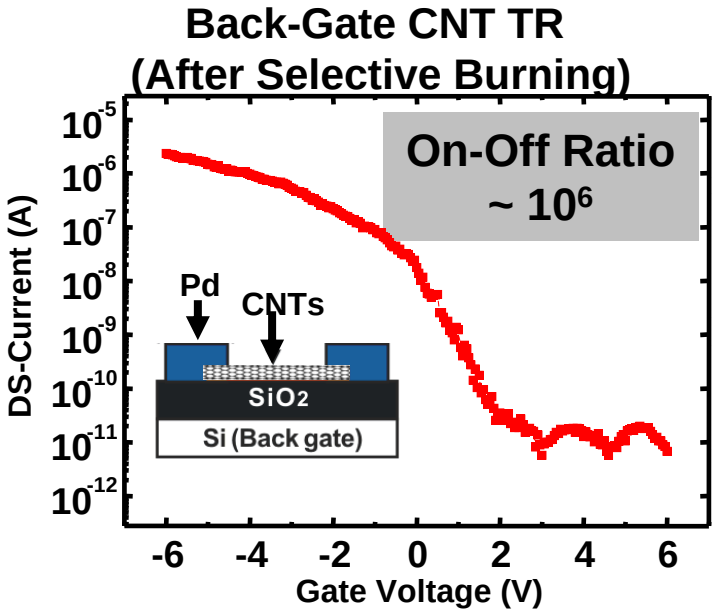




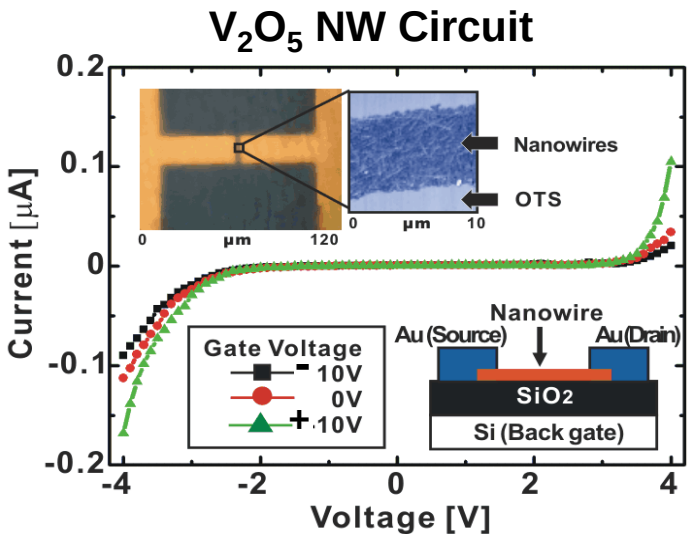
Nature Nanotech. 1, 66 (2006)
(In Collaboration with Prof. Young-Kyun Kwon at U. of Massachusetts)

