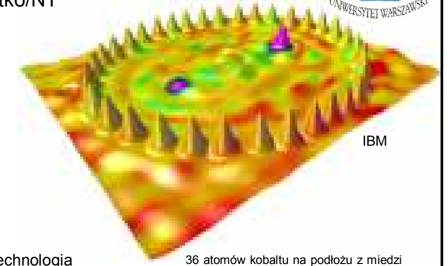
Nanotechnologie – od półprzewodników do DNA.

Jacek.Szczytko@fuw.edu.pl
http://www.fuw.edu.pl/~szczytko/NT

1. Nanotechnologia na codzień
2. Jak działa komputer?
   a) Od bramki do bramki
   b) Jak działa tranzystor
3. Prawo Moora i jego konsekwencje
   a) Więcej! Szybciej! Taniej!
   b) Wyzwania i problemy
4. Nanotechnologie
   a) CO?
      a) Studnie, druty, kropki
   b) JAK?
      a) Top-down, czyli (nano)technologia
      b) Bottom-up, czyli samoorganizacja
   c) Chem-Fiz, Bio-Fiz!



IBM

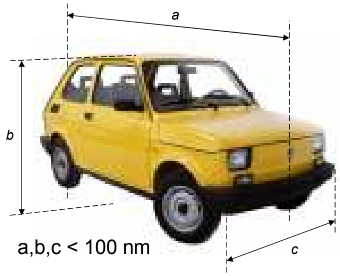
36 atomów kobaltu na podłożu z miedzi tworzy „korale kwantowe". Elektrony na powierzchni miedzi oddziałują z atomem kobaltu umieszczonym w ognisku elipsy tworząc „kwantowy miraż".

NanoTechnologia

10^{-9}

0,000 000 001

Nauka
Inżynieria
Technologia



a,b,c < 100 nm

Nanotechnologia w kulturze

Nanotechnologia na codzień

Motoryzacja (Hummer H2 sport utility truck)

Budownictwo
Samoczyszczący się beton

Elektronika
Wyświetlacze OLED

Sport

Ubrania (Nano-Tex)

AGD
Samoczyszcząca się lodówka
Samsung Nano SilverSeal

Kosmetyki

www.sts.utexas.edu/projects/**nano**modules/

Jacek.Szczytko@fuw.edu.pl http://www.fuw.edu.pl/~szczytko

Dlaczego XXI w?

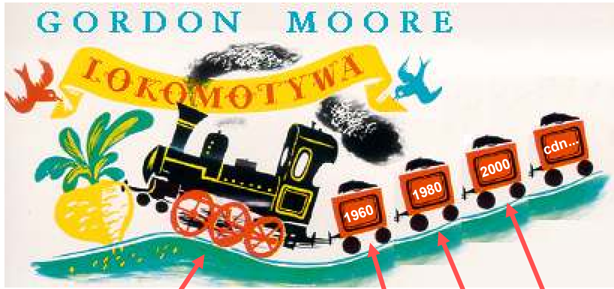
Parowóz dziejów

nano

mikro

mili

Dlaczego XXI w?



Parowóz dziejów

nano

mikro

mili

Przez ostatnie 40 lat na badania technologii krzemowej wydano bilion (ang. trillion) **10^{12} USD**

Nanotechnologia

Dual-Core Intel Xeon 7100 series (2007)

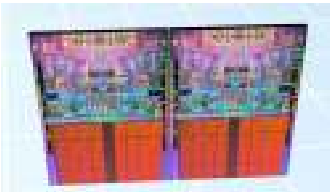
2 × 291 000 000 tranzystorów (1 300 000 000 z cache)

technologia 65 nm

Zegar 2,66 GHz

8 warstw

Moc 120 W



AMD Opteron MP HE 8000 series Dual-Core (2006)

243 000 000 tranzystorów

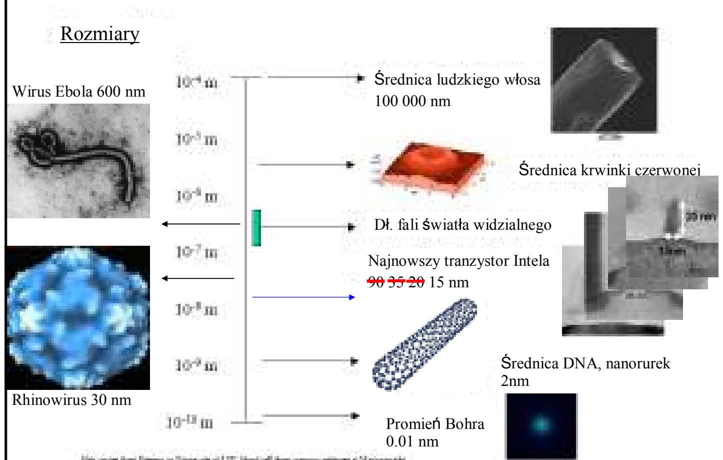
technologia 90 nm.

Zegar 1,8 GHz

9 warstw

Moc 68 W

Nanotechnologia



Ebola http://www.brettrussell.com/personal/ebola.html

Dlaczego XXI w?

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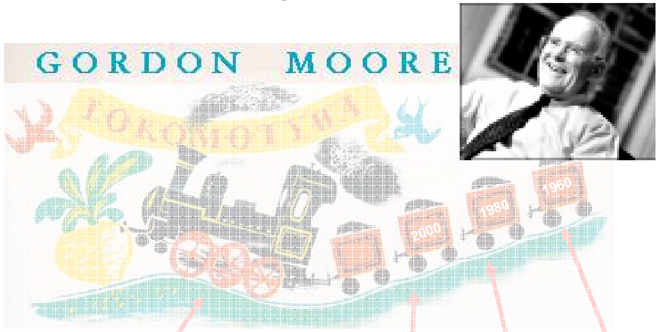


Parowóz dziejów

mili

mikro

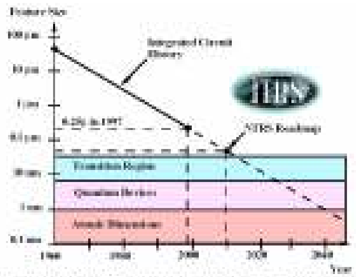
nano

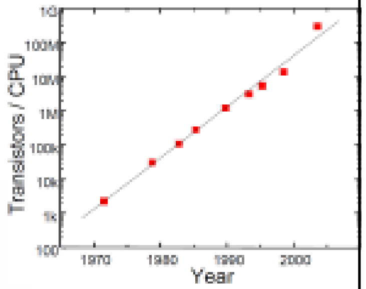
Przez ostatnie 40 lat na badania technologii krzemowej wydano bilion (ang. trillion) 10^{12} USD

TRENDY: Pierwsze Prawo Moore'a

Ilość komponentów (tranzystory, połączenia, izolacje itd.) w IC podwaja się co około 18 miesięcy.

Rozmiar liniowy komponentów również zmniejsza się wykładniczo w czasie.





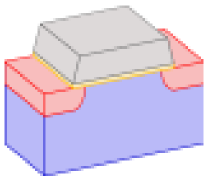
Te trendy nie mogą być kontynuowane w nieskończoność.

