AC 2007-2045: APPLICATION OF NANOTECHNOLOGY FOR ENERGY CONVERSION AND STORAGE

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Dr. Kannan's areas of expertise and research interests include low temperature synthesis of meta stable nanoscale electrocatalysts, electrode active materials and structure-property relationships through physicochemical characterization. The focus is mainly on hydrogen and direct methanol fuel cells for stationary as well as automotive applications.

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Application of Nano-technology for Energy Conversion and Storage

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Introduction

Arizona State University at the Polytechnic campus has recently received funding from the National Science Foundation (NSF) under the program called, Advanced Technology Education. One of the project goals is to develop curriculum in the field of *alternative energy technologies* both for four-year and two-year degree seeking students who are pursuing BS and AAS degrees respectively. The department of Electronic Systems at ASU's Polytechnic campus is in the process of launching a new degree concentration beginning fall 2007 within the existing TAC of ABET accredited BS degree program. This paper focuses on a new undergraduate course "**Application of Nanotechnology for Batteries, Solar, and Fuel Cells**", one of the targeted courses that will be developed to highlight the potential of nano-materials in the energy area.

The Electronic Systems Department (ESD) recently received approval from the ASU administration to implement a new concentration, Alternative Energy Technologies both at BS and MS degree levels. The BS degree requires a minimum of 21 credit hours of course work in the concentration area. The course, Application of Nano-technology for Energy Conversion and Storage is one of the required courses for this concentration. The curriculum structure that is adopted in the ESD for course delivery is lecture/lab format to address the different learning styles of our students has received positive feedback from the students with regard to this particular course material delivery. The students in this class will be involved in synthesizing carbon nano-tubes and evaluating them in actual devices in the laboratory. This course emphasizes relevance of nanomaterial for energy conversion and storage applications. The BS degree program is a TAC of ABET accredited program and the course outcomes align with ABET outcomes

Course Objectives

This main objective of this course is to give a theoretical and practical overview of nanotechnology with applications in energy conversion and storage. The specific objectives of this course are to familiarize with nanomaterials, manufacturing processes, characterization and also reliability characteristics. In addition, the course will also provide an opportunity for "co-operative learning" and technical report writing. Upon completion of the course on **Application of Nanotechnology for Batteries, Solar and Fuel cells**, students will understand the fundamental laws governing energy conversion and storage efficiency, the importance of favorable nanomaterials in the energy conversion, and storage application and reliability of materials.

Course Modules

As mentioned in the introduction section, the department of Electronic Systems at ASU's Polytechnic campus is offering a new concentration, Alternative Energy Technology (ALT). The concentration encompasses a detailed exposure to the alternative energy technologies with a special focus on solar-photovoltaic, batteries and hydrogen-fuel cell technologies. The proposed course will be one of the core courses to introduce students to applications of nanotechnology through four different modules. The modules are selected in order to have hierarchy in student learning in three different areas (fuel cells, batteries and solar photovoltaics) of alternative energy technologies. The modular nature of this proposed course will offer the benefit of allowing students to register for varying credit hours depending on their interest/requirement. The course contents are given below in four modules:

1. **Nanotechnology**
   - What is in the nanotechnology
   - Synthesis and characterization of carbon nanotubes
   - Energy related application areas
   - Implications for philosophy, ethics, and society

2. **Smart Batteries**
   - Nanomaterials for anodes
   - Nanomaterials for cathodes
   - Battery performance and cyclability
   - Nanomaterials synthesis

3. **Fuel cells**
   - Role of nanochain, nanofibers, nanotubes in low temperature fuel cells
   - Application areas
   - Fabrication of electrodes and evaluation of performance with nanomaterials

4. **Solar Cells**
   - Band gap and nanomaterials
   - Energy conversion efficiency
   - Performance and reliability of nanomaterials based solar cells

Module 1 deals with the introduction of the basics of nanoscale science, technology, and engineering. Attention will be focused on three basic elements: the fundamental science, engineering and science applications, and the societal implications of this emerging science and technology, relevant to the energy area. The societal issues of nanotechnology are discussed below in detail.