Nanotube/Nanowire-Based Integrated Devices



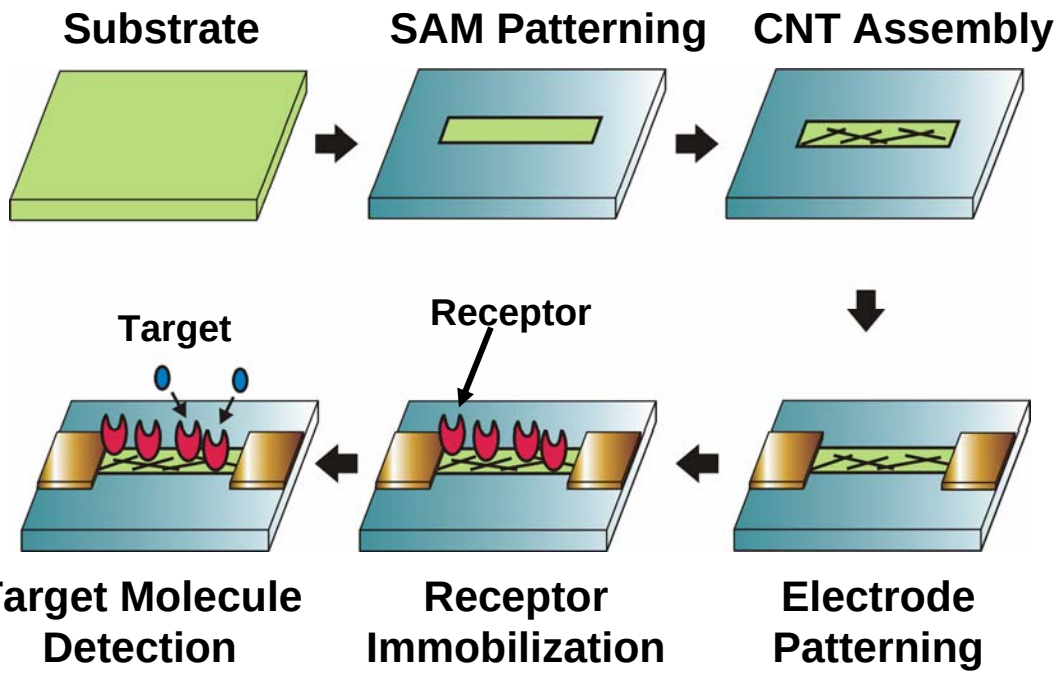


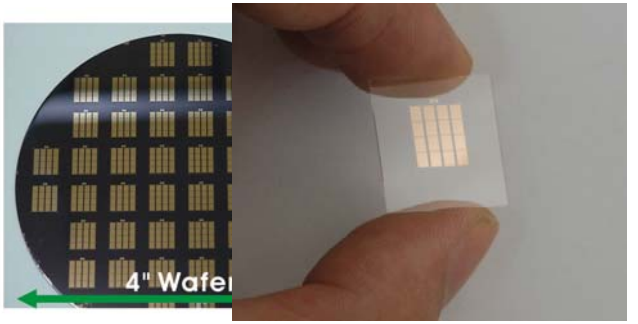
논문에 발표안된 일부 자료는
삭제되었음을 양해부탁드립니다.

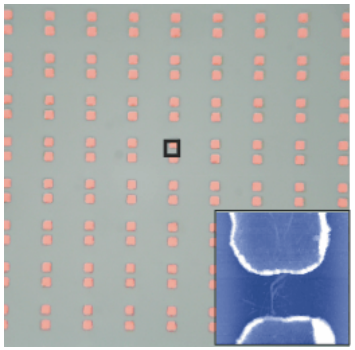


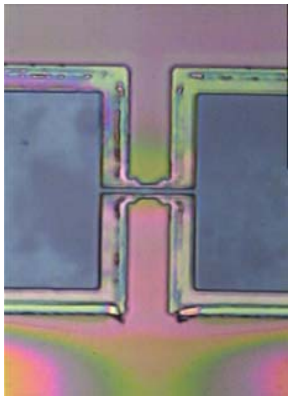
Nature Nanotechnology 1, 66 (2006), *Advanced Materials* 17, 2361 (2005)

