AC 2011-2565: INTEGRATION OF NANOMANUFACTURING RESEARCH INTO CURRICULAR EDUCATION AND OUTREACH

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Integration of Nanomanufacturing Research into Curricular Education and Outreach

Abstract

Research in nanoscience, nanotechnology and nanomaterials has grown in leaps and bounds worldwide over the last decade. A well-trained workforce with a strong grounding in nanomaterials and nanotechnology is a strong national competitive advantage. Research funding from multiple sources has enabled the authors' lab to work with nanomaterials for diverse applications including the electronic, magnetic and, starting recently, biomaterials sector. Processes that continue to be investigated include the pulsed laser deposition process and the magnetron beam sputtering process. Materials are fabricated in the form of thin-film composites, multilayered structures and nanowires. Materials under investigation include Ni magnetic nanoparticles, Ni-TiN-Ni multilayered structures, and TiN nanowires. These materials have been characterized by advanced structural and property characterization techniques including X-Ray diffraction, field Emission Scanning Electron Microscopy and Physical Properties Measurement Systems.

Graduate students and post-doctoral scholars have always been trained and mentored. Careful planning and grant-writing has enabled leveraging of this research work for deployment into curricular education at both the undergraduate and graduate levels. Beyond extending classroom lectures to hands-on participation opportunities and demonstrations in the authors' labs, the students have been afforded the opportunity to experiences a day of touring at a world-renowned national research lab as well as to explore career opportunities. Further, multi-level outreach activities that have been successfully organized utilizing the lab's resources have benefited a large number of the community and other institutions. These include talented young students from community high schools, middle and high school teachers, and community college students and teachers. The paper will survey the innovative approaches, with specific examples, used to enliven the content as well as encourage active participation and discovery-based learning at all levels of learning.

I. Introduction

Rapid advances and innovations in nanotechnology have undoubtedly increased scientific and engineering capacity to create and utilize materials and devices with novel functions through the control of matter at the nanometer scale. Besides, these advances and innovations have also laid the foundation for a paradigm shift in educational opportunities and challenges for engineering education communities to engage the interest and broaden the vision of diverse students in science and engineering, to foster critical thinking and innovation, and to enhance science and engineering literacy. Looking at some of the central roles of nanomaterials in the advancement of computer, communication, medicine, defense and energy technologies, the importance of nanomaterials research and education cannot be overstated. According to recent communications[1-4], the National Science Foundation (NSF) has estimated that the world will require two million trained nanotechnologists by 2015. With only around 20,000 researchers and scientists conversant with nanotechnology at present, universities and colleges around the world are rising to this challenge and offering a rapidly increasing number of courses, at a variety of levels, with 'nano' in their titles. We are actively involved in nanomaterials-based research for the past several years. We have enhanced undergraduate nanoscience and engineering education in the area of devices and systems using the practical approach of direct engagement of graduate and undergraduate students in the advanced laboratories and ongoing research projects. This approach has enabled the students more effectively with the knowledge of the fundamentals of nanoscience and engineering and proficiency to conduct research and develop economically-viable nano-devices with innovative applications in all spheres of daily life. The goal is to expose undergraduate students to the design, manufacturing and characterization of nanostructured material systems and device prototypes. This was accomplished by providing students with classroom instruction heavily aided by hands-on laboratory learning, with a systems emphasis. This papers reports our work on integrating nanomanufacturing processes into curricular education and outreach using the research results obtained by a team of professors, graduate and undergraduate students.

II. Integration of Nanomanufacturing Research into the Curriculum

The first research area involves the manufacturing of nanoscale magnetic particles. This topic has attracted the attention of many research groups and industries throughout the world because the materials produced show outstanding properties as compared to their bulk counterpart [1-2]. An undergraduate student was paired with a graduate student to embed nanocrystalline nickel crystallites in a silver matrix using the pulsed laser deposition (PLD) process at temperature from room temperature up to 400 °C. The deposition temperature was increased beyond 400 °C because the oxidation of matrix materials takes place above 400 °C. Nickel and silver or gold targets were alternately ablated using a multitarget system. The depositions were carried out on sapphire substrates in a high vacuum environment (~ 6 × 10^{-7} Torr). Shown in Figure 1 is the picture of the REU student doing a PLD experiment to make a sample with configuration of$Ag_{1000}/Ni_{3000}/Ag_{200}$ and $Au_{1000}/Ni_{3000}/Au_{200}$, where the subscript refers to number of pulses of laser applied. Figure 2 shows a typical XRD pattern for the Ni nanoparticles embedded in Ag matrix in the above configuration. These were deposited on r-plane sapphire substrates. The result obtained was used in a course focused on Fundamentals of Nanomaterials offered by us in the Department of Mechanical Engineering, entitled MEEN 685 - Fundamentals of Nanoscience and Engineering.