- Co zastąpi technologię Si?
- Z czego będzie wynikała ta zmiana technologii?

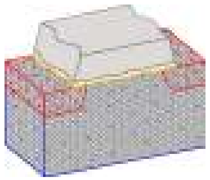
EKONOMIA

Źródło: Intel

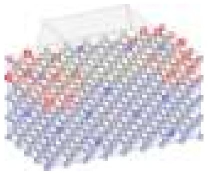
Granice miniaturyzacji?



Myślimy, że tranzystor jest zbudowany tak.



25 nm MOSFET
Produkcja od 2008



4,2 nm MOSFET
Produkcja ???

Asen Asenov, Glasgow
David Williams *Hitachi-Cambridge*

IEEE Trans Electron Dev 50(9), 1837 (2003)

Nanotechnologie

CO?

- Studnie, druty, kropki

JAK?

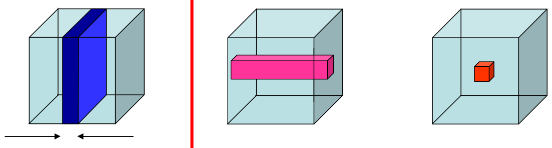
- Top-down, czyli (nano)technologia
- Bottom-up, czyli samoorganizacja

Google: **Jacek Szczytko**
Login: **…**
Hasło: **…**

Jacek.Szczytko@fuw.edu.pl http://www.fuw.edu.pl/~szczytko

Struktury niskowymiarowe
Low-dimensional Semiconductor Systems

Studnie kwantowe | Druty kwantowe | Kropki kwantowe

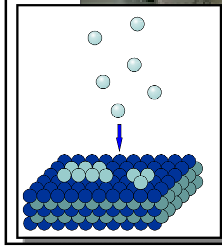


2D | 1D | "0D"

Dyskretna struktura elektronowa

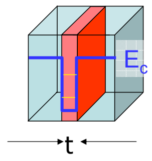
Hubert J. Krenner

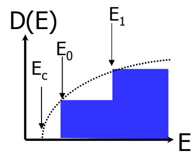
MOCVD



MOCVD→ Osadzanie z atomową precyzją warstw o różnym składzie lub domieszkowaniu

Studnia kwantowa

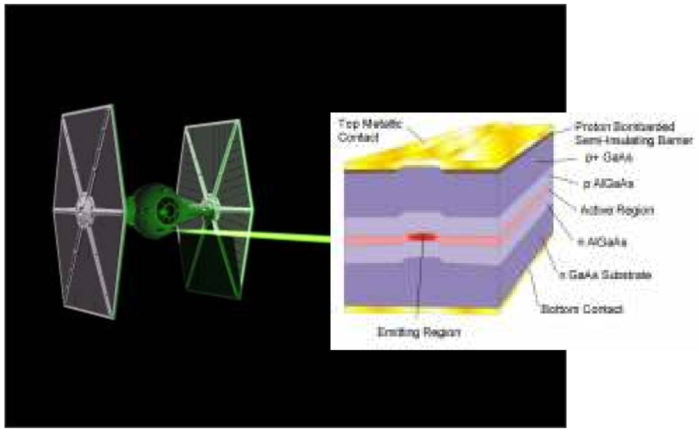




2D

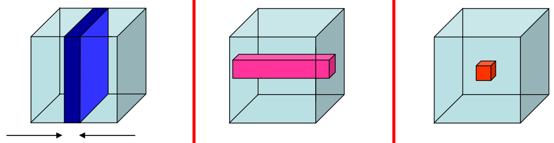
Studnie Kwantowe

Lasery półprzewodnikowe



Struktury niskowymiarowe
Low-dimensional Semiconductor Systems

Studnie kwantowe | Druty kwantowe | Kropki kwantowe



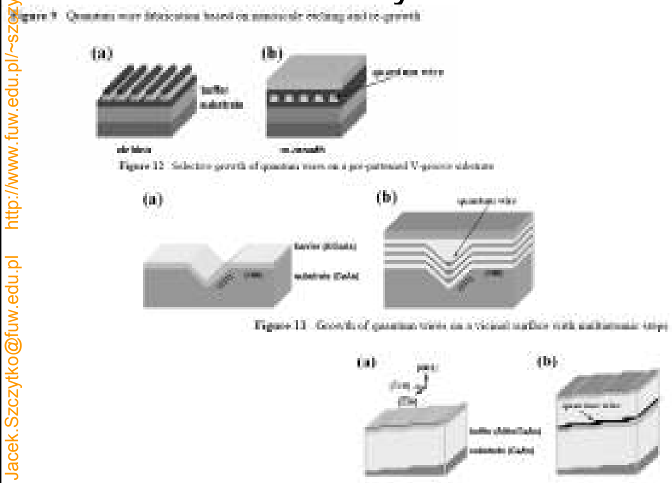
2D | 1D | "0D"

Dyskretna struktura elektronowa

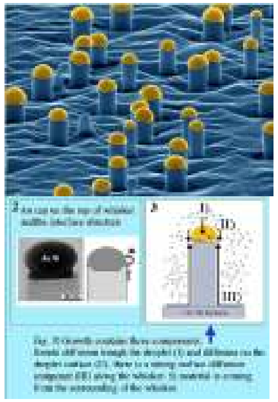
Hubert J. Krenner

Druty

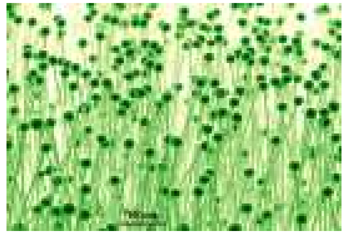
Jacek.Szczytko@fuw.edu.pl http://www.fuw.edu.pl/~szczytko



Druty



http://www.mpi-halle.mpg.de/~mbe/



www.ece.odu.edu/q_seminar.htm

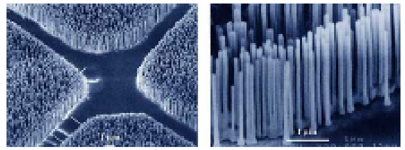
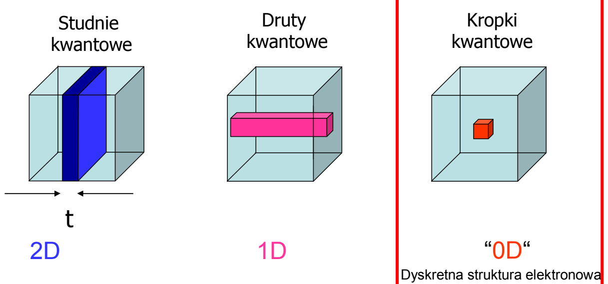


