AUTOMATION AND CONTROL INSTITUTE
TAMPERE UNIVERSITY OF TECHNOLOGY

HELSINKI UNIVERSITY OF TECHNOLOGY
Control Engineering Laboratory

7606082 Graduate Seminar in Microsystem Technology

Nanotechnology

Quan Zhou

Course information

- 7606082, Graduate Seminar in Microsystem Technology, 3 cu
- Goals
  - Understand what is nanotechnology
    - Difference from nanoscience
  - Understand the state of art of nanotechnology
    - Different aspects of the nanotechnology
  - Get familiar with references
- Course material
  - Scientific American, September 2001 issue (starting point)
  - Internet resources
  - Other text
    - Drexler: Nanosystems, etc
- Requirements
  - Oral presentations (2)
  - Written reports
  - 80% participation
- Meetings (8):
  - 27.09
  - 04.10, 11.10, 08.11, 15.11, 22.11, 29.11,
  - 13.12
- Contact information
  - Quan Zhou
  - SD 106
  - Email: quan.zhou@tut.fi
  - Phone: 2645

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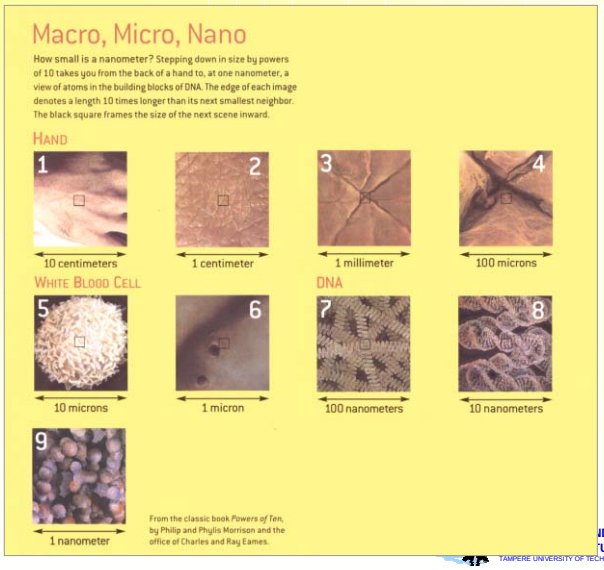
What is nano and nanotechnology?



- What is nano?
  - 1 billionth
- Nanotechnology
  - Science fiction?
  - Science?
  - Technology?

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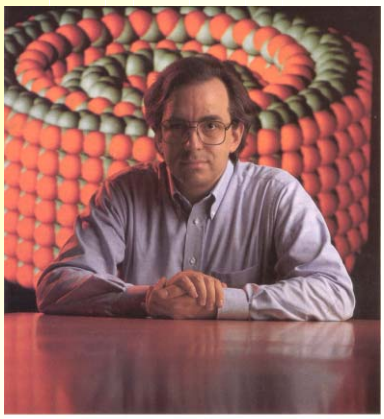
People you should know

RICHARD FEYNMAN predicted the rise of nanotechnology in a landmark 1959 talk at Caltech. "The principles of physics," he said, "do not speak against the possibility of maneuvering things atom by atom." But he also anticipated that unique laws would prevail; they are finally being discovered today.



