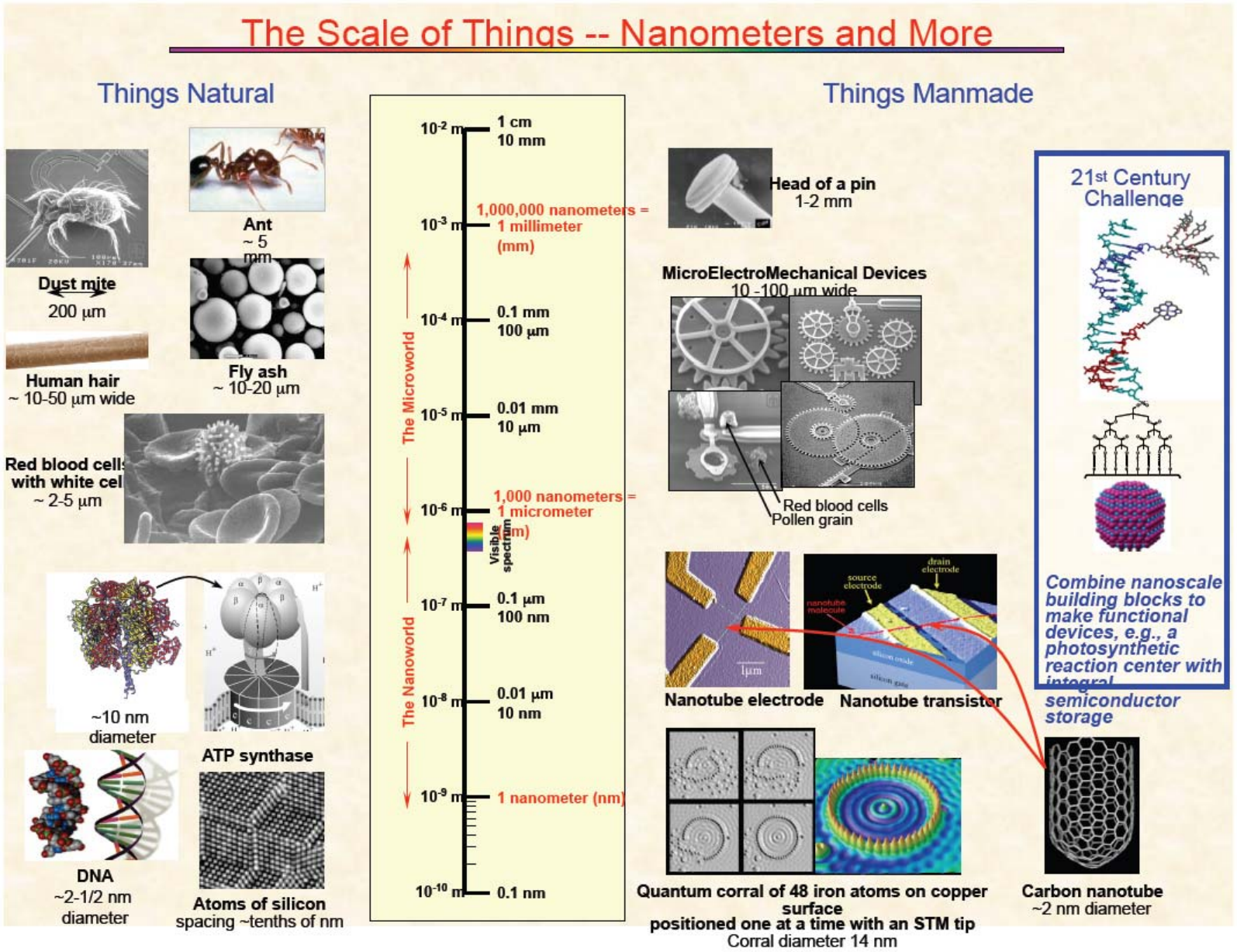
Nanotechnology towards practical applications: new challenges and opportunities

서 갑 양

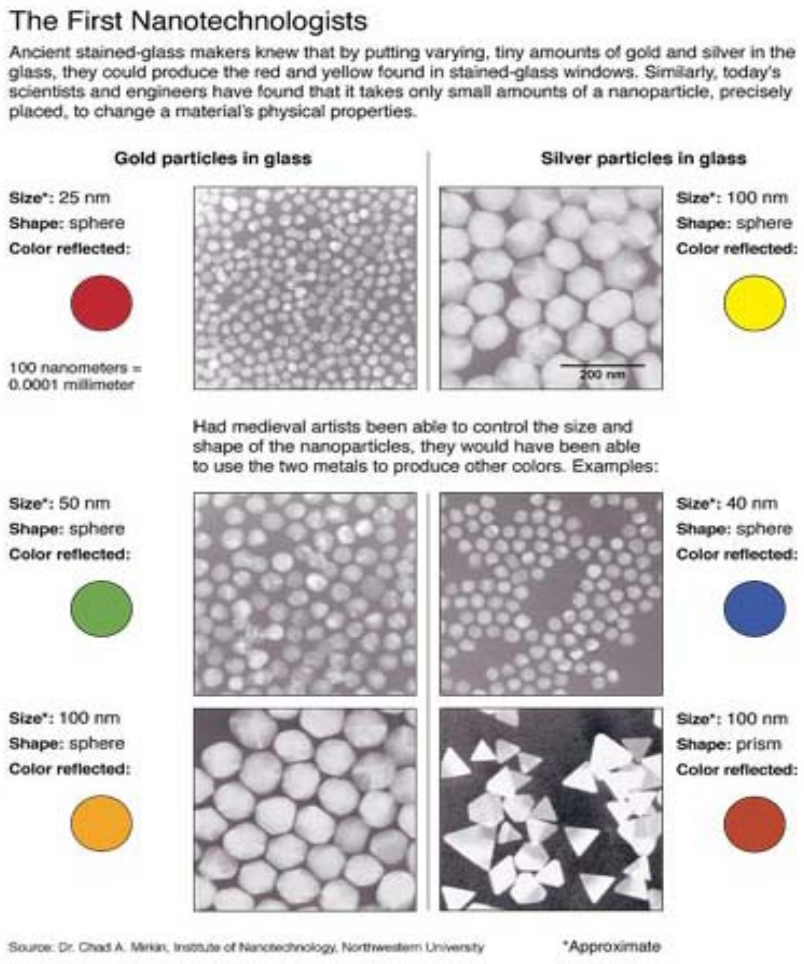
서울대학교 기계항공 공학부

E-mail: sky4u@snu.ac.kr
http://nftl.snu.ac.kr



ref) Joseph M. Pickel, ACS Fall Meeting 2007

The First Nanotechnologists



Chad Mirkin, Northwestern University, in NYTimes article by K. Chang - 2005

Nanotechnology is the Science of Interfaces

- Surface effects

  For 30 nm particle: 5 % of atoms are on surface

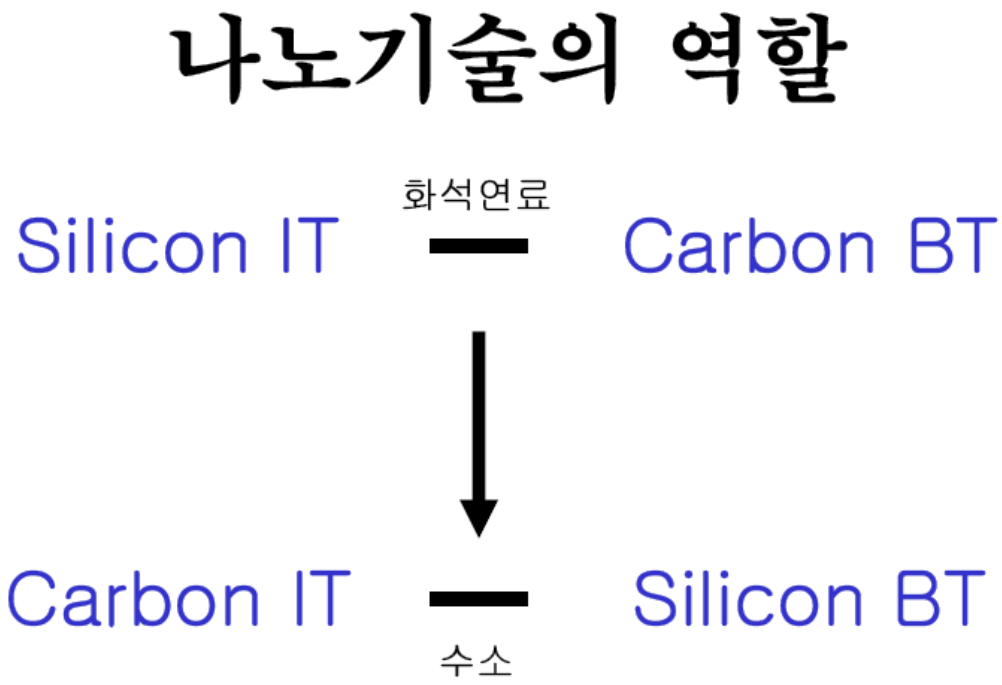
  For 3 nm particle: 50 % of atoms are on surface

- Interfaces of Scientific Disciplines
  - Materials, biological, physical sciences all contribute!

나노기술이 고려해야 할 패러다임 변화 (1)

- 웰빙(Well-being)
- 명품(Valued goods)

나노기술이 고려해야 할 패러다임 변화 (2)



기술영역의 파괴(교차)와 확대

The avalanche of nanotechnology journals

- ~50 journals in the category of “nanoscience and nanotechnology” (ISI Web of Science)
- Artwork is important: seeing is believing
- Most journals are newly developed with low half-life time.

ISI Web of Knowledge℠

Journal Citation Reports®

RETURN TO MARKED LIST

2008

MARKED JOURNAL LIST

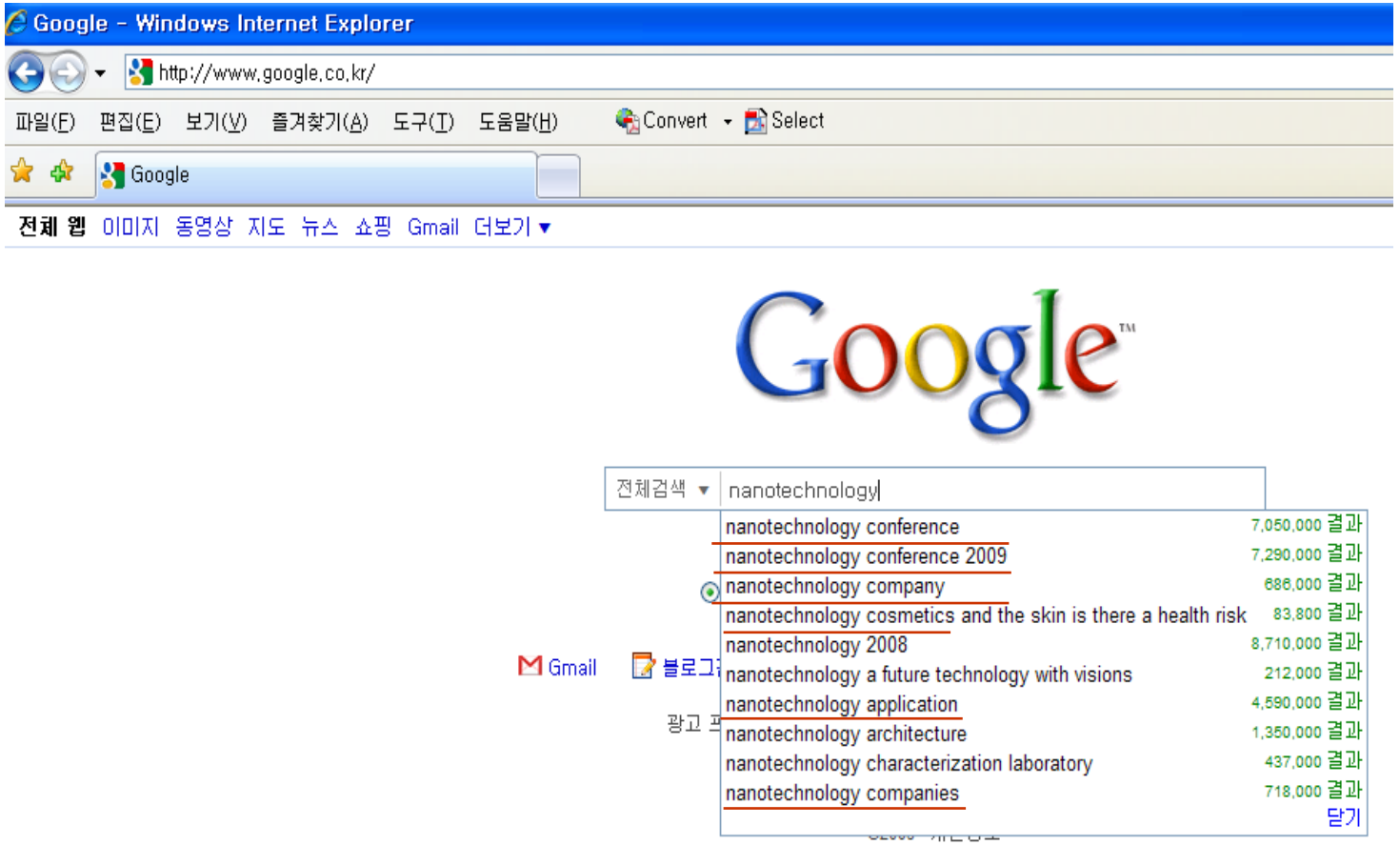
Sorted by: Impact Factor

Abbreviated Journal Title	ISSN	2008 Total Cites	Impact Factor	5-Year Impact Factor	Immediacy Index	2008 Articles	Cited Half-life	*Eigenfactor*™ Score	*Article Influence*™ Score
NAT NANOTECHNOL	1748-3387	2927	20.571	20.588	5.097	93	1.6	0.02934	11.120
NANO LETT	1530-6984	37089	10.371	12.189	1.524	817	3.7	0.25267	4.487
NANO TODAY	1748-0132	376	8.795	9.231	1.077	13	1.8	0.00283	3.270
SMALL	1613-6810	5016	6.525	7.292	0.856	319	2.5	0.03695	2.576
NANOMEDICINE-UK	1743-5889	567	6.093	6.093	0.768	56	1.7	0.00354	1.857
ACS NANO	1936-0851	703	5.472	5.472	1.389	296	0.9	0.00214	1.823
NANOTOXICOLOGY	1743-5390	101	3.720	3.720	0.444	18	1.5	0.00047	0.855
NANOTECHNOLOGY	0957-4484	16291	3.446	3.727	0.507	1397	2.9	0.09877	1.231
MICROFLUID NANOFLUID	1613-4982	783	3.314	4.194	0.827	133	2.3	0.00434	1.222
J NANOPART RES	1388-0764	1806	2.299	3.118	0.476	170	4.0	0.00900	1.015

