PHY 480/PHY 580 Course Outline
PHYSICS OF NANOSTRUCTURED MATERIALS
Spring 2007

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Class time	12-1:50 pm, Each Friday in S-281
Credits:	2-4 credits
Nature	Research based class. The class is open to seniors and graduate students in most scientific disciplines. As the subject is developing at a very rapid rate, it is required that the students conduct extensive and exhaustive search on their own, using vast library database and some of the basic references provide at the end of this document.
Books (Reference)	Nanostructures and Nanomaterials: by Cao Nanostructured and Advanced Materials for Applications in Sensor, Optoelectronic and Photovoltaic Technology, by **Vaseashta** And references (specific to your own topic)
Expectation	PHY 480: A term paper on a topic provided by the Professor.* PHY 580: A term paper (topic must be approved by your professor and the term paper must illustrate your own contribution) * PS 582 (Independent study) (topic must be approved by your professor and the term paper must illustrate your own contribution) * Students will be required to present their work to the class towards the end of the semester. If you are presenting your work in a national/international conference, the presenting author may opt to substitute his/her practice presentation in class with a formal presentation (for grade). Please maintain a portfolio of literature.
Grading	PHY 480: Project (including write up) 75%, Presentation 25% PHY 580: Project (or publication 75%), Presentation 25% PS 582: Project (or publication 75%), Presentation 25% *(All projects, publications, and presentations are based on individual efforts)

Background:
This is a seminar-style course designed to introduce interested students to current developments in nanoscale science, one of the hottest research areas in physics today. The study and manipulation of matter on the nanometer scale is a thriving area of research, with profound implications for technology (e.g. nanoelectronics, nanostructured materials, nanobiology) and pure science (e.g. What is the nature of the transition from quantum to classical behavior?). The aim of this class is to familiarize students with the main issues and techniques relevant to physics on the nanometer scale. Questions that will be addressed include:

- How can we fabricate objects and devices on the nanometer scale?
- What measurement techniques allow us to examine such systems?
- What length, energy, and time scales are relevant when trying to understand nanoscale systems?
- What are the quantum contributions to electrical properties?
- Why don't we see such quantum effects all the time?
- Do we understand electron correlations (magnetism, superconductivity) on these scales?
- Can individual molecules be used as circuit elements?

Course Overview
Nanoterminology and definitions: Classification scheme for Nanomaterials: Top-down versus bottom-up manufacturing. Carbon as a nanomaterial; review of the bonding and properties of diamond, graphite and carbon blacks. Fullerenes; synthesis methods; geometry and properties of buckyballs, higher fullerenes and buckyonions.

Properties, chemical reactivity and applications of C60 thin films and fullerite crystals. Doping of fullerenes. Fullerides.

Nanotubes:

Carbon nanotubes; synthesis methods; geometric aspects of nanotubes. Armchair, zigzag and chiral nanotubes. Mechanical, thermal and electronic properties of nanotubes. Carbon nanotubes for nanoelectronics, field emission sources, gas storage.

Nanowires:

Fabrication strategies, conventional lithography versus self-assembly; quantum conductance effects in metal nanowires.

Semiconductor nanowires; fabrication strategies; quantum conductance effects in semiconductor nanowires; porous Si, nanobelts.

Nanoparticles:

Metal clusters; preparation methods; magic numbers, stability. Metal nanoparticles- preparation; wet chemical synthesis routes; hydrosols and organosols; stabilization mechanisms; cluster compounds; monolayer protected nanoparticles; phase transfer methods; reverse micelles; electrochemical methods; core-shell nanoparticles. Synthesis of high aspect ratio nanoparticles. Synthesis of nanoparticles for environmental remediation

Self-assembly of nanoparticles; definition, driving forces, solvent evaporation methods; 2-D rafts and 3-D supercrystals, particle shape effects, ordered bimodal crystals, nanoalloys, designer interfaces. Electrochemistry of nanoparticles. Introduction to molecular self-assembly. , Self-assembled structures in biology. Organic and inorganic approaches to self-assembly. Self-assembly in supramolecular systems.

Directed self-assembly of nanoparticles; self-assembled monolayers, thiol and silane monolayers; nanostamping, dip-pen lithography; Langmuir-Blodgett films: topological substrate patterning, hydrophobic/hydrophilic substrate patterning; DNA directed self-assembly. Biomineralization and the generation of nanoparticles by bacteria, Molecular machines and devices.