NANOSCRIBE K. Eric Drexler conceived the concept of molecular machine systems

K. Eric Drexler, author of *Nanosystems, Molecular Machinery, Manufacturing, and Computation, 1992*

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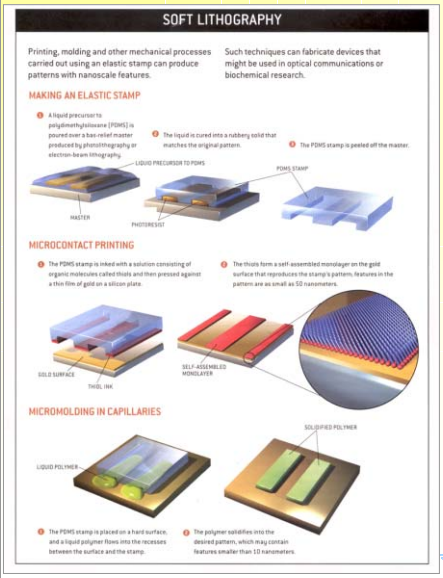
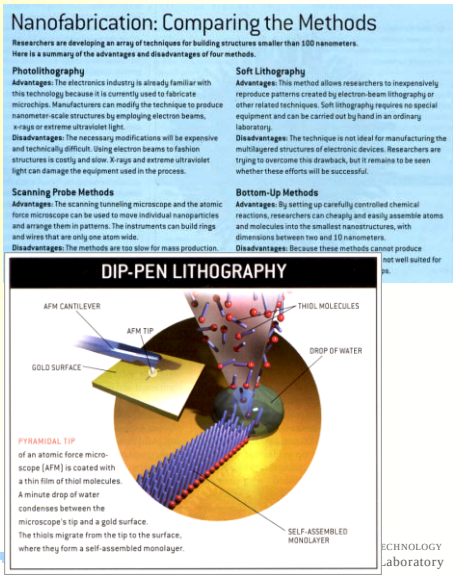
What is nanotechnology?
A technology of making things small?





ECHNOLOGY
aboratory

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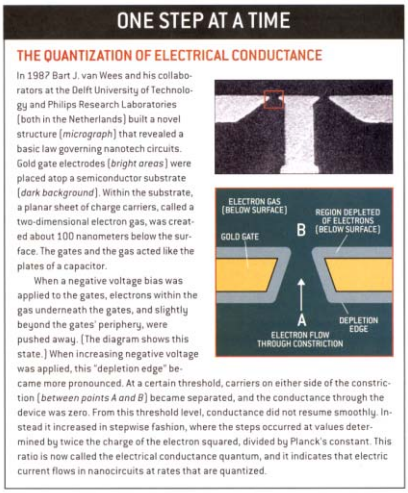
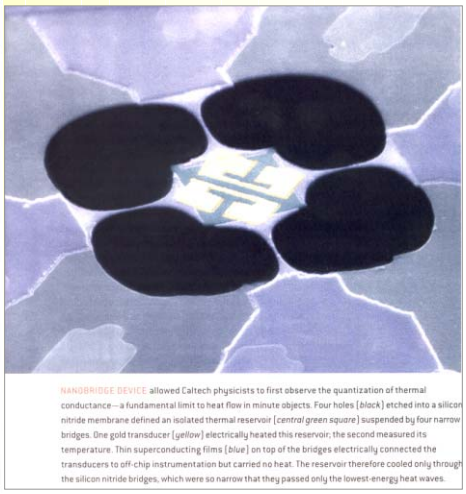
What is nanotechnology?
A science of understanding the tiny?

Quantization electrical conductance and thermo conductance are discoveries of 1987 and 1990s!





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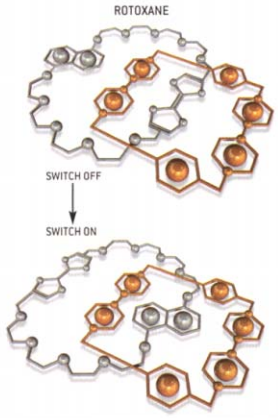
What is nanotechnology?
Something called nanoelectronics?

NANOTRANSISTORS

MOLECULAR TRANSISTORS could be the building blocks of electronics on the nanometer scale. Each of the two molecules shown here conducts electricity like a tiny wire once a chemical reaction—oxidation reduction—alters its atomic configuration and switches it on. In the diagram, each stick represents a chemical bond; each intersection of two sticks represents a carbon atom; and each ball represents an atom other than carbon.

