NANOTECHNOLOGY: A MULTIDISCIPLINARY APPROACH TO UNDERGRADUATE ENGINEERING AND TECHNOLOGY EDUCATION

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Abstract *—Nanotechnology has been emerged as one of the hot-button fields of scientific study during this new century and rarely has a technology attracted as much publicity within a few years as Nanotechnology. Yet, the study of nanotechnology science is mostly available for researchers and postgraduate level education. The Department of Mechanical Engineering Technology, MET, at the University of Cincinnati has taken the lead to introduce the concept of Nanotechnology Science at the undergraduate level for engineering and technology education. In this context, an introductory curriculum has been established to meet the essential needs for this promising and challenging area of science. The curriculum includes: definitions, a brief history of nanotechnolgy, fabrication of nanoparticles; buckyballs and carbon nanotubes; characterization techniques, concept of nanofluids and smart structures. Perception of nanobiomedical engineering (nanoimplants, nanocarriers in drug delivery, nanobiosensors, cellular and tissue engineering). In this paper, a detailed description for this curriculum is introduced.*

Index Terms—Nanotechnology, curriculum, nanomaterials, nanobiomedical.

INTRODUCTION

Rarely has a technology attracted as much publicity within a few years as Nanotechnology. The scientific journals, via the daily newspapers to the television documentary at peak viewing time. New companies and products are incorporating the prefix "nano" in their name. Everyone wants to get in on the act. As a conclusion; the financial world is sensing a new boom [1]. But what is so exciting about this particular size range? What is so special about phenomena that occur in the world on the scale between one and a few hundred nanometers?

As a matter of fact; when we enter the “nanoworld” in the range from one to a few hundred nanometers; we are dealing with the order of magnitude of molecules: large molecules, for example proteins and synthetic polymers [2]. Working at that level of length scale would create new advanced materials, devices, and systems with new superior properties and characteristics [3]. In general; the fundamental objective of nanotechnology is to model, simulate, design and manufacture nanostructures and nanodevices with extraordinary properties and assemble them economically into a working system with revolutionary functional abilities. Furthermore, nanotechnology offers a new paradigm of groundbreaking material development by controlling and manipulating the fundamental building blocks of matter at nanoscale, that is, at the atomic/molecular level [4]. Based on its promising future, several research initiatives have been undertaken both by government and members of the private sector to intensify the research and development in nanotechnology and hundreds of millions of dollars have been committed [5]. Research and development in nanotechnology is likely to change the traditional practices of design, analysis, and manufacturing for a wide range of engineering products. This impact creates a challenge for the academic community to educate (engineering and other bioscience) students at the postgraduate level with the necessary knowledge, understanding, and skills to interact and provide leadership in the emerging world of nanotechnology. Currently some universities offer selective graduate programs in nanoscience and nanotechnology in collaboration with research centers [4]. Nevertheless, the academic community is reacting slowly to prepare the workforce for emerging opportunities in nanotechnology at the undergraduate level education. At such level, nanotechnology should be taught by creating both knowledge-centered and learning-centered environments inside and outside the classroom [6]. Since the nanotechnology is advancing so fast, activities that encourage creative thinking, critical thinking and life-long learning should be given the highest priority. Because nanotechnology is multidisciplinary; a multidisciplinary curriculum that encompasses a broad understanding of basic sciences intertwined with engineering sciences and information sciences pertinent to nanotechnology is essential [7]. Based on that, introductory nanotechnology courses should be established and taught at the undergraduate engineering and technology education to assist the students facing the challenges presented by nanotechnology. These Introductory nanotechnology courses should be taught more from the perspectives of concept development and qualitative analysis rather than mathematical derivations, [4].

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In this paper, an introductory curriculum for nanotechnology is introduced to the undergraduate engineering and technology education.

COURSE DESCRIPTION

This is an introductory course to nanotechnology science. A working knowledge of the basics in some areas of nanotechnology will be introduced with emphasis on nanomaterials and nanobiomedical applications. The course includes: an introduction, brief history of nanotechnology. Fabrication of nanoparticles; buckyballs and carbon nanotubes as well as introducing their chemical, optical, thermal, electrical, magnetic and mechanical characteristics. Instrumentations and characterization techniques using Atomic Force Microscopy, (AFM), Scanning Electron Microscopy, (SEM), Transmission Electron Microscopy, (TEM), Scanning Probe Microscopy, (SPM). Concept of nanofluids and smart structures. Nanosolar and thermal energy storage in nanocomposites. Perception of nanobiomedical; nanoimplants, nanocarriers in drug delivery, nanobiosensors, DNA-based nanostructures, and cellular and tissue engineering. NEMS and nanodevices.

