AC 2010-1785: INSTRUCTIONAL LABORATORY FOR VISUALIZATION AND MANIPULATION OF NANOSCALE COMPONENTS USING LOW COST ATOMIC FORCE MICROSCOPES

Salahuddin Qazi, SUNY Institute of Technology

Salahuddin Qazi is a full Professor at the School of Information Systems and Engineering

Technology, State University of New York Institute of Technology (SUNYIT), Utica, NY. He teaches and conducts research in the areas of Fiber Optics, Optical and Wireless Communication, and Nanotechnology. Dr. Qazi is recipient of several awards including the William Goodell award for research creativity at SUNYIT and engineering professionalism by Mohawk Valley Engineering Executive Committee, and forging closer relations with the IEEE Mohawk Valley section. He is a Senior Member of IEEE and a member of ASEE.

Robert C Decker, Mohawk Valley Community College

Mr. Robert C. Decker is a Professor in the Center for Science, Technology, Engineering, and Mathematics at Mohawk Valley Community College in Utica, NY where he instructs courses in the Electrical Engineering Technology program. His collaborative efforts include curriculum and materials development in highly automated technology and nanotechnology education. He is a member of IEEE.

Instructional Laboratory For Visualization and Manipulation of Nanoscale Components Using Low Cost Atomic Force Microscopes

Abstract

Visualization and manipulation of nanoscale components in the field of nanotechnology has many applications including bottom-up nanomanufacturing and the manipulation of DNA and viruses, prototyping of single electron transistors, and characterization and monitoring of Micro-Electro-Mechanical Systems (MEMS) and semiconductors.

Scanning probe microscopy tools including the scanning tunneling microscope (STM) and the Atomic Force Microscope (AFM) provide the tools for visualization and manipulation of these nanoscale materials. Scanning probe microscopes have been expensive and were used mainly by research universities and high tech industries. However, due to the increasing need for STM/AFM tools for teaching purposes, leading manufacturers of STM/AFM instruments have developed lower cost, high-value scanning probe microscopes with more user-friendly interfaces for student use. Developing new learning facilities and forging collaboration between different academic institutions and industry will lead to new curricula which will help train a knowledgeable workforce with suitable background to meet the demand of nanotechnology based industries.

The purpose of our paper is to discuss the results of establishing an instructional lab for the visualization and manipulation of nanoscale components using low cost AFMs for two and four year engineering technology programs. Development of an interdisciplinary minor in nanotechnology will also be discussed. This effort is supported through the National Science Foundation under the Course Curriculum Laboratory Improvement (CCLI) program.

Introduction and Background

Recent growth in the field of nanotechnology has put a new demand on educators to train a knowledgeable workforce in this field with suitable background to meet the demand of nanotechnology based industries. According to Jack Uldrich [1] of Nano Veritas, the U.S. will need between 1 and 2 million new workers trained in nanoscience, with a majority requiring skills that must be taught at undergraduate level. Developing new learning facilities and forging collaboration between different academic institutions and industry will lead to new curricula which will help to meet the demand for technical personnel.

SUNYIT (State University of New York Institute of Technology) located at Marcy, New York and MVCC (Mohawk Valley Community College) located at Utica, New York, are currently teaching and developing courses in the area of nanotechnology, MEMS and semiconductor manufacturing technology in their practice oriented engineering technology programs. Both institutions are also involved in introducing elements of nanotechnology in other courses and programs. In order to provide hands–on instruction for these programs, it is important to include experimental study of ultra-small scale phenomena from the micro scale down to the atomic scale by way of visualization and manipulation of nanoscale components. Nanoparticles, such as quantum dots and nanowires, DNA, carbon and other polymer molecules promise a variety of potential applications from data storage to single electron devices, nanoelectromechanical systems and nanophotonics. Inclusion of the experimental study of ultra- small scale phenomenon in engineering technology programs is important to train the students in the field of nanotechnology. This form of study enhances their understanding of the material world down to the smallest levels of matter, the nano-and atomic scales where intuition and text book examples alone are not sufficient [2].

