Applied Physics Undergraduate Courses

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Applied Physics Breadth Courses

Fall semester	Spring semester
18-300:	**18-310:**
Fundamentals of Electromagnetics	**Fundamentals of Semiconductor Devices**
Prerequisite: 18-220	**Prerequisite: 18-220**

Applied Physics Depth Courses

Fall semester

18-412: Field Effect Devices and Technology

Prerequisite: 18-310

18-416: Data Storage Systems

Prerequisite: 18-300 OR 18-310

Spring semester

18-401: Electromechanics

Prerequisite: 18-300

18-402: Applied Electrodynamics

Prerequisite: 18-300

18-410: Physical Sensors, Transducers and Instrumentation

Prerequisite: 18-300 OR 18-310 OR 18-321

Applied Physics Capstone Design Courses

Fall semester

18-513: Antenna Design for Wireless Communications

Prerequisite: 18-402

Spring semester

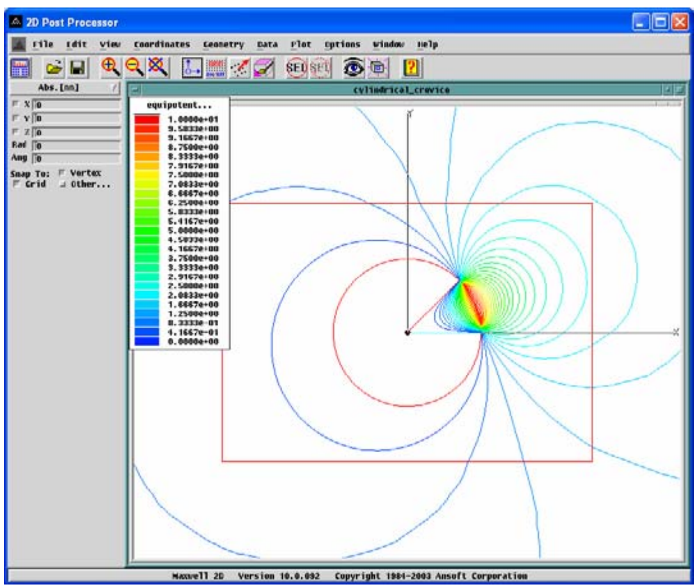
18-517: Data Storage Systems Design

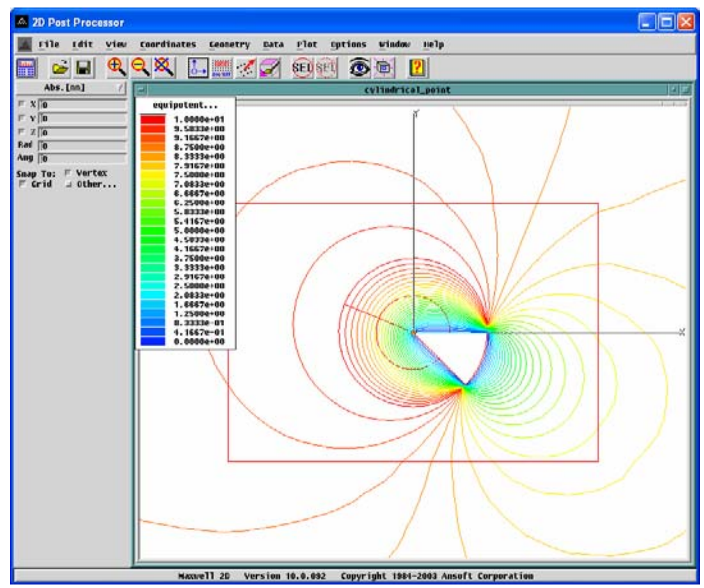
Prerequisite: 18-416 OR (18-300 AND 18-396) OR (18-310 AND 18-396)

18-300: Fundamentals of Electromagnetics

This course introduces electromagnetic principles and describes ways in which those principles are applied in engineering devices and systems. Topics include vector calculus as a mathematical foundation for field descriptions, Maxwell's equations in integral and differential forms with associated boundary conditions as descriptions of all electromagnetic principles, quasistatic electric fields in free space and in materials, superposition for known charge sources, conduction and polarization, resistance and capacitance, charge relaxation, analytic and numerical methods for electric field boundary value problems, quasistatic magnetic fields in free space and in materials, superposition for known current sources, magnetization, inductance, magnetic diffusion, and analytic and numerical methods for magnetic field boundary value problems.

Breadth course, offered every **fall** semester. Prerequisite: 18-220.





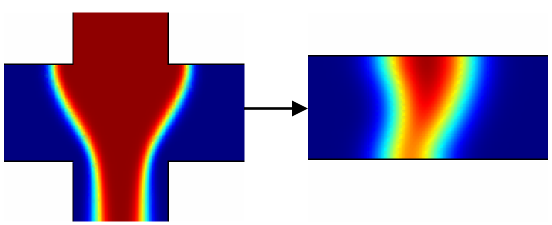
Microfluidic device modeling

We are creating a first generation of CAD tools for synthesis of microfluidic networks, involving optimization of performance parameters (e.g. resolution of bands of biological particles separated by electrophoresis) and chip area.

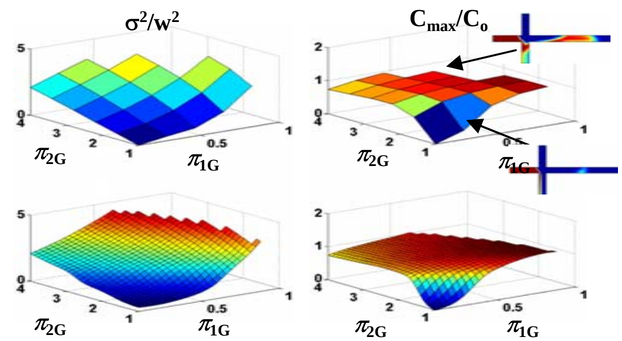
Solutions of the partial differential equations (PDEs) that govern individual devices in a microfluidic network require computationally expensive numerical solvers for each individual device. Simulations of networks of devices are infeasible beyond a few interconnected devices. Repeated simulations for optimization require a strategy that avoids brute force PDE solutions.

We have created neural network representations of individual devices, wherein the neural nets are trained on PDE solutions and subsequently used in efficient descriptions of interconnected device characteristics.

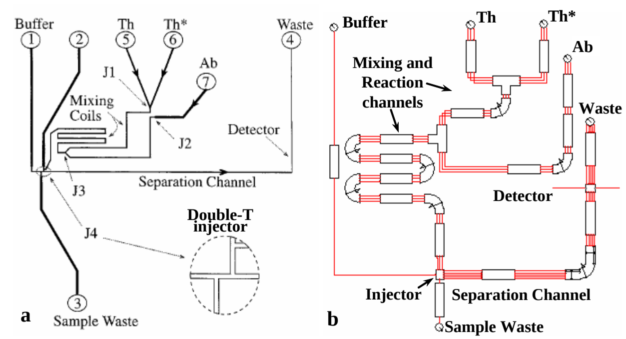
<u>Example</u>: a finite element simulation of a microfluidic cross injecting a band of particles into a channel for subsequent electrophoretic separation ...



... becomes a neural network in a space of dimensionless parameters ...