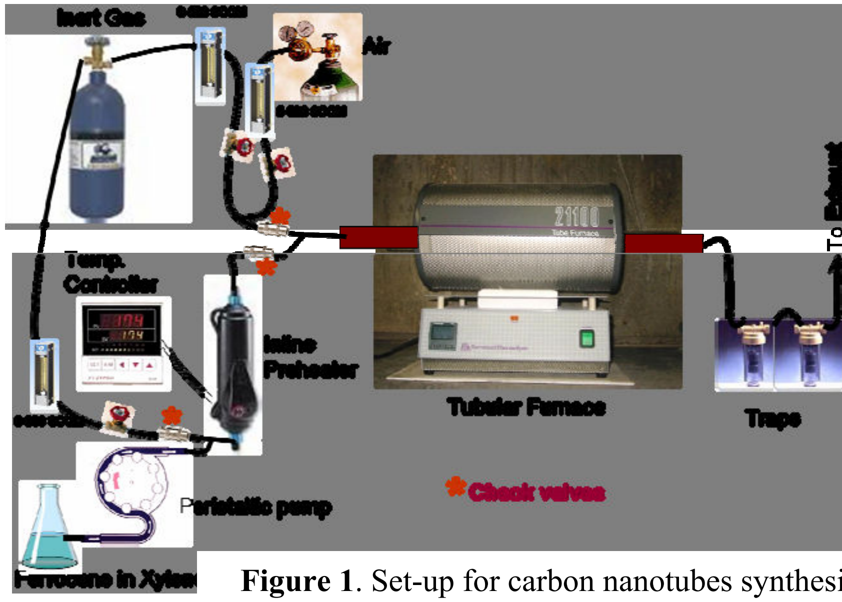


Figure 1. Set-up for carbon nanotubes synthesis

As part of this proposed new course for the Alternative Energy Technology concentration, students will be involved in synthesizing carbon nanotubes and characterizing them using transmission electron microscope. Currently, a set-up carbon nanotubes synthesis is being established at department (see figure 1).

Nanotechnology is seen as a transformative technology that has the potential to stimulate scientific innovation while greatly benefiting society. However, the enthusiasm with which the scientific and technical communities are embracing the technology is being tempered by concerns over possible downsides, including risks to human health. The safety concerns of nanotechnology in energy conversion and storage would be thoroughly discussed. Nanotechnology is leading to the development of new materials and devices in many fields that demonstrate nanostructure-dependent properties. However, concern has been expressed that these same properties may present unique challenges when addressing potential health impact. Airborne particles associated with engineered nanomaterials are of particular concern, as they can readily enter the body through inhalation. Research into the potential occupational health risks associated with inhaling engineered nanostructured particles is just beginning[1, 2].

Maynard and Kuempel[2] explore this idea further, noting that the scale-dependent properties of nanomaterials are not necessarily associated with particle diameter, but with material. Although these two criteria relate to inhalation exposure, they are sufficiently broad to encompass all potential routes of exposure, and provide a useful working framework for distinguishing between materials and products that are less likely to present health risks than those that are more likely to have some adverse health implications. Figure 2 shows some examples of unbound nanometer-diameter particles (in powders, aerosols, and liquid suspensions); agglomerates and aggregates of nanometer-diameter particles, where nanostructure-based functionality is retained; aerosolized liquid suspensions of nanomaterials; and the attrition (or comminution) of nanomaterial composites through various mechanisms[1].

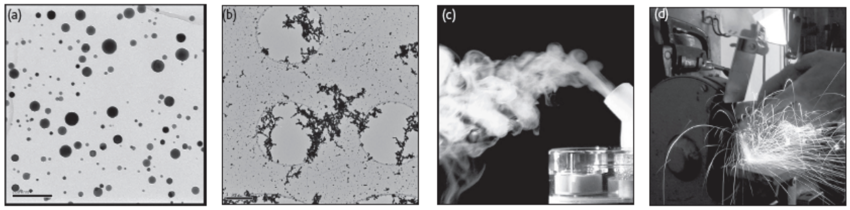
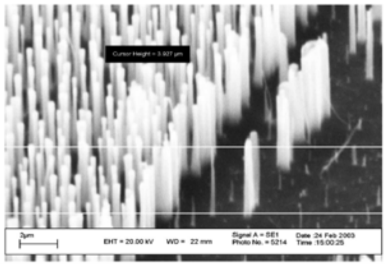


Figure 2. Examples of engineered nanomaterials likely to be of concern to human health: (a) Unbound nanometer-diameter particles (in air or liquids) (b) Agglomerates of nanometer-diameter particles (in powders, air, and liquids) (c) Aerosols of nanometer-structure particle suspensions, solutions, or slurries (d) Particles released while working with or using nanostructured materials, through machining, grinding, or wear and tear[1].