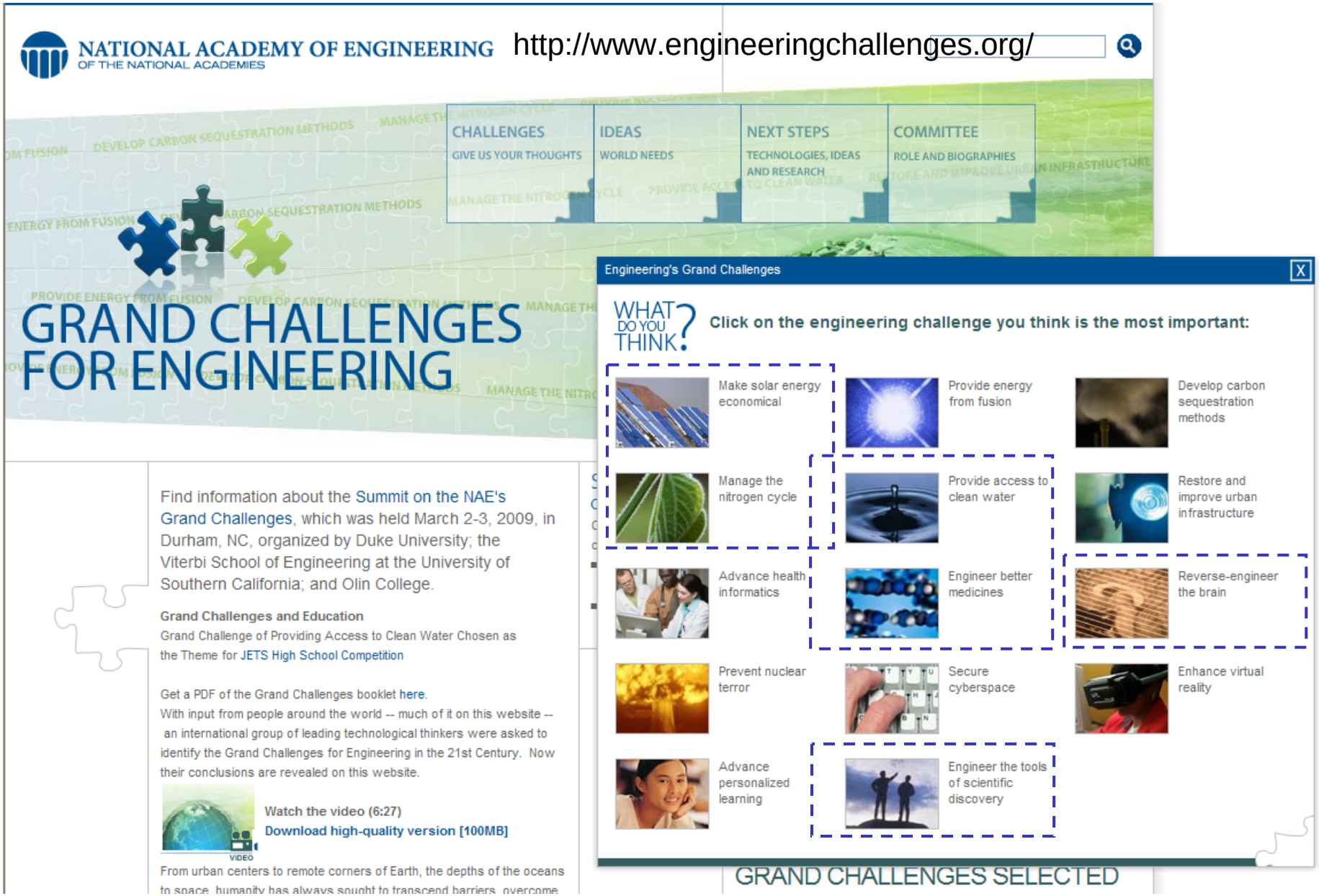
Mark	Rank	Abbreviated Journal Title (linked to journal information)	ISSN	JCR Data						*Eigenfactor*™ Metrics	
				Total Cites	Impact Factor	5-Year Impact Factor	Immediacy Index	Articles	Cited Half-life	*Eigenfactor*™ Score	*Article Influence*™ Score
☐	1	J FLUID MECH	0022-1120	30950	2.315	2.714	0.422	450	>10.0	0.06626	1.393

Google search: "Nanotechnology"

- Nano-conference is a good business.
- People are now talking about the second revolution of nanotechnology.
- Applications?



14 Engineering Challenges from NAE in USA



Engineering's Grand Challenges

WHAT DO YOU THINK?

Voting Results:

Make solar energy economical

Votes: 9263

Provide energy from fusion

Votes: 5639

Provide access to clean water

Votes: 4719

Reverse-engineer the brain

Votes: 3240

Advance personalized learning

Votes: 2637

Restore and improve urban infrastructure

Votes: 2212

Engineer the tools of scientific discovery

Votes: 2189

Develop carbon sequestration methods

Votes: 1984

Advance health informatics

Votes: 1605

Engineer better medicines

Votes: 1584

Prevent nuclear terror

Votes: 1527

Secure cyberspace

Votes: 1427

Enhance virtual reality

Votes: 1381

Manage the nitrogen cycle

Votes: 1346

Potential Impact of Nanoscience and Technology: Humanity's top ten problems for next 50 years

Energy

Water

Food

Environment

Poverty

Terrorism & war

Disease

Education

Democracy

Population

2004	**6.5**	**Billion People**
2050	**~ 10**	**Billion People**

Ref) Joseph M. Pickel, ACS Fall Meeting 2007

국가 나노기술7대 중점 기술분야 도출

- 나노융합소재(6):
  나노입자소재, 나노광소재, 나노환경소재 등

- 물성평가해석(4):
  물성계측 및 표준화 기술, 초고감도 광 및 질량 감지 기술

- 안정성 평가(4):
  나노제품 인체안정성 및 위해성 평가

- 차세대 소자(6):
  나노 열전소자, 그래핀 소자, 나노안테나 소자, 저전력 고효율 소자

- 나노공정/장비(4):
  친환경 나노공정 및 설계기술, 나노분해능 청정 가공장비 기술

- 나노 바이오(6):
  친환경 소재, 다기능 나노바이오 입자, 단세포 in-vivo 동력학

- 나노 에너지 (5):
  클린연료 발굴, 수소 및 솔라패널 등 혁신적인 에너지원 발굴

Nanotechnology challenges

- Many interface problems:
  uncertainties and reproducibility issues
  defect control, detection, healing at interfaces

- Multiscale integration and production:
  positioning and assembly of nanomaterials

- Potential threats:
  environment, health, safety (EHS)

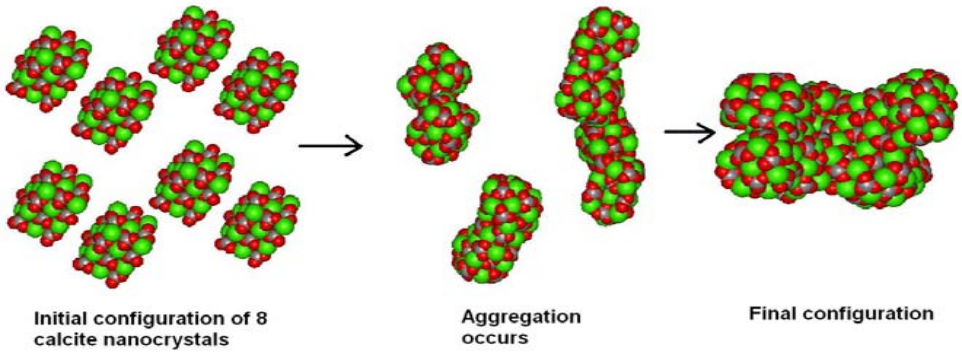
- Fabrication gray regime (10 ~ 50 nm):
  Top down + bottom up

- Materials issues
  ITO -> Graphene (?)

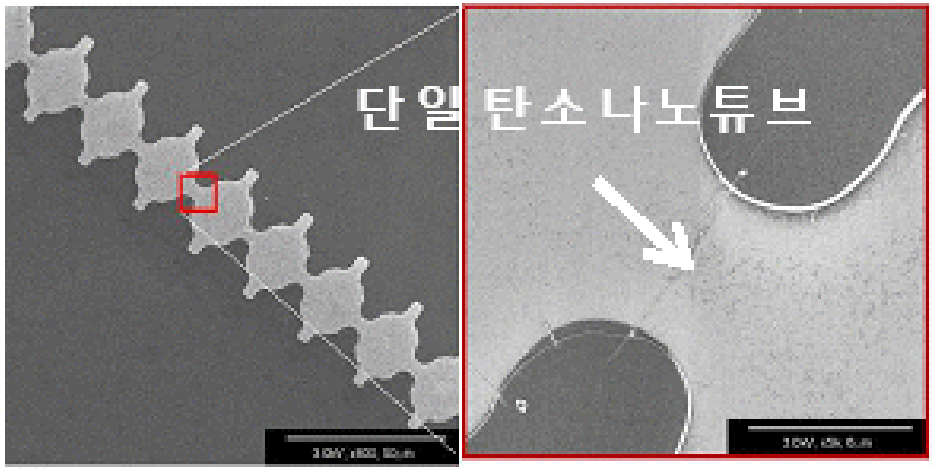
- Social responsibility, ethics

Many interface problems

< Aggregation >



< Interfacial contact >



Multiscale integration and manufacturing

- **Paradigm shift to multiscale design and manufacturing (MDM)**
- **Among papers published during 2000 – 2008 in MDM, mechanical engineering takes up more than 60%**

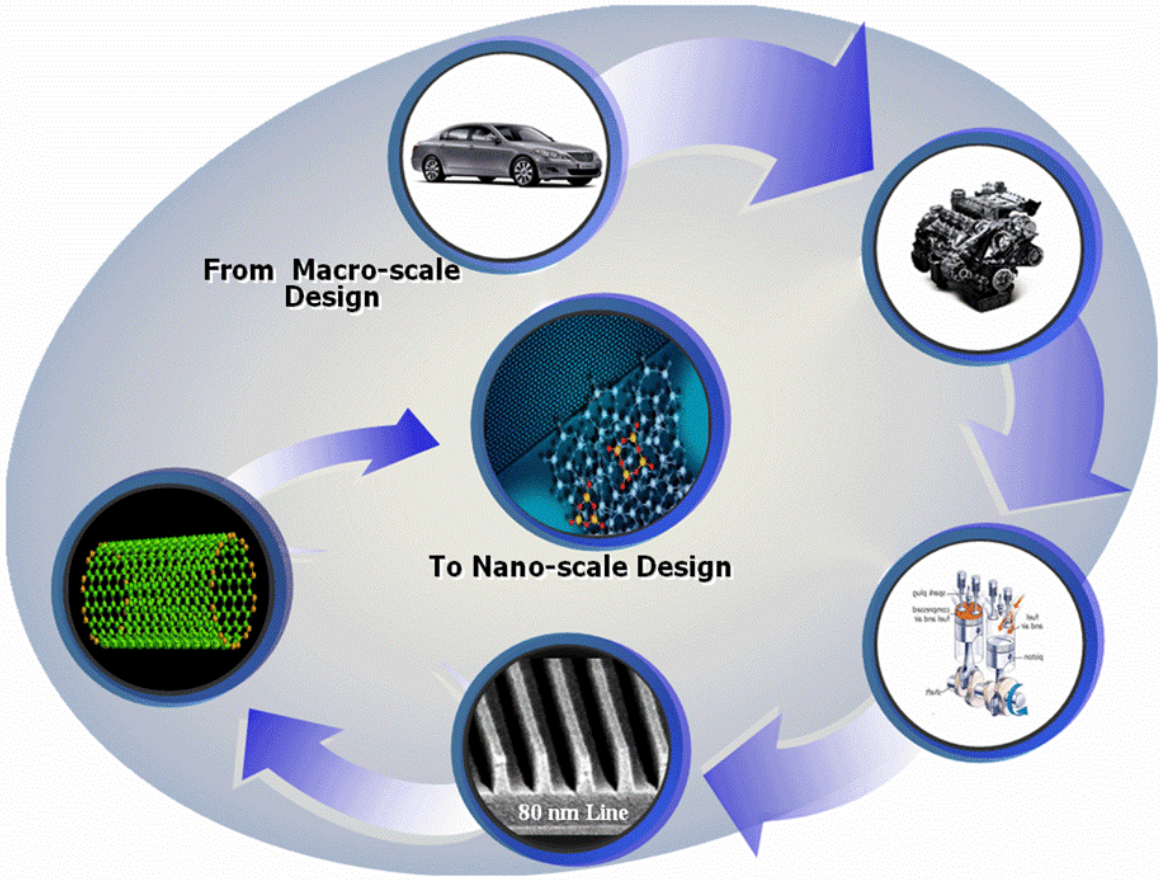
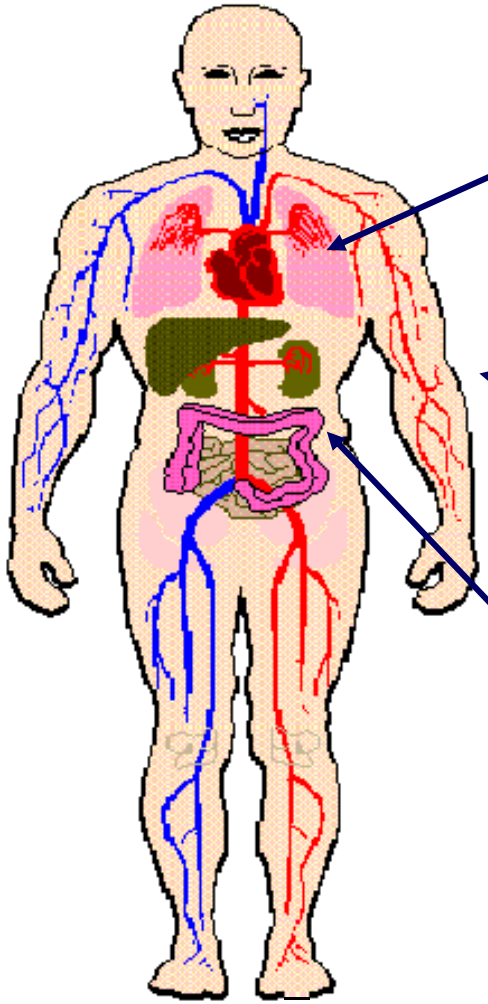


Figure. New paradigm of multiscale design and manufacturing for next generation automobile

Potential threats



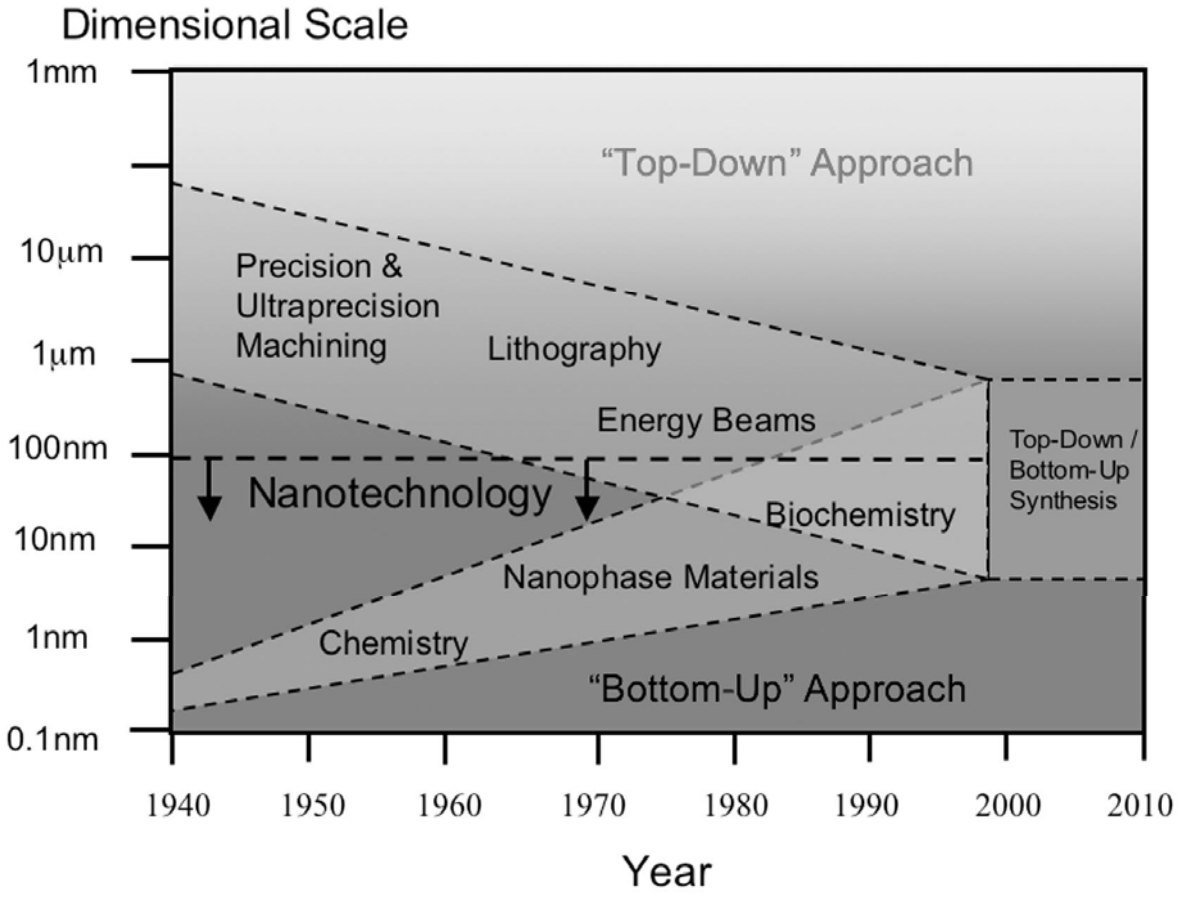
Inhalation: Inhaled particles induce inflammation in respiratory tract, causing tissue damage.
Example: Inhalation of silica particles in industrial workers causes “silicosis”.