Figure 1. An REU student making a nanostructured sample using the PLD process

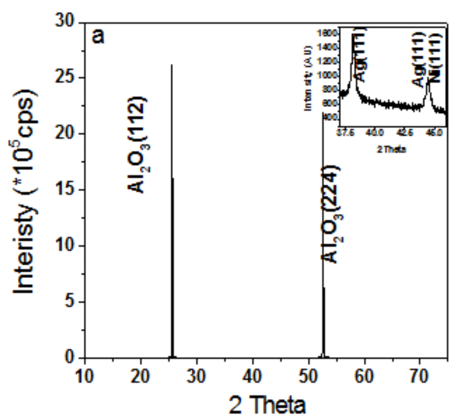

Figure 2. XRD patterns of the Ni nanoparticles in silver matrix.

The second topic related to nanomanufacturing research is the synthesis and modification of titanium nitride nanowires, again using the PLD method. Graduate students have fabricated TiN nanowires on MgO substrate. The schematic diagram of TiN nanowire growth process is shown in Figure 3. After the deposition (Figure 4), the graduate students were required to characterize the samples by scanning electron microscopy (SEM) to examine the morphology of the nanowires (results shown in Figure 5). The successful story of TiN nanowire growth and characterization was incorporated in a graduate course on nanotechnology (**MEEN 785: Nanomaterials**) offered to graduate students. The results obtained in these areas have been published [3-5] and also serve as additional reference study materials for future students of these courses. Hence, students have been involved in active learning and generation of knowledge for future students.

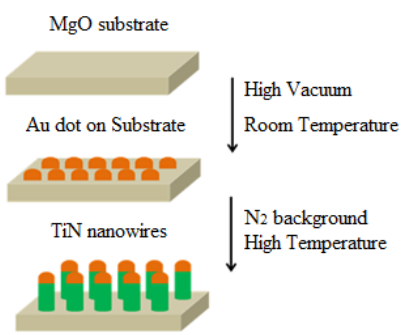

Figure 1. SEM images of TiN nanowires on MgO substrate with different magnification (a) 120 K and (b) 200 K.

Figure 4. Graduate student authors engaged in the PLD assisted fabrication of TiN nanowires.