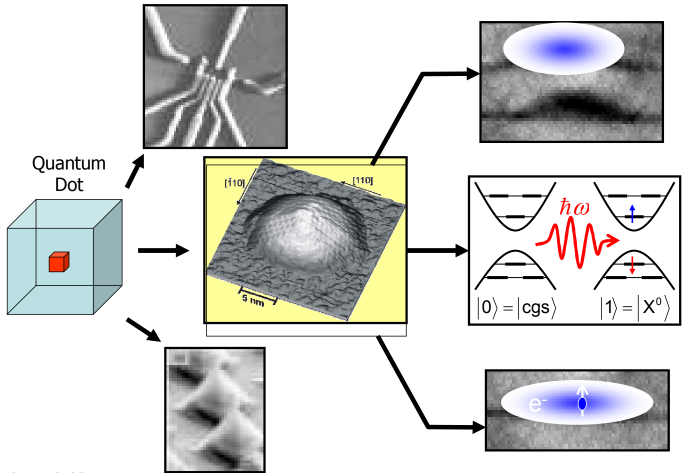
Photo by Peidong Yang/UC Berkeley, courtesy of *Science*

Struktury niskowymiarowe

Low-dimensional Semiconductor Systems



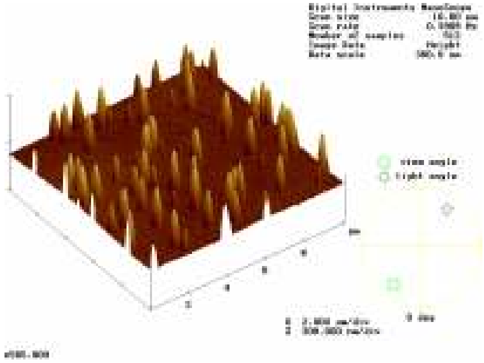
Hubert J. Krenner



Hubert J. Krenner
Walter Schottky Institut and Physik Department E24, TU München

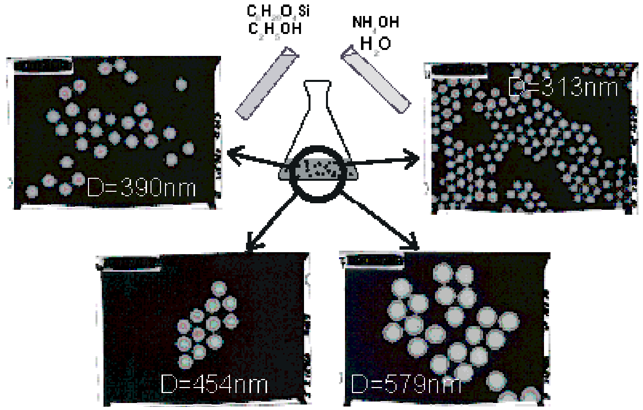
Jacek.Szczytko@fuw.edu.pl http://www.fuw.edu.pl/~szczytko

GaN/AlGaN QD's



Wzrost – K. Pakuła, AFM - Rafał Bożek

Synteza kropek kwantowych



http://www.icmm.csic.es/cefe/Fab/synthesis.html

Synteza kropek kwantowych

Nanotechnologie

CO?

- Studnie, druty, kropki

JAK?

- Top-down, czyli (nano)technologia
- Bottom-up, czyli samoorganizacja

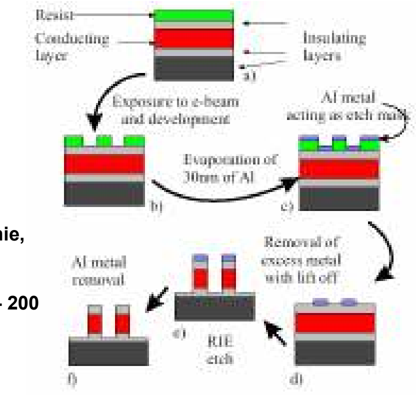
Jacek.Szczytko@fuw.edu.pl http://www.fuw.edu.pl/~szczytko

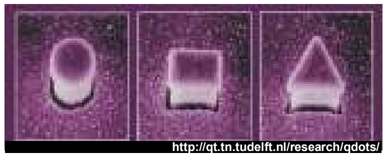
Top-down

Vincent Laforet/The New York Times

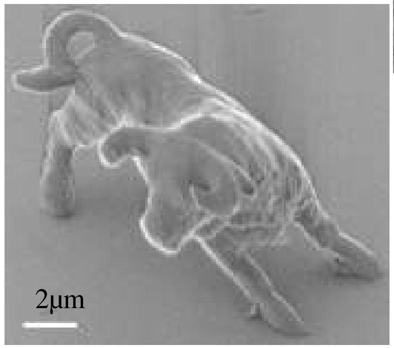
W jaki sposób produkowane są układy scalone?

1. **Dominuje technologia krzemowa**
2. **Obecne układy ~ 10^9 - 10^{10} tranzystorów**
3. **Podłoża - 300mm, ~ 10^3 chipów**
4. **Fotolitografia, naświetlanie, trawienie etc**
5. **Typowo ~20 masek, 150 - 200 kroków procesów**





Nano Tech Web



[S. Kawata *et al.*, *Nature* **412**, 697 (2001)]

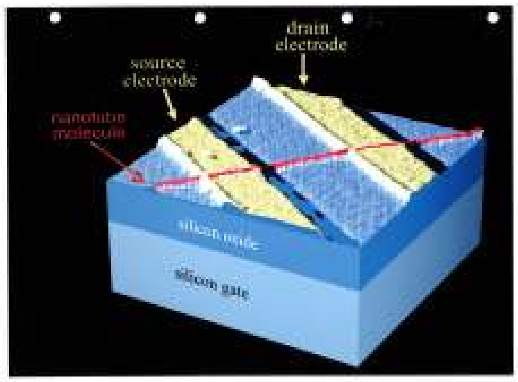
7µm

(3 hours to make)

λ = 780nm

resolution = 150nm

Nanotubes as molecular quantum wires



Cees Dekker

TU Delft

Jacek.Szczytko@fuw.edu.pl http://www.fuw.edu.pl/~szczytko

Nanotechnologie

CO?
- Studnie, druty, kropki

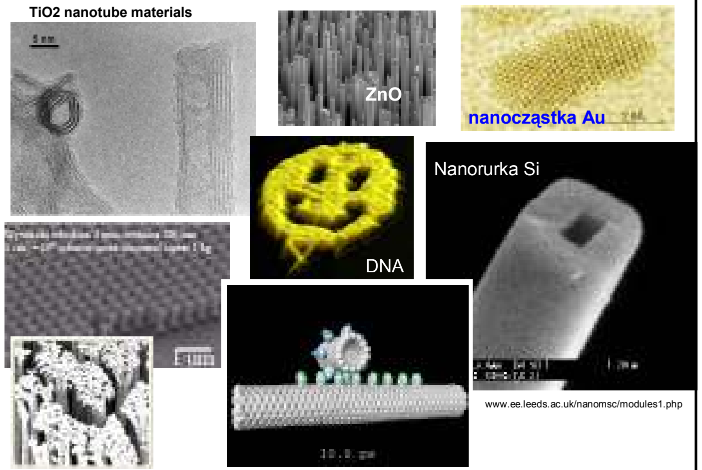
JAK?
- Top-down, czyli (nano)technologia
- Bottom-up, czyli samoorganizacja