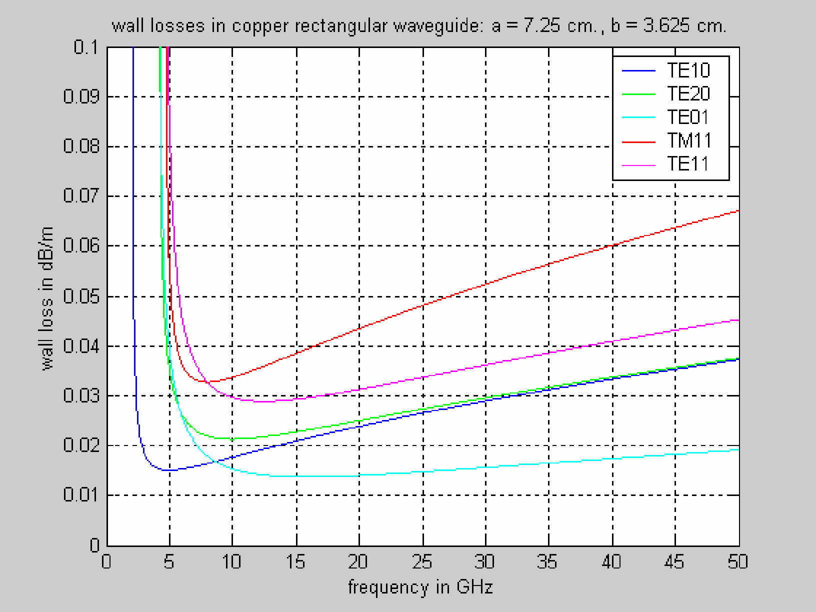
... used in a network simulation of a competitive immunoassay microchip ...

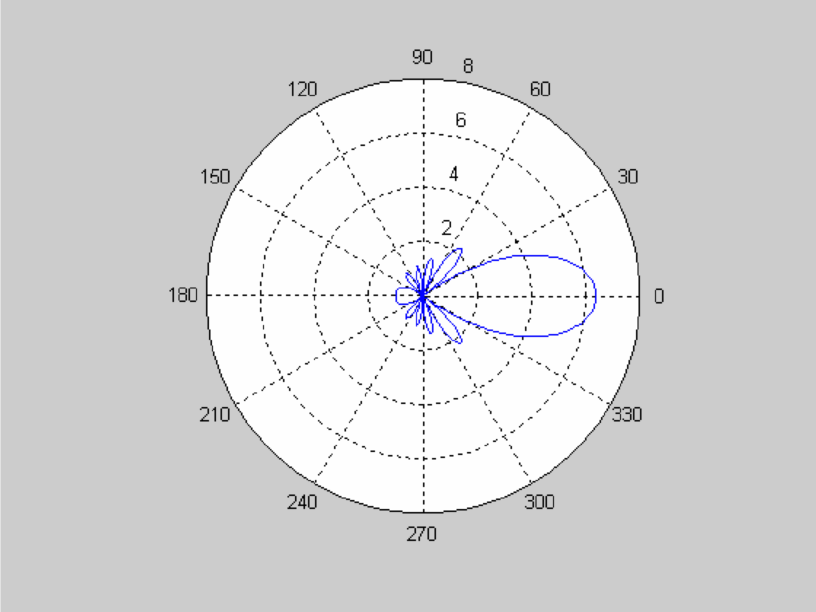


18-402: Applied Electrodynamics

This course builds upon the electric and magnetic field foundations established in 18-300 to describe phenomena and devices where electromagnetic waves are a central issue. Topics include: review of Maxwell's equations, propagation of uniform plane waves in lossless and lossy media, energy conservation as described by the Poynting Theorem, reflection and transmission with normal and oblique incidence upon boundaries, sinusoidal steady state and transients on 2-conductor transmission lines, modal descriptions of waveguides, radiation and antennas.

Depth course, offered every **spring** semester. Prerequisite: 18-300.

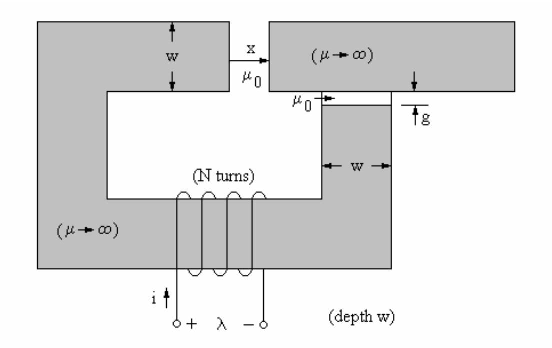


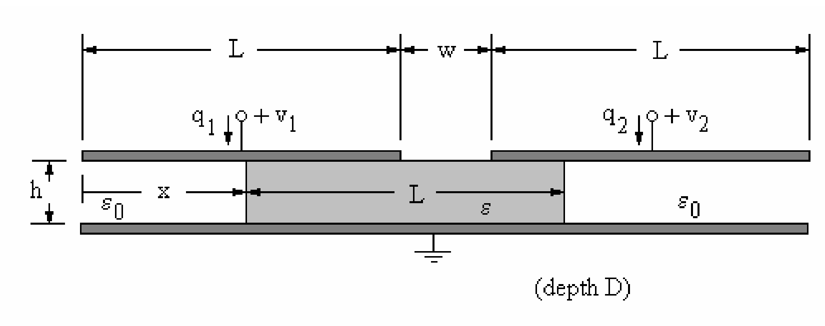


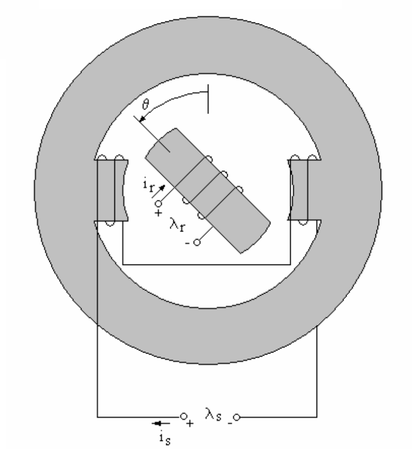
18-401: Electromechanics

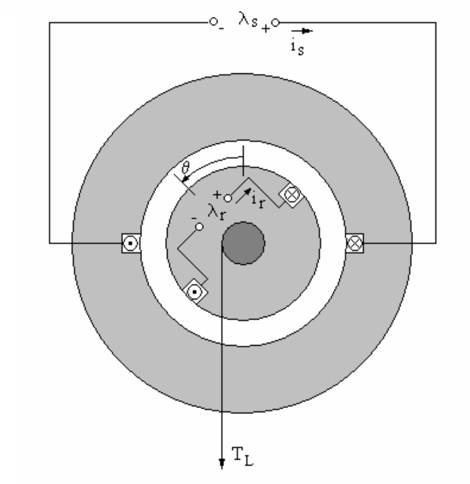
This course provides a broadly based introduction to interactions between mechanical media and electromagnetic fields. Attention is focused on the electromechanical dynamics of lumped-parameter systems, wherein electrical and mechanical subsystems may be modeled in terms of discrete elements. Interactions of quasistatic electric and magnetic fields with moving media are described and exemplified. Unifying examples are drawn from a wide range of technological applications, including energy conversion in synchronous, induction, and commutator rotating machines, electromechanical relays, a capacitor microphone and speaker, and a feedback-controlled magnetic levitation system.

Depth course, offered every other **spring** semester. Prerequisite: 18-300.





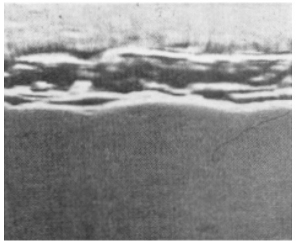


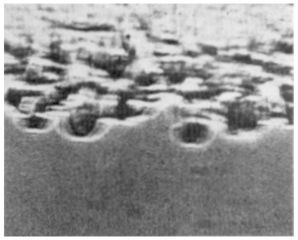


Electrohydrodynamic instabilities in microfluidic systems

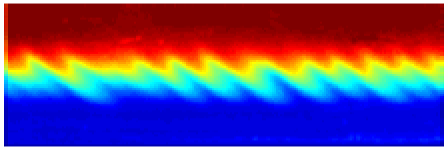
Electrohydrodynamic (EHD) instabilities in fluid systems that involve conductivity gradients in electric fields involve a two-way coupling between electrical and mechanical subsystems.

We did fundamental work in this area 3 decades ago, describing instabilities in devices at the scale of 1 – 10 millimeters ...