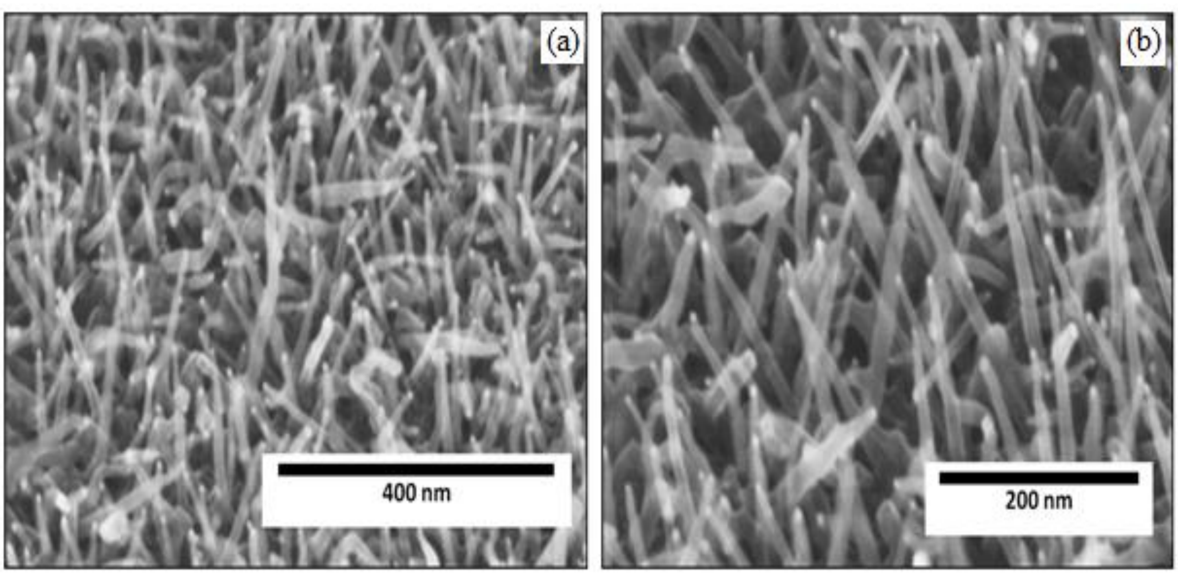

Figure 5. SEM images of TiN nanowires on MgO substrate with different magnification (a) 120 K and (b) 200 K.

III. Student Training and Development

Over 50 undergraduate students, 15 graduate students, and several other researchers have worked on classroom and/or funded research projects led by the authors. They have received training/exposure to research equipments such as PLD, sputtering, thermal evaporation, X-ray diffraction (XRD), atomic force microscopy (AFM), SEM, transmission electron microscopy (TEM), thickness profilometer, physical property measurement system (PPMS), vibrating sample magnetometer (VSM), four probe method, etc. We have also developed two new courses in the Department of Mechanical Engineering that are related to nanoscience and nanoengineering. These courses are: (i) **MEEN 685-Fundamentals of Nanoscience and Engineering**-This course was offered in Spring 2009. The salient topics of this course were: Top-down and bottom-up approaches for nanoparticle synthesis, characterization of nano-materials, nanofabrication by self-assembly and self-organization, bio-inspired self-assembly of nanostructure, molecular electronics, geometry, synthesis and properties of nanoscale carbon, dendrimer molecular architecture of nanoscale polymers, nanoscale polymer additives such as nanoclay and nanosilica. The formative assessment in the form of an anonymous Blackboard based survey was administered to the entire class. (ii) **MEEN 785: Nanomaterials**: This was a special topic course on nanomaterials, offered for the first time at 700 level. The main objectives of the course were to (i) Develop an understanding for nanomaterials technology, (ii) Develop an understanding of new techniques used in studying nanomaterials, and (iii) Understand some of the theory describing differences between nanomaterials and bulky materials. The emphasis was to lead students into the nanofield and prepare them for future scientific and technological exploration through discussing some typical nanomaterials such as nanoscale carbon, nanoarrays, multilayers, organic molecules used in single atom-like devices, and biological motors and gears. The special feature of this course was a day-long visit by all the students to Oak Ridge National Laboratory (ORNL) for seminars and lab tours. The seminar lectures were given by worldwide recognized ORNL scientists in their respective areas. The speakers were Dr. David Christen, Dr. Thomas Thundat, and Dr. Stephen Pennycook (Figure. 6). The lectures were followed by tours to the lab of these three scientists when the students had opportunities to see several state-of-the-art fabrication and characterization equipment in the area of nano and biomaterials such as TEM, STEM (Dr. Pennycook's Lab), high temperature superconducting tape fabrication equipment (Dr. Christen's Lab) and, fabrication of bio sensors systems (Figure.7). The students enjoyed every moment at ORNL and were greatly impressed with your knowledge and accomplishments in the field and facilities. This kind of interaction gives the young students a very different perspective and respect for advanced research.

Figure 6. Lecture by Dr. David Christen, Dr. Thomas Thundat, and Dr. Stephen Pennycook during the visit of MEEN785 class students to ORNL.

Figure 7. Lectures were followed by a group lunch and tours to various labs.