One instrument used in the study of ultra small scale phenomena by way of visualization and manipulation belongs to the family of scanning probe microscopy (SPM), known as scanning tunneling microscope (STM). This device was invented by Binning and Roher at IBM Lab, in 1981. The other member of this family is the Atomic Force Microscope (AFM), invented in 1986. In both the AFM and STM, the measurements are performed with a sharp probe scanning over the surface while maintaining a very close spacing to the surface. The measurement in STM relies on electron tunneling from the tip to the sample surface and the resulting tunneling current varies with tip-to-sample gap and this signal is used to create an image. STM is used to generate real-space image for conductive surfaces. The AFM measures the topography by detecting the forces between the tip and the sample, which can be insulator, semiconductor or an electrical conductor. This technique is non destructive and can be performed in air both for conductors and insulators. It can be easily applied to physiological environments to investigate biological samples and also has the potential of measuring small forces on a local scale [3, 4, 5]. AFM can also be used as a manipulation tool to move and arrange nanoparticles and to build nanostructures. Currently, particles of around 10 nm are routinely manipulated with AFM and it has been utilized in applications such as prototyping single electron transistor, building of templates such as stamps or molds and manipulation of biological molecules [6,7,8,9]. The imaging capability of AFM combined with manipulation allows precise control of nanoscale components over which nanostrucures are moved and characterized at each step of manipulation or assembly.

Scanning probe microscopes have been expensive and were used mainly by the research universities and high tech industry. However due to the increasing use of AFM for teaching purposes, the leading providers of AFMs have developed low cost, high-value scanning probe microscopes. The goal of our project is to set up an instructional lab using low cost AFM and develop instructional material for visualization and manipulation of nanoscale components for two and four year engineering technology programs. The paper will discuss our efforts in establishing an instructional lab after the first year of our award. The following sections discuss the proposed instruction modules, provide a list of courses in which these modules will be used, and discusses the project accomplishments and the development of interdisciplinary survey minor in nanotechnology at SUNYIT. The paper also gives conclusion based on our study, references and an appendix for bid specifications of AFMs.

Instructional Modules

The project seeks to establish specialized laboratory facilities and curriculum support materials for engineering technology programs currently offered at the SUNYIT and at its partner institution MVCC which are both units of the SUNY system. Applied technology programs of study common to these facilities include electrical engineering technology (EET), mechanical engineering technology (MET), and civil engineering technology (CET). In 2001, MVCC established a semiconductor manufacturing technology (SMT) associate degree in applied sciences (AAS) program. Preliminary articulation agreements for continued study in the EET and MET program have also been developed with SUNYIT. SUNYIT and MVCC are partners in a cross-registration program that facilitates student enrollment in non-duplicated courses offered at each campus. SUNYIT and MVCC have long-standing articulation agreements for continued study at the baccalaureate level and have developed joint admissions agreements for these programs that have been in place since 2002. To achieve further collaboration the two institutions have embarked on a joint project relating to developing instructional material for their hand-on programs curriculum in engineering technologies.

The following proposed instructional modules, featuring visualization and manipulation of nanoscale components using low cost AFM, can help the educational institutions provide an understanding of ultra small scale phenomena and also help train a workforce to meet the demand of nanotechnology based industries set to drive our economy.

1. Study of visualization by way of imaging using AFM in contact mode, tapping mode and phase imaging mode
2. Study of visualization by way of using AFM in Lift Mode allowing separate and simultaneous imaging for topographical images of electric and magnetic forces
3. Imaging of silicon wafers, thin films, metals, insulators, and photoresist, polymers using tapping mode
4. Imaging of composite material, microphase separation pattern of untreated thin film and coatings using phase imaging mode
5. Imaging of carbon nanotube for defects, polysilicon material for surface roughness and of MEMS for cracks and flaws
6. Study of AFM for manipulation of nano particle, nano tubes and nano wires
7. Nanopatterening and nanolithography
8. Manipulation of carbon nanotube for making nano wires

Teaching Strategies

In terms of pedagogical model, the intent is to identify the need for visualization tools and the capabilities and operation of AFM tools. In this case, the methodology will be to introduce visualization methods, identify the technology used in AFM and other related technologies, and follow this with hands-on directed activities. Evaluation through observation of performance and written instruments conducted in process will be used. An example of such activities is given below:

1. Interactive Power Point lecture with student materials provided on SPM principles to include need for high magnification visualization tools, scanning tunneling microscopy, static and dynamic AFM, static mode, tapping mode and other dynamic modes.
2. Individual Assignment – Web-based research activities about AFM Tools. Students will be directed to research the operation of the AFM utilizing web-based

software simulation tools and completing a K-W-L sheet prior to lab.