Bottom-up

Wydział (nano)Chemii UW

http://www.chem.uw.edu.pl/labs/elektrochemia/Nanogaleria/nanogaleria.htm

Nanorurki, nanowąsy i kropki



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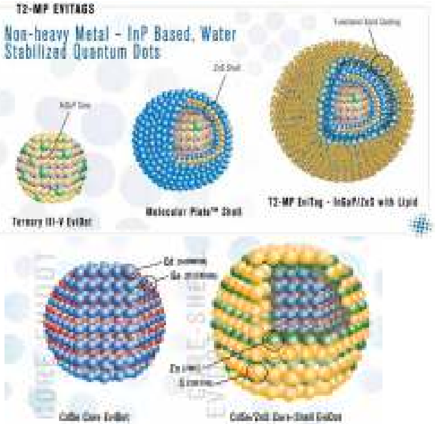
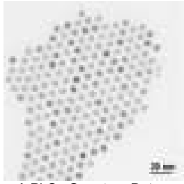
Kropki kwantowe + bio

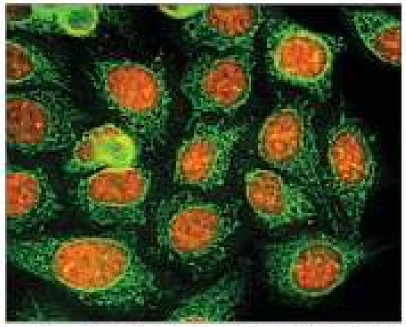




A PbSe Quantum Dot as seen through a transmission electon microscope (TEM).

http://www.evidenttech.com/

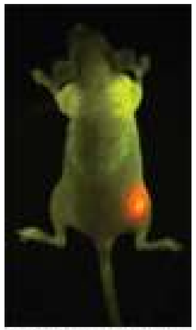
Kropki kwantowe + bio

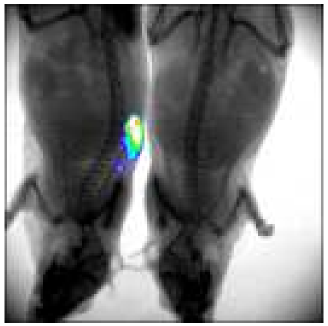


Double duty. Green quantum dots cling to mitochondria in the cytoplasm; orange ones label proteins in the same cells' nuclei.

Science, Vol 300, Issue 5616, 80-81 , 4 April 2003

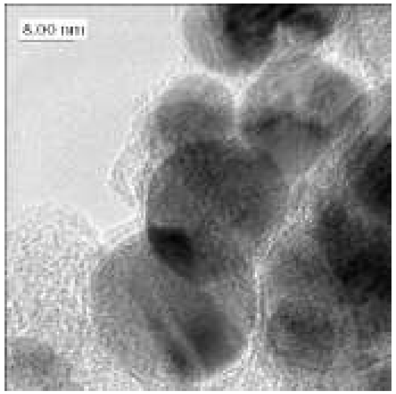
Kropki kwantowe + bio

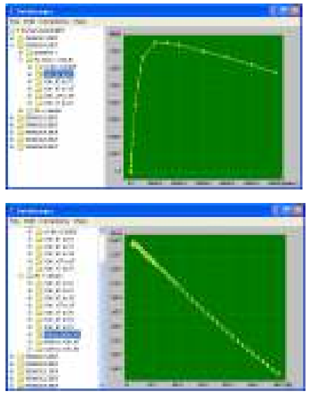




Science, Vol 300, Issue 5616, 80-81 , 4 April 2003

Magnetyczne QD's

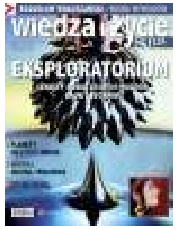




Jacek Szczytko

Jacek.Szczytko@fuw.edu.pl http://www.fuw.edu.pl/~szczytko

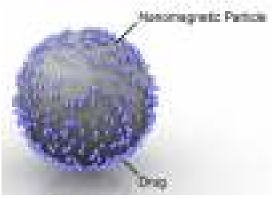
Ferrofluid

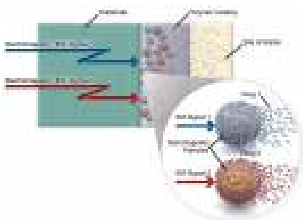


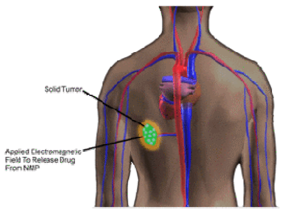
Ferrofluid

Akademia Górniczo Hutnicza

Magnetyczne QD's







http://www.biophan.com/index.php?option=com_content&task=view&id=262&Itemid=426

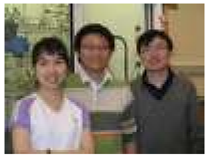
Magnetic photonic crystals

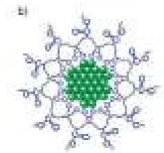
Photonic Crystals

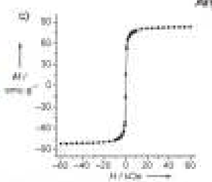
DOI: 10.1002/anie.200701992

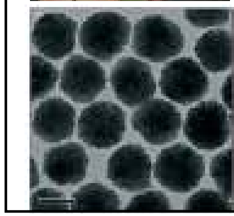
Highly Tunable Superparamagnetic Colloidal Photonic Crystals

Jianping Ge, Yongxing Hu, and Yadong Yin



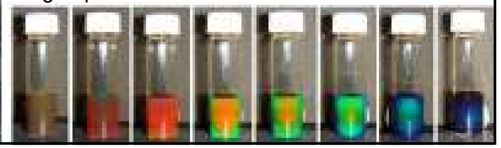






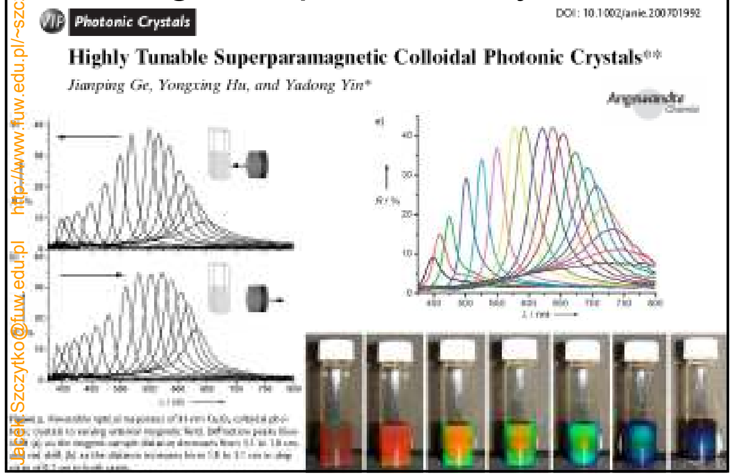
Fe_3O_4 120 nm

UC RIVERSIDE Newsroom



Magnetic photonic crystals

Jacek.Szczytko@fuw.edu.pl http://www.fuw.edu.pl/~szczytko


VIP Photonic Crystals

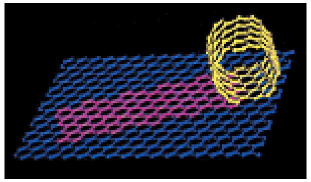
DOI: 10.1002/anie.200701992

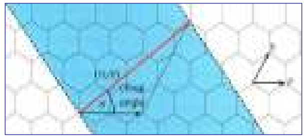
Highly Tunable Superparamagnetic Colloidal Photonic Crystals

Jianping Ge, Yongxing Hu, and Yadong Yin

Nanorurki

Nanorurki można sobie wyobrazić jako warstwy atomów węgla (takie jak w graficie), które zostały zrolowane.



