Nanoscience I

Lecture 1

Introduction

“Nanopipettes”

C$_{60}$ molecules on an Al(111) surface
Overview of course content

• Basics of physics and science at the nanoscale and in low-dimensional systems
• Experimental methods for characterising nanostructures
• Properties of different nanomaterials and nanoparticles
• Synthesis of nanomaterials and nanoparticles
• Nanocarbon
• Nanocomposites
• Nanoelectronics and optics
• Nanotechnology and energy
• Nanomedicine
• Impact on society: Ethics and business
Course information

Prerequisites
For admission, knowledge equivalent of introductory courses in Physics, 30 hp, and Mathematics, 30 hp, is required.

Course objectives
After successfully passed course the student should be able to
• present an overview of the various areas of nanoscience,
• explain some basic phenomena appearing on the nanoscale, within low-dimensional physics and chemistry
• describe the most important methods for the synthesis of nanostructures, and choose method depending on the need for a certain structure
• describe the most important methods for characterizing nanostructures, and choose characterization method for a certain investigation
• give examples on and analyze some applications of nanotechnology.
• seek and critically find literature about research on nanoscience.
Course information

**Teaching**
*Lectures:* 8 (8x2 h). Presentations of the main areas of nanoscience, with examples from research and applications.
*Seminars* 5 (4x2h, 1x8h). Students will be given tasks to present a theme or a new finding within nanoscience and nanotechnology.
*Labwork:* (2x4 h). See below.
The course will require a high degree of self studies.
Guest lecturers may be invited for specific areas.

**Project**
Each student has to choose a specific subject within the areas of nanoscience, seek information from different sources including research papers, write a report and make an oral presentation of the project at the end of the course, on May 28th.
Course information

Teachers
Kjell Magnusson, room 21F213, tel. 7001215, Kjell.Magnusson@kau.se
Hanmin Zhang, room 21F206, tel. 7002120, Hanmin.Zhang@kau.se
Course admin: Kerstin Moatti, room 21F311A, tel. 7001192, Kerstin.Moatti@kau.se

Course literature

Examination
This course is graded within Engineering programs with U (Fail), 3, 4 or 5. For other students grades are given as U, G or VG.
Grades are based in part on the project report and presentation, and in part on the result on a written examination, given first time on June 5th. To pass the course an active participation in the seminars and an accepted lab-report for Lab 2 is required.
Course information

Preliminary lecture plan
Course starts on Wednesday April 1st, 10.15-12.00 in room 21C215
Lecture content
1 Course information; What is nano?
2 Tools of nanoscience
3 Nanomaterials: Carbon
4 Nanomaterials: Composites
5 Nanoelectronics and optics
6 Nanotechnology and energy
7 Nanomedicine
8 Nanotechnology and business. Course evaluation

Labwork
Lab 1. Nanomicroscopy, visits and demonstrations: SEM, AFM, STM, 4h
Lab 2. Preparation of nanostructures: spin-coating, inspection with AFM, 4 h.
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What is nanoscience and nanotechnology?

Definition of nanotechnology by the USA National Nanotechnology Initiative:

Three requirements:

1. Research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1 - 100 nanometer range.
2. Creating and using structures, devices and systems that have novel properties and functions because of their small and/or intermediate size.
3. Ability to control or manipulate on the atomic scale.

Cross-disciplinary:
The Royal Society (UK):

"Nanoscience is the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale.

Nanotechnologies are the design, characterisation, production and application of structures, devices and systems by controlling shape and size at nanometre scale"
Dimensions in Science
Powers of 10
The Scale of Things – Nanometers and More

Things Natural

- Ant ~ 3 mm
- Human hair ~ 60-120 µm wide
- Fly ash ~ 10-20 µm
- Red blood cells, with white cell ~ 2-5 µm
- DNA ~ 2-12 nm diameter
- ATP synthase
- 1,000 nanometers = 1 micrometer (µm)

Things Manmade

- Head of a pin 1-2 mm
- Micro-Electro-Mechanical (MEMS) devices 10-100 µm wide
- Pollen grain
- Red blood cells
- Zone plate x-ray “flea” Outer ring spacing <25 nm
- Self-assembled, Nature-inspired structure Many 10s of nm
- Quantum coral of 48 iron atoms on copper surface positioned one at a time with an STM tip
- Nanotube electrode
- Carbon nanotube ~ 1 nm diameter
- Carbon buckyball ~ 1.3 nm diameter

The Challenge
The use of nanoparticles has a long history. Examples:

- Stained glass in medieval churches
- Silver particles in photographic films
- Chemistry: most molecules are in the nanometer size

But this is not nanoscience (as defined)

- **1959:** The physicist Richard Feynman predicts electronic circuits and machines on the nanometer scale, i.e. nanotechnology, in his famous speech: "There is plenty of room at the bottom”. But there were no tools…

- **1981-82:** Gerd Binnig and Heinrich Rohrer at IBM in Zürich invent the scanning tunneling microscope (STM).