CNT Junction-Based Biosensors

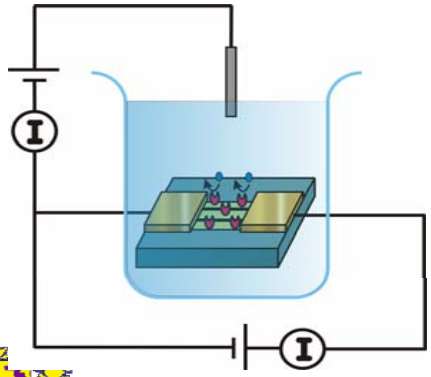








64K (256 x 256) Array



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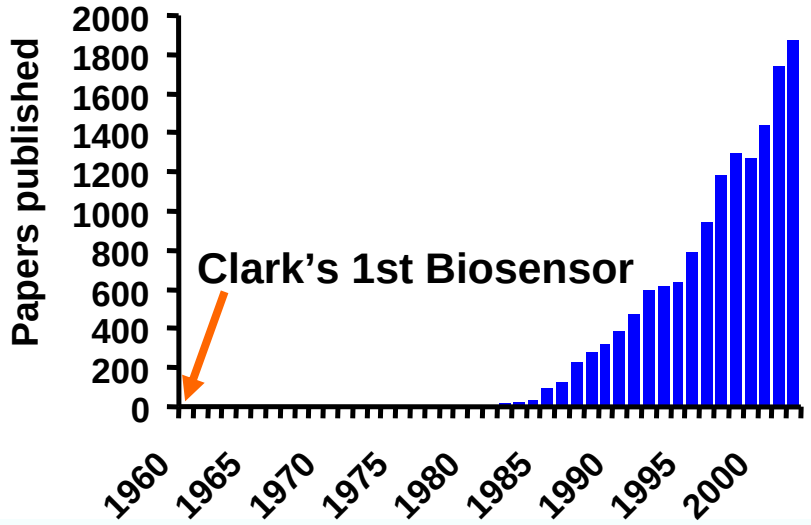
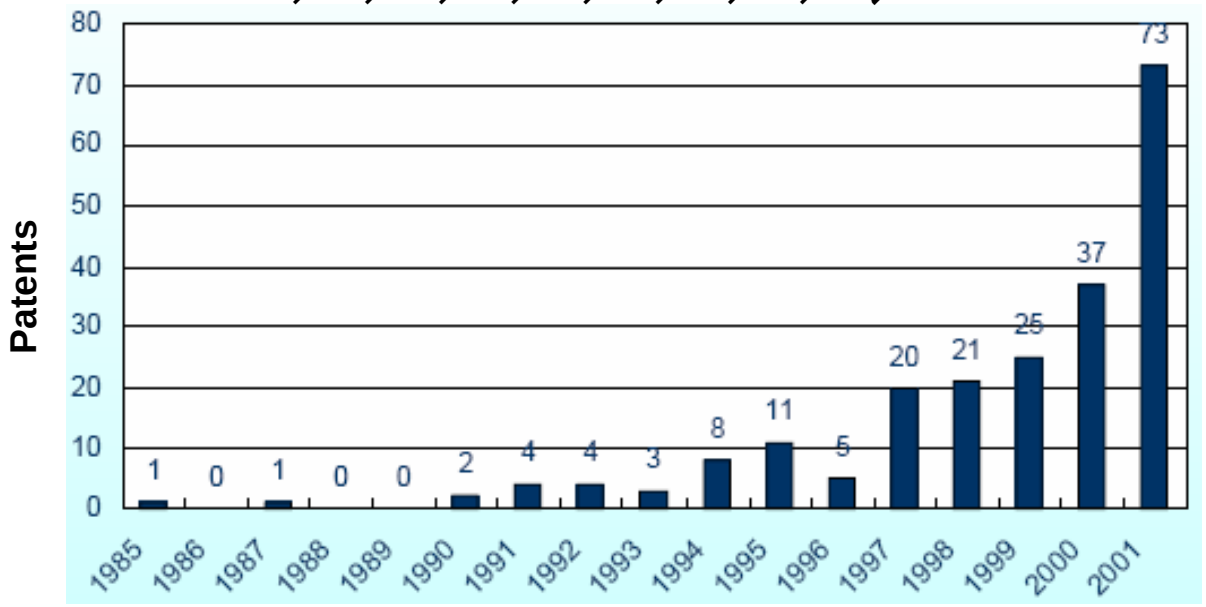
Selective Detection of Various Molecules

논문에 발표안된 일부 자료는
삭제되었음을 양해부탁드립니다.