PRE-REQUISITES

- This curriculum has been designed for the undergraduate engineering and technology education.
- Students from all majors are welcomed to attend.
- Junior standing: undergraduate engineering and technology education.

TEXT BOOK

There is no text book for the course. Instead, there will be references given and assignments to read current research papers and technical review articles that will be available on the web and through the university of Cincinnati library. Some of the material from the lectures will also be posted on the university of Cincinnati black board following the lectures.

NEEDED REFERENCES

- Nanotechnology: Content and Context, C. Kelty and K. Kulinowski, (Rice University, 2005).
- Nanotechnology: A Gentle Introduction to the Next Big Idea, M. Ranter and D. Ranter, (Prentice Hall, NJ, 2003).
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-Nanobiotechnology: Report of the National Nanotechnology Initiative Workshop, 2003. (free download at http://www.nano.gov/nni_nanobiotechnology_rpt.pdf).

GOALS/OBJECTIVES

The main goal of this introductory course is to gain a state-of-the-art understanding of nanotechnology in the context of the issues surrounding it and the history preceding it. In this aspect, a working knowledge of the basics in some areas of nanotechnology will be introduced with emphasis on nanomaterials, nanobiomedical, NEMS and nanodevices.

Additionally, the course will:

- Provide understanding, characterization and measurements of nanostructure properties.
- Prepare students to conduct research and development of economically feasible and innovative applications of nanodevices in all spheres of our daily life.

CLASSROOM PROCEDURE

- The course is ten weeks in duration and consists of three lecture hours per week.
- Students are expected to attend all class periods and contributed to discussion.
- A significant part of the final course grade will rest on participation, determined by attendance at the class sessions or lectures and on actual contributions to class discussions.

STUDENTS' OUTCOMES

- Each student is expected to deliver three presentations:
* First one (Depicting an Application): the student chooses an area of interest in nanotechnology and talks about its main features in details.
* Second one (Expanding a Topic): the student introduces an expanded topic in his field of interest.
* Third one (Article Critics): the student introduces a recent scientific article and criticizes it.
- Research project: each student is expected undertake a small research project to explore the state of the art in his area of interest in nanotechnology.
- The plan is to arrange for project reports to be delivered in oral and/or poster session styles at the end of the term.

GRADING SCALE

- Class Participation 30%
- In-class, short presentation 30%
- Final Project 40%

COURSE OUTLINE

The detailed course outline is shown in Table I.

TABLE I
Course outline

Week #	Topic
Week#1	**Introduction**: - course mechanics and motivation, definitions and brief history of nanotechnology, length scale, nanotechnology is multidisciplinary, importance of nanotechnology, state-of-the-art research projects, self assembly, current and future investments of nanotechnology. **Nanotechnology characterization and modeling**: - measurement, simulation and modeling.
Week#2	**Nanoparticles**: - definition & importance. **Fabrication**: - wet chemical, mechanical, form-in-place, and gas phase synthesis. **Applications** - biomedical, optical, thermal, environmental, magnetic, Mechanical, surface coatings, electronic, and personal care.
Week #3	**Buckyballs** - Carbon atom, carbon allotropes, fullerenes, discovery, definition, types & structures. **Fabrication** - arc discharge method, and Smalley's apparatus. **Properties** Chemical, optical, thermal, and mechanical **Applications** - cagey strategy, drug delivery, superconductors, lubricants, optical devices, and polymer additives.
Week #4	**Carbon Nanotubes** - discovery, definition, types & structures (single wall CNTs, and multi wall CNTs). **Fabrication** - laser ablation technique. **Properties** Chemical, optical, thermal, and mechanical. **Defects** - atomic vacancies **Applications** - biosensors, scaffolds for cell culture, drug delivery.
Week #5	**Nanomaterials and Nanocomposites** - Definitions and fabrication. **Nanofluids** Definition, fabrication, and applications **Smart Structures** Definition, fabrication, and applications
Week#6	**Instrumentation and characterization techniques** - Atomic Force Microscopy, (AFM). - Scanning Electron Microscopy, (SEM). - Transmission electron microscopy, (TEM). - Scanning Probe Microscopy (SPM).
Week#7	**Nanobiomedical**: - introduction, nanoimplants, nanocarriers in drug delivery, nanobiosensors, DNA-based nanostructures, cellular and tissue engineering.
Week #8	**Role of Nanotechnology in Renewable Energies** - Nanosolar, and thermal energy storage in nanomaterials.
Week #9	**- Semiconductors and Nanoelectronics**
Week #10	**MEMS, Sensors, Micro/Nano devices**

CURRICULUM SNAPSHOTS

A summery for chosen parts of the proposed curriculum, [8], will be introduced in the following sections.