Thermal and chemical properties of metal nanoparticles; size- dependant melting; surface area and chemical reactivity, surface active sites; supported metal nanoparticles as catalysts; Case studies; Au for low temperature CO oxidation; three-way automotive catalyst.

Electronic properties of metal nanoparticles; the Kubo gap, effect of size and temperature on the metal-insulator transition of isolated nanoparticles; the capacitance and charging energy of metal nanoparticles; Coulomb blockade effects and the single electron transistor; Collective electronic properties of nanoparticle assemblies, electron hopping versus interparticle tunneling; Nanosensors, pressure and chemical sensors, nanonoses.

Optical properties of metal nanoparticles: optical absorption and transmission through metal sols and thin films; Rayleigh scattering, Mie theory, surface plasmon resonances; effect of particle size and shape on color.

Magnetic properties of metal nanoparticles: ferromagnetism and superparamagnetism, exchange energy and relaxation time; size-dependant saturation magnetization and coercive fields; future implications for magnetic recording media; targeted drug delivery and therapies based on magnetic nanoparticles.

Semiconductor nanoparticles- fabrication; Cluster compounds, quantum-dots from MBE and CVD, wet chemical methods, reverse micelles, electro deposition, pyrolytic synthesis; self-assembly strategies. Photocatalysis on nanoscale semiconductor surfaces.

Semiconductor nanoparticles- size–dependant physical properties; melting point, solid-state phase transformations; excitons; band-gap variations-quantum confinement, effect of strain on band-gap in epitaxial quantum dots; single particle conductance.

Semiconductor nanoparticles – applications; optical luminescence and fluorescence from direct, bandgap semiconductor nanoparticles, surface-trap passivation in core-shell nanoparticles, carrier injection, polymer-nanoparticle LED’s and solar cells, electroluminescence; barriers to nanoparticle lasers; doping nanoparticles, Mn-ZnSe phosphors; light emission from indirect semiconductors, light emission form Si nanodots. Synthesis of core-shell nanostructures. Environmental applications of core-shell nanomaterials., Chemical sensing using nanoparticles. Hollow nanoparticles.

Inorganic nanoparticles- fabrication; oxidation of metal clusters, vapor phase decomposition, sol-gel processing, colloidal methods, consolidated ceramic nanoparticles.

Inorganic nanoparticles- size-dependant properties; effect of ionicity or covalency on melting point, solubility; quantum confinement effects on bandgap, point defect populations in ionic conductors. Magnetic nanostructures, Computational nanotechnology

Inorganic nanoparticles – applications; Case studies; TiO_2 – photocatalysis, the Gratzel solar cell, opaque-transparent transition in sunscreens; ZnO; sunscreens, pigments, varistors.

Nanoporous inorganic materials; natural minerals, zeolites and pillared clays, surfactant templated MCM materials, anodic dissolution of alumina; applications as catalyst hosts and molecular sieves.

In the last decade there have been profound advances in man's ability to physically interact in numerous ways with small numbers of molecules and even individual atoms. In addition to the fundamental scientific discoveries, practical technologies have been developed and have been rapidly and successfully commercialized. Today's research is likely to lead in the next decade to single electronic memory chips that have more storage than today's largest hard drives, bioprobes that can chemically sense and perform reactions at selected molecules within a single living cell, computing chips that are based on the quantum interference between single electrons, and materials, structures and electronic devices self-assembled through our detailed knowledge of chemical affinities. Thus, nanotechnology is expected to dramatically change electronics, computers, manufacturing, medicine, and the physical sciences over the next several decades. This special topics course will survey the current state-of-the-art in Nanotechnology through selected readings, special topic reports from the students, and invited guest lecturers from researchers in the field.

The objectives of the class are as follows: To survey the current state-of-the-art in Nanotechnology through selected readings, special topic reports from the students, and invited guest lecturers from researchers in the field. To become aware of the opportunities for using currently developed nanotechnology (as well as Nanotechnology that is in a developmental stage) in scientific and engineering activities. To recognize and appreciate the practicality of manipulating small clusters of atoms. To review fundamentals that help to unify ideas from across disciplines and technical areas.