IV. Research Experience for Undergraduate (REU) activities

Due to the continuously disappearing boundaries between graduate and undergraduate education, we have been regarding undergraduate education and research as a forefront task in our research projects. Besides, class-room teaching and mentoring, we actively involve undergraduate students in our research projects. Three undergraduate students worked on the NIRT project with the PI during the summer of 2008; two from off-campus and one from on-campus (Figure 8). The students were exposed and engaged in thin film technology and surface engineered materials research. The intent was to steer them strategically into acquiring the right combination of information, thinking and operational skills that would help them to enter, explore, and succeed in future careers with no boundaries. The three REU students were each able to write a more than fifty page dissertation type report. The reports were then hard bound. The hard-bound dissertation will be a permanent document possessed by each REU student and based on anecdotal feedback from past participants, constitute a point of pride and testament to their quest for advanced research and education. The three dissertation titles are:

1. "Synthesis and Properties of Single and Bimetallic Magnetic Nanoparticles: An Undergraduate Research Experience"
2. "Fabrication and Characterization of Gold/Nickel/Gold nanostructures by the Pulsed Laser Deposition Method: An Undergraduate Research Experience"
3. "Fabrication of YBCO Thin Films with Embedded Nanostructured CeO_2 by the Pulsed Laser Deposition Technique"

Figure 8. 2009 REU participants

V. K-12 Educational and Outreach Activities

The activities under this category consisted of two parts, namely, student-oriented (Young Scholar program) activities and teacher-oriented (Research Experiences for Teachers, Figure 9) activities. The teacher oriented activity involved a six-week research project along with a series of lectures and workshops. One of the two high school teachers selected worked on self assembly of magnetic materials, The other worked on self-assembly of nanodots in high temperature superconducting thin films. student oriented outreach activities included a variety of one-day lab tours, demonstrations of scientific principles, and a two-day camp for high school students.

Figure 9. A high school teacher working on a PLD system with a graduate student (left) and another high school teacher observing the laser plume during PLD of YBCO and Au targets (right).

VI. Students Response and Future implications

The usefulness and effectiveness of nanomanufacturing courses were evaluated using a mixed-method design. Students were required to complete content-specific, pre- and post-tests. A review of pre-/post- assessment data suggests that students experienced positive change-in-learning related to course content, with the greatest strides being made within the domain of Structural Characterization. Similarly, at the end of an outreach activity, especially a camp or a workshop, each student was requested to provide an oral as well as written feed-back about the camp/workshop experience. While most of the students enjoyed the camp/workshop activities, they wanted the duration of the camp/workshop to be extended and also provisions made for even more hands-on experiences. A mother of one of the students also participated in a two-day nanocamp feed-back session who told that her middle school daughter had a most wonderful time in the camp and her interest and science and engineering has enhanced tremendously. The students were also requested to provide their contact information for recruitment for future activities.

With North Carolina A&T State University (NCAT) status as the nation's leading producer of African-American engineers, our efforts toward integration of nanomanufacturing research into curricular education are expected to provide a significant number of underrepresented minority students with training and mentoring focused on the economic and intellectual powerhouse area of nanotechnology. Besides the obvious benefit of attracting the best undergraduates into graduate research, our students will also be engaged in passing on the learning downstream through helping with summer camps for K-12 educators and school visitations to help attract the enrollment of high-quality students from across the nation. The teaching and outreach activities will continue as in the past to impact graduate and undergraduates from all the engineering departments in the College of Engineering at NCAT. The undergraduate students impacted by these initiatives are expected to form an excellent talent pool for NCAT's traditional graduate engineering programs, as well as non-traditional graduate programs newly instituted at NCAT, such as the graduate programs of the ERC-supported Bioengineering master's program and the graduate programs of the Joint School of Nanoscience and Nanoengineering (JSNN). JSNN is a joint venture between two state universities (NCAT and University of North Carolina at Greensboro, UNCG) in Greensboro, North Carolina.

VII. Conclusion

Using research funding from multiple sources, we have worked with nanomaterials for diverse applications including the electronic, magnetic and, starting recently, biomaterials sector. Processes that have been investigated include the pulsed laser deposition process and the magnetron beam sputtering process. University students as well as community participants have directly been involved in the fabrication of thin-film composites, multilayered structures and nanowires. Materials under investigation include magnetic nanoparticles, Ni-TiN-Ni multilayered structures, and TiN nanowires. The participants also gained experience with advanced structural and property characterization techniques including X-Ray diffraction, field Emission Scanning Electron Microscopy and Physical Properties Measurement Systems. Graduate students and post-doctoral scholars have traditionally been trained and mentored by the authors, but careful planning and grant-writing has enabled leveraging of research work for deployment into curricular education at both the undergraduate and graduate levels as well as outreach activities.

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