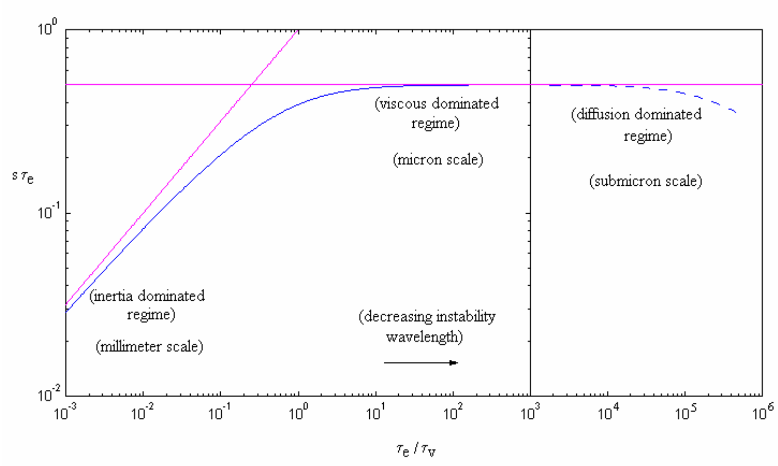
Much more recently, EHD instabilities have been observed in electrokinetic microsystems in the context of bioanalytical techniques including capillary electrophoresis and isoelectric focusing ...



(magnified image courtesy J. G. Santiago, Stanford Univ.)

This mechanism is potentially useful in driving mixing processes in low Reynolds number flows, but is also potentially limiting in systems where the goal is to minimize sample dispersion.

Much about the physical mechanism is understood on the basis of our old work. But what is new and important at the much smaller scale of microfluidic systems is the effect of diffusion on instability dynamics ...



Our current work in this area is aimed toward simple fundamental understanding of the incipience and growth rates of EHD instabilities in microfluidic devices, as a basis for design decisions for micro total analysis systems (μTAS).

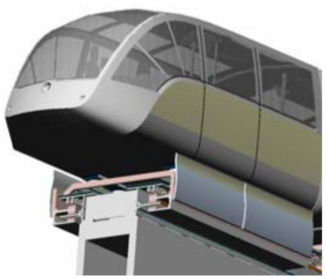
Permanent magnet based low-speed MAGLEV

High speed MAGLEV systems based upon both attractive and repulsive magnetic levitation are operational in Europe and Japan ...

(Transrapid, Germany)

(MLX01, Japan)

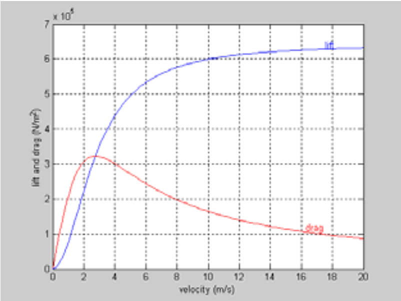
We are working, as part of a team coordinated by General Atomics, San Diego, on a low speed MAGLEV system that carries Halbach permanent magnet arrays on the vehicle. The vehicle, easily capable of negotiating sharp turns and steep grades, is competitive with modern light rail urban transportation systems. A full scale test system is currently being tested at General Atomics, and an operational system is planned to link separate parts of the campus of California University of Pennsylvania.



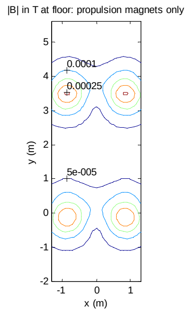
Electrical & Computer ENGINEERING

We are contributing fundamental understanding and analysis in two areas:

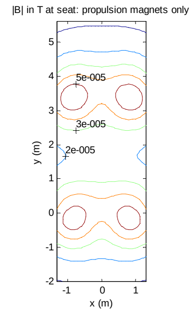
1. Lift and Drag as functions of vehicle speed as determined by interaction of moving three dimensional Halbach array field structures with the fixed laminated copper track:



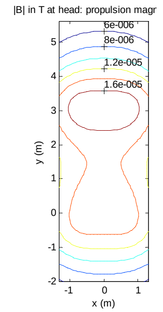
2. Passenger compartment magnetic field levels:



(floor level)



(seat level)

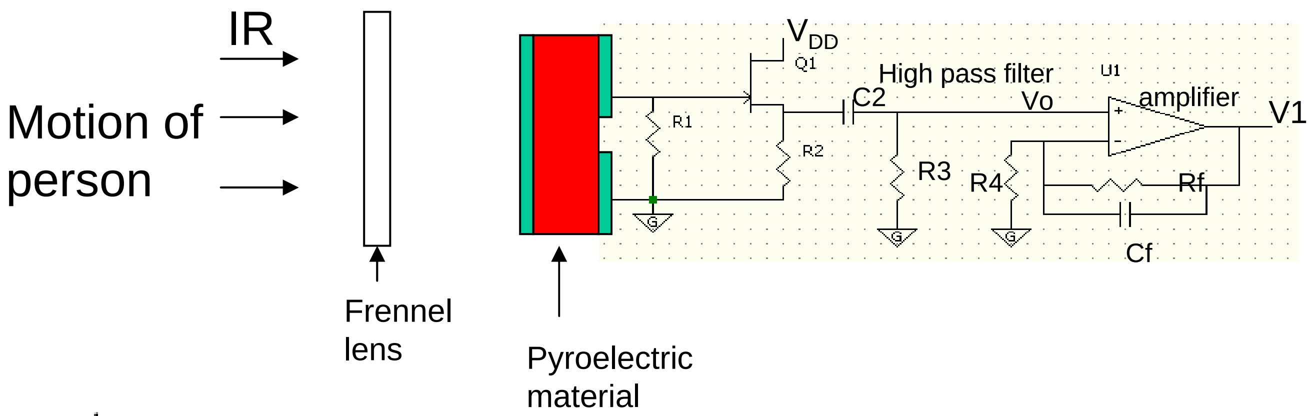


(head level)

18-410: Physical Sensors, Transducers and Instrumentation

While modern electronic circuits have become largely digital, the physical world, and consequently, the electronic interface to the physical world remains fundamentally analog. Therefore, sensors, transducers, and the initial signal processing remain in the analog domain. Simultaneously, the commercial market place optimizes sensor technology based upon multiple attributes including cost, detectivity, size, speed, etc. In this course we explore both the many types of possible responses to various physical stimuli, as well as the instrumentation, electronic detection, signal conversion and signal processing techniques used to bring the physical event into the electronic world in a practical manner. This requires that we learn about the diversity of physical phenomena, materials and devices that can be used to convert the various forms of physical energy into electronic signals. Due to the significant diversity of physical phenomena, the course requires reading from textbooks, the technical literature and patent literature. The course is taught via the case method with student participation via oral and written reports. The student should arrive with a strong interest in, and basic understanding of, physics, material science, chemistry and analog electronic circuits as taught at the sophomore and junior course level.

Depth course, offered every **spring** semester. Prerequisite: 18-303 OR 18-310 OR 18-321.