바이오 센서 관련 논문 및 특허 동향

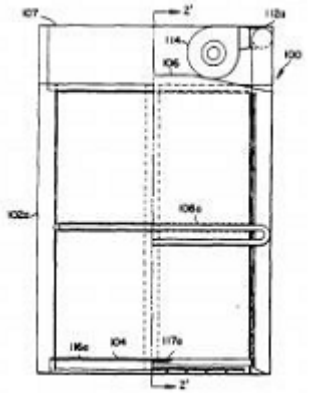


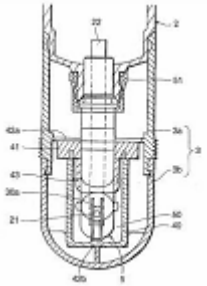


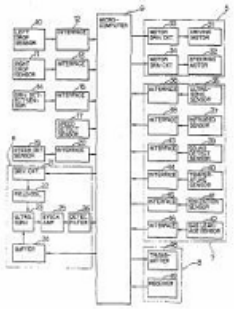
특허의 예

공개번호	출원일	특허권자	대표도면
KR 2006-017217	**2004.08.20**	**(잘 알려진 국내 핸드폰 회사)**	
제목	휴대용 단말기 및 이를 이용한 식품의 신선도 측정방법		
식품에서 발생되는 화학성분을 검출하는 전자코 센서 시스템을 휴대용 단말기(휴대폰)에 탑재시켜, 소비자가 식품의 신선도를 체크할 수 있도록 한 휴대용 단말기			
공개번호	출원일	출원인	대표도면
KR 2006-0036593	**2004.10.26**	**(잘 알려진 국내 통신 서비스 회사)**	
제목	구취측정 센서가 구비된 휴대용 단말기 및 그 사용 방법		
휴대용 단말기 내부에 구취의 농도를 측정할 수 있는 가스센서를 부착하여, 측정된 구취측정 데이터와 진단기준 데이터를 비교하여 건강 또는 질병 상태를 판단하는 휴대용 단말기			

특허 정보원 발간 “유비쿼터스 생화학 센서 시스템 특허 동향” 참조

등록번호	등록일	특허권자	대표도면
US 4987767	**1991.01.29**	외국 회사	
제목	**Exposive detection screening system**		
폭발물/마약/음주류 등의 증기(**pavor**), 농도 등을 검출하기 위한 샘플링 챔버와, 화학 물질 분석과 전체적인 시스템의 제어를 위한 데이터 처리 시스템 등을 구비하여 폭발물, 마약 등의 금지품목을 검출하기 위한 스크린 시스템			

등록번호	등록일	특허권자	대표도면
US 5711862	**1998.01.27**	외국 회사	
제목	**Portable biochemical measurement device using an enzyme sensor**		
효소 센서를 이용하여 생화학 물질을 측정하기 위한 휴대용 기기로, 효소 센서와 효소 센서의 수분을 유지시키기 위해 액체 매체로 채워진 챔버를 포함하는 덮개 등을 구비함			

등록번호	등록일	특허권자	대표도면
US 5446445	**1995.08.29**	잘 알려진 국내 핸드폰 회사	
제목	**Mobile detection system**		
가정과 사무실 등의 화재와 가스 누출 및 침입자 등을 감지하여 외부 모니터, 경찰서, 소방센터 등에 알리기 위한 이동 검출 시스템(이동로봇)으로, 내부에 가스 누출 감지 센서와 온도 센서 및 이온화(**ionization**) 센서 등을 구비함			

기술 개발 상황

<생화학 고속 검지 기술 특허 개수>

국 가	한국	미국	일본	유럽	계
모바일 관련 키워드가 들어갈 경우(A)	37	61	58	29	185
모바일 관련 키워드 제거할 경우(B)	1140	1797	5548	1033	9,518
비율 (A/B, %)	3.25%	3.39%	1.05%	2.81%	1.94%

- 생화학 검지 기술은 이미 성숙기에 들어섰으나, 이를 소형화하는 기술 개발이 미비하다
- 따라서, '소형' 생화학 센서 기술의 확보여부가 궁극적인 기술 경쟁력을 결정
- 특허정보원 발간 "유비쿼터스 생화학 센서 시스템 특허 동향" (2006년) 참조

관련 시장

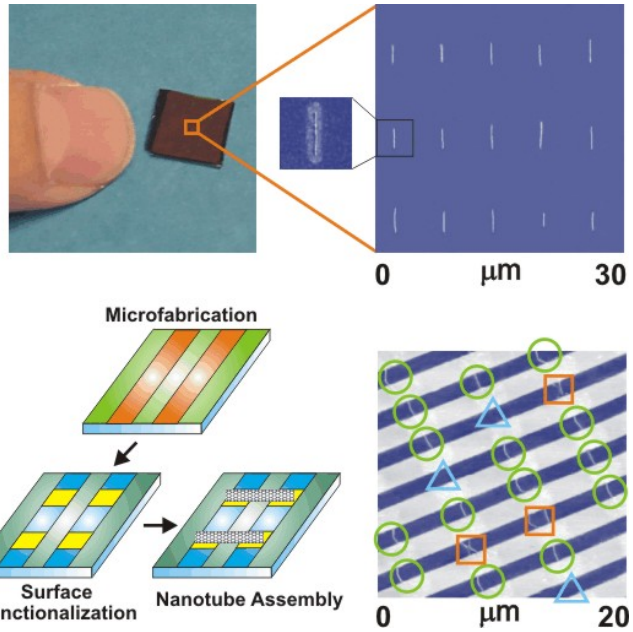
(단위 : 억불)