Dermal exposure: Particles may enter body through the skin. Potential hazards are unknown at present.

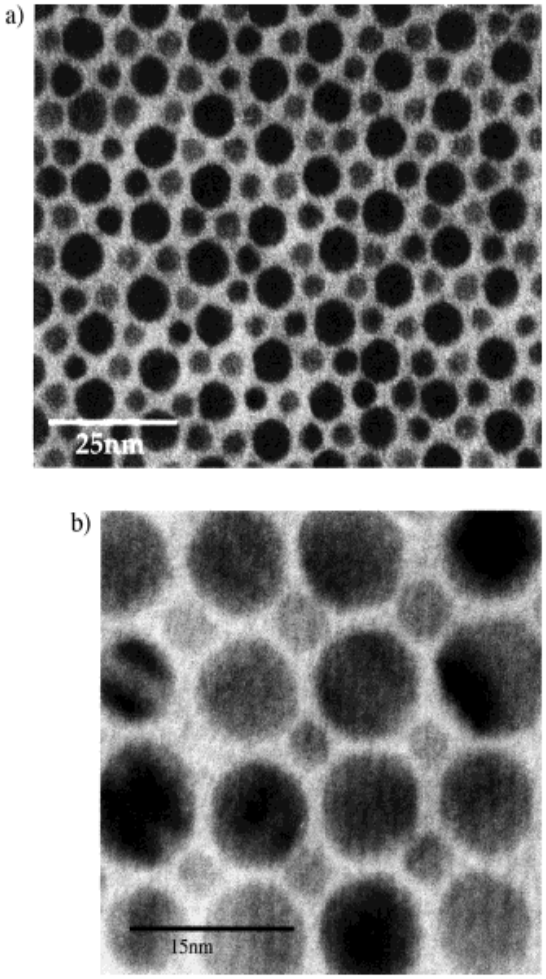
Ingestion: nanoparticles may cause liver damage. Ingested nanoparticles (i.e. for oral drug delivery) have been found to accumulate in the liver. Excessive immune/inflammatory responses cause permanent liver damage.

Fabrication gray zone (10 ~ 50 nm)

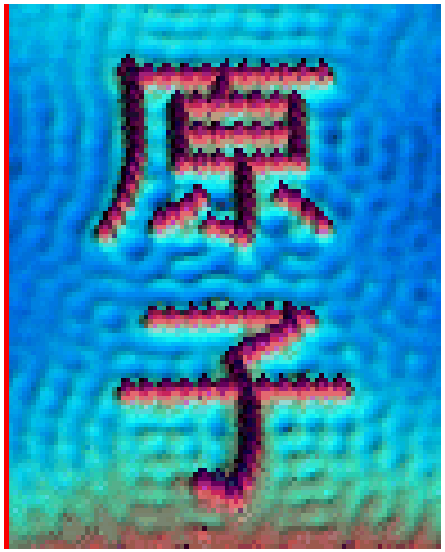
Top-down vs. Bottom-up



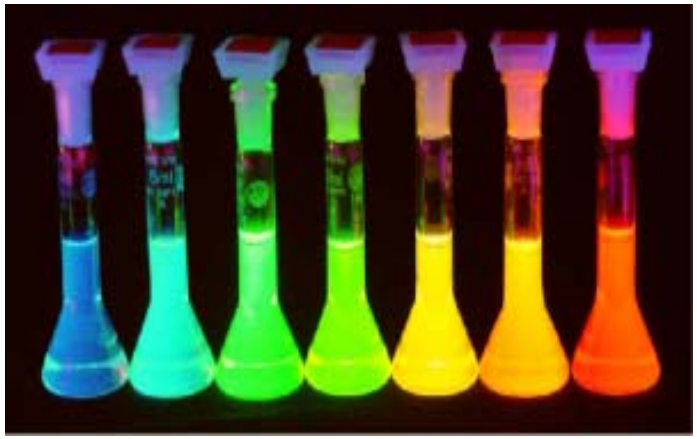
The beauty of nanotechnology, but…



Rafts of bimodal Au nanoparticles forming superlattice arrays



Atomic manipulation

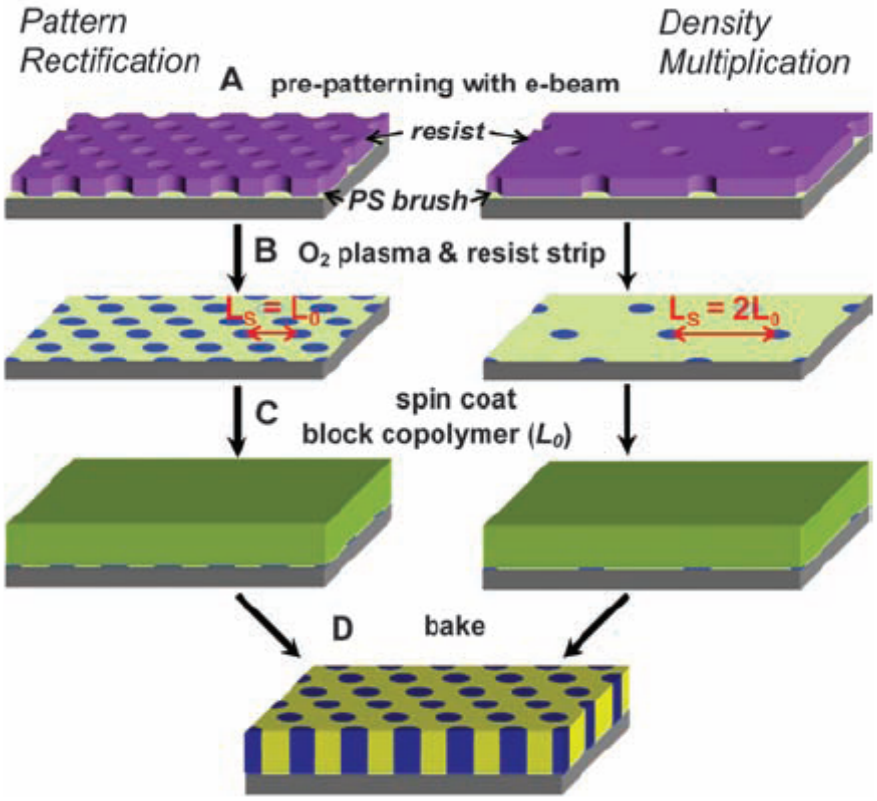


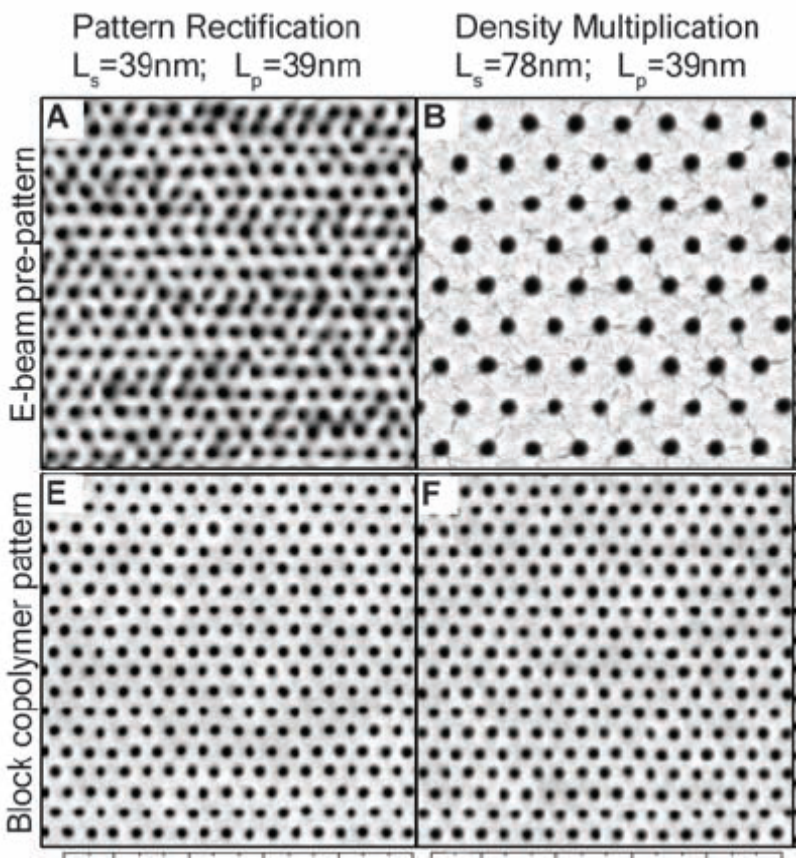
Quantum Dot

Fabrication gray zone (10 ~ 50 nm)

E-beam + BCP lithography

- Process to create lithographically defined chemically prepatterned surfaces and subsequent directed assembly

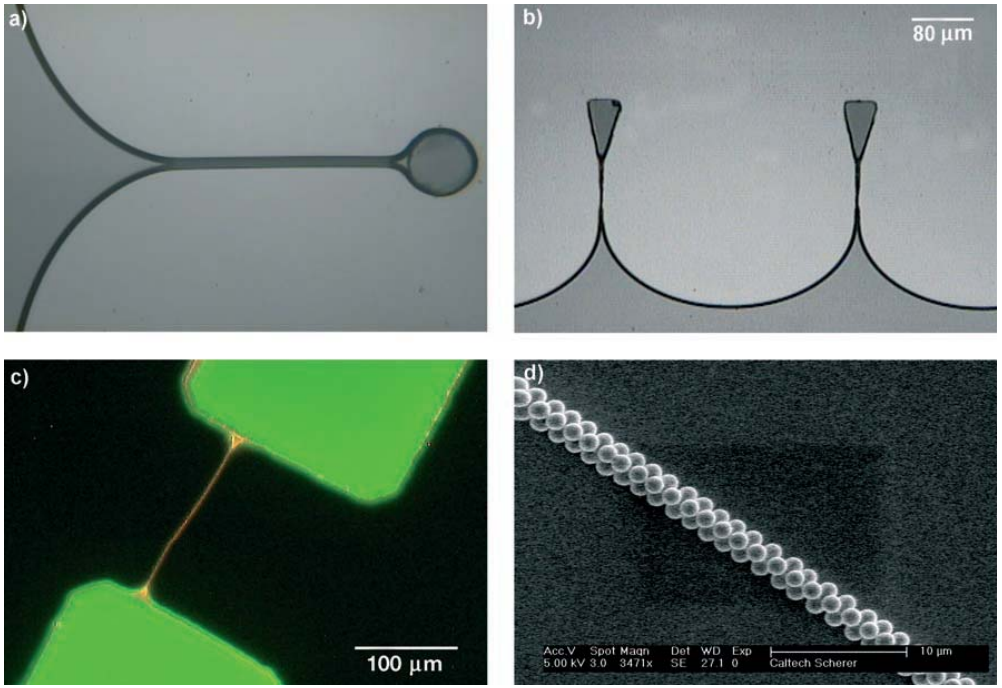




Science 321, 936 (2008)

Fabrication gray zone (10 ~ 50 nm)

Lithography + surface tension



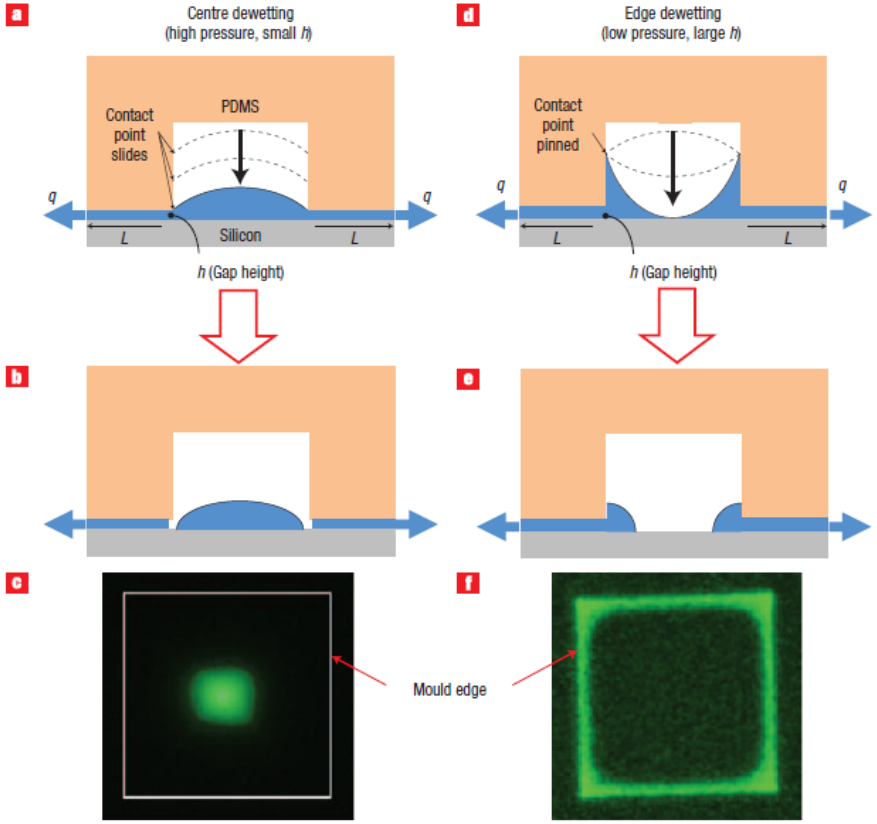
Results showing the effects of various pinning points and surfactants, and included self-assembled particles. a) A circular pinning point in a BSA solution. b) Triangular pinning points in a Triton X-100 solution. c) A quantum-dot line forming between two square pinning points. d) SEM image of self-assembled 2-mm-bead arrays.