Electrical & Computer ENGINEERING

- MEMS based: Micro-Electro-Mechanical Systems
  - Grating Light Valve Technology (Optical Diffraction)
    - Displays, Signal Processing, etc. --- Ref: www.siliconlight.com
  - Accelerometers (airbag deployment … hard disk drives)
  - Pressure (tire pressure to… microphones)
  - Etc…

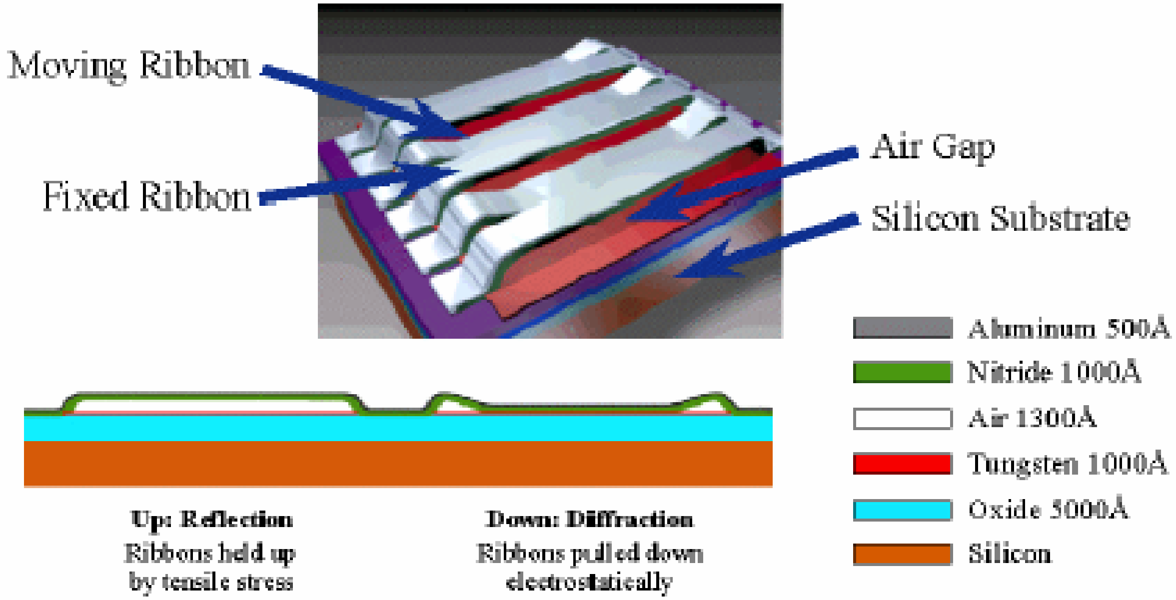
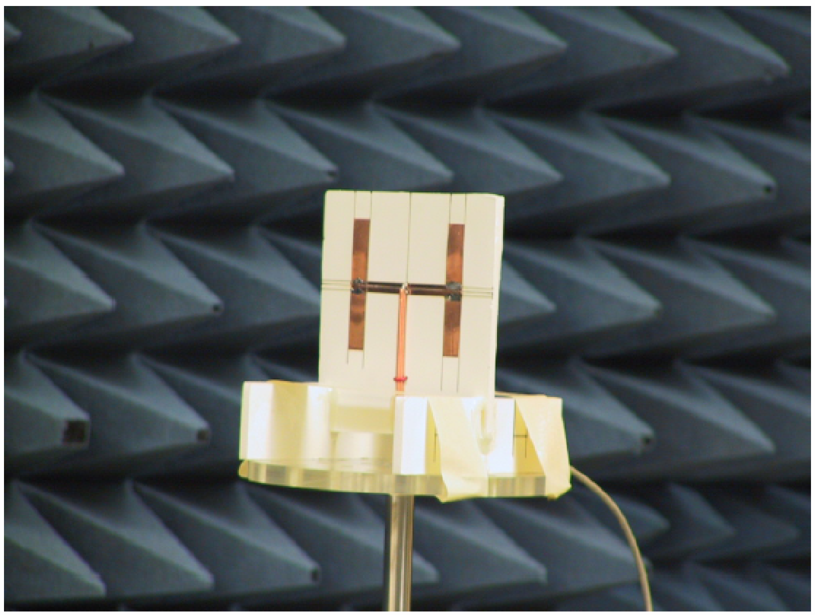


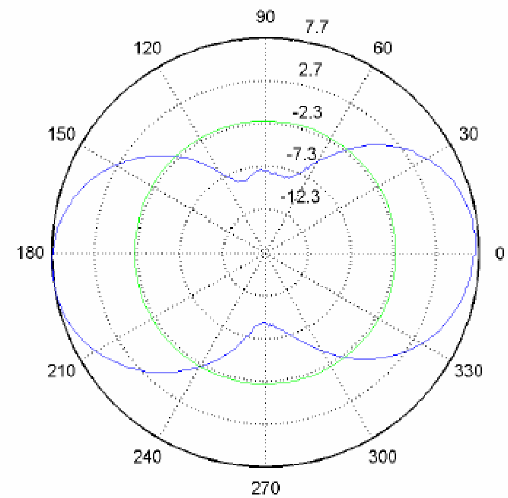
Figure 2: Build using IC fabrication technology, the Grating Light Valve consists of pairs of fixed and movable ribbons located approximately a quarter wavelength above a silicon dioxide layer.

18-513: Antenna Design for Wireless Communications

The demand for wireless products is growing at an impressive rate. Antennas are critical but often misunderstood components of these products. This course will provide an introduction to the design of antennas for wireless applications. This will include the fundamental theory of electromagnetic radiation, basic antenna concepts, antenna measurements, numerical design tools, and the design of several types of widely used antennas. Also discussed will be policy issues related to licensing and use of the electromagnetic spectrum, and how these issues impact antenna design. Students will work in small groups to design, construct and test an antenna to meet stated specifications.

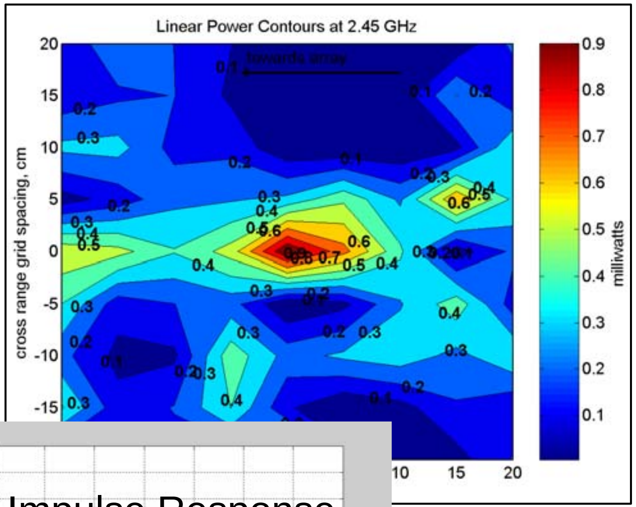
Capstone Design course, offered every **fall** semester. Prerequisite: 18-402.

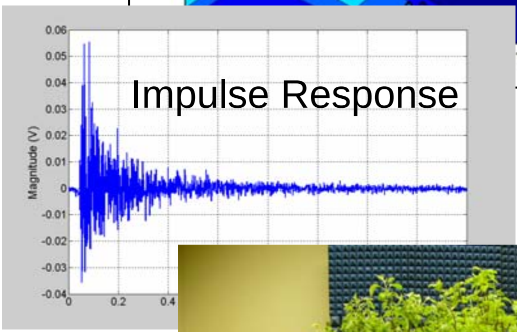




Electromagnetic Time Reversal Radar

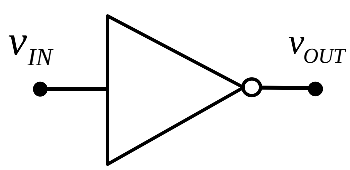
- Time reversal symmetry of Maxwell's Equations
  - Recording echoes from a transmission, reversing them, and playing them back results in energy refocusing at the source location
- Super-resolution focusing
  - When multiple scatterers are present, focused spots of order half a wavelength can be achieved an arbitrary distance from the transmit antenna array
- Improved Radar detection in clutter
  - Time reversal techniques can be used to focus energy where changes occur, in effect placing more energy on the target and increasing detection sensitivity

