“Nothing is small, nothing is great. Inside us are worlds. What is small divides itself into what is great, the great into small.”

Edvard Munch (Norwegian artist)
Course objectives

• Present the connection between phenomena at different scales (from quantum aspects to macroscopic behavior) – how macroscopic properties are the consequence of nano/quantum scale features
• Use of general methodologies for analyzing multi-domain systems, independent of scale (e.g. bond graph modeling)
• Exploit and understand the characteristic aspects of designing at small scales
• Engineering applications: devices and systems at nano/microscale
• To prepare you for exploring more advanced case studies in EECE301, by providing an integrated background

Introductory lecture

• The Instruction Team
• EECE 300 Motivation
• EECE 300 Outline
• Website: http://courses.ece.ubc.ca/300
• Nanotechnology and Microsystems Option Overview
Instructors

• Dr. Karen Cheung
  • Email: kcheung@ece.ubc.ca
  • For course related emails: include [EECE300] in the subject
  • Office: Kaiser 3064
  • Ph.D. (2002) in Bioengineering, University of California Berkeley
  • Post-doctoral experience in EPFL, Switzerland
  • Research interests: BioMEMS; microfluidic lab-on-a-chip systems; implantable neural interfaces; chemical sensors; inkjet for tissue engineering and drug screening.

Instructors

• Dr. Edmond Cretu
  • Email: edmondc@ece.ubc.ca
  • For course related emails: include [EECE300] in the subject
  • Office: Kaiser 3063
  • Former Senior Designer and Senior Manager at Melexis, Belgium (inertial microsystems for cars)
  • Research interests: biomedical applications of microsystems (e.g. ultrasound imaging), inertial microsystems, novel microtransducers technologies (e.g. inkjet printed), multidisciplinary modeling
Motivation

- Understand, from an engineering perspective:
  - **WHY** do you need to change the way you get a certain functionality at micro/nanoscale
  - What is **SPECIFIC** in dealing with micro/nanosystems
  - **HOW** to design systems at small scales (what interactions are dominant)
  - Limitations and advantages compared to the macroworld
  - **Richard P. Feynman** [1959]”There’s plenty of room at the bottom” : *Why cannot we write the entire 24 volumes of the Encyclopedia Brittanica on the head of a pin?*

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“**There’s Plenty of Room at the Bottom,**”  *Richard Feynman, 1959*

*Smallest Feature*

\[ \text{ROOM!!} \]

1 nm 1 mm 1 mm 1 m

Atom  Virus  Bacterium  Cell  Blue Whale

**Factor of 300 to go!!**
Chapter: Dimensional ranges

Example: electric motors

- Magnetic- actuated motor
- Electrostatic rotary motor
- Glucose-fueled biological motor (Hiratsuka[2006])

Why change the principles?
Example 2: Cricket wind receptors

• Shimozawa [1999] - Minimum amount of mechanical energy necessary to cause a neuronal spike in the wind receptor cell of cricket is determined at the order of $kT$ ($4 \times 10^{-21}$ J at 300°K) => the mechanoreceptors operate at the level of the thermal noise of Brownian motion

• The energy threshold of the mechanoreceptor is far below that of single photon quantum of visible light (ca. $3 \times 10^{-19}$ J). The mechano-receptor is 100 times more sensitive than photoreceptors.

• Adapted functionality through natural evolution – **nonlinear sensing mechanism**, known as **stochastic resonance**

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TI – DLP (Digital Light Processor)

• Light-modulating chip
• >100000 individually addressable micromirrors (10x10um$^2$)
• Binary tilting: ±7.5°
• 0.8um CMOS SRAM on the substrate, beneath the layer of mirrors

Courtesy Texas Instruments
Sandia Microengines

Courtesy Sandia National Laboratories, SUMMiT™ Technologies, mems.sandia.gov

Gear train

Torsional Ratcheting Actuator - a high torque rotary electrostatic actuator

Inertial sensors

3-axis accelerometer (Berkeley)

Vibratory gyroscope (Sandia Labs)
Microturbines

- Gas-turbine engine at uscale (1g)
- High power densities (50W/cm³)
- 20-30 times better energy densities than that of the best battery technology
- Estimation: it will consume < 10g/hr of hydrogen fuel

MIT microturbine

Lab-on-chip (STMicroelectronics)

- DNA-based detection of sepsis-causing bacteria
- Reduced reaction times and costs

Courtesy STMicroelectronics
IBM “millipede” project

- High-density data storage based on nanomechanical AFM-like tips
- Thermomechanical storage densities ~1Tb/in² (well beyond magnetic recording)
- High data rates due to highly parallel operation of the thermomechanical probes

Microsystems markets

Trends:
- **Increase in functional integration** => more cost/area than before
- Increase in bio-medical applications and MEMS-based ink-jet printers

Source: In-Stat/MDR, 7/03
In the Long Term (~2014 Through 2020)

Enhancing Performance

Implementation of Advanced, Non-Classical CMOS Device with Enhanced Drive Current [Process Integration, Devices, and Structures]