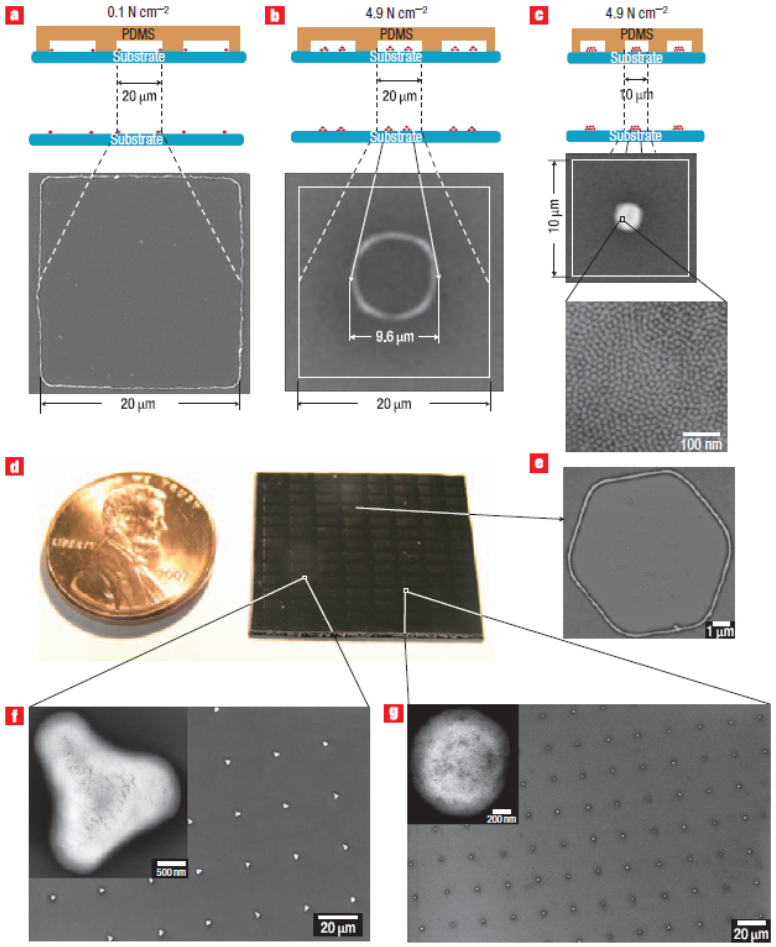
cf) Typical coffee staining effect by evaporation from edges with pinning (no regular patterns formed)

Nano Letters, 6, 271-276 (2006)

Fabrication gray zone (10 ~ 50 nm)

Lithography + surface tension





Nano Nanotechnology, 3, 682-690 (2008)

Social Responsibility, Ethics…
Need Understanding & Responsibility

"Military applications of molecular manufacturing have even greater potential than nuclear weapons to radically change the balance of power."

Admiral David E. Jeremiah, USN (Ret)

Former Vice Chairman, Joint Chiefs of Staff

November 9, 1995

"Even with all its unknowns, even with all its perils and risks, who'd say no to nano?"

Ed Regis, author of *Nano, the emerging science of nanotechnology: remaking the world – molecule by molecule*, 1995, p.308

Social Responsibility, Ethics…
Need Understanding & Responsibility

"Our most powerful 21st-century technologies : robotics, genetic engineering and nanotech are threatening to make humans an endangered species."

Bill Joy

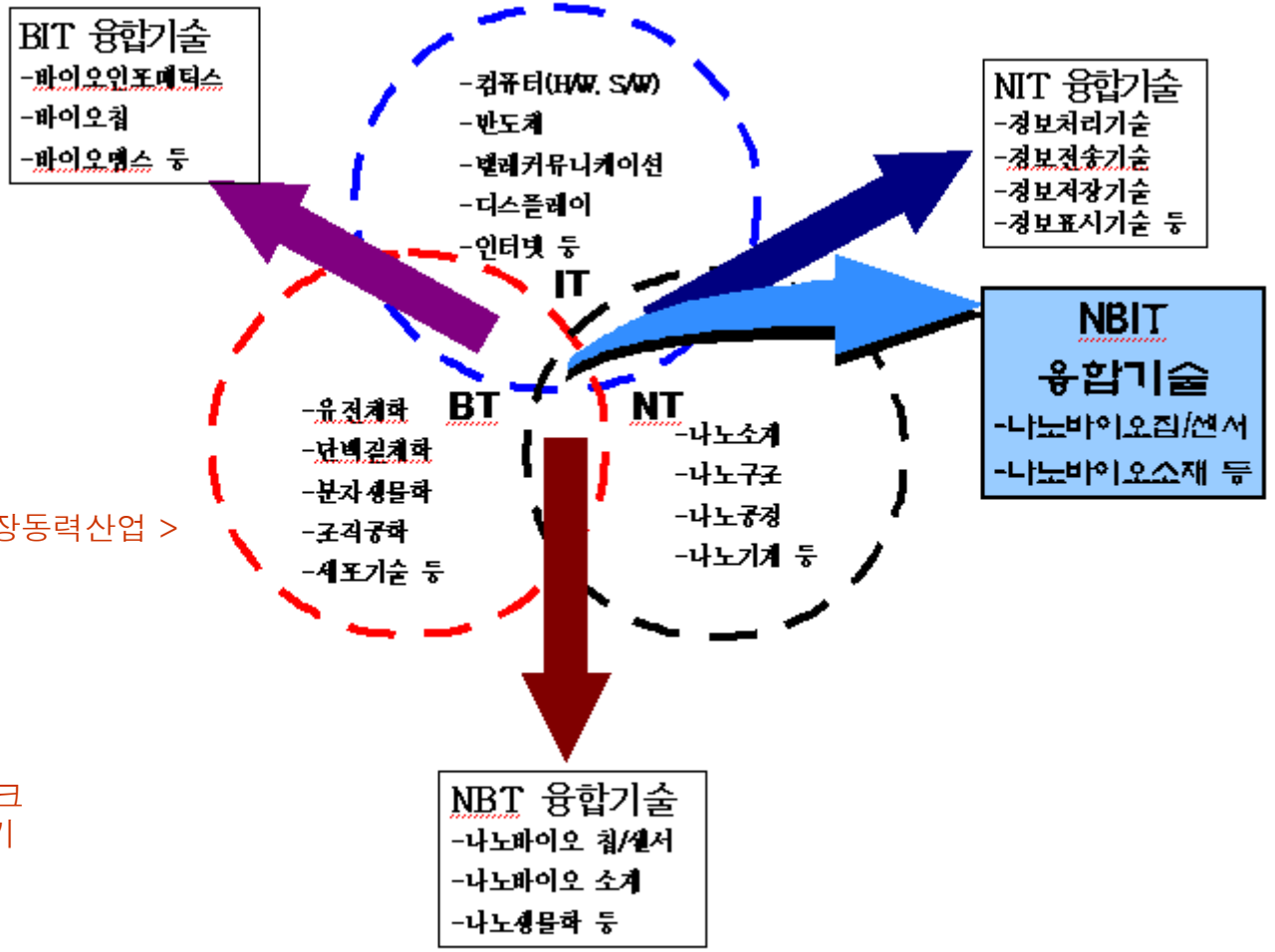
http://www.wired.com/wired/archive/8.04/joy.html

"If everyone has this technology, then if it *can* be abused, it *will* be abused. And if it can destroy the biosphere, that's threat enough for me."

K. Eric Drexler

Nanotechnology opportunities: NBIT 융합기술

- 나노 수준의 물질제어를 바탕
- 바이오기술, 정보기술을 전혀 새로운 형태의 기술로 발현시키고
- 파생되는 기술변화가 궁극적으로 사회.문화 패러다임까지 변화시킬 수 있는 첨단.신생 기술들



〈그림 1〉 NBIT 융합기술의 개념도

< 10대 차세대 성장동력산업 >
- 디지털 TV/방송
- 디스플레이
- 지능형 로봇
- 미래형 자동차
- 차세대 반도체
- 차세대 이동통신
- 지능형홈네트워크
- 바이오신약..장기
- 디지털컨텐츠
- 차세대전지

〈표 1〉 각 융합기술의 범위

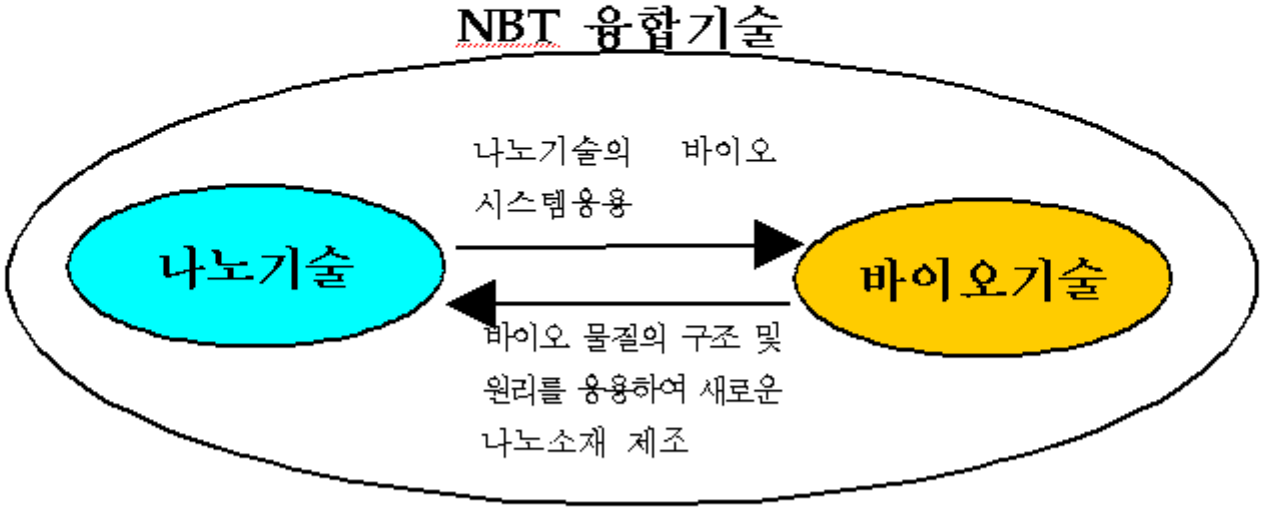
구분	세부기술분야	대표기제품(예)
NBT	나노바이오칩/센서	나노바이오센서, DNA칩, 단백질칩, Lab-on-a-chip (LOC) 등
	나노바이오소재	생체모방 나노소재, 기능성 나노소재 등
	나노생물학	바이오/화학 센서, 광바이오시스템, 생체나노머신 등
NIT	정보처리분야	양자컴퓨터, 나노전지 등
	정보전송분야	나노복합 광통신용 광소자, 실리콘 나노점의 전광소재/소자 원천기술제품 등
	정보저장분야	테라급 초고밀도 자기 정보저장 매체 등
	정보표시분야	차세대 리소그라피 원천기술, MEMS 기술제품 등
BIT	바이오인포메틱스 (Bioinformatics)	DNA해석 소프트웨어, 단백질해석 소프트웨어, 바이오 DB 마이닝 등
	바이오멤스 (BioMEMS)	초고밀도 집적회로, 초소형 기어, 초미세 기계구조물 등

〈표 2〉 융합기술의 활용분야 및 사례

활용분야	활용 사례
건강한 삶 추구	- 효율적인 진단 및 치료 시스템 구축 - 질병의 예방·치료 및 인공장기 이식을 통한 수명의 연장
안정적 식량 확보	- GMO, LMO 기술을 통한 대량 식량생산 - 병해충에 강한 품종개량 등을 통해 식량 증산에 기여 - 농수축산 먹거리의 보관·저장·가공 기술의 획기적 개발
에너지/환경여건 개선	- 화석에너지원의 발굴·채굴·수송·저장의 효율화 - 태양에너지, 수소활용 에너지 등 재생에너지 이용의 활성화 - 자원효율 증가, 폐기물 저감, 오염물질 배출 저감을 통한 환경오염의 원인 제거
국가안전 확립	- 첨단무기와 장비를 통한 군사력 강화 - 자연재해 및 재난의 감지·예측·방지·구난기술 확보에 의한 사회안전 시스템 향상

NBT 융합기술

NBT 융합기술은 "나노기술의 원리와 기법들을 바이오시스템에 적용하여 세포나 분자수준에서 다룰 수 있도록 하거나, 기존 생체시스템의 원리를 이용하여 새로운 구조를 갖는 나노소재·시스템을 제조가 가능할 수 있도록 해주는 융합기술 분야"이다.



〈그림 2〉 NBT 융합기술

Nanobot: Medicine

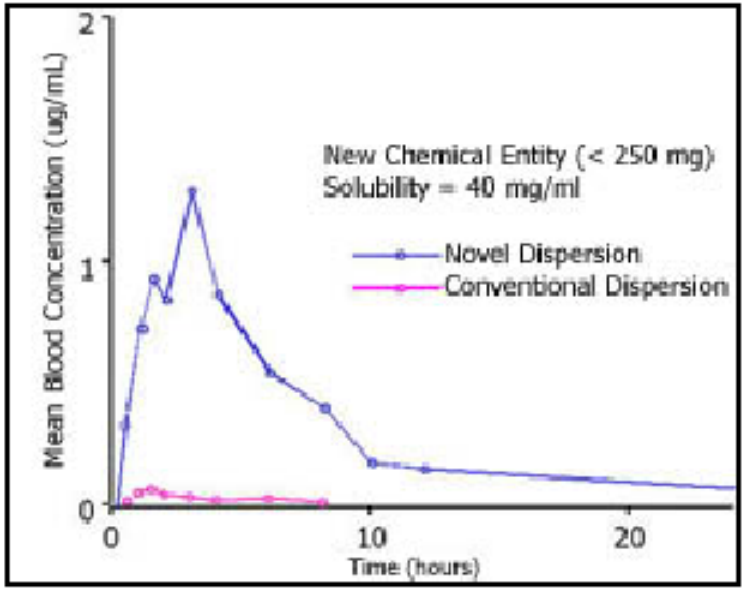
심장근육 이용한 '머슬봇' 개발...암세포 골라죽이는 로봇 (2004, UCLA)

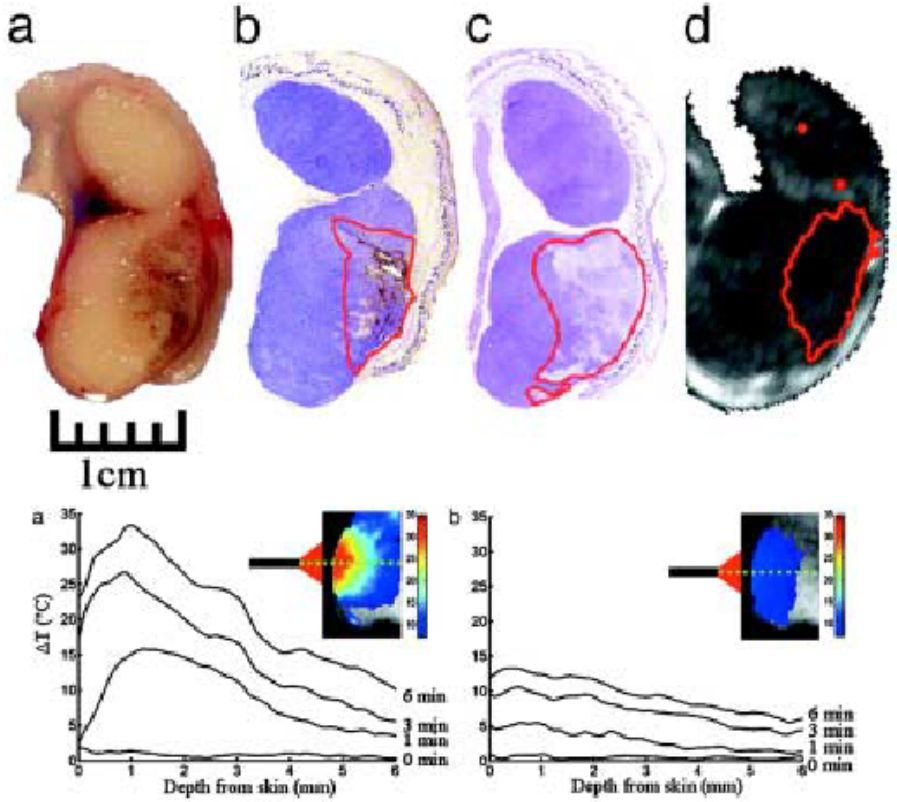
동력원? 미오신, 다이네인, 키네신... (천연모터)

Nanobot: Medicine

Nanomedicine: 약물 전달 (Drug Delivery)