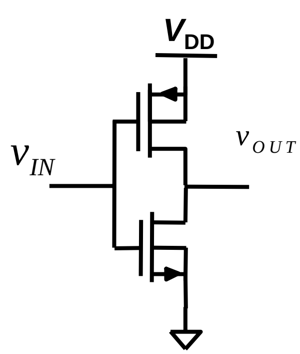


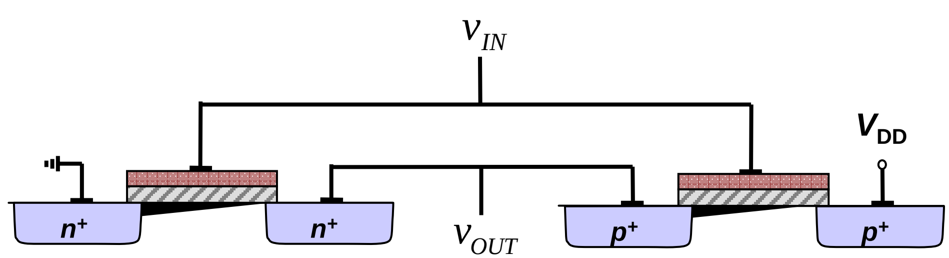


18-310 Fundamentals of Semiconductor Devices

- Modern electrical circuits are basically complicated plumbing systems of carriers, namely electrons and holes.
- Circuits use transistors to carefully route, combine, subtract, and multiply these carriers in order to achieve enormously complex functions.
- This course teaches us how, on a fundamental level, we can control the flow of electrons and holes by using the basic physical properties of semiconductor materials.
- It will provide the insight and foundational understanding critical for designing the cutting-edge circuits of tomorrow.

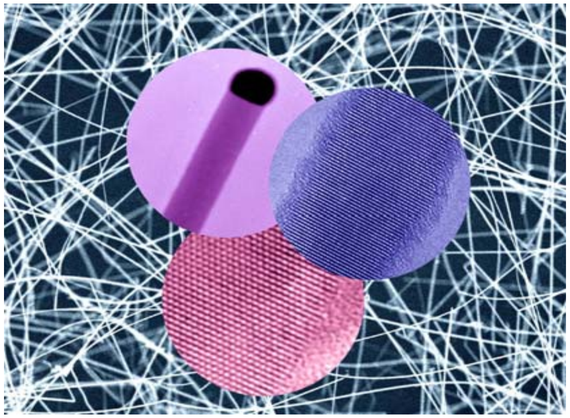


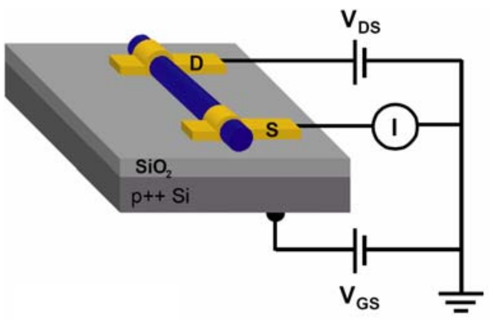


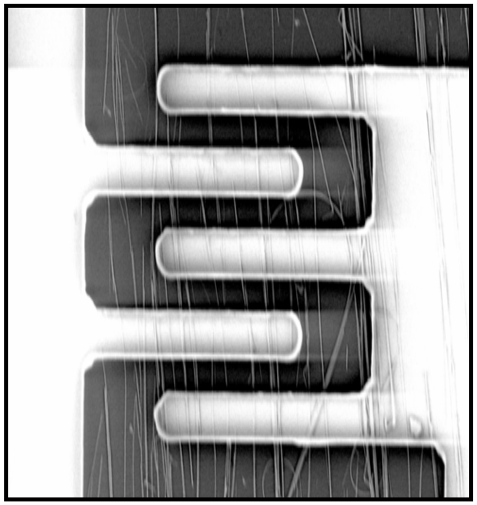


Research: Analog and RF circuits using nanoscale materials

- **Semiconductor nanowires, carbon nanotubes, others ….**
- **Emphasis on exploring non-digital applications for these emerging technologies:**
  - RF, e.g. LNA's, mixers, etc.
  - Low power data conversion (A/D, D/A)
  - General analog, e.g. low noise amplifier





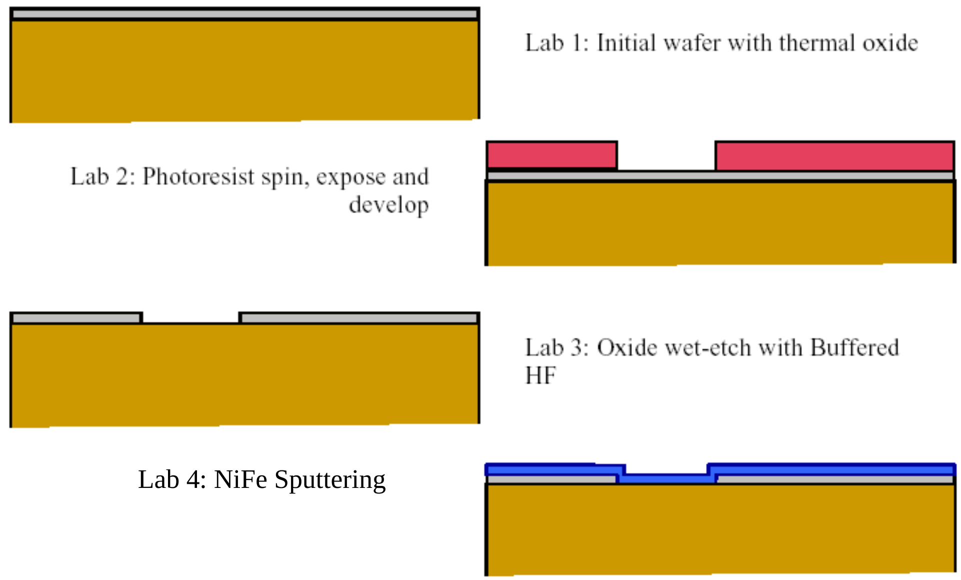


Electrical & Computer ENGINEERING

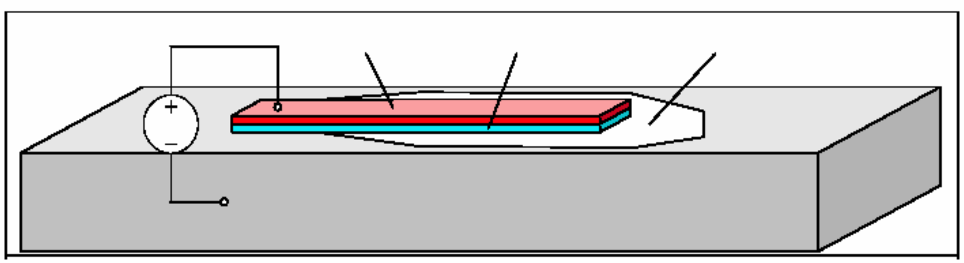
18-819 Micro and Nano Systems Fabrication

- TOPICS
  - Optical characterization
  - Profilometery
  - Wet Etching
  - Dry Etching
  - Photolithography
  - Thin film sputtering
  - Electrical Measurement
  - Magnetic Measurement