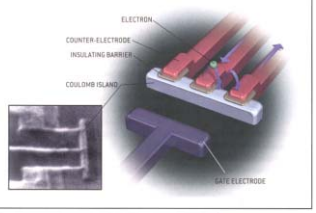


TAKING CHARGE

SINGLE ELECTRONICS

Advances in nanofabrication allowed Theodore A. Fulton and Gerald J. Dolan to build a single-electron transistor at Bell Laboratories in 1987 (*micrograph*). In this structure the controlled movement of individual electrons through a nanodevice was first achieved. At its heart was a coulomb island, a metallic electrode isolated from its counter-electrodes by thin insulating oxide barriers (*diagram*). The counter-electrodes led up to the macroscale laboratory instrumentation used to carry out the experiments. An additional gate electrode (visible in the diagram but not the micrograph) was offset from the coulomb island by a small gap; it allowed direct control of the charge introduced to the island. Electric current flowed through the device from one counter-electrode to another, as in a conventional circuit, but here it was limited by the stepwise hopping of electrons onto and off the coulomb island.

Fulton and Dolan's experiments demonstrate both the fundamental physics of single-electron charging and the potential of these devices as ultrasensitive electrometers: instruments that can easily detect individual electron charges. Circuits that switch one electron at a time could someday form the basis for an entirely new class of nanoelectronics. The advent of such single electronics, however, also presages problems that will have to be faced as conventional electronic circuits are shrunk to the nanoscale.



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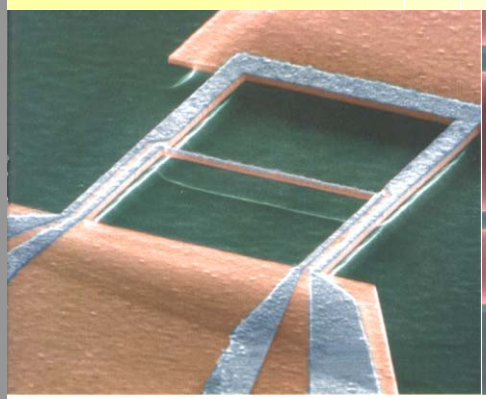
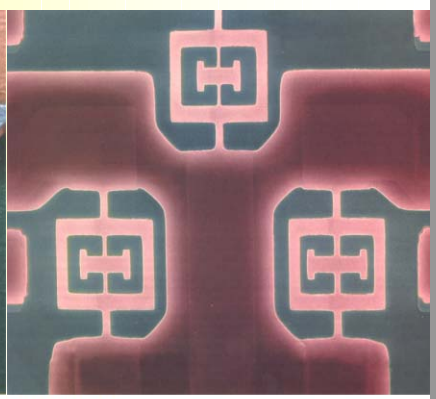
What is nanotechnology?
Some nano mechanism that works?





NANOMECHANICAL AMPLIFIER overcomes the vexing problem of communication with the macroworld by providing up to 1,000-fold amplification of weak forces. Two suspended bridges (*left* and *right*) of monocrystalline silicon carbide support the central crossbridge, to which the signal force is applied. Thin-film electrodes (*silver*) atop these structures provide very sensitive readouts of nanoscale motion.

NOVEL NANOTECH DEVICES, such as these nanoelectromechanical resonators, are enabling scientists to discover the laws of physics that regulate the unique properties of matter at the mesoscale.

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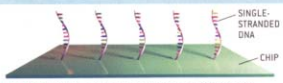
DNA Computing

WHY LIMIT OURSELVES TO ELECTRONICS? Most efforts to shrink computers assume that these machines will continue to operate much as they do today, using electrons to carry information and transistors to process it. Yet a nanoscale computer could operate by completely different means. One of the most exciting possibilities is to exploit the carrier of genetic information in living organisms, DNA.

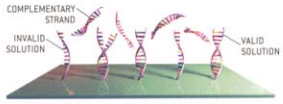
The molecule of life can store vast quantities of data in its sequence of four bases (adenine, thymine, guanine and cytosine), and natural enzymes can manipulate this information in a highly parallel manner. The power of this approach was first brought to light by computer scientist Leonard M. Adleman in 1994. He showed that a DNA-based computer could solve a type of problem that is particularly difficult for ordinary computers—the Hamiltonian path problem, which is related to the infamous traveling-salesman problem [see "Computing with DNA," by Leonard M. Adleman; SCIENTIFIC AMERICAN, August 1998].