3. Group Activity – Imaging Samples Using AFM
   Students will work in teams of three. Each team will perform sample preparation and a second team will use one of the AFM instruments to perform imaging on prepared samples. Each team will rotate assignments to use the analysis software utilizing another team's sample data. Following this activity, the teams will re-assemble to report out on the imaging and discuss results. Imaging of the same samples will be performed on both instruments and comparisons between instruments will be made.
4. Second Activity – Post-processing and analysis of software.
   - Interactive Power Point lecture with student materials provided on Post-Processing software used with AFM, Software tools, Capabilities and Data Interpretation
   - Laboratory Activity
     Students will work individually to further utilize post-processing software for analysis of previously gathered visualization data. Students will provide written report on sample data analyzed.
5. Review of Materials
   Teams previously assembled will prepare a set of questions on the material covered in the lecture and activities. Each team will present questions for discussion to the instructor. Questions will be used in assessment tools with additional questions as deemed necessary by the instructor.

<u>Courses in which the Instructional Modules will be used</u>

The proposed modules will be piloted to enhance the experimental understanding of ultra nano-scale phenomena in the following courses at the SUNYIT and MVCC.

- Introduction to Nanotechnology (ETC 290). Currently offered as 2 credit course will change to 3 credit by introducing lab activity using AFM
- MEMS based Nanotechnology (ETC 392). Currently offered as 2 credit courses will change to 4 credits by adding extra material on NEMS and introducing lab activity using AFM. The new course is named as Fundamentals of Microelectromechanical Systems (MEMS) and Nanoelectromechanical systems (NEMS)
- Nanotechnology Research (ETC 495). A new 3 credits course introduced for the interdisciplinary survey minor in nanotechnology
- Wireless Communication Systems (ETC 421) contains elements of nanotechnology like radio frequency (RF) MEMS
- Optical Communications (ETC 483). Contains elements of nanotechnology including optical MEMS. It one of the capstone courses for students of electrical engineering technology department.
- The modules will also be extended to other courses including, Thin Film Technology, VLSI design, Manufacturing Processes, whenever they are offered. Web access is also planned to increase the usage.

In the two-year program at MVCC, Introduction to Semiconductor Manufacturing (ET 289) course is included in the plan of study. Certain features and structures in semiconductors can be visualized with the AFM equipment. In addition, High Vacuum Technology (ET 290) is also part of this program. Investigation of thin films in this course using the AFM as a visualization tool will be included. It is our intent that the technicians will have an opportunity to gain hands-on experience with the AFM as a measurement tool from these activities.

We will also be using these instructional facilities in the summer camps on Nanotechnology for secondary school students and teachers. The PI provided one presentation in one of these camps last summer. These presentations introduce concept of scale and dimensions to students and provide real –world example of nanotechnology with the intent of developing their interest in science in science, technology, education and math (STEM) programs.

Project Accomplishments

We are currently in the second year of the award and we will be seeking extension for an additional year. The project accomplishments during this time included selecting our first AFM, and using it in our classes and demonstrating it in various presentations. We also arranged a workshop on AFM for engineering technology faculty at MVCC and sought feedback for further work and improvement. An interdisciplinary survey minor in nanotechnology was also developed for undergraduate students at SUNYIT. A second, more advanced desk top AFM is in the final process of being purchased. The details of our accomplishments are given below:

- After receiving the award in May 2008, we researched into the availability of low cost educational AFMs to provide hands on experience to our undergraduate engineering technology students. Based on our budget and the availability of AFMs, we decided to purchase two AFMs, first a basic portable model costing approximately $ 40-50 K followed by a more advanced second desk top model costing $ 60-70 K. In order to prepare bid specification for the appropriate AFM, we participated in various workshops, consulted faculty from other Institutions using AFMs, and invited AFM manufactures to demonstrate their products. The presentations and demonstrations included "Surface Characterization by Atomic Force Microscopy" by Veeco Instrument at SUNYIT which was attended by the students and faculty from two year and 4 year engineering technology programs.