Major ecological concerns associated with sustainability of nanotechnological methods for the production and functional implementation of nanoparticles is very well discussed in a review in the literature[3]. Nanotechnology could be highly beneficial in catalytic applications; however, their dispersion in the environment could make it impossible to take remediative action if safety issues pose concern[4]. Hopefully, governments and industry around the world will continue to ensure relevant risk-research is appropriately directed and well-funded, and that new research will mark a significant reduction in uncertainty over how to assess and manage the risk to health of engineered nanomaterials in the workplace[5].

Module 2 deals with the application of nanotechnology in smart batteries. Today lithium-ion batteries are the power sources of choice for popular portable electronics, such as cellular phones, PDAs, and laptops. Nanotechnology is the best tool for achieving breakthroughs in lithium battery anodes and cathodes. Significant improvements are obtained with nanostructured anode active materials. Figure 3 shows the morphology of silicon nano pillars using a specific template technique[6]. Advanced nanostructured oxide anodes demonstrate high cycling stability and high power characteristics. Synthetic methods play a critical role in attaining the required morphology and crystalline nature of anode materials as shown in figure 4[7].

Improvements on cathode active materials are also critical for the progress of lithium-ion batteries. Considerable efforts are directed to replace the high cost, partially toxic $LiCoO_2$ with more affordable and sustainable materials like $LiFePO_4$ as well as vanadium based cathodes[8, 9]. For example, nanomaterial coated $LiCoO_2$ cathodes were shown to exhibit very high specific capacity with exceptionally high cyclability[8]. Vanadium oxides synthesized at low temperature in nanostructure shows a reversible capacity of as high as 300 mAh/g[9].



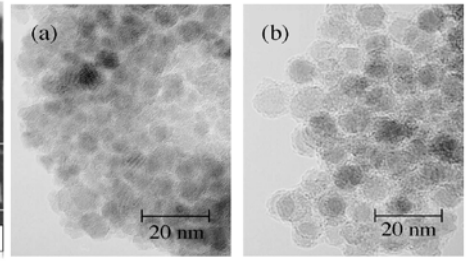


Figure 3. SEM image of a silicon anode having a nano pillar surface morphology[6].
Figure 4. TEM images of (a) as-prepared γ-Fe_2O_3 and (b) after heat-treatment at 400 °C in vacuum[7].

Module 3 deals with the application of nanotechnology in the fuel cells area, more specifically on PEMFCs. The course will focus on the unique properties (electronic, thermal, mechanical, etc.) of carbon nanotubes and nanofibers as catalyst support materials for fuel cell application. A general schematic of PEM fuel cell is given in figure 5. The current research findings of the author will be integrated into the course. For example, nanosized platinum catalyst on multiwalled carbon nanotubes and gas diffusion layer using nanochain/nanofibers carbon will be the key components in this module[10-12]. Several opportunities for students' participation will be created to conduct small projects using carbon nano-tubes that introduce the current literature and research in fuel cells.

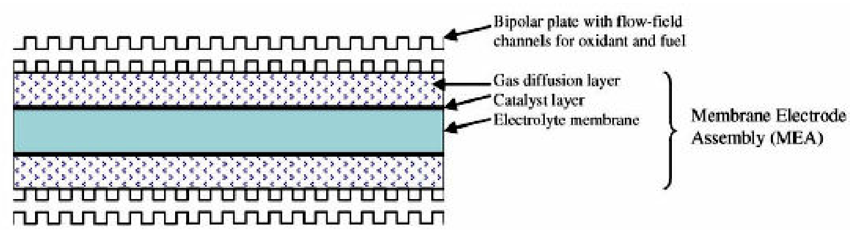


Figure 5. General Schematic representation of Polymer Electrolyte Membrane Fuel Cell.