PROPOSED COURSE TOPICS

- ✓ Introduction: R. P. Feynmann, "There's plenty of room at the bottom"
- ✓ Scale sizes across disciplines
- ✓ The Semiconductor Technology Roadmap
- ✓ Carbon nanotubes, nanowires, buckyballs, nanowhiskers, nanoparticles and nanoparticle crystals.
- ✓ Unifying fundamentals: i.e. review of modern physics, de Broglie relationship of waves and particles,
- ✓ band structures in semiconductors and quantum confined structures, basics of organic chemistry leading to pi/sigma bonds, basics of molecular chemistry and cell biology
- ✓ Fabrication: CVD, Lithography, Patterning and its Limits and Challenges:
- ✓ Optical, E-beam, Ion beam, proximal probe, soft lithography, nanoimprinting, atom optics
- ✓ Atomic scale imaging of surfaces: AFM, STM, STPM, RHEED, XPS, TEM
- ✓ Nanoelectronics/Quantum Electronics:
- ✓ Single electron transistor and related quantum devices, molecular electronics
- ✓ Interesting molecular structures
- ✓ Self assembly: Self assembled monolayers, polymer micropillar arrays, DNA based assembly
- ✓ Biological aspects:
- ✓ Biosensors, measurements of biological molecules, applications of biological molecules in device fabrication, molecular motors

Principal References:

Journals:

Journal of Vacuum Science and Technology B.
Science
Nature
Nanotechnology
APL
JAP

Books

General

DiNardo, Nanoscale Characterization of Surfaces and Interfaces. VCH/Wiley (1994)
Marti and Amrein, eds., STM and SFM in Biology. Academic Press (1993)
Hoch, Jelinski and Craighead, Nanofabrication and Biosystems. Cambridge (1996)
Nalwa, ed., Handbook of Nanostructured Materials and Nanotechnology. AP (1999)
Ando et al, Mesoscopic Physics and Electronics. Springer 1998
Vaseashta et al, Nanostructures and Advanced Materials, Springer (2005).

General solid state

H. Ibach and H. Luth. Solid State Physics, an Introduction to Theory and Experiment. Springer-Verlag.
N. Ashcroft and N.D. Mermin. Solid State Physics.
C. Kittel. Introduction to Solid State Physics
P.M. Chaikin and M. Lubensky. Condensed Matter Physics
W. Harrison. Solid State Theory

Nanoelectronics and nanoscale physics

Y. Imry. Introduction to Mesoscopic Physics Oxford University Press.
D.K. Ferry and S.M. Goodnick. Transport in Nanostructures. Cambridge University Press.
S. Datta. Electronic Transport in Mesoscopic Systems. Cambridge University Press.

References:

Quantum corrections to electrical conduction, Landauer formula, conductance quantization

B. J. van Wees, H. van Houten, C. W. J. Beenakker, J. G. Williamson, L. P. Kouwenhoven, D. van der Marel, C. T. Foxon, "Quantized conductance of point contacts in a two-dimensional electron gas," PRL**60**, 848 (1988). - constriction comparable to electron wavelength.

E. Scheer, N. Agrait, J.C. Cuevas, A.L. Yeyati, B. Ludoph, A. Martin-Roderos, G.R. Bollinger, J.M. van-Ruitenbeek, C. Urbina, "The signature of chemical valence in the electrical conduction through a single-atom contact," Nature **394**, 154 (1998). - similar idea, in real metal.

Aharanov-Bohm effect

R.A. Webb, S. Washburn, C.P. Umbach, R.B. Laborite, "Observation of h/e Aharonov-Bohm oscillations in normal-metal rings" PRL**54**, 2696 (1985).

Universal Conductance Fluctuations

W.J. Skocpol, P.M. Mankiewich, R.E. Howard, L.D. Jackel, D.M. Tennant, A.D. Stone, "Universal conductance fluctuations in silicon inversion-layer nanostructures,"PRL **56**, 2865 (1986). - transport sensitive to details of disorder.

T. L. Meisenheimer and N. Giordano, "Conductance fluctuations in thin silver films," PRB **39**, 9929 (1989).; N.O. Birge, B. Golding, and W. Haemmerle, "Conductance fluctuations and 1/f noise in Bi," PRB **42**, 2735 (1990). - transport sensitive to motion of single impurities!