Introduction

- Nanotechnology is multidisciplinary approach: Figure 1 shows the main characteristic of nanotechnology.

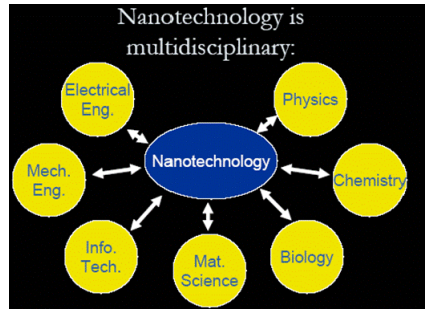

FIGURE. 1
NANOTECHNOLOGY IS MULTIDISCIPLINARY APPROACH.

- Current and future investments: as shown from Figure 2 the investments in nanotechnology have been doubled four times in less than one decade.

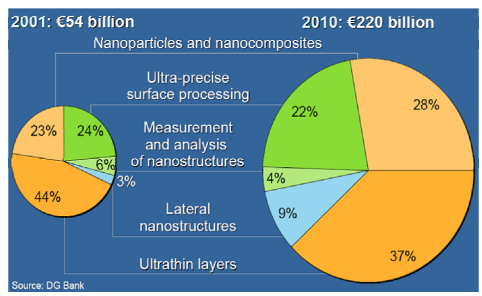

FIGURE. 2
INVESTMENTS IN NANOTECHNOLOGY.

- Length scale: Figure 3 shows that the size of nanodevices would be in the order of magnitude of human cells or even less than them.

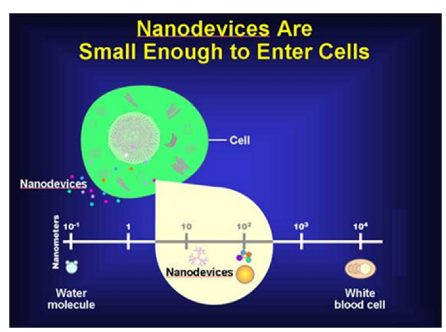

FIGURE. 3
LENGTH SCALE.

Buckyballs

Buckyballs are defined as compounds composed solely of an even number of carbon atoms, which form a cage-like fused-ring. Buckyballs come in all sizes. The best known and most stable fullerene, buckminsterfullerene (C60), nicknamed buckyball). The hollow structure of the (C60) is able to entrap other smaller species such as helium, while at the same time not reacting with the fullerene molecule, Cagey Strategy. Figure 4 shows the structure of fullerene-60 (C60) which contains an entrapped hydrogen molecule.

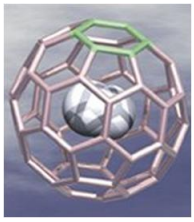

FIGURE. 4
CAGY STRATEGY: DEPICTION OF A MOLECULE OF HYDROGEN TRAPPED INSIDE A BUCKYBALL

Carbon Nanotubes, CNTs

A carbon nanotube is essentially a graphite sheet rolled up to form a hollow tube and sometimes capped with half-buckyballs. The graphite sheet consists of carbon atoms arranged in hexagons, with each atom being bound to three others to form a flat sheet. Figure 5 shows different structures of CNTs.

FIGURE. 5
DIFFERENT STRUCTURES OF CNTS.

Carbon Nanotubes Production

Laser Ablation Technique: a pulsed laser vaporizes a graphite target in a high temperature reactor while an inert gas is bled into the chamber. The nanotubes develop on the cooler surfaces of the reactor, as the vaporized carbon condenses. A water-cooled surface may be included in the system to collect the nanotubes, Figure 6.

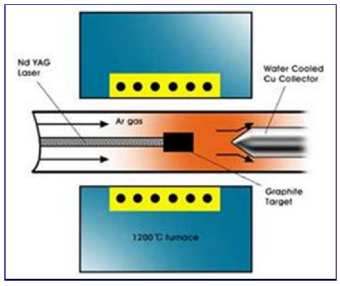

FIGURE. 6
LASER ABLATION TECHNIQUE.

Instrumentations and characterization techniques

The Atomic Force Microscope, (AFM), "eye of nanotechnology": AFM is a very high-resolution type of (SPM), with demonstrated resolution of fractions of a nanometer, more than 1000 times better than the optical diffraction limit. A microscale cantilever with a sharp tip (probe) at its end that is used to scan the specimen surface. Figure 7 shows a block diagram for the AFM.

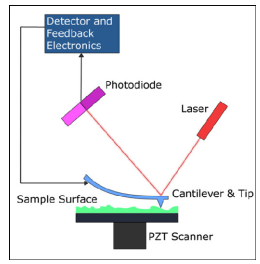

FIGURE. 7
BLOCK DIAGRAM OF AFM.