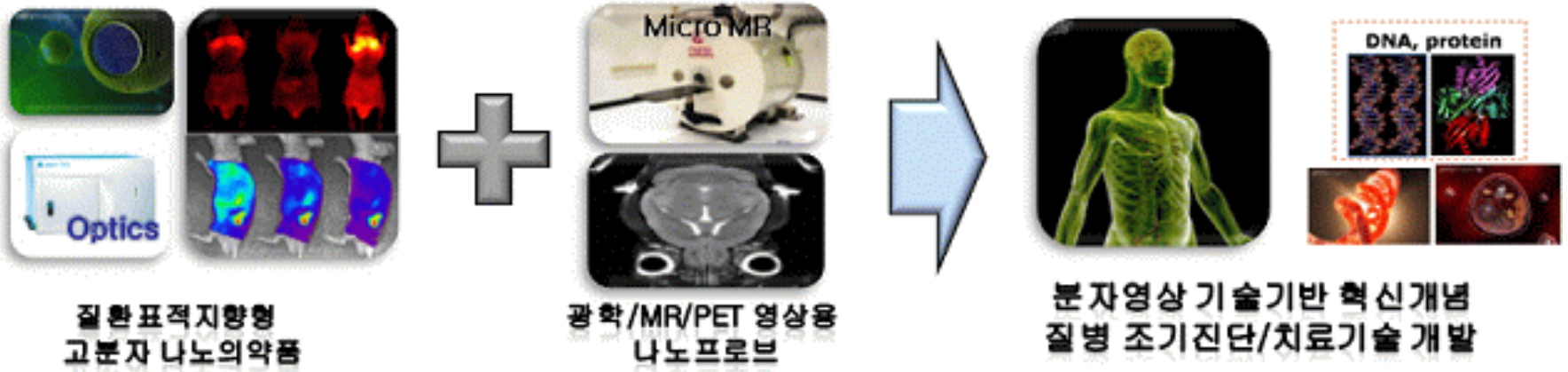
- **Drug delivery using nanoparticles**
- **Faster dissolution**
- **Faster absorption**
- **Enhanced bioavailability**



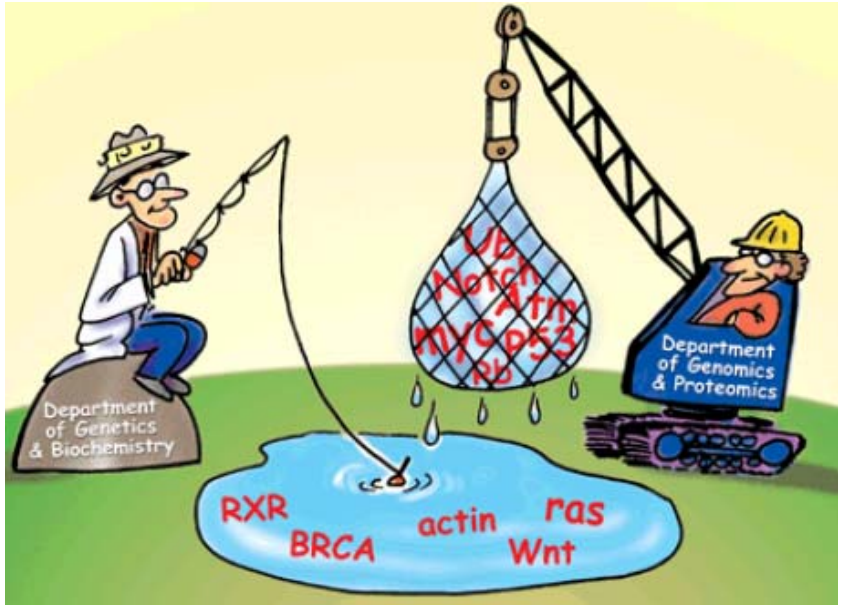


Nanomedicine: 분자영상 (Imaging)

➢ 질환 조기진단/치료 기술 개발



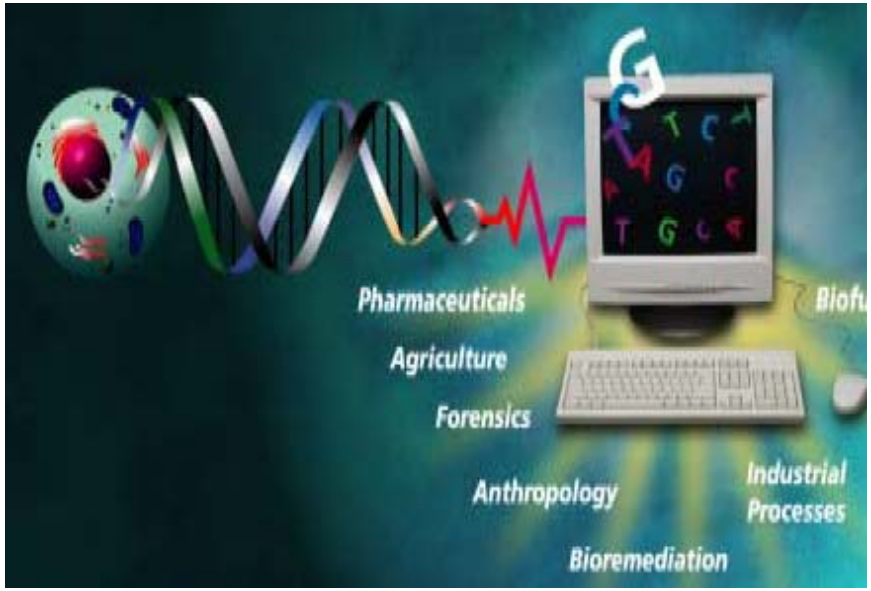
Nanomedicine: 바이오칩, 조직공학



대규모 생명정보의 발굴

Human Genome Project
BioDigital Convergence
정보의학

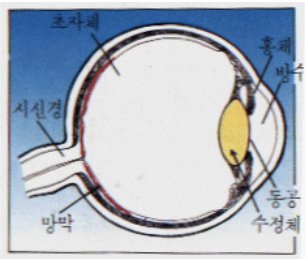
생명복제 기술
줄기세포 치료
이종간 장기이식



맞춤의학, 예측의학의 시대

자연모사공학(Biomimetics)

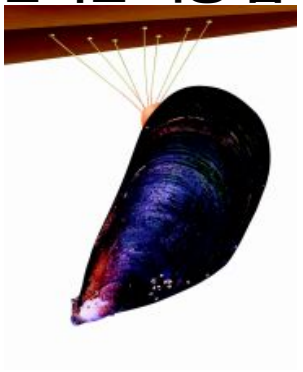
눈의 구조



카메라

상어피부 돌기구조

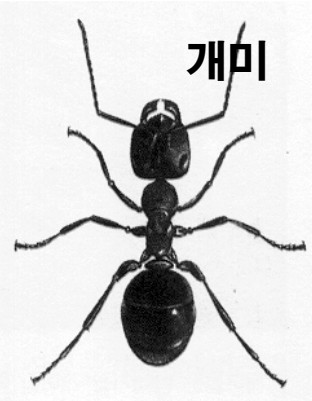
홍합 단백질 이용 접착제



엉겅퀴 씨앗

벨크로 테이프 딱정벌레 껍질응용

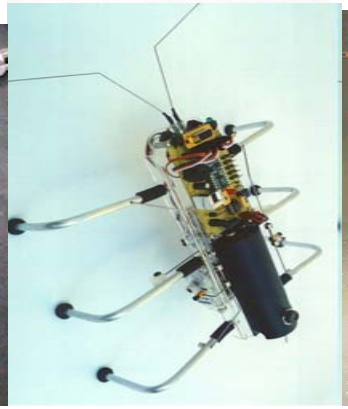
개미

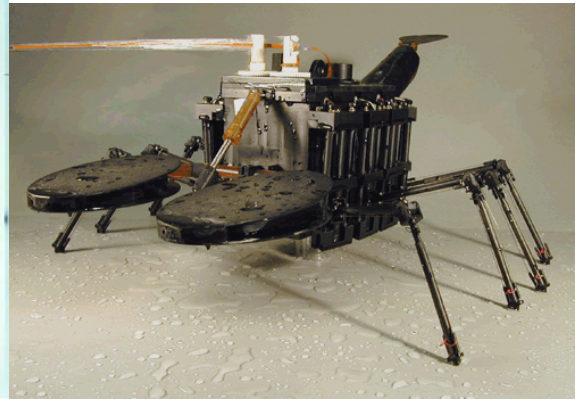


가재

자벌레

최적화된 구조와 기능

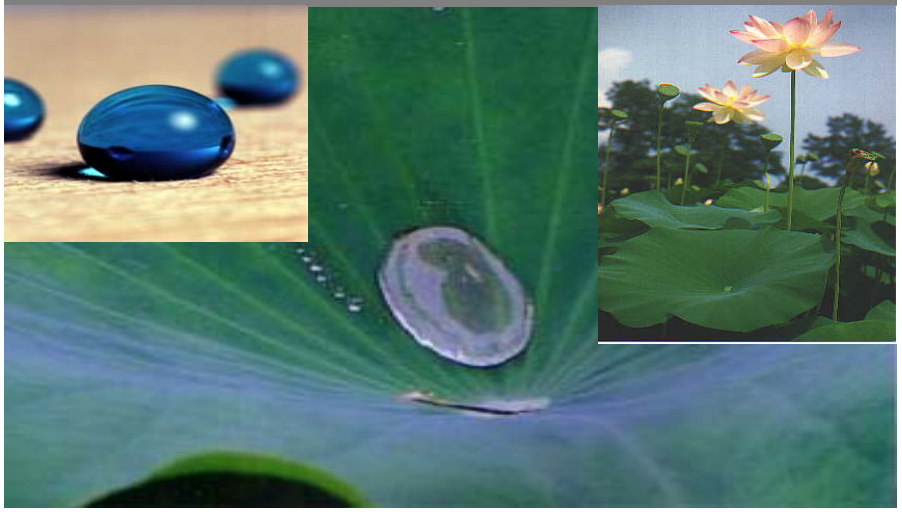




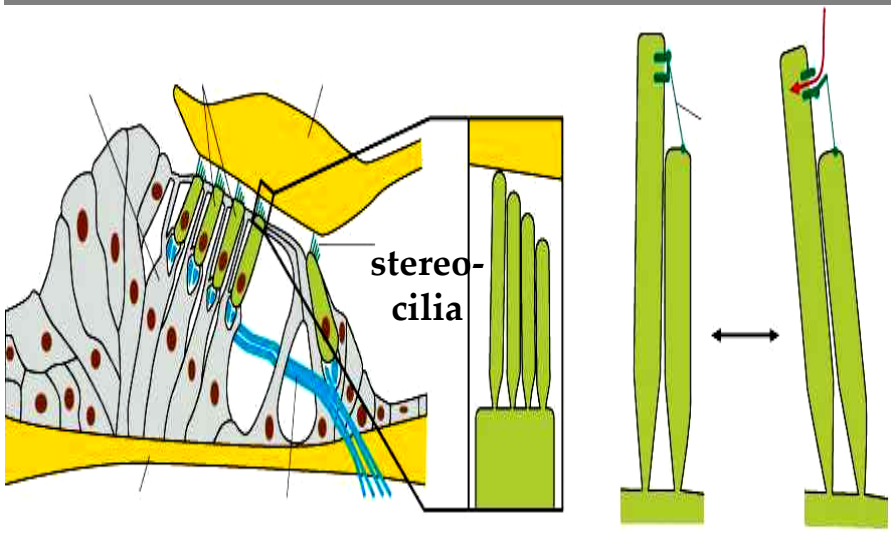
자연나노섬모의 예

Nano Hair (접착기능)

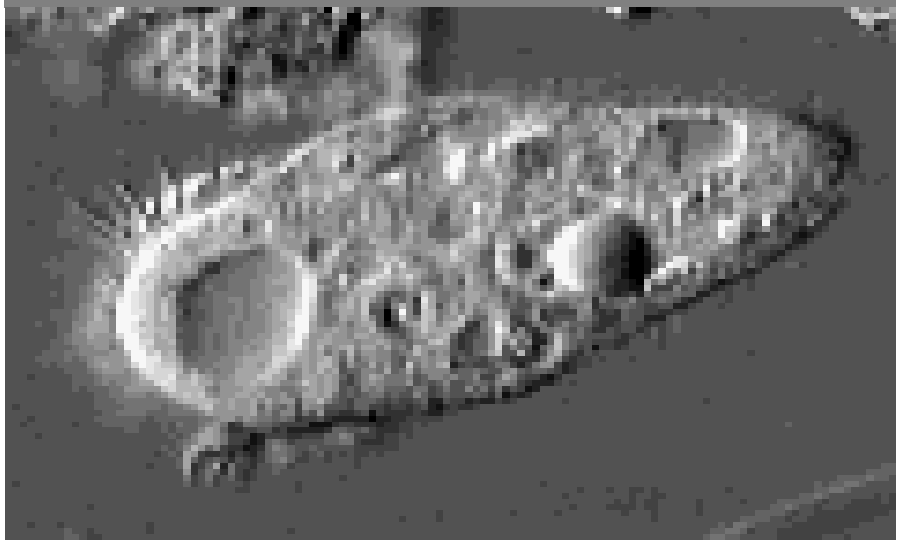
Nano Turf (자정기능)



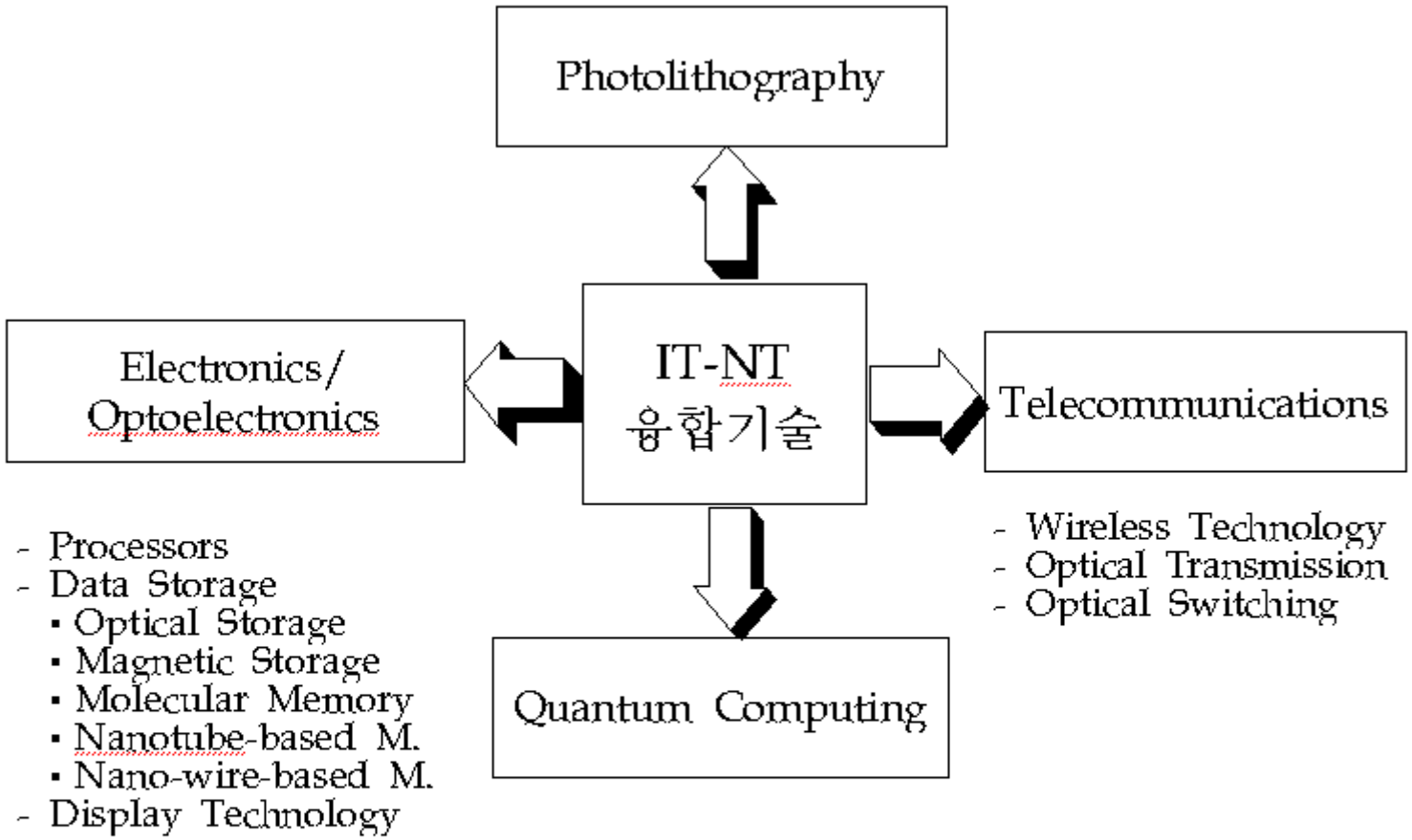
Nano Cilia (센싱기능)