In our research, it was found that the available instruments varied in the level of standard and optional features including the capabilities of imaging in air as well as liquids. All of the instruments we encountered included both contact force and intermittent contact mode imaging, and as such, this was included as a basic requirement in the bid specification. Ease of replacement of cantilever tips and cost of these tips was also a consideration in the selection of the AFM. A bid specifications, as given in the Appendix (A) was developed and sent to various manufactures of AFMs. We selected our AFM based on the quotations received from Veeco Instruments, Nanoscience Inc., and Agilent Inc.

Our first AFM was also purchased with the goals of low cost and portability in mind so that we could use it at both campuses. We selected Nanoscience EasyScan AFM, a portable model for educational purposes.

- After receiving basic -training from the manufacturer we demonstrated the use of AFMs in various classes at SUNYIT and MVCC. The students of MEMS Based Nanotechnology (ETC 392) course at SUNYIT used the manufacturer's manual to become familiar with the AFM and, made some basic measurements. We are currently developing instructional material for the basic model and are awaiting the delivery of the more advanced AFM system to develop further instructional modules. A presentation on the "Visualization and Manipulation of Nanoscale Component Using Low Cost AFM" was made at the New York State Engineering Technology Association Spring 2008 conference for faculty and students of two year and four year engineering technology programs.

- A workshop was offered to MVCC faculty to demonstrate the visualization of a few samples with the objective of generating some questions on potential usage in different departments. From that, we developed a plan for a longer professional development workshop. The following workshop survey was used to generate post-workshop questionnaire given below.

  1. Were you familiar with atomic force microscopy prior to the workshop?
  2. Do you have a better understanding of the operation of an AFM?
  3. Did you have any ideas of applications for this tool prior to the workshop?
  4. If so, what were they?
  5. If you didn't have any applications in mind prior to the workshop, do you have any now?
  6. If so, what are they?
  7. Would you be interested in attending a longer workshop on AFM?
  8. If so, how long (half day, full day, etc)?
  9. What areas would you like to see addressed in a workshop on AFM?
  10. Please indicate your academic area (e.g. science, engineering, technology, etc).

Feed back by the participants showed interest in pursuing the use of AFM for physical and biological science programs as well as the semiconductor and materials science areas identified earlier and an increased understanding of the applications for AFM.

- A second, more advance desk top AFM has since been ordered. The CALIBER SPM SYSTEM, manufactured by Veeco Instruments is designed to provides a highly affordable solution for materials and surface sciences, polymer studies, thin films and coatings, as well as biomaterials and inorganic. It performs tapping mode, phase imaging, and Lift Mode, Contact, Lateral Force Microscopy (LFM) and Point, Spectroscopy (force-distance measurements. It also performs Magnetic Force Microscopy (MFM) with an optional MFM tool kit and Nanolithography with complimentary Nano Plot Nanolithography Software and permits analysis of any size sample in air. Nano Plot Nanolithography Software enables creation of lithographic patterns on sample surface by AFM. We have also ordered additional 10-micron Clip mount Z-scanner for operation in Liquids and STM Scanner Option consisting of the actual xyz scanner, a preamplifier, necessary cabling, and a stage file, table top vibration isolation platform and different type of cantilevers and microlevers with Gold reflective coating.

Interdisciplinary Survey Minor in Nanotechnology

To capture the interest across disciplines an interdisciplinary survey minor in nanotechnology has been developed for undergraduate students at SUNYIT. The following description will appear in the college catalog:

Nanotechnology has many commercial applications in the area of health care, computer technology, manufacturing, environment, agriculture and others. Its full implementation will have a broad economic and social impact. According to the National Science Foundation (NSF) products incorporating nanotechnology will contribute approximately $1 trillion to the global economy by the year 2015. About two million workers will be employed in nanotechnology industries, and three times that many will have supporting jobs.