Module 4 deals with nanotechnology that offers several benefits when making inexpensive and efficient solar cells on a large scale. In this context, nanostructured layers in thin film solar cells offer three important advantages. First, due to multiple reflections, the effective optical path for absorption is much larger than the actual film thickness. Second, light generated electrons and holes need to travel over a much shorter path and thus recombination losses are greatly reduced. Third, the energy band gap of various layers can be tailored to the desired design value by varying the size of nano-particles. This allows for more design flexibility in the absorber and window layers in the solar cell. In particular nano-structured CdS, CdTe and TiO_2 are of interest as window and absorber layers in thin film solar cells[13].

In one of the examples shown above in figure 6, nano-crystalline CdTe films were deposited on ITO coated glass substrates. The particle sizes of 10 nm and a blue shift in the absorption with an effective band gap of 2:8 eV were obtained. This opens the possibility of using nano-crystalline n-type CdTe as a window layer in an n-CdTe/p-CdTe homojunction

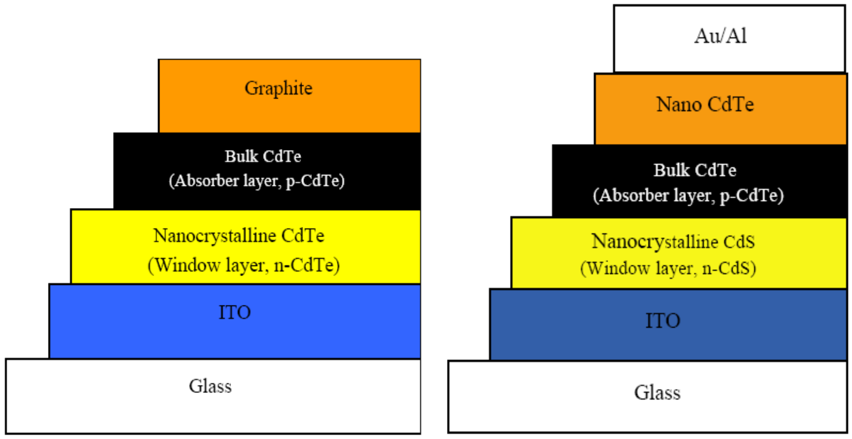


Figure 6. Device configurations of a Glass/ITO/n-Nano-CdTe/p-bulk CdTe/graphite and a glass/ITO/n-nano-CdS/p-bulk CdTe/nano-CdTe/Au solar cells[13].

solar cell. Nano-crystalline CdS films on ITO-coated glass substrates exhibited particle sizes of 15 nm and an effective band gap of 2:98 eV as compared to the 2:4 eV value for the band gap of bulk CdS. This makes nano-crystalline CdS a better window material in an n-CdS/p-CdTe heterojunction solar cell. Also, there is increasing interest in using ZnO as an alternative to TiO_2 in photoelectrochemical solar cells that employ high-surface area, nano-structured substrates. Columnar ZnO films may offer fundamental advantages over nanoporous TiO_2 such as improved electrical transport properties[14]. Nanosized ZnO has recently gained interest as an alternative to TiO_2 in Gratzel-type solar cells.

Conclusion

"**Application of Nanotechnology for Batteries, Solar, and Fuel Cells**" is one of the targeted undergraduate courses developed to highlight the potential of nano-materials in the energy area. Integrated lecture/laboratory format is adopted to allow this three credit hours course to cover the following topics: introduction to the basics of nanoscale science, technology, and engineering. The approach of this industry-responsive course is to offer project-oriented modules which are consistent with the ASU Polytechnic mission of combining academic content with latest industrial practices. The modules offered in this course place broad exposure to the scientific and engineering principles along with hands-on laboratory experiments in various disciplines including batteries, fuel cells and solar photovoltaics. The main focus of the course is providing the overall assessment of key features and issues related to the development of nanoscale science and engineering, emphasizing the interdisciplinary nature of this field. Attention will be focused on three basic elements: the fundamental science, engineering and science applications, and the societal implications of this emerging science and technology, relevant to the energy area.

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