Nano Cilia (이동기능)



NIT 융합기술



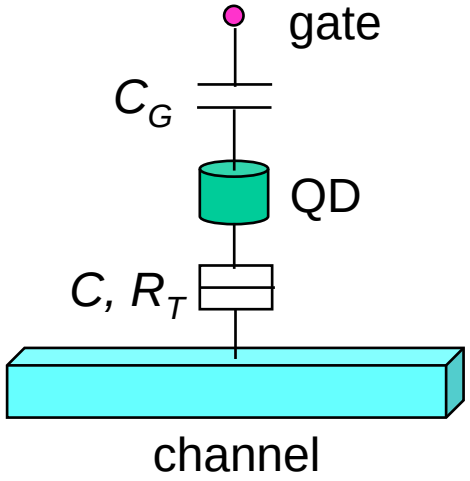
주 : ITFIND 주간기술동향, NIT 및 BIT 융합기술의 개요 및 시장전망(2002. 10)를 일부 재구성함

〈그림 3〉 NIT의 응용분야

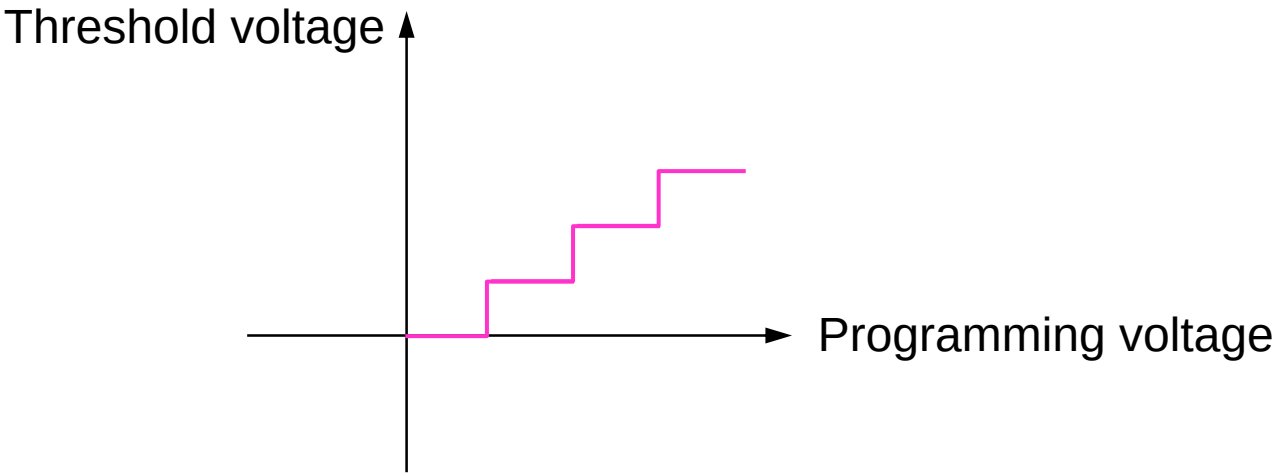
Single Electron Memory

- Application of nano : single electron memory
  combination of Single Electron Box
  and EPROM

  ⇒ use of SEB for single
  electron control and
  MOSFET for charge sensing

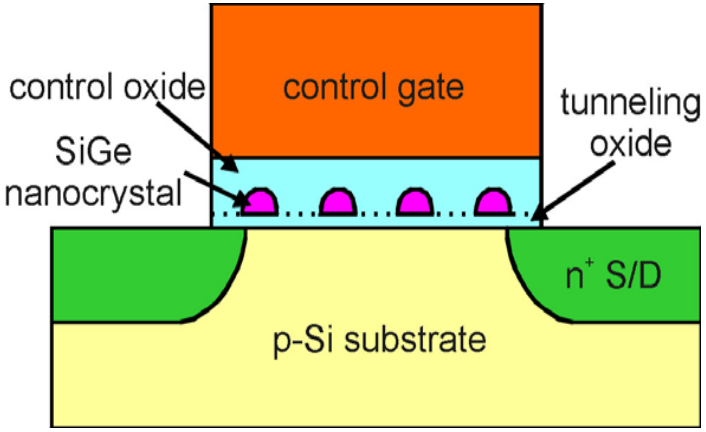


- Characteristics of single electron memory



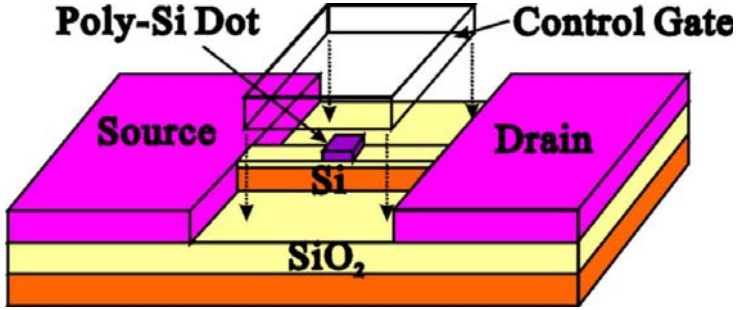
Single Electron Memory Structures

- Nanocrystal memory
  - Ease of fabrication
  - Fluctuation of dot numbers



(*Tiwari, et al., 1995*)

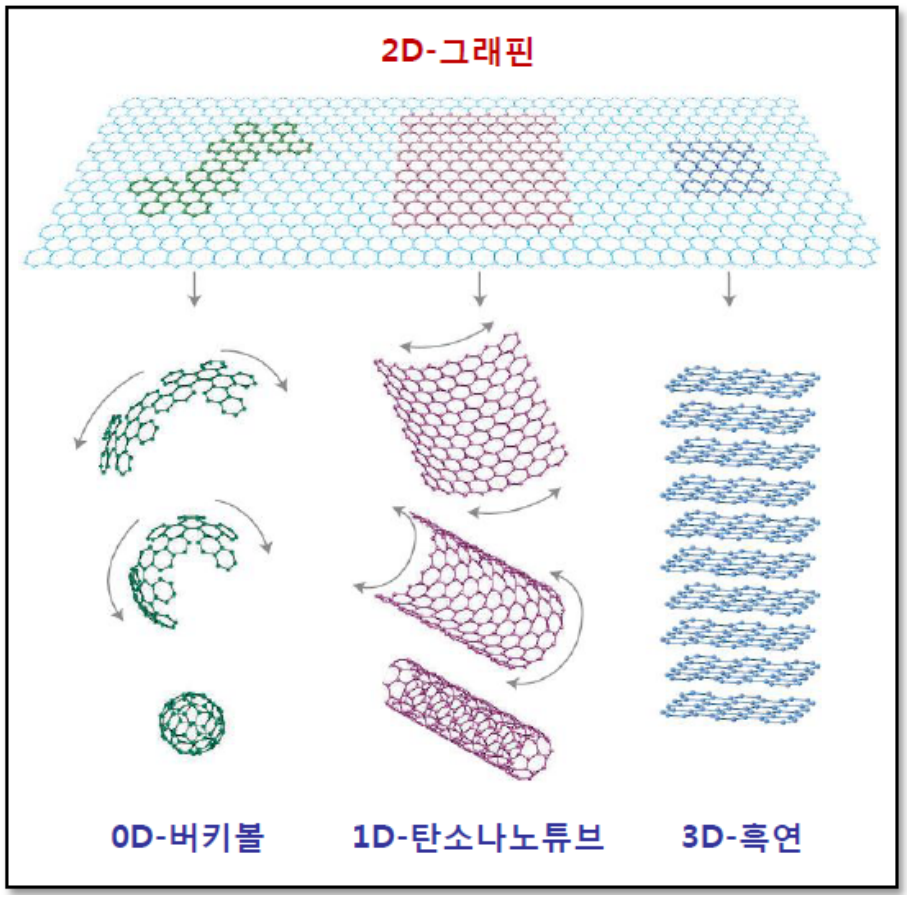
- Single dot memory
  - Clear V_T staircase
  - Fabrication relatively difficult

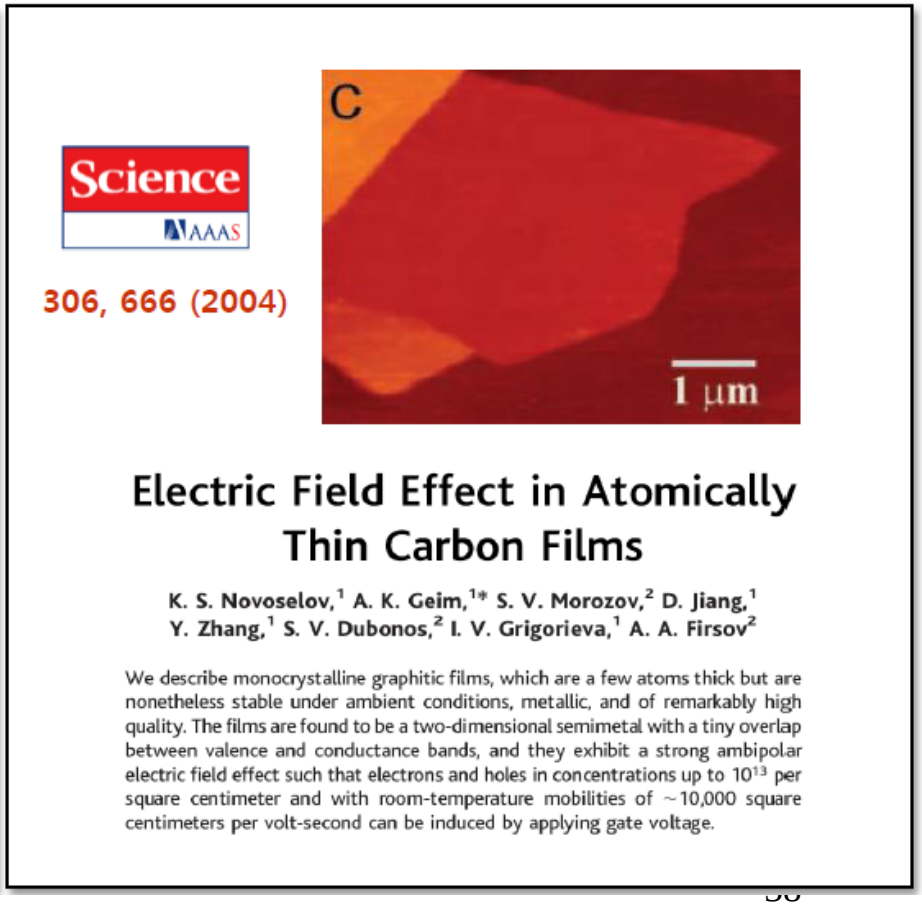


(*Chou, et al. 1997*
Nakajima, et al. 1997)

Graphene: new wonder material

- 그래핀의 구조
  - 2차원적 탄소소재: 육각형으로 공유결합된 단일층의 sp^2 혼성탄소 배열
  - 2004년 Geim등이 기계적 분리법으로 처음 특성규명





By courtesy of Prof. Sangwook Kim, KAIST

Graphene: new wonder material

▪ 그래핀 기판의 물성

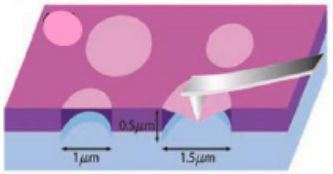
- 높은 내열성/내화학성: 고온공정 (~1000 ℃) 가능
- 낮은 열팽창 계수: 3.0 $\times 10^{-6}$ K^{-1} [Si : 4.7 $\times 10^{-6}$ K^{-1}, Cu : 16.5$\times 10^{-6}$ K^{-1}]
- 기체/액체 barrier 특성 우수, 원자수준으로 평평한 기판, 우수한 투명도

▪ 낮은 제조 단가

- 저가의 그라파이트 (20원/g)를 원료로 제조

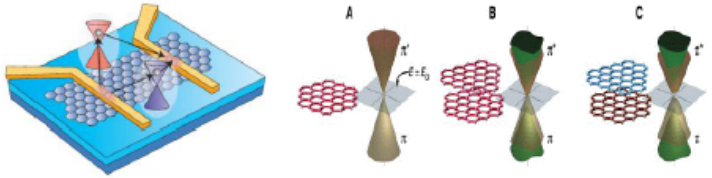
▪ 기계적/열적 특성

- 기계적 유연성, 높은 탄성계수 ~ 1.0 TPa
- 높은 열전도도: ~ 5$\times 10^{3}$ Wm^{-1} K^{-1}
- 낮은 열팽창 계수: 3 $\times 10^{-6}$ K^{-1} (Si : 4.7 $\times 10^{-6}$ K^{-1})



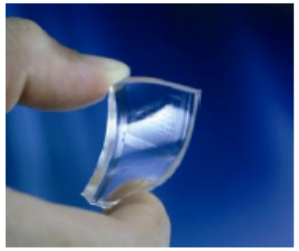
▪ 전기적 특성

- 15,000 $cm^2V^{-1}s^{-1}$ 이상의 매우 높은 전하이동도
- 화학적 개질을 통한 전기 전도도 제어 가능



▪ 광학적 투명성

- Optoelectronic 소자 재료로 적합



초고효율 유기 태양전지 개발

소재기술 (NT 기반)

소재기술 (NT기반기술)

1) 고신뢰성 유기 solar cell소재
- 광대역 고흡수율 고분자
- 광대역 고흡수율 저분자
- High mobility 고분자
- High mobility 저분자

2) 고신뢰성 nanocrystal
- 고전도도 nanocrystal
- 고반사도 nanocrystal
- nanocrystal 합성기술
- nanocrystal 분산기술

3) Flexible 기판 소재
- PET, PS, PEN 등 flexible 기판 기술

4) Flexible 전극 소재
- 고반사도 전극 재료
- 고투과도 전극 재료
- High fatigue 특성 전극 재료

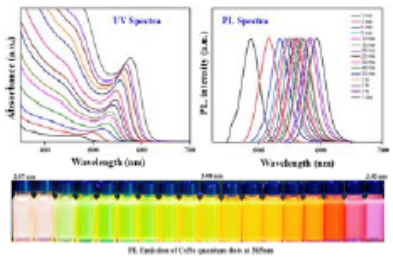
5) 저온 passivation
- 저온 passivation 재료
- 저온 증착기술

Solar cell 기술 (NT기반 ET/IT융합기술)

Flexible 유기태양전지 기술 (NT기반 ET/IT 융합기술)

1) Flexible 유기태양전지
- 광대역 single cell / tandem cell 구조 유기태양전지
- 유·무기 하이브리드 광대역 single cell / tandem cell구조 태양전지
- 광대역 양면흡수 태양전지