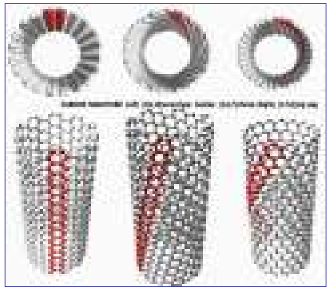


Orientacja jest zdefiniowana przez wektor chiralny (n,m)

$c_h = n\,a + m\,b$

Rozróżniamy orientacje:

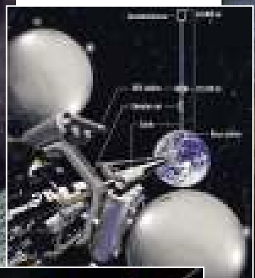
- **Armchair**
- **Zig-zag**
- **Chiral**

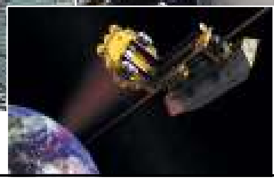


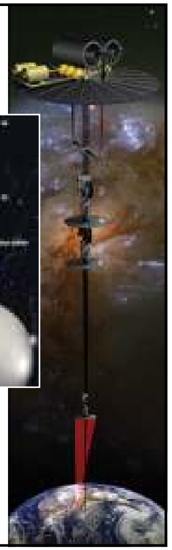
J.Basak, D.Mitra, S.Sinha „*Carbon nanotube: the next generation sensors*" presentation

Paweł Tomasz Pęczkowski

Winda do nieba







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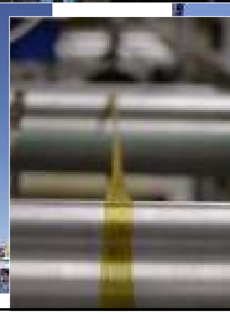
http://www.spaceelevator.com/

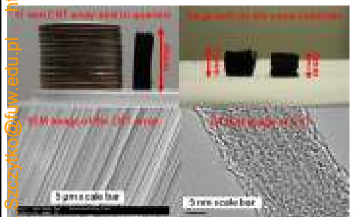


Winda do nieba

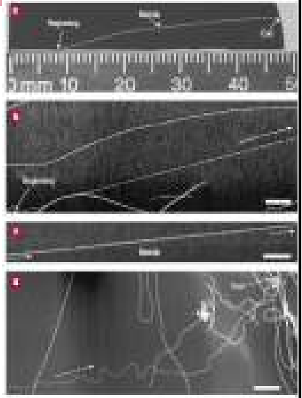

LETTERS

Ultralong single-wall carbon nanotubes

nature materials | VOL 3 | OCTOBER 2004 | www.nature.com/naturematerials



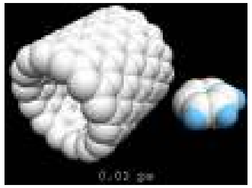
http://www.uc.edu/news/NR.asp?id=5700



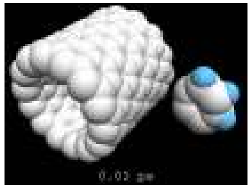
Jacek.Szczytko@fuw.edu.pl http://www.fuw.edu.pl/~szczytko

Nanomaszyny

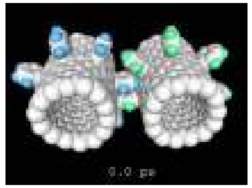
Benzen + CN



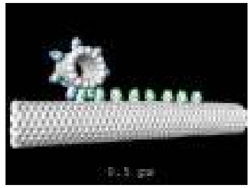
Za wolno



W sam raz



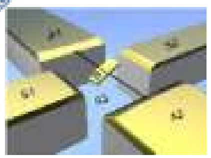
Gear Rotation in a Vacuum 200 rot/ns

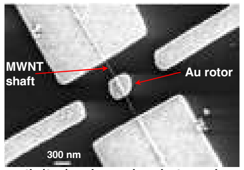


Powered Sharf

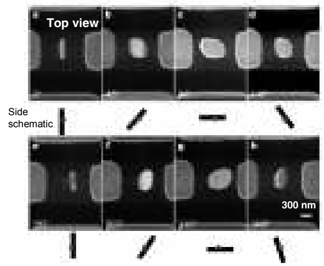
http://www.ipt.arc.nasa.gov

First Synthetic Nanomotor





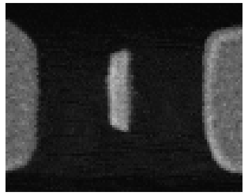
Schematic (top) and scanning electron microscopy (SEM) image (bottom) *of LBNL's synthetic nanomotor. A 300 nm Au plate rotor (R) is attached to a multi-walled carbon nanotube (MWNT) which acts as a support shaft and is the source of rotational freedom. Electrical contact to the rotor plate is made via the MWNT and its anchor pads (A1, A2). Three stator electrodes, two on the SiO_2 surface (S1, S2) and one buried beneath the surface (S3), provide the control elements.*



SEM images *showing the rotation of the rotor actuated by applying appropriate voltage sequences to the stators. The MWNT, barely visible, runs vertically through the middle of each frame. The schematic diagrams located beneath each SEM image illustrate a cross-sectional view of the position of the nanotube/rotor-plate assembly. The rotor can rotate through a full 360 degrees for thousands of cycles without apparent degradation or wear.*

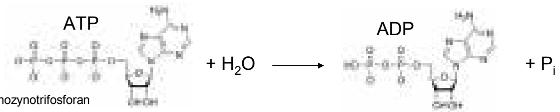
http://www.lbl.gov/msd/PIs/Zettl/03/07_nanomotor/03_7_nanomotor.html *Alex Zettl, 03-7*

Nano-motor



Model for the Kinesin Mechanism

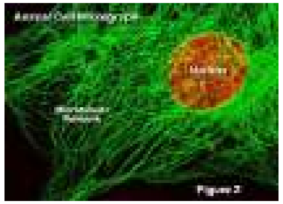
http://www.fuw.edu.pl/~szczytko



adenozynotrifosforan

mov-muscmyosinmotrev6.mov

mov-procmotconvkinrev5.mov



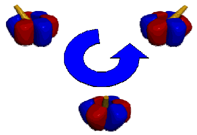
Kinesin is a dimeric motor protein that travels processively towards the microtubule plus end by taking 8 nm steps, which corresponds to the distance between adjacent alpha/beta tubulin binding sites. We have sought to define the structural changes in the motor that explain the direction of movement and the basis of head-head coordination during processive motility.