To continue MOSFET scaling to less than $L_e = 15$ nm, it is quite likely that the device structure will change to advanced non-classical CMOS such as multiple-gate, ultrathin body (UTB) MOSFETs. In these devices, various “technology boosters,” such as mobility enhancement by strained Si, elevated source/drain, high-k gate dielectric, and metal gate electrode, will likely be simultaneously implemented with the new device structure. In UTB MOSFETs having less than 10 nm Si thickness, various quantum effects will impact the electric characteristics. Toward the end of the Roadmap timeframe, devices will increasingly be operated in the quasi-ballistic mode, where the current path will be enhanced by parameters different from those currently known. Eventually, carbon nanotubes, nanowires, and other high transport channel materials (e.g., germanium or III-V thin channels on silicon) may be needed. Choice of the optimum device structures, their physical characterization, and construction of cost-effective processing flows will become very important along with construction of their circuit architecture.

Future transistor? 1 nm crossed wires. Alireza Nojeh, UBC
Some Canadian Companies

- ATI
- Gennum
- PMC-Sierra
- Tundra
- Zarlink
- Micralyne
- DALSA
- RIM
- SweetPower
- SST Wireless
- Epod
- GM, Ford, Chrysler, AFCC
- Aerospace (Bombardier, MDA, Boeing, United Technologies)

Infrastructure for Nano/Micro?

- At UBC
  - [www.ampel.ubc.ca](http://www.ampel.ubc.ca)
  - [www.mina.ubc.ca](http://www.mina.ubc.ca)
- CMC Microsystems
- Universities
- By Contract
EECE 300 Course related information

- **Lectures** Tuesday, Thursday, 11:00-12:30
  FNH 50 (Food, Nutrition, Health)
- **Website** http://courses.ece.ubc.ca/300/
- **In Class Participation** (iClicker) (15%)
- **Homework** (5%)
- **In Class Midterm** (30%)
- **Final Exam** (50%)
Course Stuff

• Relevant articles and lecture notes will be posted as course proceeds.
• Laptop use: please be considerate and avoid distracting other students.
• Academic Integrity:
  – The act of copying other people's written words or ideas without proper referencing is considered plagiarism and is unacceptable.

Missing Background

• Bonds: Determine stiffness, mechanical properties, electronic conduction.
• Energy and Temperature: Determine motion of atoms/molecules, resistance, noise, drag, direction of reactions, irreversibility, etc.
• Properties of fluids, particularly at small scales.
• Basic mechanical properties of materials.
Course outline

Topics:

1. From atoms to bonds, solids and mechanics of materials – applications of elasticity theory at microscale

2. Fluids and flow at small scales. Pressure and viscosity. Scaling effects and dimensional analysis.


4. Concluding lectures (time permitting): Information and energy in artificial and biological systems at small scales.

Complements: EECE 352

- Intro to Quantum.
- Band structure, carriers, conduction.
- Dielectrics and Piezoelectric materials.
- Magnetic materials.
Related Courses at UBC

- EECE 300 Molecules to Mechanisms (E. Cretu, K. Cheung)
- EECE 301 Topics in Nanotechnology and Microsystems (E. Cretu, K. Cheung)
- EECE 400 Nanotechnology and Microsystems Project
- EECE 402 Sensors and Actuators in Microsystems (B. Stoeber)
- EECE 403 Micro/Nanofabrication and Instrumentation Laboratory (A. Nojeh)
- EECE 404 Nanotechnology and Nature (K. Cheung)
- EECE 432 Biomedical Microdevices (K. Cheung)
- EECE 489/509 Microsystems Design (E. Cretu)
- EECE 531 Nanoscale Modeling & Simulation (A. Nojeh)
- EECE 573 Micro and Nano Fabrication Technologies (K. Takahata)
- MECH 555 Fundamentals of Microelectromechanical Systems (B. Stoeber)

Option Structure

www.ece.ubc.ca

Option: Nanotechnology and Microsystems
Overview
Structure
NanoTechnology and MicroSystems

- New 3rd & 4th Year Option
- 12 Faculty
- 20 Students per year
- Theory and Practice
- Core Electrical + Nano/Micro

Required Courses 3rd Year

- EECE 300 (3) Molecules to Mechanisms
  (Instead of EECE 314, System Software Engineering)

- EECE 301 (2) Topics in Nanotechnology and Microsystems
  (Instead of EECE 361, Signals and Systems Laboratory)
Required Courses 4th Year

- EECE 400 Nanotechnology and Microsystems Project
- EECE 401 NanoTechnology in Electronics
- EECE 402 Sensors and Actuators for Microsystems
- EECE 403 Micro/Nanofabrication and Instrumentation Laboratory

Project Experience
EECE 402: Sensors and Actuators for Microsystems

Instructor: Boris Stoeber

Microsystem Applications
- accelerometer
- gyroscope
- personal transporter
- game console
- airbag
- micro-mirrors
- data projector

Class Content
- Fabrication of Microelectromechanical Systems (MEMS) technology, standard processes
- Modelling of Microelectromechanical Systems
  smart materials
  mechanical systems
  microfluidic systems
- Design of MEMS Sensors and Actuators
  multi-parameter detectors, “smart” sensors, optical MEMS

