QUANTUM MECHANICS FOR NANOSTRUCTURES:
FIRST COURSE IN NANOELECTRONICS FOR ENGINEERS

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The motivation for the development of a new course for undergraduate engineering majors

In the 21st century nanotechnology and nanoscience became a new scientific frontier. The fast and extraordinary progress in nanoscience in the last 15 years is demonstrated by the fact that twelve scientists working in this field were awarded Nobel prizes. We live in the era of nanoscience with anticipated changes as those brought in by the industrial revolution. **Nanoelectronics and nanotechnology are considered to be a revolutionary technology that will help to solve most of current problems facing the world.**
The curriculum in Science and Engineering must evolve accordingly to ensure that universities are keeping pace with the needs of society and industry. One of the ways to do this is to include in the undergraduate curriculum nanoscience and nanotechnology courses at an early stage. The properties of new nanoscale materials, novel fabrication and characterization techniques, applications, as well as the operational principles of nanodevices and systems are solely determined by quantum-mechanical laws and principles. Education in nanoscience has to begin by studying basics of quantum mechanics. **Quantum mechanics courses are taught predominantly in a traditional way** beginning with the history of the development of quantum mechanics, theory of operators, and solution of Schrödinger equation for toy examples from the quantum-mechanical toolbox. **We are developing a different way of teaching quantum mechanics.**

The combined lecture/lab course for undergraduate engineering majors

The new course on quantum mechanics, which we are developing, is a combined lecture/lab course where students will be taught quantum mechanics laws and principles considering different nanostructures, which are the backbone of modern nanodevices. The combination of lecture and lab parts of the course will be done in the following way. For the course adapted for teaching at UB we have following experimental setups for eight groups with two students per group.

Lab 1: Measurement of Planck's constant
Lab 2: Diffraction of light by a double-slit – one photon at a time
Lab 3: Photoelectric effect: waves behaving as particles
Lab 4: Atomic spectra; hydrogen Balmer lines; sodium D-doublet
Lab 5: Introduction to atomic-force (AFM) and scanning-tunneling (STM) microscopy
Lab 6: Study of quantum dots using AFM
Lab 7: Photoluminescence from quantum dots
Lab 8: Reflectance studies of subbands in GaAs/AlGaAs quantum wells.

The following topics are covered in the lecture part of the course:
1. Nanoworld and quantum physics
2. Wave-particle duality and its manifestation in radiation and particle behavior
3. Layered nanostructures as the simplest systems to study electron behavior in one-dimensional potential
4. Additional examples of quantized motion
5. Approximate methods of finding quantum states
6. Quantum states in atoms and molecules
7. Quantization in nanostructures
8. Nanostructures and their applications

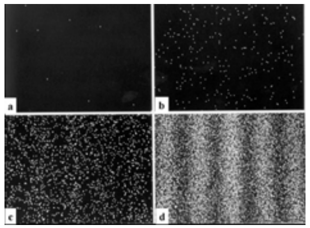

Figure 1. In Lab 2 we demonstrate the wave-particle duality of light quantum – photon. Here we see the build-up of the interference fringes created by photons that pass the double slit one photon at a time.

Teaching strategies for the new course

The main emphasis in both the lecture and lab parts of the combined course is made on the deeper understanding of quantum-mechanical notions and the corresponding mathematics behind it. **It was famously noted by Niels Bohr that anyone who does not feel dizzy learning quantum mechanics for the first time does not understand a word.** Thus, it is important to help students to overcome this dizziness. For this purpose **we will use a Clickers system** for immediate students' response - to control how the undergraduates understand conceptually new quantum-mechanical notions.

Figure 2. The TurningPoint keypad used by UB students for a response in a classroom.

We extensively use Java-applet simulation tools in our teaching. We have already developed several educational Java applets which are available at our website**:** http://www.eng.buffalo.edu/Courses/ee340/. New educational Java applets will be developed. Our experience shows that using applets at recitations and for homework assignments positively affect the students' learning abilities.

Dissemination and outreach

Using lecture and lab materials as a basis, a new introductory textbook for undergraduates as well as a manual with the solutions of homework problems are written and will be published by Cambridge University Press. The lab manual for course will be also disseminated. We have long-lasting collaboration between UB and University of Puerto Rico (UPR). A teaching assistant from UPR has visited UB in July 2009 to participate in the development of experiments from the lab part of the combined course.

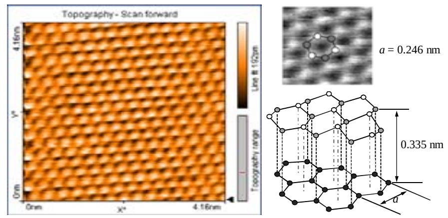

Figure 3. Teaching assistant from UPR Edgar Mosquera Vargas has obtained the image of graphite surface using STM. It is clearly seen that the upper layer of graphite is not flat: the white atoms have no neighbors lying exactly under them in the adjacent layer, while gray atoms have attracting atoms exactly under them in the adjacent layer. Therefore, white atoms are slightly above the plane and gray atoms are slightly below the plane.