2) 반도체 양자점 태양전지
- 반도체 양자점 합성 기술
- 반도체 양자점 single cell / tandem cell 구조 태양전지

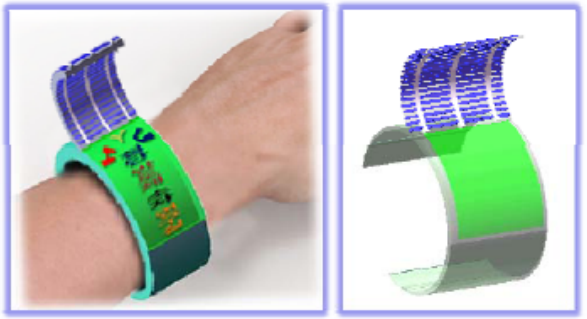


15% 이상의 초고효율 flexible 태양전지 개발 (NT/IT/ET 복합기술)

15% 이상의초고효율 광대역 flexible 태양전지 (NT, ET, IT 복합기술)

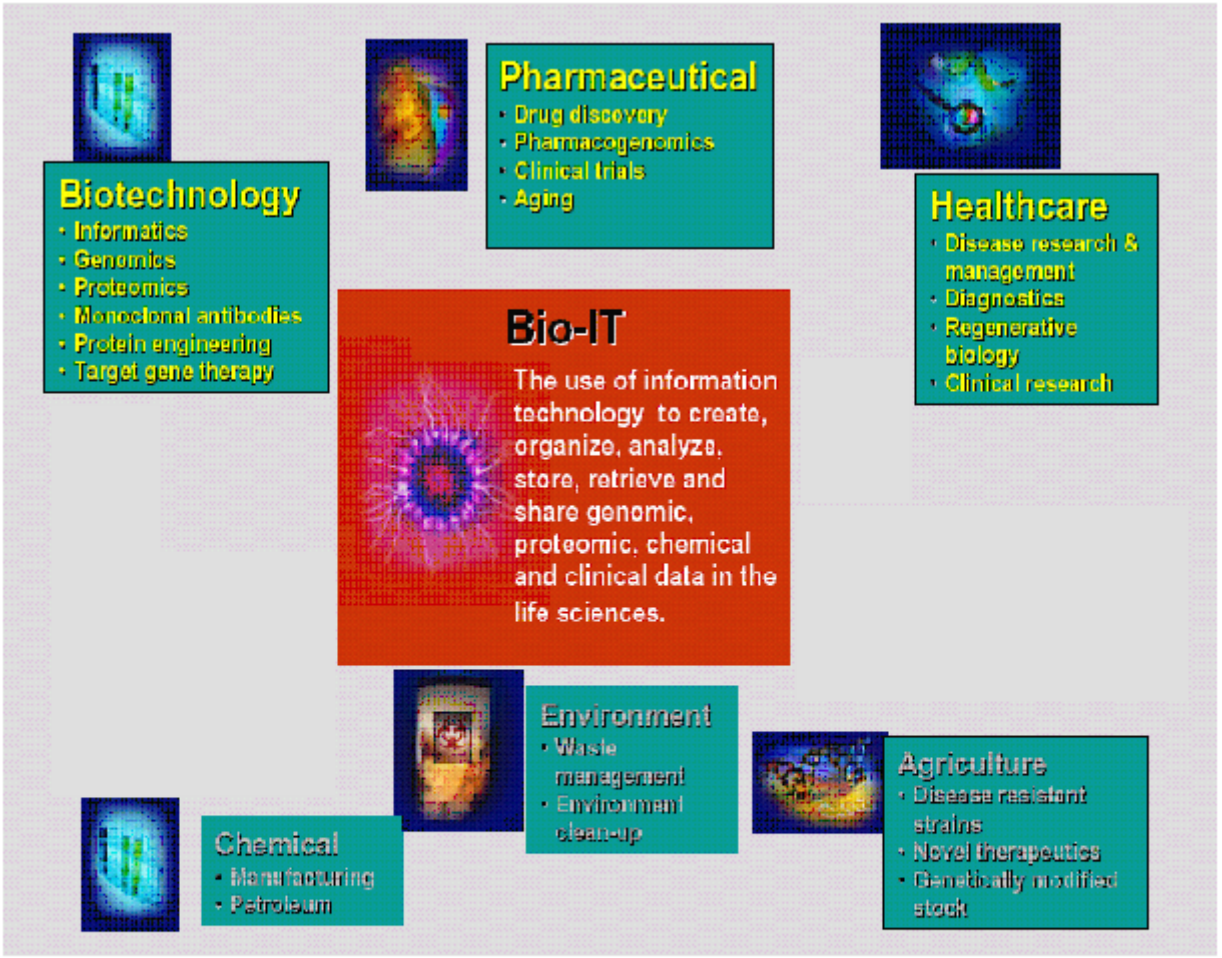
1) 고신뢰성 광대역 tandem cell structure flexible 태양전지
- 고신뢰성 광대역 tandem cell 구조 flexible 태양전지 구조개발
- 고신뢰성 유·무기 하이브리드 광대역 tandem cell구조 flexible 태양전지 구조 개발

2) 고신뢰성 광대역 양면흡수 태양전지
- 고신뢰성 광대역 양면흡수 태양전지 구조 개발



3) 고신뢰성, 저단가 양산공정기술
- Roll-to-Roll
- Ink-jet printing
- Screen printing

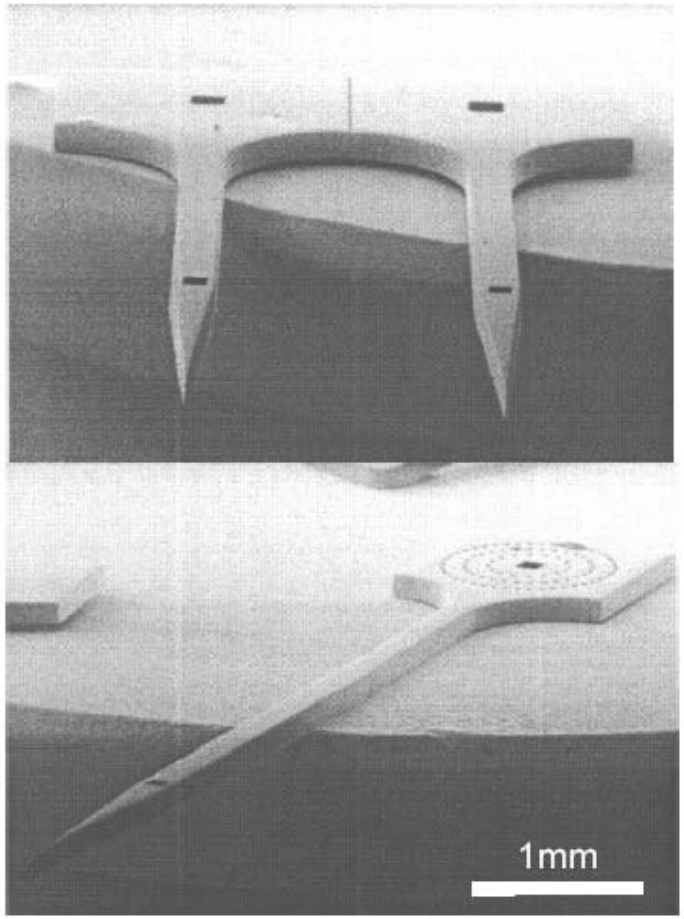
BIT 융합기술

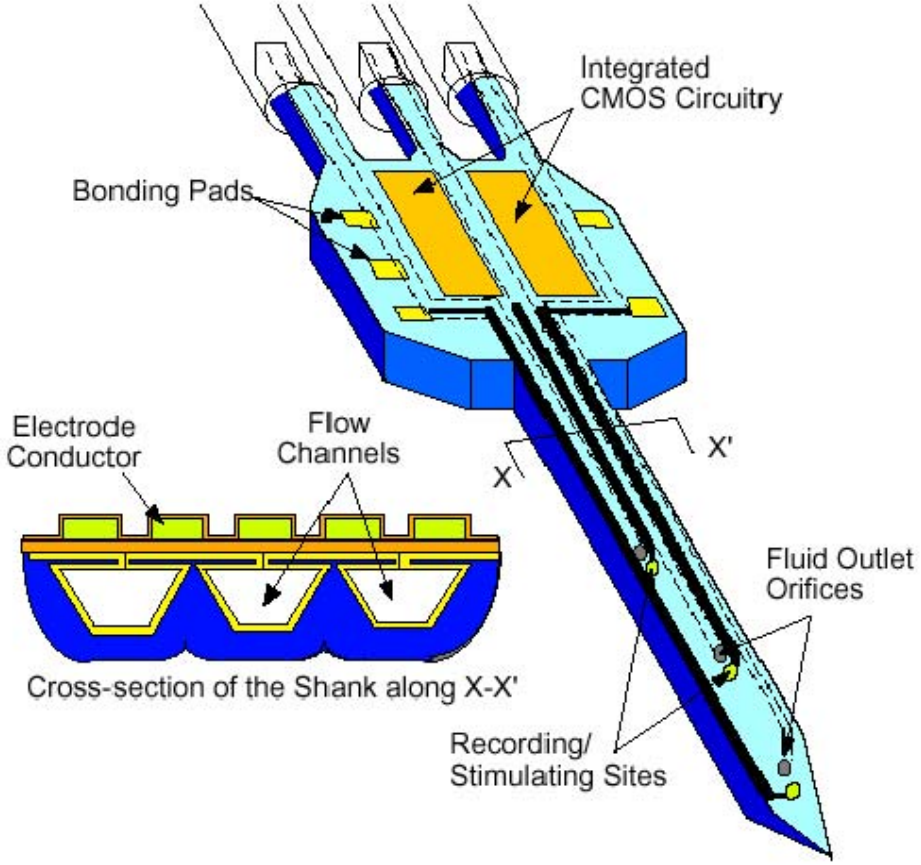


자료: http://webby.ctaalliance.org/MCBI/BioIT_presentations.html,
Presentations from the Bio-IT Workshop, 2003

〈그림 4〉 BIT의 활용사례

Drug Delivery Platforms

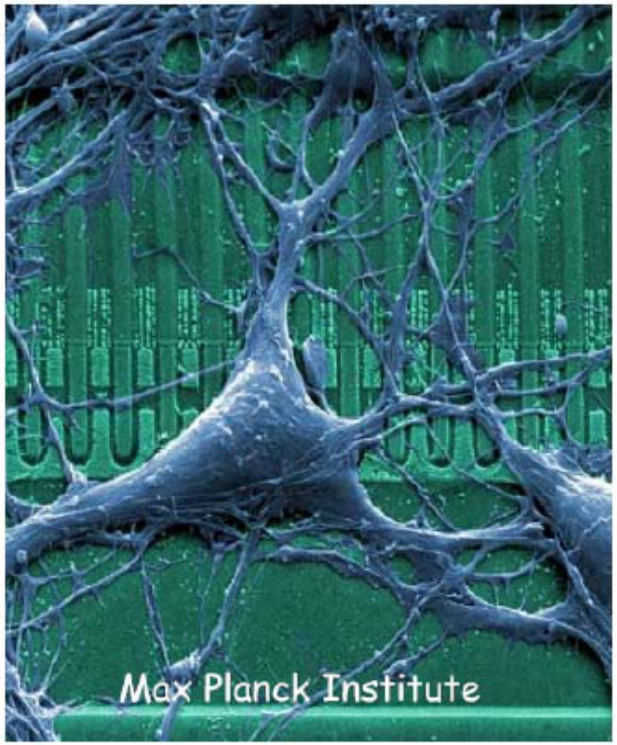


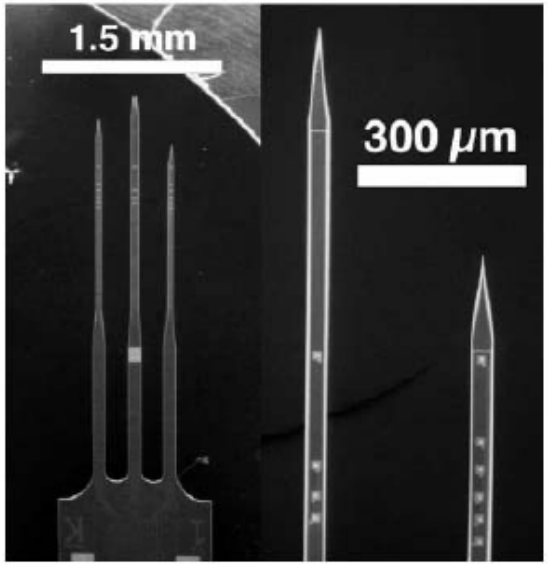


Photos courtesy of N. Talbot and A. Pisano, UC Berkeley
Diagram courtesy of K. Wise, U. Michigan.