Smart Structures Based Nanocomposites

Smart structures are capable of sensing and reacting to their environment in a predictable and desired manner, through the integration of various elements, such as sensors, actuators, power sources, signal processors, and communications network.

Case of Study-Experimental Approach

Objectives: develop a smart sensor array based nanofibers for damage and defect detection in structural materials where component inspection is impractical such as buried structure and structure in remote locations.

Applications: applications may include aircraft, spacecraft, bridges, pipelines, wind turbines, and ships.

Hypothesis: the electrical conductivity of the conductive ink changes as a function of applied strain and damage.

Fabrication: a structural health monitoring system consisting of robust conductive ink based nanofibers, and a data acquisition system based on DC-resistance measurement is developed.

Results: Figure 8 shows a crack in conductive nanofiber ink strip showing conductive nanofibers bridging fracture edge.

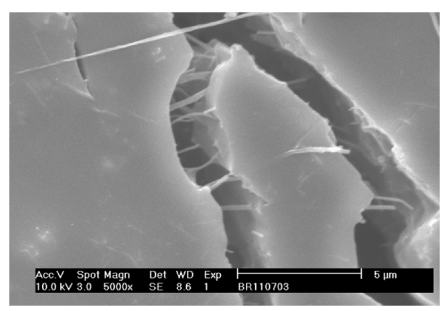

FIGURE. 8
CRACK IN CONDUCTIVE NANOFIBER INK STRIP SHOWING CONDUCTIVE NANOFIBERS BRIDGING FRACTURE

Fabrication of Nanocomposites Based Nanofluids

Nanofluids are fluids that flow within nanoscale passages or fluids that contain nanoscale solid particles.
Importance: they are advanced heat transfer fluids with higher thermal conductivity properties. The presence of the nanoparticles in the fluids increases their effective thermal conductivities and consequently enhances their heat transfer characteristics [9].

Case of Study-Numerical Approach

A two-dimensional simulation model based on Lagrangian multiphase approach for nanoparticle-filled fluid, (Nanofluid), which flows around microfiber matrix, is introduced to investigate and predict the nanoparticles trajectories and their interactions with the fluid flow and the microfiber walls, Figure 9.

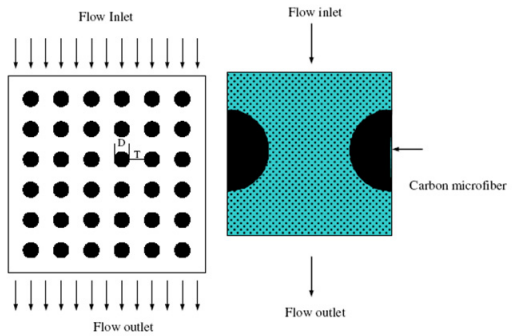

FIGURE. 9
NANOFLUID INFILTRATION THROUGH MICROFIBER MATRIX

Nanobiomedical

Nanoscaffolds: Aoki et al. [10] have made an attempt to development of CNTs as scaffolds for cell culture. CNT scaffolds were formed on polycarbonate membranes by vacuum filtration and cell proliferation and morphology were investigated using a SEM. Bone-forming cell on CNTs have showed excellent proliferation with extension of cell morphology in all directions. The results have also suggested that CNTs can be used as scaffolds with excellent similarity for cell adhesion, Figure 9.

FIGURE. 9
CNTS ARE APPLIED FOR A SCAFFOLD FOR CELL CULTURE

CURRICULUM SHORTCOMINGS

The main shortcoming for the proposed curriculum is that it does not include lab sessions. Nevertheless, the plan is to include the following lab sessions by fall 2010.
- Atomic Force Microscopy Demonstration.
- Synthesis of Carbon Nanotubes.
- Imaging Carbon Nanotubes.

CONCLUSIONS

It is necessary to prepare undergraduate engineering and technology students to face the challenges presented by nanotechnology. A multidisciplinary introductory curriculum that encompasses a broad understanding of basic sciences intertwined with engineering sciences and biomedical sciences pertinent to nanotechnology has been introduced to the students at the undergraduate engineering and technology education. The main goal of this introductory course is to gain a state-of-the-art understanding of nanotechnology in the context of the issues surrounding it and the history preceding it. A working knowledge of the basics in some areas of nanotechnology has been introduced with emphasis on nanomaterials, nanobiomedical, and NEMS. It is highly recommended to include lab sessions in the introduced curriculum. The lab sessions would include (AFM) demonstration, synthesis of CNTs, and at least one of the imaging techniques.

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