PROCESS FLOWS



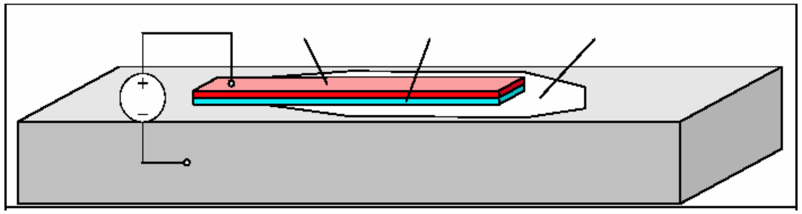
NANOFABRICED DEVICES



NANOFAB TOOLS

Electrical & Computer ENGINEERING

18-819 Micro and Nano Systems Fabrication

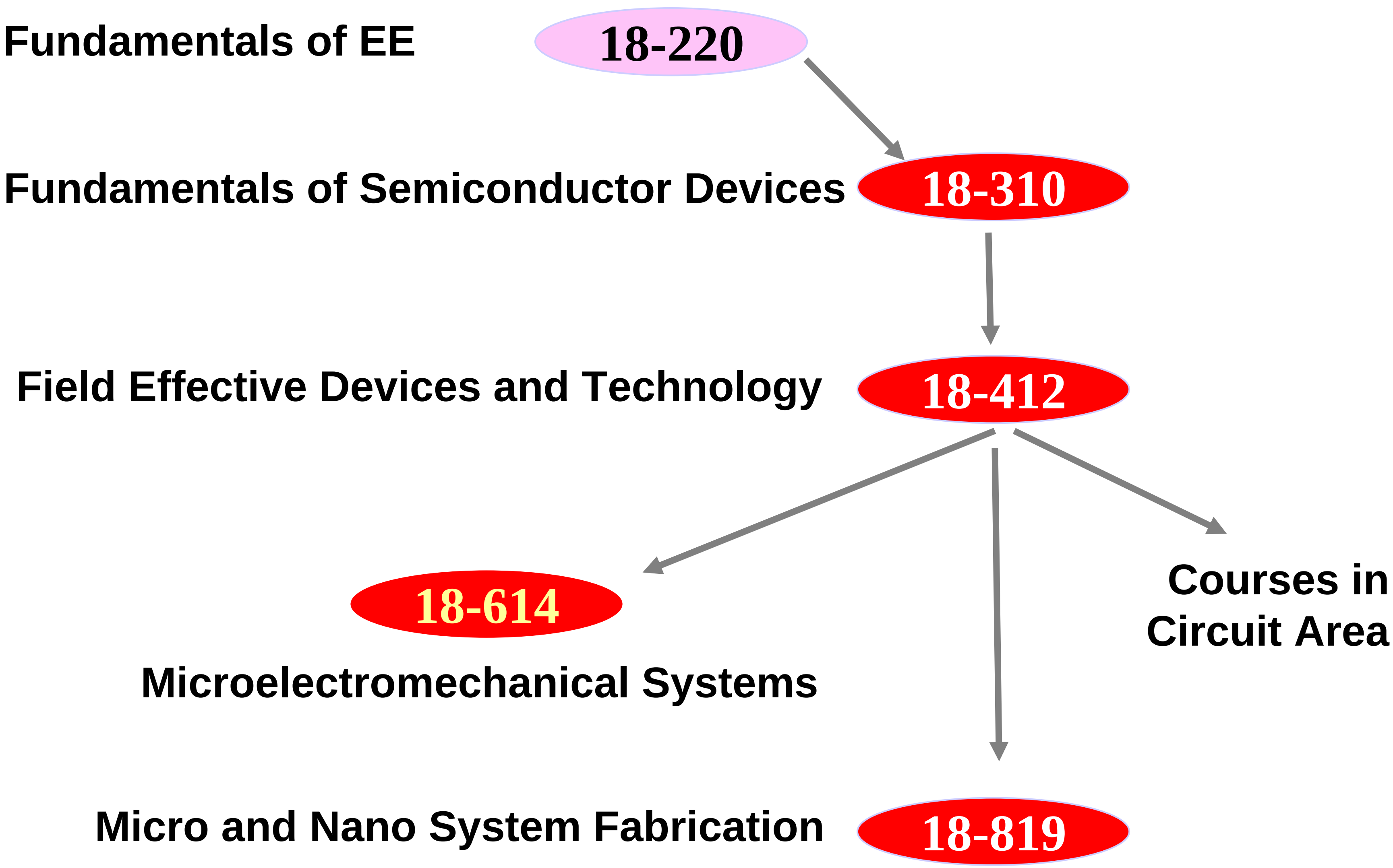


- Course Structure
  - Weekly lectures
  - Weekly labs,
    building to a final device for test
  - Lots of time in nanofab and testing labs

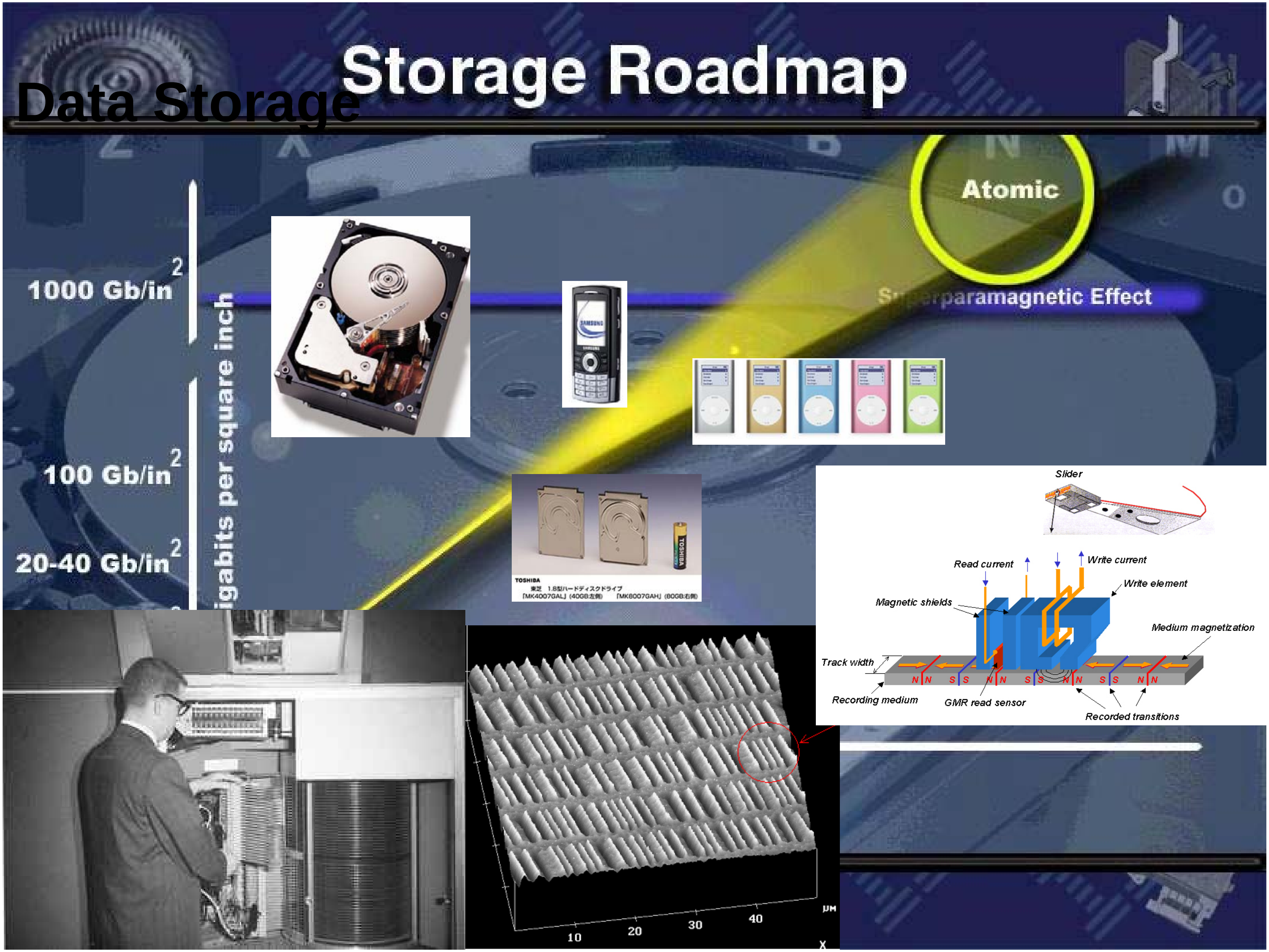
- Course will be renumbered as
  - 18-615 Micro and Nano Systems Fabrication