Jacek.Szczytko@fuw.edu.pl

http://valelab.ucsf.edu/research/res_mec_overv.html

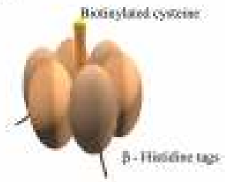
http://www.sns.gov/workshops/nni_05/presentations/050617_pincus_philip_nni05.pdf

Bio-nano-silnik (ATPaza)

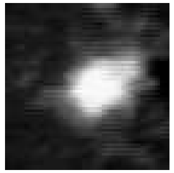


A

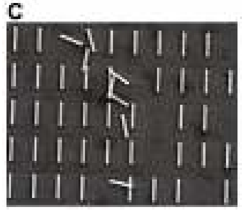
B



http://www.linkclub.or.jp/~hiikoysd/ryohei/papers.html



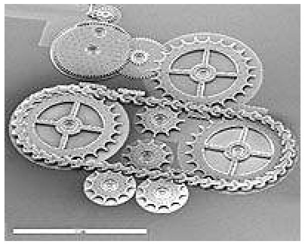
C

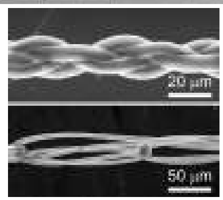


D

http://www.foresight.org/Conferences/MNT6/Papers/Montemagno/index.html

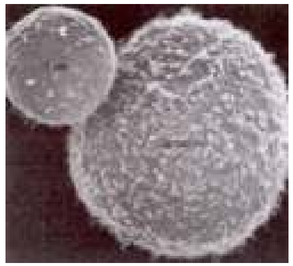
Nanoroboty

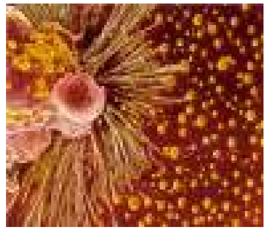




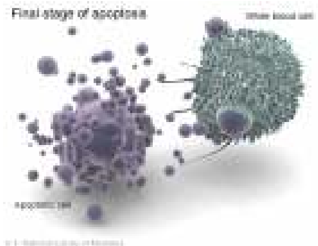
Nano Tech Web

Nanoroboty



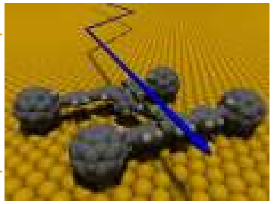


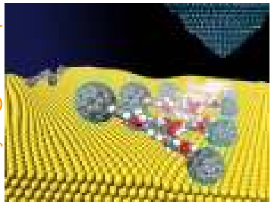
makrofagi



Nano-samochód

Jacek.Szczytko@fuw.edu.pl http://www.fuw.edu.pl/~szczytko





Y. Shira/Rice University

They found the nanocar was quite stable on the surface remaining parked until the surface was heated above 170 °C - presumably because of strong adhesion between the fullerene wheels and the underlying gold. Flat gold surface was used to prevent the nanocar actually roll around on its fullerene wheels, rather than slip like a car on ice. Between 170 °C and 225 °C, the researchers observed that the nanocar moved around by translational motion and pivoting. The translational motion was always in a direction perpendicular to the handcar's axle, indicating that it moves by rolling rather than sliding.

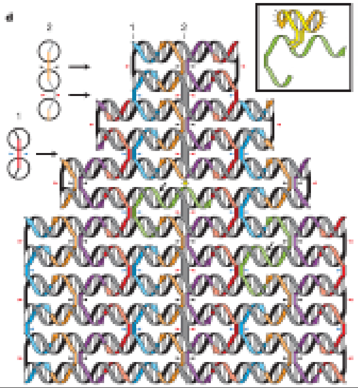
http://www.nanonewsnet.com/index.php?module=pagesetter&func=viewpub&tid=4&pid=2

Nano i bio (DNA)

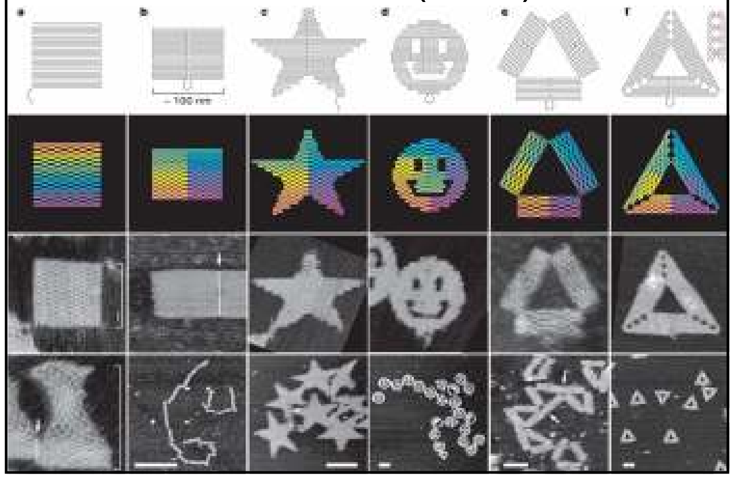
Vol 440|16 March 2006|doi:10.1038/nature04586 nature

Folding DNA to create nanoscale shapes and patterns

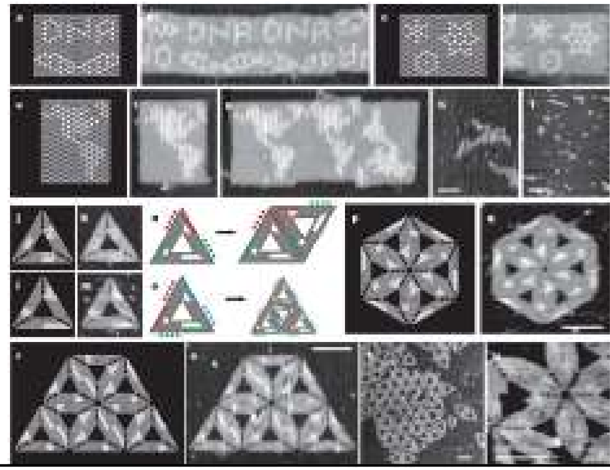
Paul W. K. Rothemund[1]



Nano i bio (DNA)



Nano i bio (DNA)



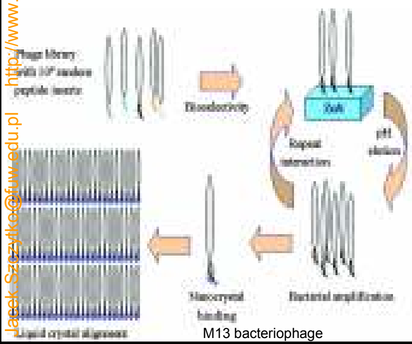
Nano i bio

Jacek.Szczytko@fuw.edu.pl http://www.fuw.edu.pl/~szczytko

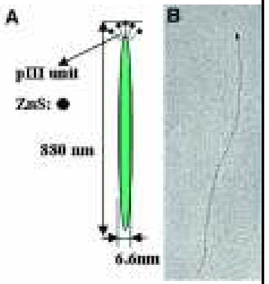
Ordering of Quantum Dots Using Genetically Engineered Viruses

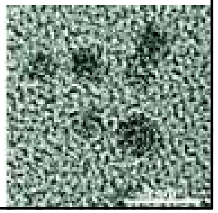
Seung-Wuk Lee, Chuanbin Mao, Christine E. Flynn, Angela M. Belcher*†