Adleman started by creating a chemical solution of DNA. The individual DNA molecules encoded every possible pathway between two points. By going through a series of separation and amplification steps, Adleman weeded out the wrong paths—those, for example, that contained points they were not supposed to contain—until he had isolated the right one. More recently, Lloyd M. Smith's group at the University of Wisconsin–Madison implemented a similar algorithm using gene chips, which may lend themselves better to practical computing [*diagram*].

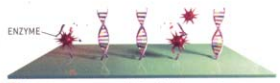
Despite the advantages of DNA computing for otherwise intractable problems, many challenges remain, including the high incidence of errors caused by base-pair mismatches and the huge number of DNA nanoelements needed for even a modest computation. DNA computing may ultimately merge with other types of nanoelectronics, taking advantage of the integration and sensing made possible by nanowires and nanotubes. —*C.M.L.*



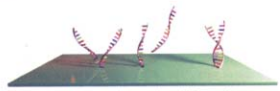
1 Single DNA strands are attached to a silicon chip. They encode all possible values of the variables in an equation that the researchers want to solve.



2 Copies of a complementary strand—which encodes the first clause of the equation—are poured onto the chip. These copies attach themselves to any strand that represents a valid solution of the clause. Any invalid solutions remain a single strand.



3 An enzyme removes all the single strands.

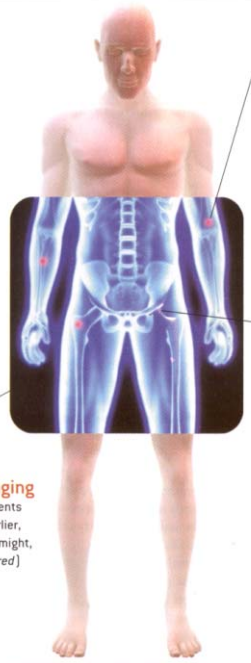


4 Other processes melt away the added complementary strands. These steps are repeated with all the clauses of the equation.

5 The DNA strand that survives this whole process represents the solution to the whole equation.

A GRAND PLAN FOR MEDICINE

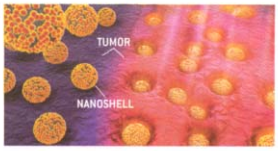
The National Nanotechnology Initiative includes among its goals, or "grand challenges," a host of futuristic improvements in the detection, diagnosis and treatment of disease. Some are depicted here. The goals, many of which are far from being realized, also feature new aids for vision and hearing, rapid tests for detecting disease susceptibility and responses to drugs, and tiny devices able to find problems—such as incipient tumors, infections or heart problems—and to relay the information to an external receiver or fix them on the spot.



1 GOAL: Improved Imaging

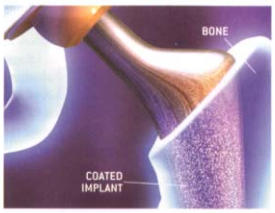
Improved or new contrast agents would detect problems at earlier, more treatable stages. They might, for instance, reveal tumors [*red*] only a few cells in size.

2 GOAL: New Ways to Treat Disease



Nanoparticles would deliver treatments to specifically targeted sites, including places that standard drugs do not reach easily. For example, gold nanoshells [*spheres*] that were targeted to tumors might, when hit by infrared light, heat up enough to destroy the growths.

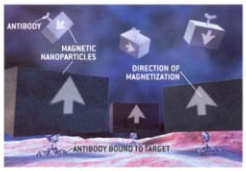
3 GOAL: Superior Implants



Nanometer-scale modifications of implant surfaces would improve implant durability and biocompatibility. For instance, an artificial hip coated with nanoparticles might bond to the surrounding bone more tightly than usual, thus avoiding loosening.