An interdisciplinary survey minor in nanotechnology is proposed for students majoring in engineering, engineering technologies, computer sciences, natural sciences, nursing and health studies, business and telecommunications. The minor will provide knowledge and skills valuable to students planning to seek employment or graduate studies in fields related to microelectronics, information storage, optoelectronics, pharmaceuticals, agriculture and medicine.

Nanotechnology is inherently interdisciplinary and bridges across physics, biology, material science, and chemistry. This interdisciplinary minor survey program in nanotechnology requires 20 credits of which 12 credits in group two must be taken at SUNYIT.

Group one: (8 credits)

- PHY 101 General physics
- CHE 110 Essentials of Chemistry
- BIO 101 Introduction to Biology

Group two: (12 credits)

- ETC 290 (3 credits) Introduction to Nanotechnology
- ETC 392 (4 credits) Fundamentals of Microelectromechanical Systems (MEMS) and Nanoelectromechanical Systems (NEMS)
- MTC/ITC 336 (2 credits) Material Science Applications
- ETC 495 (3 credits) Nanotechnology Research

Suggested courses in student's major which may be taken as elective

- ETC 455 VLSI Design Fundamentals
- ECE 332 Semiconductor Devices
- MTC/CTC 461 Fluid Mechanics and Systems

- ITC 311 Manufacturing Operations
- PHY 415 Introductory Quantum Mechanic
- BIO 275 Microbiology
- BUS 375 Entrepreneurial Functions
- CS 220 Computer Organization
- TEL 381 Introduction to Information Assurance

Conclusion

Our effort in bringing low cost AFM with its visualization capabilities to the classroom, helped enhance our curriculum in Engineering Technology by understanding phenomenon that are taking place at nanoscale dimensions. Our informal evaluation showed that students are genuinely interested in nanotechnology and their interest in studying physics, chemistry and biology is increased. This increased interest motivated us to introduce a interdisciplinary survey minor in nanotechnology. More work is needed to develop instructional material and experimental facilities to involve faculty and students across the disciplines. We want to extend our work in the area of nanolithography and nanomamipulation using the advanced Veeco Caliber AFM when it arrives on the campus in March 2010. We observed in our research for selecting the AFMs that several of the capabilities and modes of AFMs may also be realized with the purchased AFMs through the addition of optional modules and/or software packages. As such, further expansion of our systems to meet our needs may follow as the project is pursued.

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Appendix (A)

AFMs specifications for purchase bids

- Static Force (contact) Mode capability;
- Dynamic (tapping) Mode capability;
- Magnetic Force Microscopy;
- Atomic resolution STM;
- Automated (motorized) Z approach;
- Closed loop scanning with sensor-controlled scan linearization;
- Open loop scanning that eliminates the sensor from the motion control so we can use the full open loop bandwidth and have a separate set of calibration parameters for open loop scanning;
- Optical video microscope with frame grabber for viewing and positioning samples;
- At least two lock in amplifiers so we can do phase imaging and some electrical characterization, like EFM;
- Can scan 80um or larger, XY, in both closed loop and open loop;
- Has sufficient signal access capability/hardware at time of purchase for future experimentation, including both (1) ability to input external signals to record as data or use for feedback and (2) ability to output internal signals such as raw photo-detector signals and lock-in outputs;
- Closed loop nanolithography and nanomanipulation
- Image Post-Processing/Analysis software for 16 lab stations (including processing functions: plane fitting, low pass, and Fourier filtering; and analysis functions: power spectral density, roughness, grain size analysis, data sections);
- Integral Vibration isolation/damping system (active or passive)
- Vendor training/commissioning package for two individuals
- 10 mounted contact AFM probes
- 10 mounted non-contact Tapping AFM probes
- 10 Platinum/Iridium cut STM tips and one HOPG sample
- 10 unmounted gold-coated contact AFM probes
- 10 unmounted gold-coated, sharpened contact AFM probes
- Unmounted Probe Chip carrier and Toolkit