3 MAY 2002 VOL 296 SCIENCE 892

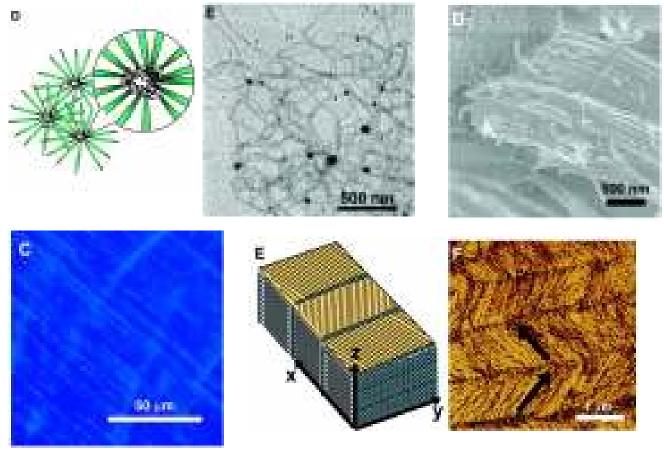


M13 bacteriophage





Nano i bio



M13 bacteriophage

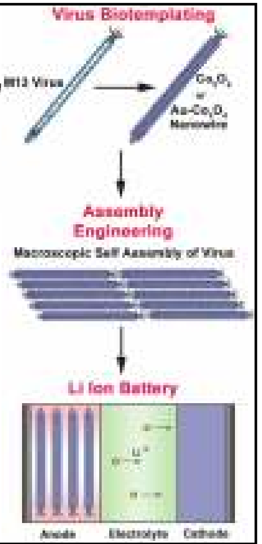
3 MAY 2002 VOL 296 SCIENCE 892

Nano i bio

SCIENCE VOL 312 12 MAY 2006 885

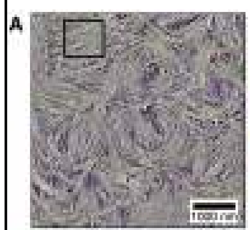
Virus-Enabled Synthesis and Assembly of Nanowires for Lithium Ion Battery Electrodes

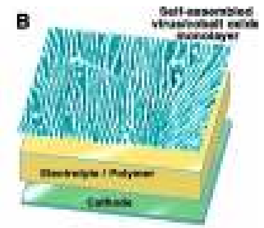
Ki Tae Nam, Dong-Wan Kim, Pil J. Yoo, Chung-Yi Chiang, Nonglak Meethong, Paula T. Hammond, Yet-Ming Chiang, Angela M. Belcher

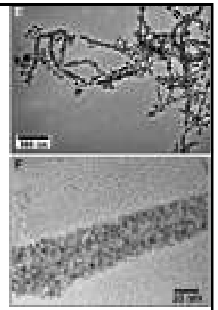


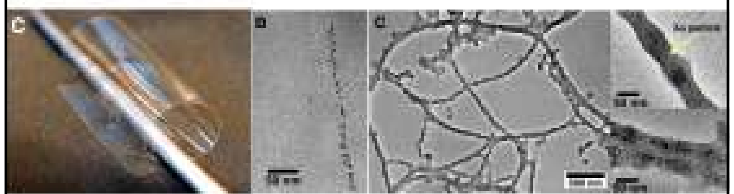
Nano i bio

SCIENCE VOL 312 12 MAY 2006 885







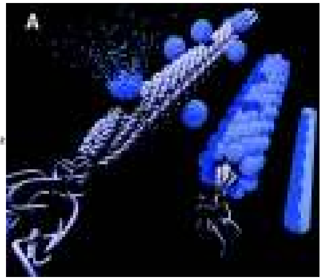


Nano i bio

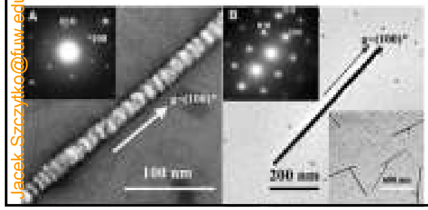

SCIENCE VOL 303 9 JANUARY 2004 213

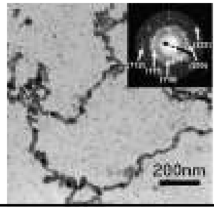
Virus-Based Toolkit for the Directed Synthesis of Magnetic and Semiconducting Nanowires

Chuanbin Mao, Daniel J. Solis, Brian D. Reiss, Stephen T. Kottmann, Rozamond Y. Sweeney, Andrew Hayhurst, George Georgiou, Brent Iverson, Angela M. Belcher



ZnS



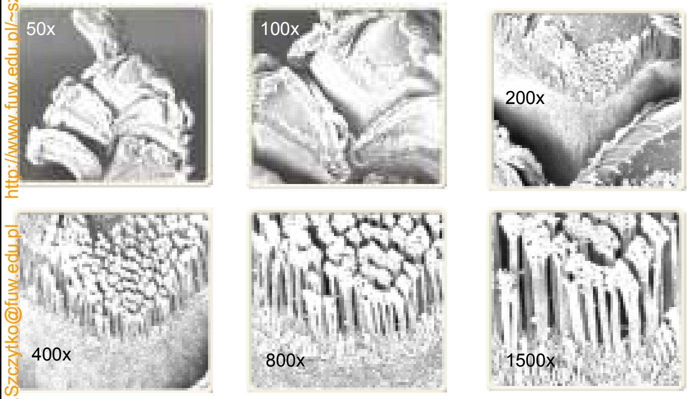


CoPt

Jacek Szczytko@fuw.edu.pl http://www.fuw.edu.pl/~szczytko

Nano i bio (gekon)

Nano i bio (gekon)



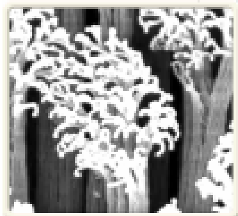
http://www.microscopy.fsu.edu/primer/java/electronmicroscopy/magnify1/index.html

Jacek Szczytko@fuw.edu.pl http://www.fuw.edu.pl/~szczytko

Nano i bio (gekon)

3000x

6000x

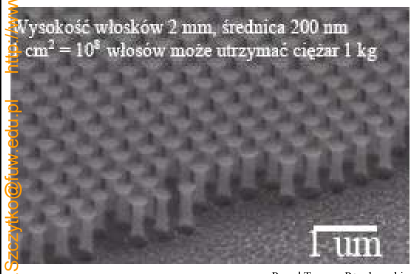


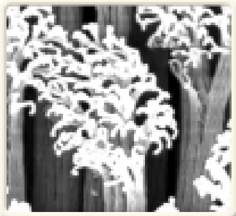
http://www.microscopy.fsu.edu/primer/java/electronmicroscopy/magnify1/index.html

Nano i bio (gekon)

Jacek.Szczytko@fuw.edu.pl http://www.fuw.edu.pl/~szczytko

6000x

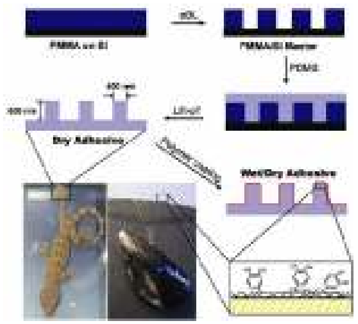




Paweł Tomasz Pęczkowski

http://www.microscopy.fsu.edu/primer/java/electronmicroscopy/magnify1/index.html

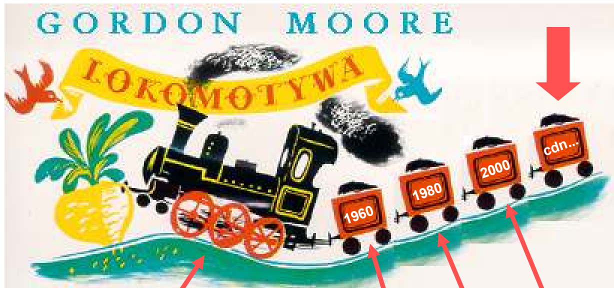
Nano i bio (gekon)



Nature 448, 338-341 (19 July 2007)

Nano i bio (gekon)

Co dalej?