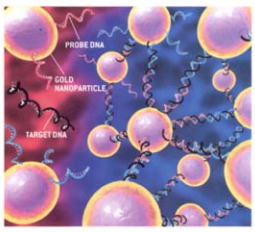
BIO-NANOTECH IN ACTION

The items here could one day enhance the speed and power of biomedical tests, such as those used to screen small samples of material for the presence of particular genetic sequences. For clarity, the images have not been drawn to scale.



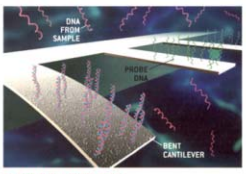
MAGNETIC TAGS

Many tests reveal the presence of a molecule or disease-causing organism by detecting the binding of an antibody to that target. When antibodies labeled with magnetic nanoparticles bind to their target on a surface (*foreground*), brief exposure to a magnetic field causes these probes collectively to give off a strong magnetic signal. Meanwhile unbound antibodies tumble about in all directions, producing no net signal. This last property makes it possible to read the results without first washing away any probes that fail to find their target.



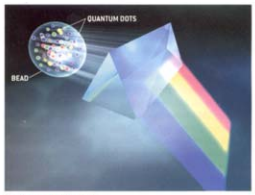
GOLD PARTICLES

Gold nanoparticles studded with short segments of DNA could form the basis of an easy-to-read test for the presence of a genetic sequence (*black*) in a sample under study. DNA complementary to half of such a sequence (*red*) is attached to one set of particles in solution, and DNA complementary to the other half (*blue*) is attached to a second set of particles. If the sequence of interest is present in the sample, it will bind to the DNA tentacles on both sets of spheres, trapping the balls in a dense web. This agglomeration will cause the solution to change color (*from red to blue*).



CLEVER CANTILEVERS

Biological samples can be screened for the presence of particular genetic sequences using small beams (cantilevers) of the type employed in atomic force microscopes. The surface of each cantilever is coated with DNA able to bind to one particular target sequence. A sample is then applied to the beams. Binding induces a surface stress, which bends the affected beams by nanometers—not much, but enough to reveal that the bent beams found their specific targets in a sample.



NANO BAR CODES

Latex beads filled with several colors of nanoscale semiconductors known as quantum dots can potentially serve as unique labels for any number of different probes. In response to light, the beads would identify themselves (and, thus, their linked probes) by emitting light that separates into a distinctive spectrum of colors and intensities—a kind of spectral bar code.

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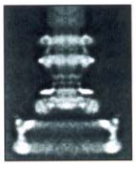
What is nanotechnology?
Even tiny tiny motors?

A TALE OF TWO MOTORS



STANDARD-ISSUE electric motor bears a superficial—albeit striking—resemblance to the biochemical rotary motor (*top right*) that turns the flagella in a bacterium.

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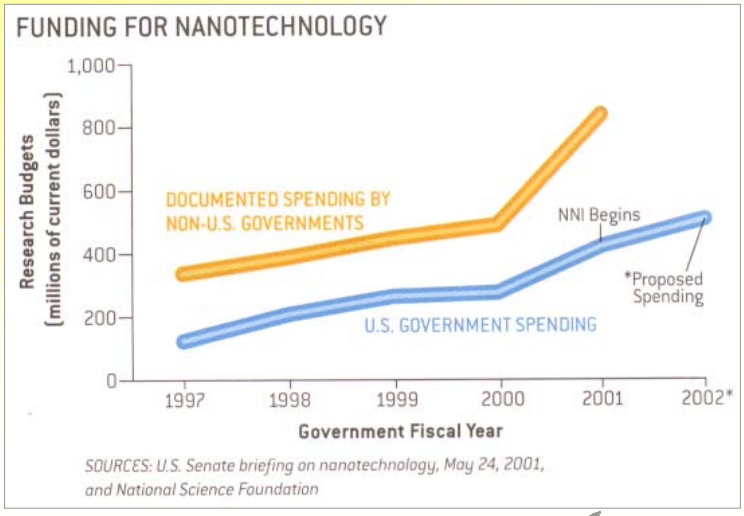
Funding?



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Information of Nanotechnology?