- Evaluations
  - Weekly lab writeups
  - Journal quality formatting and style

Semiconductor Devices and Technology



Data Storage



18-416: Data Storage Systems Topics

COURSE PHILOSOPHY

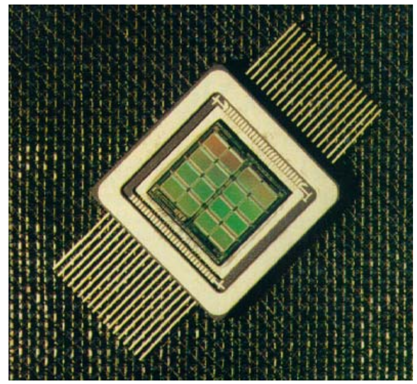
System Performance

Capacity
Data Rate
Shock Tolerance
Data Retention
…

Device Physics

Magnetic anisotropy
Thermal Decay
Device Capacitance & Inductance
Optical Reflectivity …

STORAGE SYSTEMS EXAMINED



Nonvolatile RAM

Hard Disk Drives

Optical Recording

Digital Tape Recording

18-416: Data Storage Systems Structure

- Current Course Structure
  - 6 Problems Sets
  - 6 Labs
  - 2 Exams+ Final

- Labs give hands on experience with recording in a simple devices

18-517 Data Storage Systems Design

Input user data → ECC encoder → Channel encoder → Channel write data

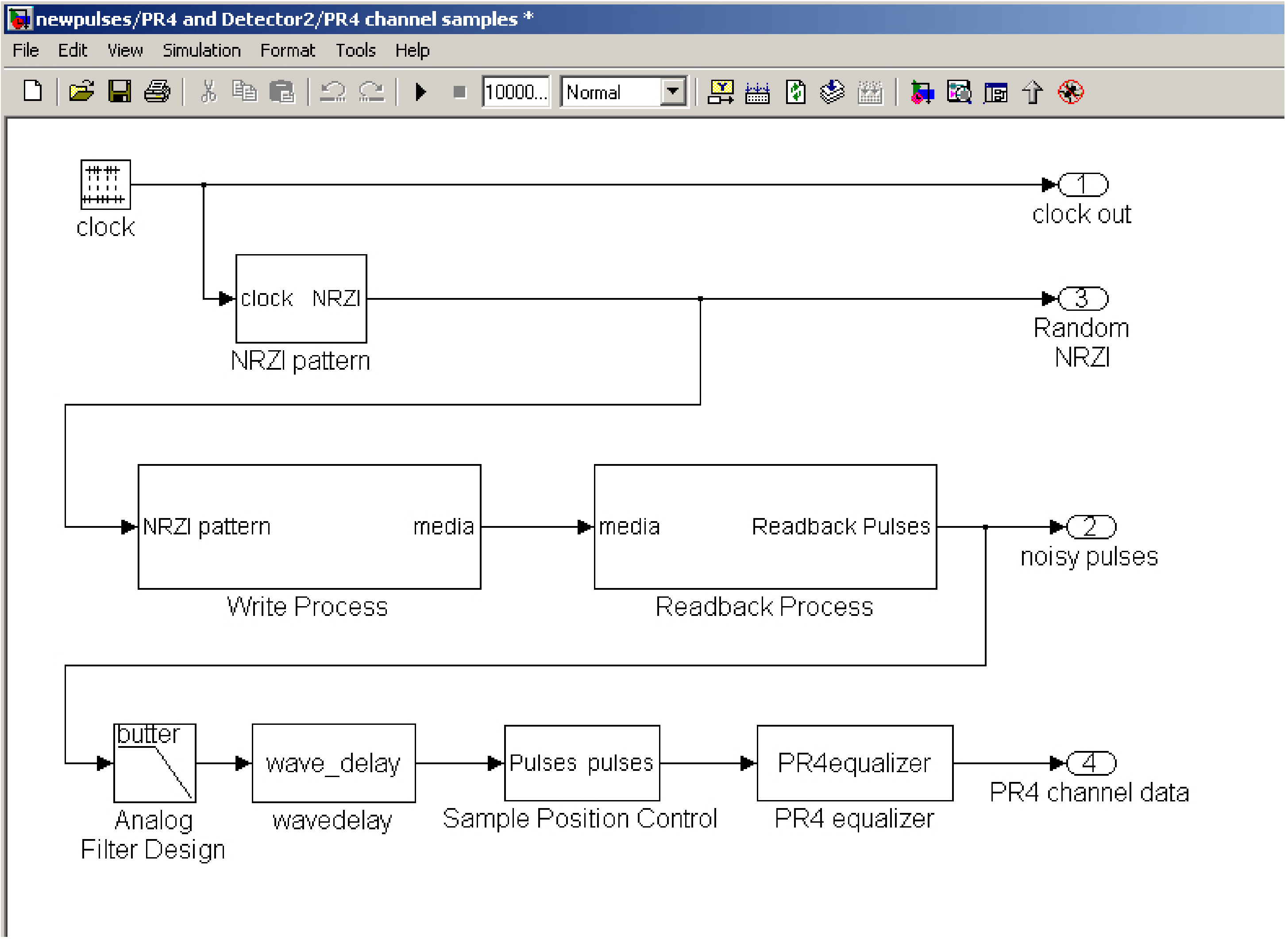
10010110 **110101101** **1011011010**

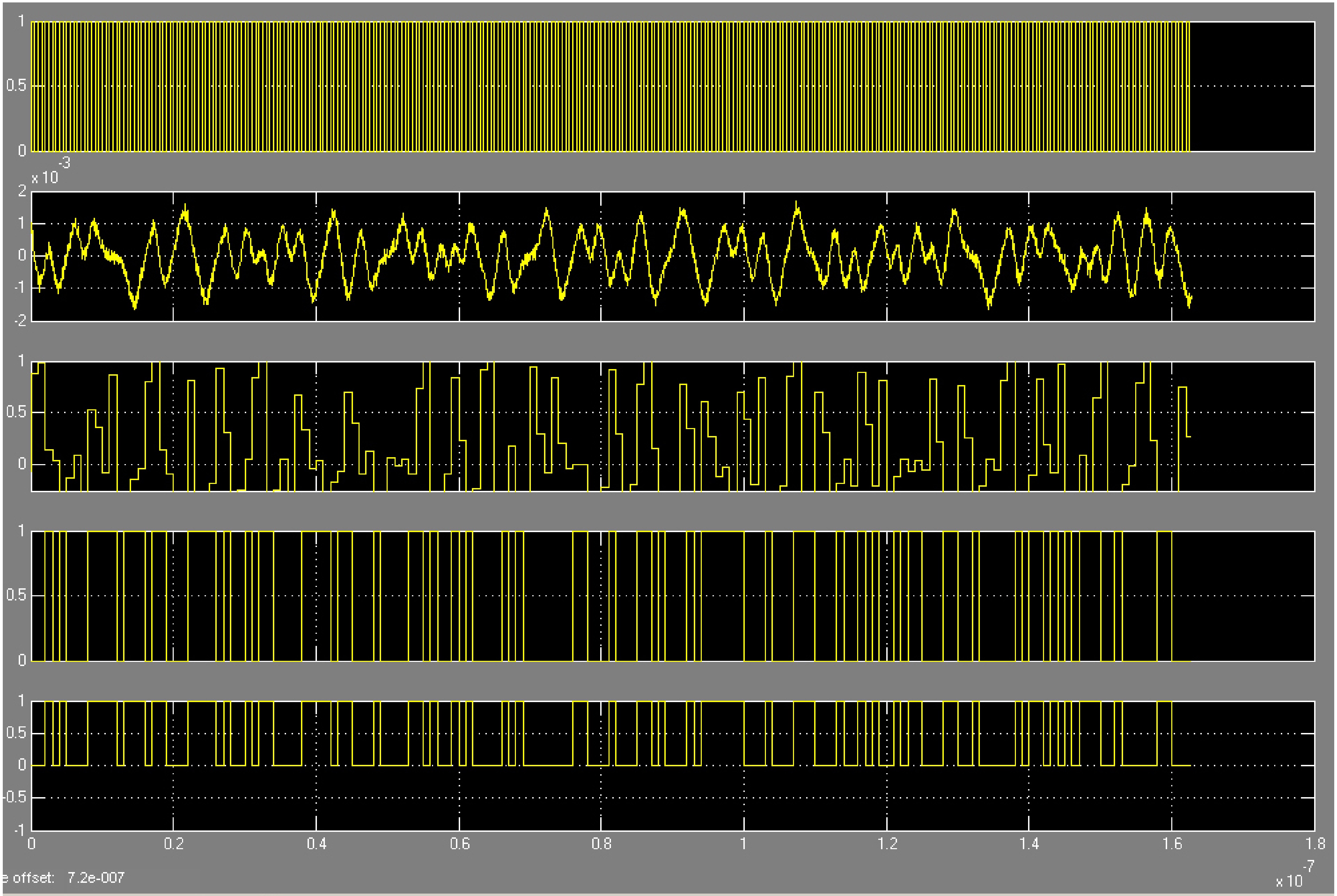
Analog readback signal → Equalizer → Detector → Channel decoder → ECC decoder → output user data