Parowóz dziejów

nano

mikro

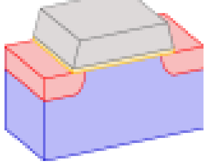
mili

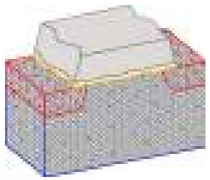
Przez ostatnie 40 lat na badania technologii krzemowej wydano bilion (ang. trillion) **10^{12} USD**

Granice miniaturyzacji?

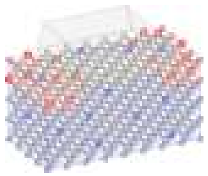
Jacek.Szczytko@fuw.edu.pl http://www.fuw.edu.pl/~szczytko

Myślimy, że tranzystor jest zbudowany tak.

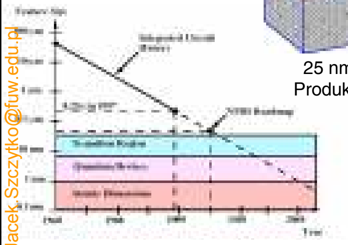




25 nm MOSFET
Produkcja od 2008



4,2 nm MOSFET
Produkcja ???



IEEE Trans Electron Dev 50(9), 1837 (2003)

Ile bitów na atom?

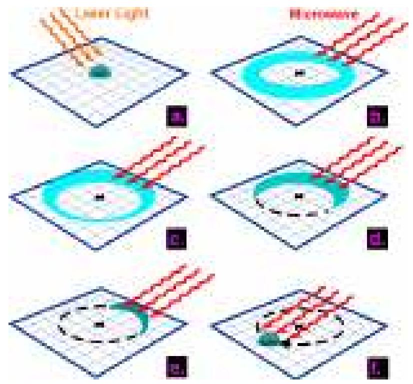
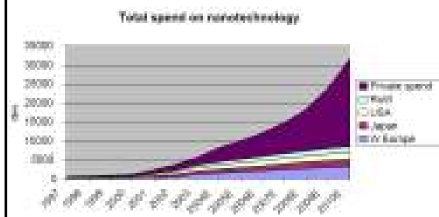
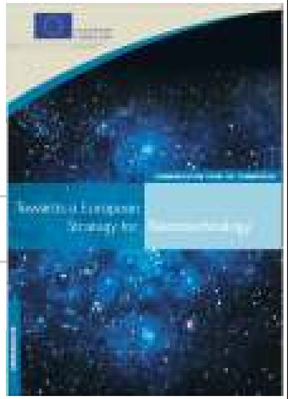


Illustration showing how to transform an electron from its usual state in an atom (a), in which it exists in a cloud of possible positions surrounding the positively charged nucleus (indicated by a plus sign), to a "Trojan state" (f), in which the electron orbits the nucleus like a planet around the sun. The name comes from Trojan asteroids, the asteroids which orbit the sun in the same orbit as Jupiter but in a place either ahead or behind the planet. To create a Trojan electron, researchers would first use laser light to put the electron into a "circular Rydberg state" in which the electron exists in a thin donut of possible positions (b). Then, a microwave beam would subsequently change the shape of the donut (c-e), shrinking the range of possible positions for the electron and ultimately causing the electron to shrink into a small droplet (or alternatively, a shortened sausage) of possible positions. This droplet then orbits the nucleus like a planet around the sun. Although not yet achieved experimentally, researchers believe that current technology could be applied to create Trojan electrons. The figure is not to scale--the circular Rydberg and Trojan states are actually hundreds of thousands of times farther away from the nucleus. In addition, the figure essentially shows just the top half of the probability cloud for the Trojan electron.

In recent computer simulations, researchers formed the word "optics" by calculating the electron cloud for a specially prepared n=50 state. In the image above, the intensity of the letters represents the relative probability for finding the electron at that place, and the color denotes the phase (relative point in the cycle) of the electron wave associated with that point in the cloud. (Image courtesy Carlos Stroud, University of Rochester, and Michael Noel.) **This research is described by Carlos Stroud and Michael Noel in the April 1999 issue of Optics and Photonics News.**

Nanotechnologie





Podziękowania

Jacek.Szczytko@fuw.edu.pl http://www.fuw.edu.pl/~szczytko

Zakład Fizyki Ciała Stałego http://www.fuw.edu.pl/~zfcs/
prof. dr hab. M. Baj

Struktury Kwantowe GaAs/AlAs

mgr B. Chwalisz
dr A. Wysmołek
dr M. Potemski (GHMFL)
prof. R. Stępniewski

Prof. M. Baj
dr hab. D. Wasik
dr J. Siwiec

Spektroskopia ultraszybka

prof. J. Gaj,
prof. M. Nawrocki,
dr hab. A. Golnik,
M. Goryca,
T. Kazimierczuk,
dr P. Kossacki,
K. Kowalik,
W. Maślana,
W. Pacuski,
B. Piechal,
J. Suffczyński,
A. Trajnerowicz

Kropki Kwantowe: GaN/Al_xGa_{1-x}N

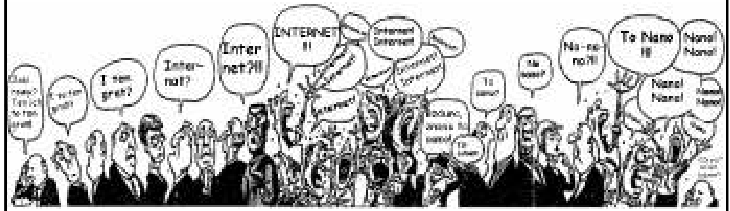
prof. R. Stępniewski
mgr K. Pakuła
mgr R. Bożek
mgr K. Surowiecka
dr A. Wysmołek
mgr B. Chwalisz
prof. J. Baranowski
dr K. Kossacki
dr K. Korona
dr hab. A. Golnik

Promieniowanie THz

dr Jerzy Łusakowski,
dr Krzysztof Karpierz,
mgr Maciej Sakowicz,
prof. dr hab Marian Grynberg

Spintronika

prof. dr hab Maria Kamińska
prof. dr hab Andrzej Twardowski
dr Jacek Gosk
dr Jacek Szczytko,
mgr Konrad Dziatkowski,
mgr Marcin Zając



Jacek Szczytko na podstawie http://www.sts.utexas.edu/projects/**nano**modules/