- Internet resources
  - Richard Feynman's original lecture "There's Plenty of Room at the Bottom": http://www.its.caltech.edu/~feynman
  - Scientific American, http://www.sciam.com/nanotech/
  - The First IEEE Conference on Nanotechnology, 28-30.10.2001, http://www.mein.nagoya-u.ac.jp/IEEE-NANO/, program
  - Nanotechnology Search Engine, http://www.nanotechnology.com/nano/default.shtml
- Paper resources
  - Scientific American, September 2001 issue
  - Other books

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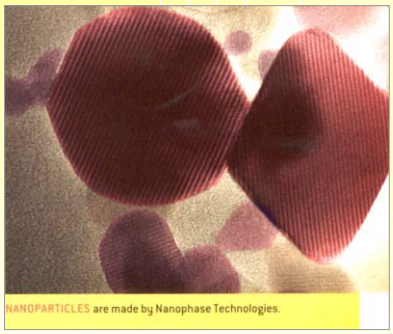
The goal of our study?



- Is nonotechnology
  - Distant basic research?
  - Physics, chemist, material people's job?
  - Biomedical people may interested?
  - **Or something might affect what I am doing**

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What we do in this course?

- Check the state of art of nanotechnology
  - Nanofabrication
  - Nanophysics (meso scale physics)
  - Nanoelectronics
  - Nanomedice
  - …
- **Try to figure out how nanotechnology might benefit us**
  - The impact to our own work filed
  - The impact to other technologies/engineering field
  - The impact to society/economy
  - …

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Want to know

- Overall picture of nanotechnology, presented people from different areas of science
- What people in the world are doing with nanotechnology
  - Their ideas
  - Their work
  - Their fears
  - Their expectations
- State of the art & milestones already achieved
- What have been achieved in the practical field, and what was the methods that was used
- Industries or companies using nanotechnology
- Market outlook
- Application in home appliances, automobile industry
- Impact of nanotechnology on economy & society
- Impact of nanotechnology to microtechnology
- Future expected developments & paths derived from nanotechnology
- Nanomachine
- Nanofabrication
- nanoelectronics
- Nanomedicine

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Presentation Topics

- How to pick topics
  - Select one or several titles, or propose your own titles
  - You can give several presentations for different issues in a same topic
- Overview of nanotechnology
- Nanofabrication
- Nanophysics (meso scale physics)
- Selected branches
  - Nanoelectronics
  - Nanomedicine
  - Nanomaterial
  - Bio-nanotech
  - Nanorobotics
  - Nanomanipulation
- Economical prospective
- Impact to our society and life
- Relation to other technologies – potential impacts (none-exhaustive list)
  - My work field
  - Microsystem technology
  - Automation engineering
  - Robotics
  - Biomedical technology
  - Environmental technology
  - Material science
  - …

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Seminar Calendar

- 27.09 Introduction
- 04.10, 14:15
  - Ricardo: Overview of nanotechnology activities
  - Oana: nanodevice
- 11.10, 14:15
  - Bo: State of art of archievments
  - Monaem: Nanoelectronics - overview
- 08.11, 13:15
  - Carlos: Industries or companies using nanotechnology
  - Oana: Modeling of nanodevices
  - Pedro: Market outlook and future prospects
- 15.11, 13:15
  - Kati: The use of scanning probe microscopy in nanoresearch
  - Katja: Nanomedicine, overview
  - Monaem: Nanoelectronics – architecture etc
- 22.11, 13:15
  - Suvi: nanostructural silicon and light emission, I & II
  - Bo: Future prospective
- 29.11, 13:15
  - Katja: Nanomedicine II
  - Ricardo: Nanorobotics
  - Carlos: Top-down nanomachines
- 13.12, 14:15
  - Kati: Nanofabrication
  - Pedro: Nanomanipulation

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Meetings and Presentations

- Prepare your presentation using Microsoft Powerpoint
- Write a short report 5-10 pages for each presentation
- Email the powerpoint file and report before Wednesday evening 18:00 to Quan.Zhou@tut.fi

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