Localization

P. M. Echternach, M. E. Gershenson, H. M. Bozler, A.L. Bogdanov, and B. Nilsson, "Nyquist phase relaxation in one-dimensional metal films" PRB **48**, 11516 (1993). - nice demonstration of weak localization as probe for coherence.

Persistent currents

L.P. Levy, G. Dolan, J. Dunsmuir, H. Bouchiat, "Magnetization of mesoscopic copper rings: evidence for persistent currents," PRL**64**, 2074 (1990).

Other coherence effects

H.C. Manoharan, C.P. Lutz, and D.M. Eigler. "Quantum mirages formed by coherent projection of electronic structure," Nature**403**, 512-515 (2000).

Quantum "dots"

L. P. Kouwenhoven, T. H. Oosterkamp, M. W. Danoesastro, M. Eto, D. G. Austing, T. Honda, S. Tarucha, "Excitation Spectra of Circular, Few-Electron Quantum Dots", Science **278**, 1788 (1997). - dots as model systems.

D. R. Stewart, D. Sprinzak, C. M. Marcus, C. I. Duruöz, J.S. Harris Jr., "Correlations Between Ground and Excited State Spectra of a Quantum Dot", Science**278**, 1784 (1997). - dots as model systems.

D.C. Ralph, C.T. Black, M. Tinkham, Gate-voltage studies of discrete electronic states in aluminum nanoparticles , PRL**78**, 4087 (1997). - dots from nanoscale metals.

Decoherence

E. Buks, R. Schuster, M. Heiblum, D. Mahalu, V. Umansky, "Dephasing in electron interference by a 'which-path' detector," Nature**391**, 871 (1998).

A.J. Rimberg, T.R. Ho, C. Kurdak, John Clarke, K.L. Campman, A.C. Gossard, "Dissipation-driven superconductor-insulator transition in a two-dimensional Josephson-junction array," PRL**78**, 2632 (1997).

P. Mohanty, E.M.Q. Jariwala, R.A. Webb, "Intrinsic decoherence in mesoscopic systems," PRL **78**, 3366 (1997). - do we **really** understand decoherence?

Nanotubes

S. Frank, P. Poncharal, Z.L. Wang, W.A. DeHeer, "Carbon nanotube quantum resistors," Science **280**, 1744 (1998). - coherence at room temperature!

S.J. Tans, A.R.M. Verschueren, and C. Dekker, "Room temperature transistor based on a single carbon nanotube" Nature**393**, 49 (1998).

S.J. Tans, M.H. Devoret, R.J.A. Groeneveld, C. Dekker, "Electron-electron correlations in carbon nanotubes," Nature **394**, 761 (1998). - "dot" from nanotube.

Marc Bockrath, David H. Cobden, Jia Lu, Andrew G. Rinzler, Richard E. Smalley, Leon Balents, Paul L. McEuen. "Luttinger-liquid behavior in carbon nanotubes," Nature **397**, 598 (1999). - the weirdness of 1d systems

Molecular electronics

M.A. Reed, C. Zhou, C.J. Muller, T.P. Burgin, J.M. Tour, "Conductance of a molecular junction," Science **278**, 252 (1997).

S. Datta, W.D. Tian, S.H. Hong, R. Reifenberger, J.I. Henderson, C.P. Kubiak, "Current-voltage characteristics of self-assembled monolayers by scanning tunneling microscopy," PRL**79**, 2530 (1997). - the "contact" problem

H.W. Fink, C. Schonenberger, "Electrical conduction through DNA molecules, Nature **398**, 407 (1999); Danny Porath, Alexey Bezryadin, Simon de Vries, Cees Dekker, "Direct measurement of electrical transport through DNA molecules," Nature **403**, 635 (2000). - fun with DNA.

C.P. Collier, E.W. Wong, M. Belohradsky, F.M. Raymo, J.F. Stoddart, P.J. Kuekes, R.S. Williams, J.R. Heath, "Electronically configurable molecular-based logic gates," Science **285**, 391 (1999); C.P. Collier, G. Mattersteig, E.W. Wong, Y. Luo, K.Beverly, J.Sampaio, F.M. Raymo, J. F. Stoddart, and J.R. Heath, "A [2]Catenane-Based Solid State Electronically Reconfigurable Switch," Science**289**, 1172 (2000). - the wiring problem.

