Advanced Project Assignment:

(1) Choose one of the problems in the attached list. OR

Propose in writing (for instructor’s approval) a problem related to nanoscience that is pertinent to your research or of your interest.

(2) Conduct the activities of the problem selected in Part (1) above.

(3) Deliver an oral 5-min presentation of the activities conducted/solution obtained in Part (2) to the class on Wednesday, April 26, 2006.

(4) Prepare a written report of the activities conducted/solution obtained Due Wednesday, April 26, 2006. (Email report to camata@uab.edu)

List of Possible Problems

1. Laser Emission in Semiconductor Nanostructures. Stimulated emission is one of the essential processes in the operation of a laser. This process can lead to efficient emission of coherent radiation (i.e., lasing) if high levels of population inversion can be sustained. Population inversion refers to a non-equilibrium electronic configuration where high-lying energy levels are populated by more electrons than low-lying ones. Population inversion is not an equilibrium condition and requires external energy (e.g., electrical or optical pumping) to be sustained. Very specific combinations of the positions of energy levels and transition lifetimes are also needed to allow population inversion. In semiconductor lasers population inversion is therefore strongly dependent on the density of electronic states. Describe how quantum well, quantum wire, and quantum dot semiconductor lasers, which exhibit low dimensional density of states, offer advantages in laser performance when compared to their thin films counterparts that are characterized by a 3D density of states.

2. Controlling Diameter and Chirality of Single Wall Carbon Nanotubes. One of the elusive goals of carbon nanotube research over the past decade has been the control of the diameter and chirality of single wall nanotubes. Control of the chirality of these nanoscale systems is of particular interest because it determines their electronic properties, i.e., whether a particular nanotube has metallic or semiconducting behavior. Advances in this area could have significant impact in
the use of nanotubes for applications in nanoelectronics. Research the carbon nanotube literature and present a review of the approaches that have been tried as well as the level of success achieved in controlling the chirality of single wall carbon nanotubes.

3. **Scherrer’s Formula and the Grain Size in Nanocrystalline Materials.** Because their wavelength falls in the range interatomic distances, X-rays are very useful in probing the atomic structure of materials. As X-rays pass through a crystalline arrangement of atoms, they undergo diffraction. Diffracted X-rays contain information about the crystal structure of the analyzed materials. In polycrystalline materials, crystalline grains find themselves oriented in a multitude of ways. This gives rise to many X-ray diffraction peaks when an X-ray beam impinges on a polycrystalline sample. As the grain size of a polycrystalline material is reduced below about 20 nm, X-ray diffraction peaks broaden in inverse proportion to the grain size. This behavior can be used to estimate the average grain size in a stress-free nanocrystalline material through the use of what became known as Scherrer’s formula. Explain the basic broadening mechanism of X-ray peaks after diffraction by a nanocrystalline material and present a derivation of Scherrer’s formula and how it is used in practice.

4. **Propagation of Electromagnetic Energy Below the Diffraction Limit of Light.** One of the intrinsic limitations of the use electromagnetic radiation in the processing, manipulation or exploitation of nanostructures is the fact that electromagnetic waves “cannot” be used to deliver and retrieve information below the diffraction limit of light. However, coupled plasmon oscillations between adjacent metallic nanoparticles or nanodots can be used to propagate plasmon modes at the nanoscale. This phenomenon forms the basis of an active research field known as plasmonics and effectively represents the transmission of electromagnetic radiation at length scales well below the diffraction limit. Conduct a literature search and describe the principles, successes, and challenges of this approach for exchange of electromagnetic radiation at the nanoscale.

5. **Gas Phase Production of Nanoparticulate Material.** Direct nucleation from the gas phase is an efficient way of generating nanoparticulate materials for many applications. Discuss how homogeneous and heterogeneous nucleation processes followed by condensation growth in aerosol reactors can be used to create nanoparticle aerosols that can be processed and used in industrial processes to synthesize large amounts of nanophase materials.

6. **Nanocrystalline and Amorphous Diamond.** Besides diamond, graphite, fullerenes, and nanotubes, significant research has been conducted in the past two decades in the fabrication and properties of nanocrystalline diamond and amorphous diamond. These materials combine in very unique way the $sp^3$ bonding that affords diamond some of its key properties such as hardness, inertness, thermal conductivity, to the possibility of low temperature deposition and amorphous matrices with tunable $sp^3/sp^2$ ratio. Review the literature and
present a summary of the current state of research and use in these nanostructured carbon materials.

7. **The Nanomachinery of the Cell.** The modern understanding of living cells and the major advances of molecular biology in the past few decades have unveiled some of the complex nanoscale machinery that goes on inside cells. The ubiquity of liquid water in the cell environment is a major driving force of numerous processes of molecular assembly that lead to sub-cellular nanoscale structures and processes. The hydrophobic effect drives proteins to fold into functional shapes and bind with one another. Such protein binding and folding generates complex nanoscale machines such as protein-synthesizing ribosomes, reinforcing scaffolds like filamentous cytoskeletons, and many other structures. The membranes that define and delimit both cells and cellular sub-compartments like the nucleus and mitochondria also form largely due to the hydrophobic effect, and constitute functional nanoscale systems that are essential for cellular activity. Based on the understanding you developed in this class, particularly on the role of non-covalent intermolecular forces in the self assembly of supramolecular systems, develop a description of the Nanomachinery of the Cell. Integration of concepts from various disciplines such as biology, chemistry, physics, mathematics, and engineering is encouraged.

8. **Nanotechnology in Drug and Gene Delivery.** Numerous nanoscale systems such as biocompatible nanoparticles, biodegradable nano-shells, and fullerenes, are potentially useful for the delivery of chemical agents and even genetic material to living cells. Among the many possible advantages of these systems are the very small sizes, which allow use minute quantities and potentially leading to low toxicity, the possibility of nanostructure-biomolecule conjugation, which may improve the targeting of specific cell types. Conduct a literature search and present an overview of how nanoscale systems are being used in the area of drug and gene delivery. To the extent possible, discuss both, general ideas and principles relevant to delivery of foreign substances to cells through nanoscale carriers and specific protocols that have been attempted to accomplish this task.