- **1986:** Binnig and Rohrer receive the Nobel Prize in Physics. The atomic force microscope (AFM) is invented. The AFM quickly becomes the most versatile and powerful tool in nanotechnology.
More history…

- 1982: First observation of quantum confinement
- 1985: A new form of carbon, the cluster \( \text{C}_{60} \), named fullerene, was discovered. Soon after other fullerenes and the carbon nanotubes were discovered. R. Smalley, R. Curl and H. Kroto got the Nobel Prize in 1996 for the discovery of \( \text{C}_{60} \).
- 1986: First observation of quantized conductance, creation of a single-electron-transistor, Coulomb blockade
- 1980s: developments in electron beam lithography
- 1991: S. Iijima discovers the carbon nanotubes
- 2001: USA: National nanotechnology initiative
The importance of nanotechnology

Nanotechnology is expected to have a similar strong impact on society as current information technology and microelectronics.

Expected economic impact: Year 2015 the nanotechnology market is worth 1 trillion USD

"In 10 years, the whole semiconductor industry and half of the medical industry are based on nanotechnology."

Research:

- USA: National Nanotechnology Initiative:
  Funding: 1.4 billion USD /year

- EU: 7:th Framework Program centered on nanotechnology

- Worldwide yearly research funding : 7 billion Euro
Applications of nanotechnology

NNI: ”While nanotechnology is in the “pre-competitive” stage (meaning its applied use is limited), nanoparticles are being used in a number of industries.

Nanoscale materials are used in electronic, magnetic and optoelectronic, biomedical, pharmaceutical, cosmetic, energy, catalytic and materials applications.

Areas producing the greatest revenue for nanoparticles reportedly are chemical-mechanical polishing, magnetic recording tapes, sunscreens, automotive catalyst supports, biolabeling, electroconductive coatings and optical fibers.”

Step assists on vans
Bumpers on cars
Paints and coatings to protect against corrosion, scratches and radiation
Protective and glare-reducing coatings for eyeglasses and cars
Metal-cutting tools
Sunscreen and cosmetics
Longer-lasting tennis balls

Light-weight, stronger tennis racquets
Stain-free clothing and mattresses
Dental-bonding agent
Burn and wound dressings
Ink
Automobile catalytic converters.
Examples of future applications:

• Advanced drug delivery systems, including implantable devices that automatically administer drugs and sensor drug levels;

• Medical diagnostic tools, such as cancer tagging mechanisms and lab-on-a-chip, real time diagnostics for physicians;

• Cooling chips or wafers to replace compressors in cars, refrigerators, air conditioning and multiple other devices, utilizing no chemicals or moving parts;

• Sensors for airborne chemicals or other toxins;

• Photovoltaics (solar cells), fuel cells and portable power to provide inexpensive, clean energy

• New high-performance materials.

• OLED (organic light-emitting diode) displays

• All lamps made of LEDs and carbon nanotubes
Swedish nano companies, examples

**Obducat AB**: world leader in nano-imprint technology

**nanoFACTORY**

Advanced instruments for TEM/STM analysis of nanostructures

**Aqunano**

Startup company, commercializing semiconductor nanowires from Lund university.

Volvo, SAAB-Scania, Tetra Pak, Sandvik, ABB, etc.
Aktörer i nanoteknikens Sverige

Områden:
- Elektronik
- Material- och Ytbehandling
- Bioteknik
- Instrument och Utrustning

Grundad på forskningskompetens från:
- K Chalmers Tekniska Högskola
- K Kungliga Tekniska Högskolan
- L Linköpings Universitet / Linköpings Tekniska Högskola
- L Lunds Universitet / Lunds Tekniska Högskola
- S Stockholms Universitet
- U Uppsala Universitet

Typ av företag:
- Fet text: Nanoteknikföretag
- Kursiv text: Företag som använder sig av nanoteknik

Chromogenics Sweden
Gyros
Nanologica
Piezomotor Uppsala
Vg Scienza
Ämig
Anderberg och Modér Accelerator
Biacore
GammaData
Gaye Healthcare Bio-Sciences

Accelerator
Bactiguard
Micronic Laser Systems
Nanoradio
Nanosep
Nanospace
Nm Spintronics
Replisaurus Technologies
Silex Microsystems
Akzo Nobel
Alphabeta
Attana
Biosensor Applications
Biovitrum
Carmeda
Emerson Network Power Energy Systems
Fir Systems
Finneon Technologies
Lightlab Sweden
Medivir
Micromy
Nilsson Intelligence Systems
Pfizer
Pondus Instruments
Syntune
Ericsson
Wallenius Marine
Xcounter
Zarlink Semiconductor
Societal and safety implications of nanotechnology

• Much discussions and research about promises, benefits, risks and social, ethical and legal implications of nanotechnology

• EU-funded project Nanologue discussed nano and society: impact, dangers and opportunities (www.nanologue.net)

• Many applications for cleaning and improving the environment

• Nanoparticles present health hazards

See www.nano.gov
Limits to smallness

Moore’s law

Source: Intel
Source: Intel
Scaling of classical physical properties

Vibrations

Frequency: \[ f \propto \frac{1}{L} \]

Classical xylophone: C-note at 256 Hz

Nanosize "xylophone": resonance frequencies close to GHz range

Problem: how to detect such small vibrations?

Scaling of classical physical properties

- Thermal time constants and temperature differences decrease
- Viscous forces become dominant for small particles in fluid media, e.g. air or liquids (compared to inertial/gravitational forces)
- Frictional forces can disappear under certain conditions, e.g. symmetric molecular scale systems, like nested carbon nanotubes

From Zettl et al., Science 289, 602 (2000)
Nanotechnology takes off
www.kqed.org/quest/television/view/189