Global Market in $M

Small Times January, 2007

By Sandia National Laboratories
Elective Courses: 9 Units, Examples

- EECE 404 (3) Nanotechnology and Nature
- EECE 432 (3) Biological Micro-Electro-Mechanical Systems
- EECE 479 (3) Introduction to VLSI Systems
- EECE 480 (3) Semiconductor Devices: Physics, Design and Analysis
- EECE 481 (3) Digital Integrated Circuit Design
- EECE 482 (3) Optical Waveguides and Photonics
- EECE 483 (3) Antennas and Propagation
- EECE 484 (3) Semiconductor Lasers
- EECE 488 (3) Analog CMOS Integrated Circuit Design
- EECE 489 (3) Microsystems Design
- MTRL 495 (3) Biomaterials
- PHYS 304 (3) Introduction to Quantum Mechanics

ECE Faculty

- Karen Cheung
- Lukas Chrostowski
- Edmond Cretu
- Andre Ivanov
- Nick Jaeger
- Vikram Krishnamurthy
- John Madden
- Alireza Nojeh
- Dave Pulfrey
- Boris Stoeber
- Kenichi Takahata
- Shuo Tang
- Konrad Walus
Other Faculty

- Shrikantha Phani
- Mu Chiao
- Frank Ko
- Eric Lagally
- Carl Hansen
- Josh Folk
- Guangui Xia
- Ryozo Nagamune
- Xiaodong Lu
- Hongshen Ma
- George Sawatsky
- www.AMPEL.ubc.ca

Nanotechnology and Microsystems Option Overview

- The Nanotechnology and Microsystems Option helps prepare students for the new age of electronics in which chips integrate mechanical, fluidic, biological and optical components, and where nanometer scale features are forcing changes in the design of transistors and other basic circuit elements.

- Students in the option receive hands-on experience through laboratory and project work which complements theory.
### Nanotechnology and Microsystems Option Overview

**THIRD YEAR**  
(Effective September 2007)

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**FOURTH YEAR**  
(Effective September 2008)

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### EECE300

An i>clicker remote is required for this course.  
You can purchase it through the bookstore.
How will we use the clicker?

✓ I pose questions on the screen during lecture.

✓ You answer using your i>clicker remote.

✓ Class results are tallied.

✓ I display a graph with the class results on the screen.

✓ We discuss the questions and answers.

You get points!

How do you vote?

Turn on the clicker by pressing the bottom “On/Off” button.

A blue “Power” light will appear at the top of the remote.
How do you vote?

When I ask a question in class (and start the timer), select A, B, C, D, or E as your vote.

I may also ask you to talk about your possible choice/answer with your neighbor or in groups.

How do you know your vote was received?

Check your “Vote Status” Light:

- **Green light** = your vote was sent AND received.
- **Red flashing light** = you need to vote again.

Not sure you saw the light? Just vote again.

Want to change your vote? You can vote again as long as the timer is still going.
Registering your i>clicker

You can earn points for your i>clicker responses [for participation and/or answering questions correctly].

Until you register your i>clicker, your responses are tied to your clicker remote ID (located on the back of your clicker), rather than to you.

When you do register, your previously recorded voting responses will be assigned to you.

1. Send email to Edmond Cretu edmondc@ece.ubc.ca

Subject: [EECE300] iClicker registration

REGISTER AT www.vista.ubc.ca
**Other Important Notes**

- You can SHARE your clicker with a friend/roommate as long as you are not using *i>clicker* in the same courses. NOTE that your friend will still need to register the clicker for his/her courses.

- You cannot share a clicker with a friend in the same class. The system will check to make sure the clicker ID is valid and that the same ID has not already been registered by another student taking the same course.

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**Other important notes**

- If you bought a used clicker, replace the AAA batteries (all of them).
  - Do not use Duracell (they are a bit short for the casing).
  - Do not use rechargeable batteries (they harm the clicker).

- Register your clicker.

- Before using a new clicker for the first time, pull the plastic tab out of the battery compartment.
Other important notes

✓ Bring your clicker to class every day!
✓ Make sure your remote is on when voting!
✓ Do not submerge your clicker in liquid (and avoid liquid near the clicker); like most electronics, liquid + your clicker is a bad combination.
✓ Contact clicker.support@ubc.ca for help.

Changing Your Frequency

✓ We are using a different frequency than the default for this class. The frequency we are using is [A].

✓ At the beginning of each class:
  • Hold your On/Off button for 2 seconds (the blue Power Light will flash)
  • Enter [A]
  • Your “Vote Status” light will turn green after you’ve entered this new frequency.

✓ Your frequency is now changed for the duration of the lecture & you may vote.
Clicker test (1)

Who is the prime minister of Canada?
A. Stephen Harper
B. Julia Gillard
C. David Cameron
D. Angela Merkel

Clicker test (2)

Richard Feynman, Nobel Prize
A. Chemistry: green fluorescent protein
B. Physics: quantum electrodynamics
C. Physiology/Medicine: penicillin
D. Peace: knowledge about man-made climate change