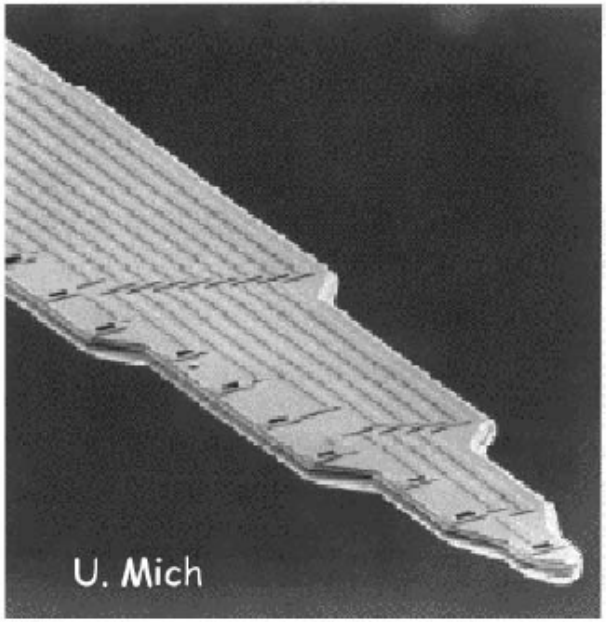
뇌세포를 이용한 소자

neuro-circuit interaction

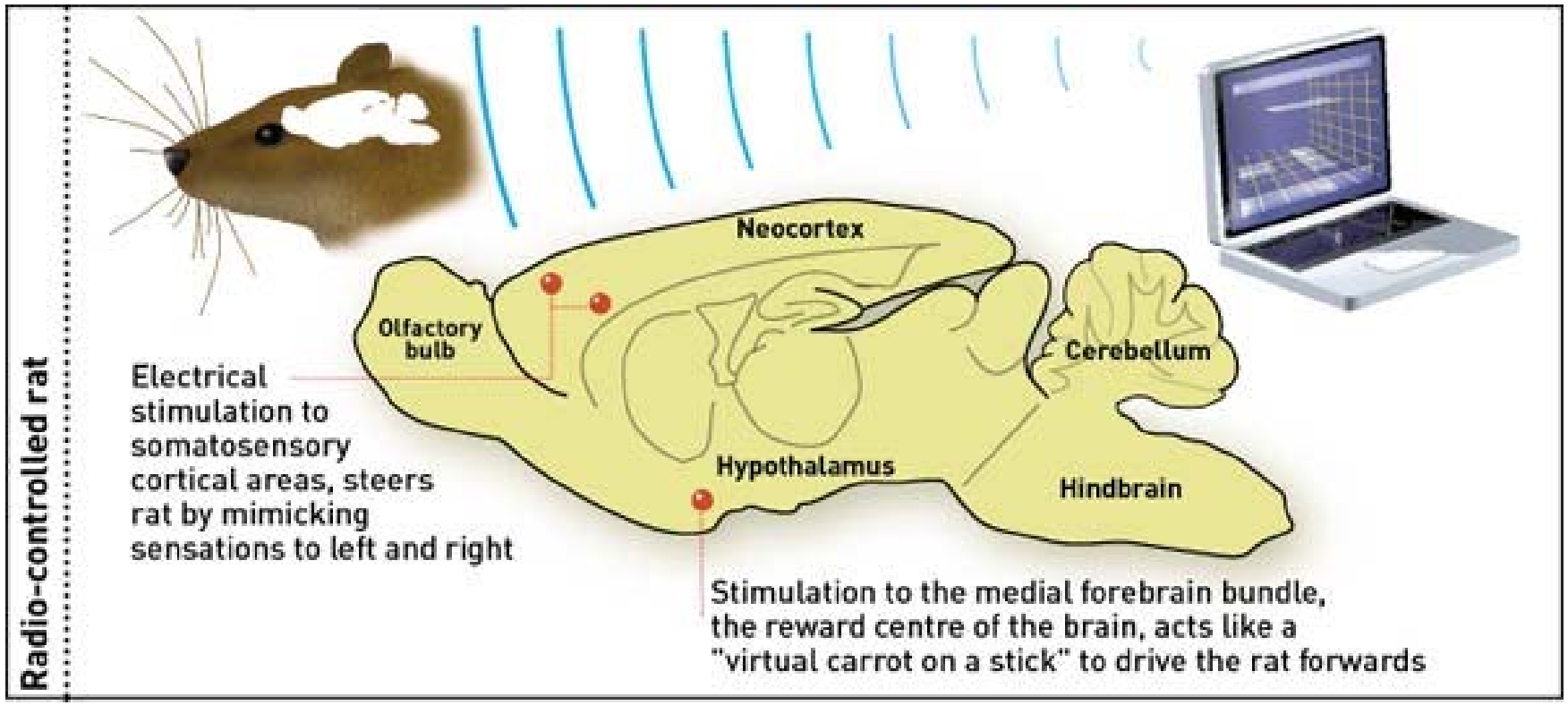




Stanford Neuro Probe

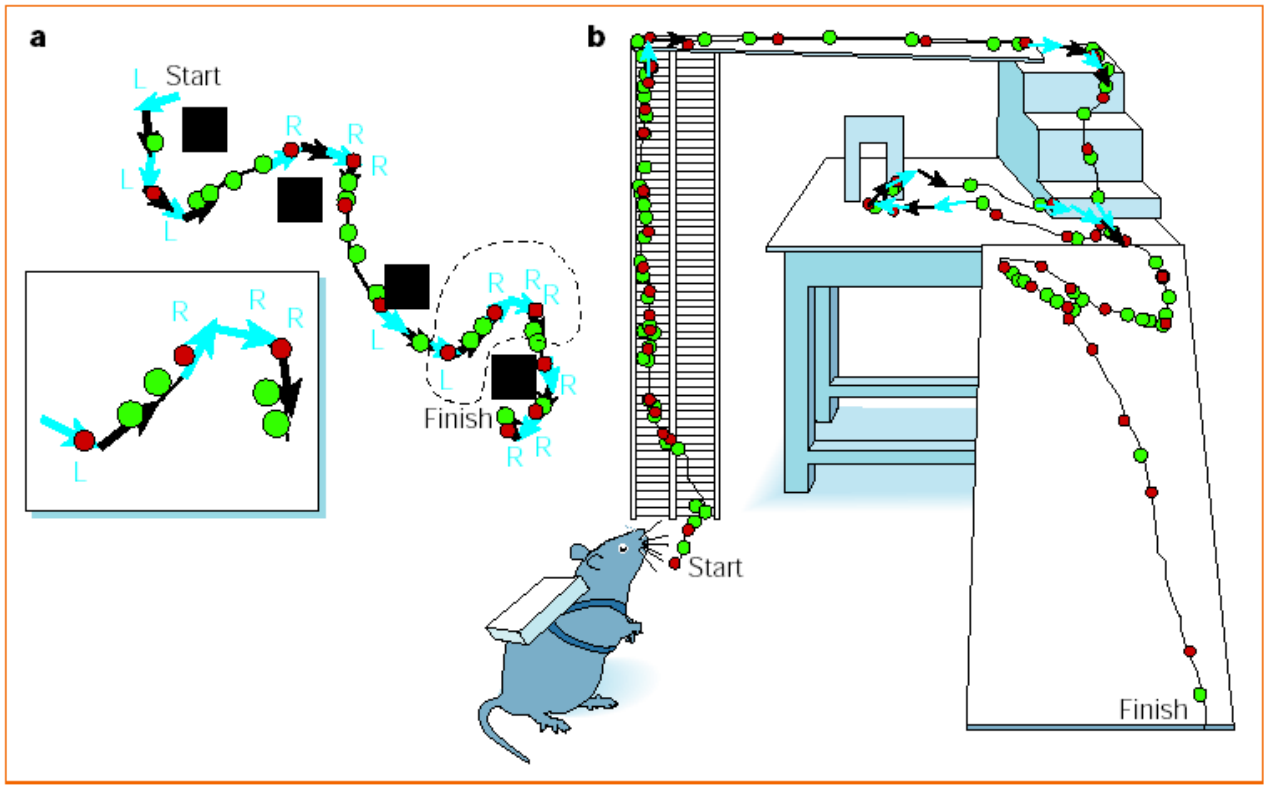


Robo-rat controlled by brain electrodes

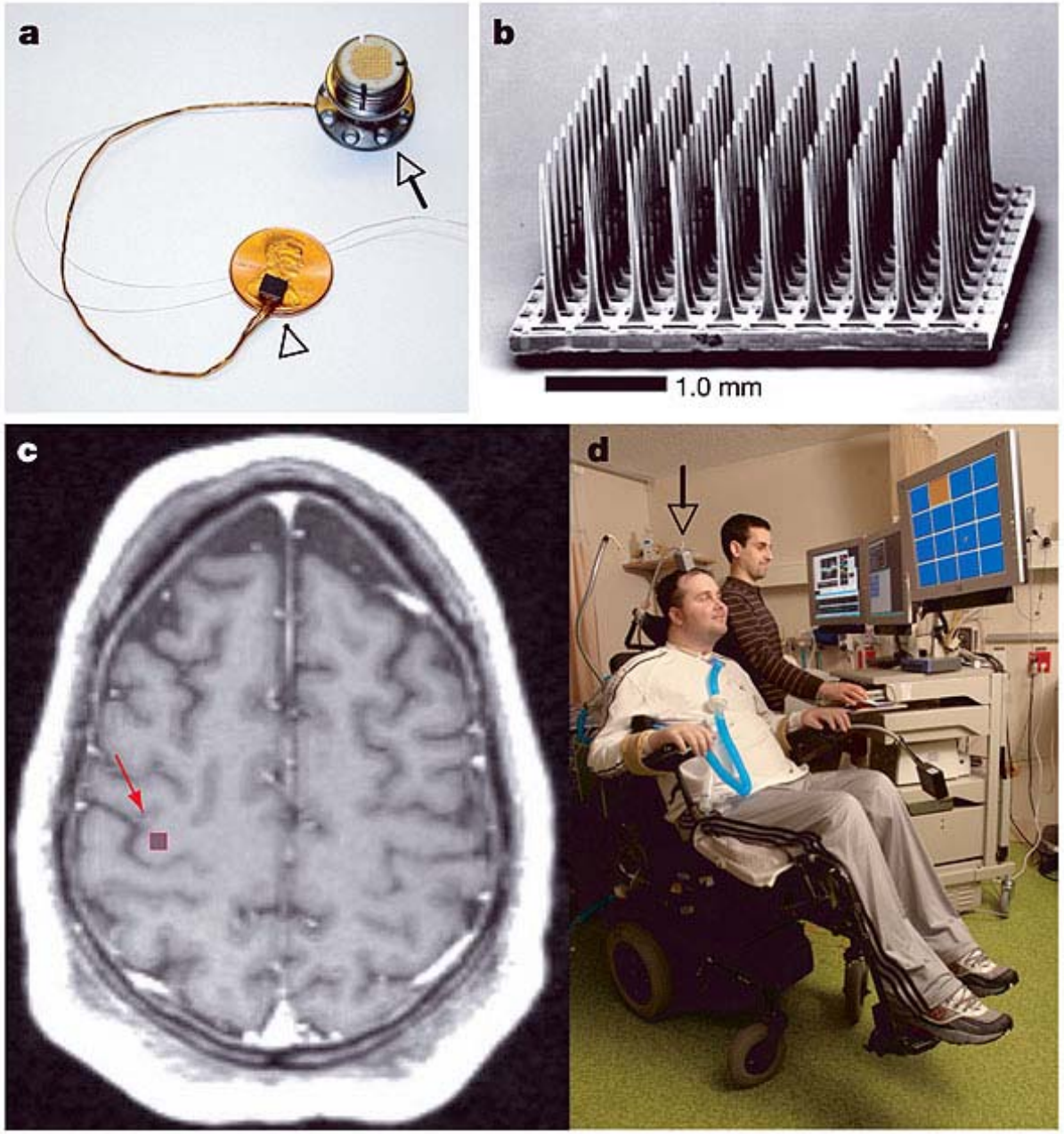


By courtesy of Prof. Jaeseung Jeong
KAIST, Department of BioSystems

Rat navigation by remote control



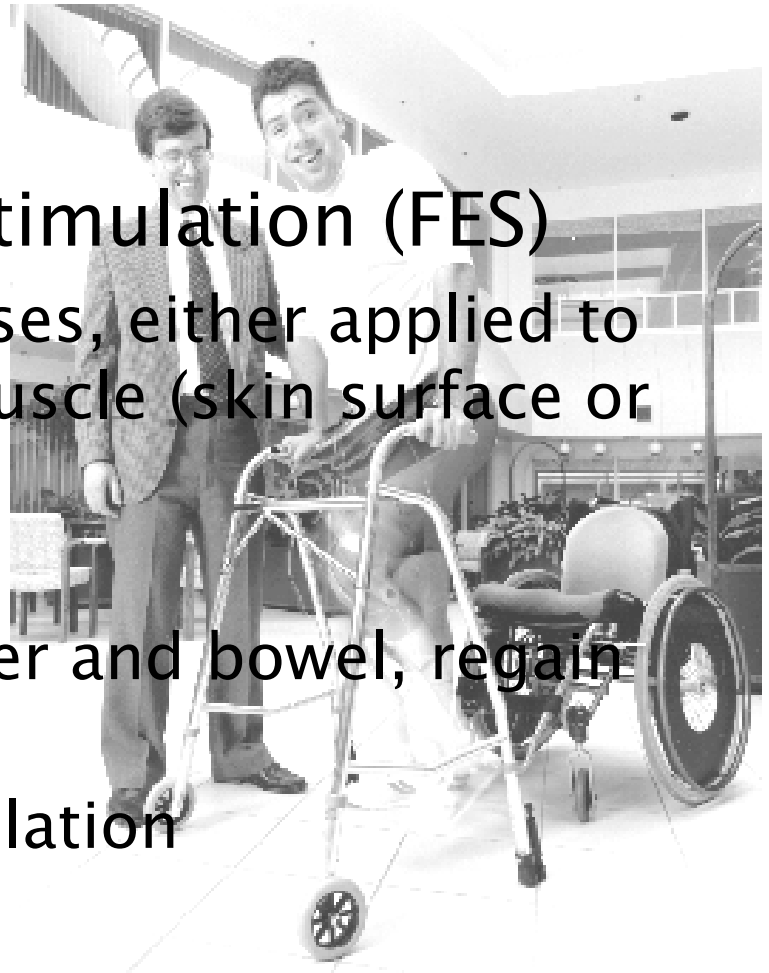
Is this the bionic man?


a
b
1.0 mm
c
d

Kevin Warwick: the first cyborg?

Rehabilitation

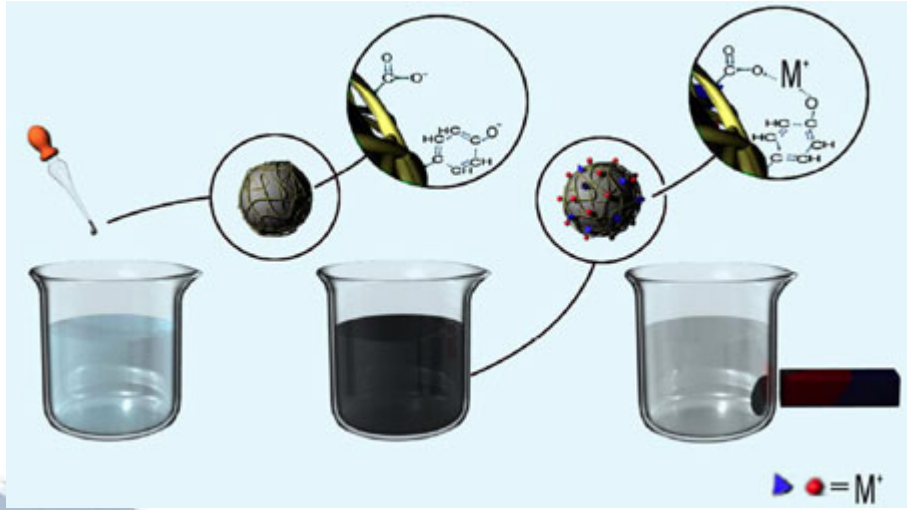
(artificial limbs o regain mobility)



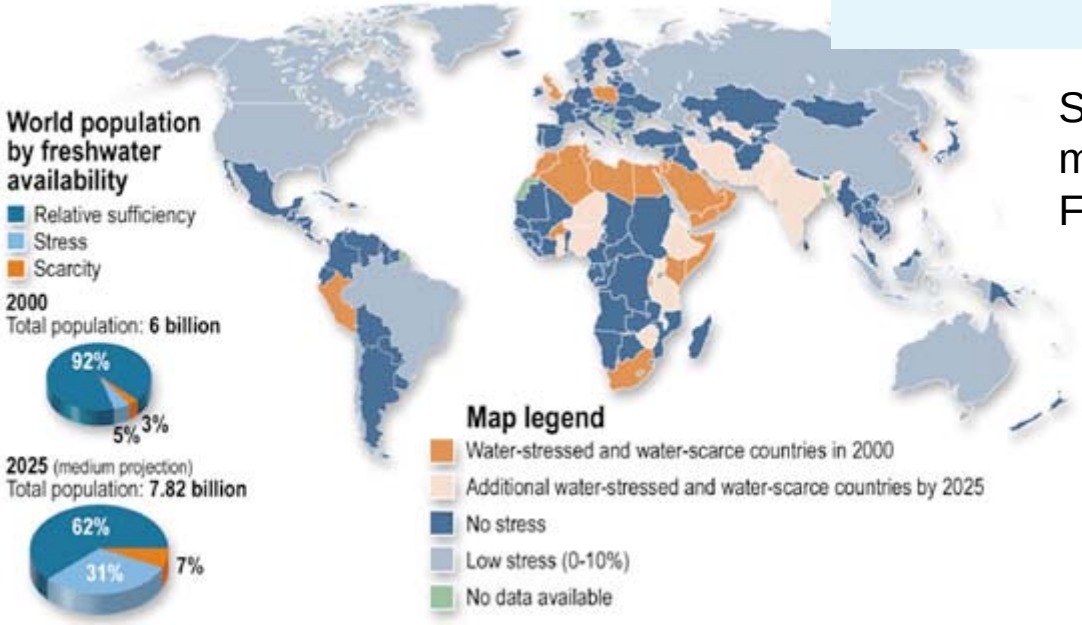
- Functional Electrical stimulation (FES)
  - It uses electrical impulses, either applied to nerves or directly to muscle (skin surface or implant).
  - Only for the Therapy?
  - Control over the bladder and bowel, regain the mobility
  - Spinal cord microstimulation

NET 융합기술

< Water treatment >



Scheme of the removal of heavy metals with the humic acid coated Fe3O4 magnetic nanoparticles.



http://www.nanowerk.com/spotlight/spotid=6810.php