Nanoscale magnetism

T. Shinjo, T. Okuno, R. Hassdorf, K. Shigeto, T. Ono, "Magnetic Vortex Core Observation in Circular Dots of Permalloy," Science**289**, 930 (2000).

W. Wernsdorfer, E. Bonet Orozco, B. Barbara, A. Benoit and D. Mailly "Classical and quantum magnetisation reversal studied in single nanometer-sized particles and clusters using micro-SQUIDs," Physica B, **280**, 264 (2000). - a review.

Nanoscale Superconductivity

A. K. Geim, S. V. Dubnos, J.G.S. Lok, M. Henini and J.C. Maan, "Paramagnetic Meissner effect in small superconductors," Nature **396**, 144 (1998). - nice result, cool technique.

A. Bezryadin, C.N. Lau, M. Tinkham, "Quantum suppression of superconductivity in ultrathin nanowires," Nature**404**, 971 (2000).

Nanoscale thermal properties

K. Schwab, E.A. Henriksen, J.M. Worlock, M.L. Roukes, "Measurement of the quantum of thermal conductance," Nature **404**, 974 (2000).

Self-assembly
E. Braun, Y. Eichen, U. Sivan, and G. Ben-Yoseph, "DNA-templated assembly and electrode attachment of a conducting silver wire," Nature**391**, 775 (1998).
C.M Niemeyer, "Progress in 'engineering up' nanotechnology devices utilizing DNA as a construction material," App. Phys. A, **68**, 119 (1999). **-** a review.

Resources on the web

http://xxx.lanl.gov
http://www.research.ibm.com/disciplines/physics.html
http://www.bell-labs.com/org/physicalsciences/
http://jas2.eng.buffalo.edu/applets/index.html
http://www.zyvex.com/nanotech/feynman.html
http://www.ftf.lth.se/nm/nm.html
http://itri.loyola.edu/nanobase/
http://www.foresight.org/
http://www.foresight.org/EOC/
http://www.zyvex.com/nano/
http://vortex.tn.tudelft.nl/
http://www.lucent.com/minds/innovating/microscapes.html
http://www.park.com/spmguide/contents.htm
http://www.di.com/appnotes/AmLab/AL-SPMMain.html
http://www.almaden.ibm.com/vis/stm/gallery.html
http://www.stanford.edu/group/quate_group/ImageFrame.html
http://www.chem.nwu.edu/~mkngrp/
http://www.cmp.caltech.edu/~roukes/
http://vortex.tn.tudelft.nl/grkouwen/kouwen.html
http://rleweb.mit.edu/rlestaff/p-asho.htm
http://marcuslab.harvard.edu
http://dynamo.ecn.purdue.edu/~datta/
http://vortex.tn.tudelft.nl/grdekker/dekker.html
http://www.physics.berkeley.edu/research/mceuen/
http://www.jmtour.com/
http://www.chem.ucla.edu/~schung/Hgrp/
http://chem.stanford.edu/group/dai/
http://cnst.rice.edu/reshome.html
http://www.ece.rice.edu/~halas/
http://nanonet.rice.edu/

Atomic-Scale Modeling of Nanosystems and Nanostructured Materials (Lecture Notes in Physics). Atomic-Scale Modeling of Nanosystems and Nanostructured Materials (Lecture Notes in Physics). Carlo Massobrio, HervÃ© Bulou, Christine Goyhenex.Â The areas covered are structural determination, electronic excitation behaviors, clusters on surface morphology, spintronics and disordered materials. For each application, the basics of methodology are provided, allowing for a sound presentation of approaches such as density functional theory (of ground and excited states), electronic transport and molecular dynamics in its classical and first-principles forms. The book is a timely collection of theoretical nanoscience contributions fully in line with current experimental advances. I n t e r n a t i o n a l S y m p o s i u m Novosibirsk, June 25â€“29, 2007. [Nanostructures: Physics and Technology 2006] [Nanostructures: Physics and Technology 2005]. Functional nanostructured materials have attracted great attention over the past several decades owing to their unique physical and chemical properties, while their applications have been proven to be advantageous not only in fundamental scientific areas, but also in many technological fields. Spray pyrolysis (SP), which is particularly facile, effective, highly scalable and suitable for on-line [Show full abstract] continuous production, offers significant potential for the rational design and synthesis of various functional nanostructured materials with tailorable composition and morphol