1011011010 **110101101** **10010110**

Electrical & Computer ENGINEERING

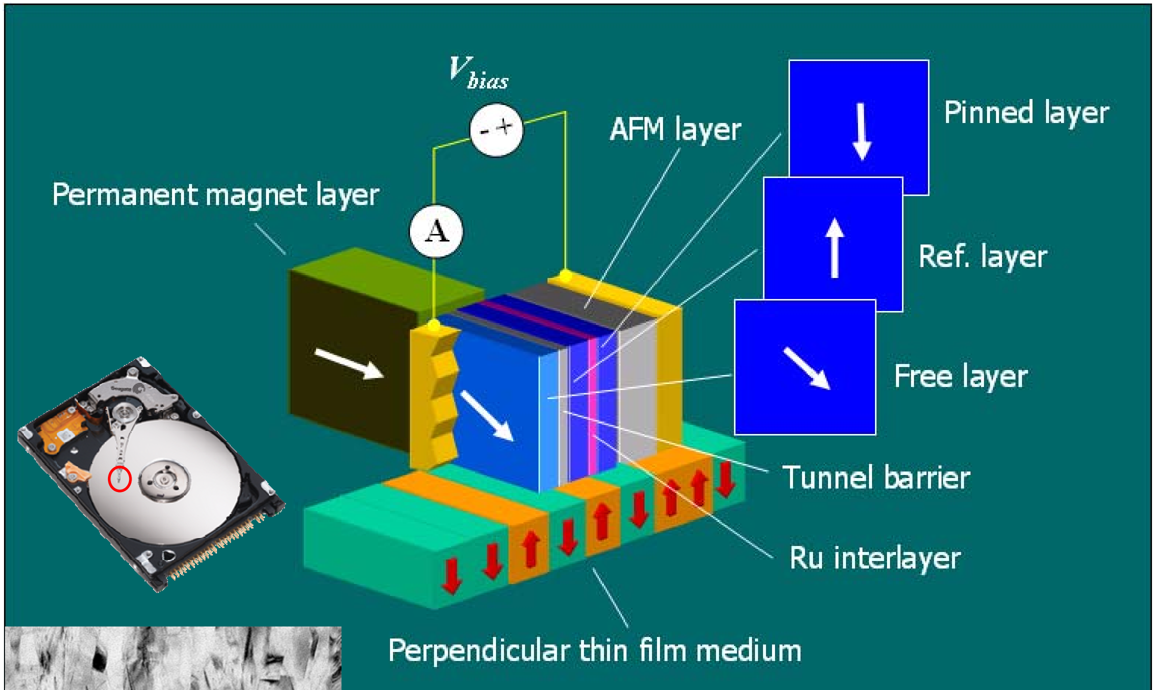
A Matlab Virtual Disk Drive

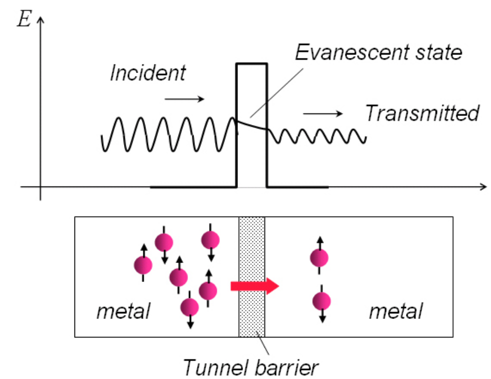




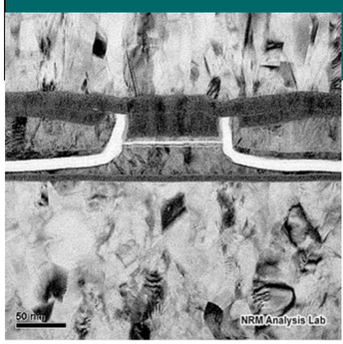
1
0.5
0
x 10^-3
2
1
0
-1
-2
1
0.5
0
1
0.5
0
1
0.5
0
-0.5
-1
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
x 10^-7
e offset: 7.2e-007

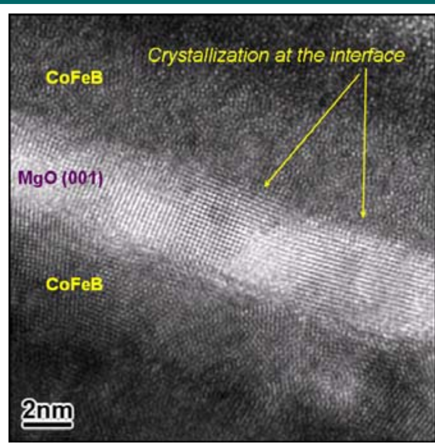
Magnetic Tunnel Junctions (MTJ)

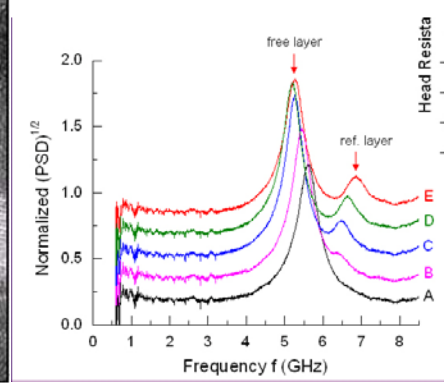


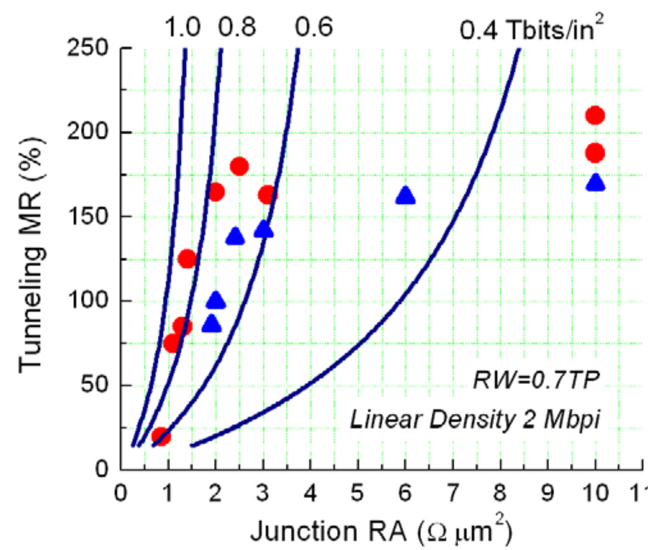


- MTJ enables magnetic flux sensor to be made as small as 10 nanometers.









Electrical & Computer ENGINEERING

Data Storage