구분		2004	2005	2006	2007	2008	2009	2010	2011	2012	CAGR
환경정보센싱	세계	13.0	23	37	76.8	137	165	461			81.24%
환경서비스업	세계	3180	3340	-	-	-	-	4180			4.66%
	국내	57	78	-	-	-	-	136			15.6%
환경자원이용업	세계	1810	1940	-	-	-	-	2600			6.22%
	국내	44	62	-	-	-	-	118			17.87%
환경설비업	세계	1590	1660	-	-	-	-	2070			4.5%
	국내	33	46	-	-	-	-	62			11.08%
가스센서	세계	25.6	27.4	-	-	-	-	-			-
	국내	0.58	-	-	-	-	-	-			-
환경/바이오센서	세계	23	25	27	29	32	35	39			9.4%
식품안전 바이오센서	세계	-	1.5	-	-	-	-	-	-	-	
항공우주 및 자동차 분야 나노센서	세계					3.4		36			225.4%
센서	세계					506		529			2.2%
U-Sensor Network	세계	-	72	-	191	-	-	768			60.55%
	국내	-	1.9	-	10	-	-	39.9			129.42%
Lab-on-a-Chip	세계				169					484	17.85
전자의료기기	세계					520		606			8.0%
RFID(i)	세계	20	30	41	53	67	83	100			30.77%
	국내	1.2	1.8	2.5	3.2	-	-	-			38.38%

정보통신 연구진흥원 발간 “유비쿼터스 생화학 센서 시스템 로드맵” (2006년) 참조

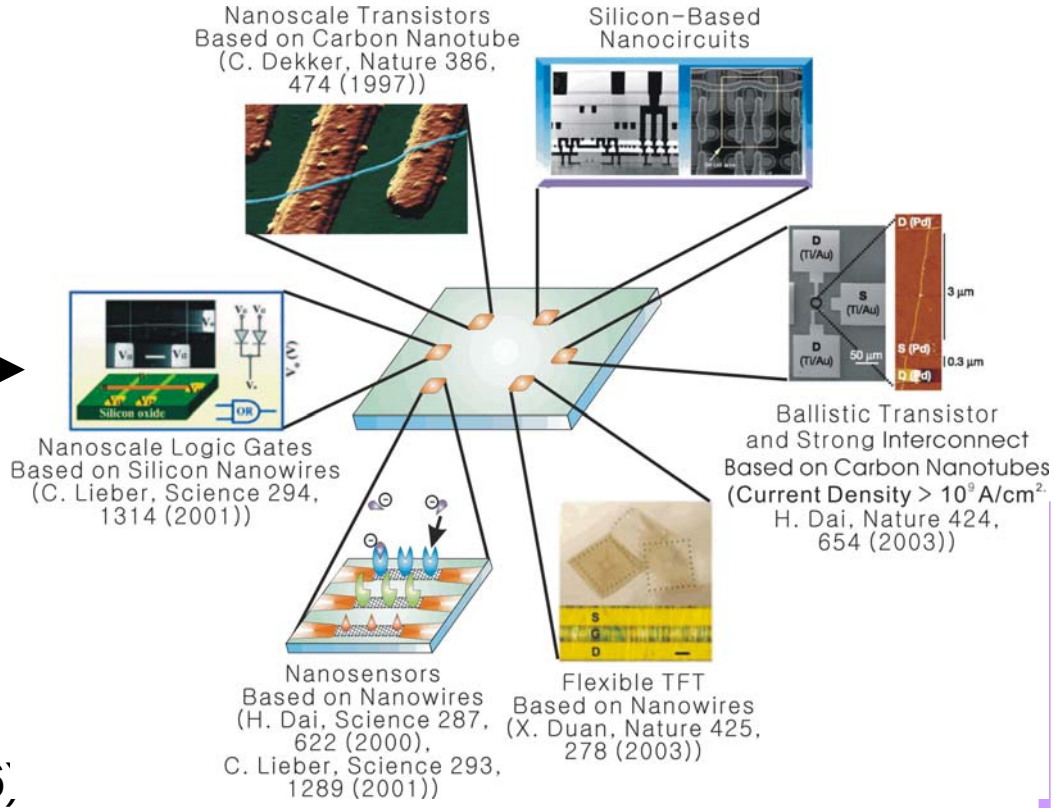
Just imagine what you can build *today*.

1cm^2 Area Patterning



Nature ***425***, 36 (2003)
Nature Nanotechnology ***1***, 66 (2006)

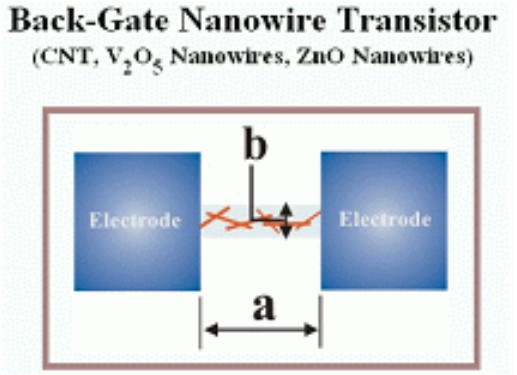
Very Large Scale Integrated Circuits Based on Nanowires

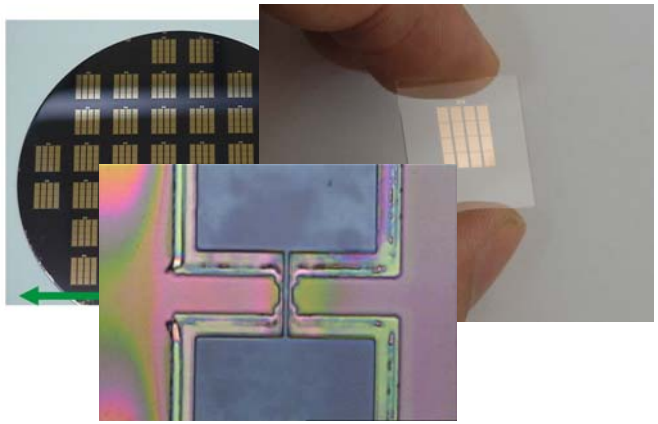


"Nanowire Integrated Circuit Foundry" Service

(http://hnd.snu.ac.kr)

An example of standard design for nanotube/nanowire devices





Substrate	Insulator Thickness	Electrode Material	Electrode Thickness	Pattern Width	
				a	b
SiO_2	1000 Å	Ti/Au, Cr/Au, Al, Pd, Pd/Au	100 Å ~	2	2
					3
					4
				3	2
					3
					4
				4	2
					3
					4
				Pattern for Sensor	

- *"Nanowire IC Foundry"* service is now open in our lab.
- It provides nanotube/nanowire integrated circuits for researchers.
- Both *standard* and *custom* designed NT/NW ciruits are possible.

Summary

1. **Dip-pen nanolithography** for direct deposition organic molecules in nanometer scale resolution.

2. **Surface-programmed assembly** process for massive nano-assembly via molecular recognition.

3. **Nanowire-based integrated devices**: integrated circuits, sensors, etc.

"Nanowire-IC Foundry" is now open in our lab!
Please let me know if you are interested in getting nanowire circuits.

Acknowledgements

Seoul National University

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Byung-Ju Kim
Tae-Kyung Kim
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Prof. Seong-Hyun Hong
Prof. Su-Hwan Kim

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Samsung

Dr. Wanjun Park
Dr. Insuk Yeo

Korea University

Prof. Kyu-Tae Kim
Prof. Jeong-Suk Ha
Prof. Yong-Doo Park

POSTECH

Prof. Gyu-Cheol Yi

Northwestern University

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Chung-Ang University

Prof. Maeng-Jae Seong

Univ. of Massachusetts

Prof. Young-Kyun Kwon

Se-Jong University

Prof. Nam-Kyung Lee

ETRI

Prof. Jong-Hyuk Park