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Nanotechnology Education on a Local Scale

Nicolas Berchenko
Rzeszow University
Al. Rejtana 16a, 35-959 Rzeszow, Poland
nberchen@univ.rzeszow.pl

Iryna Berezovska
Department of Computer Sciences, Ternopil State Technical University
56 Ruska St., Ternopil 46001, Ukraine
iberezov@hotmail.com

Abstract. *Progress in nanotechnology depends on availability of well educated specialists. The response from European higher education institutions to the need for nano-education focuses mainly on Masters courses, but other forms of education are also being developed. At Rzeszow University this problem is of high importance because the Nanotechnology Center will be launched in 2010 to become a technology and research base in the southern-eastern Poland for BA, MA and PhD degree courses and for research projects. The most important matter while developing educational materials in nanotechnology is a rapid growth of new information and a quick transition from generating new ideas to implementing those ideas in industry. This makes e-learning the most efficient teaching strategy. Its potential is used to compile a laboratory course on nanostructure characterization. A 7 step strategy is developed to conduct workshops on the methods of characterization based on teacher-guided reading the research literature.*

Keywords. E-learning, nanotechnology, Web, a laboratory course, an electronic tutorial, reading strategy.

1. Introduction

Nanotechnology is a too complicated phenomenon to have a single definition. The simplest one defines nanotechnology as a the engineering with anything smaller than 100 nanometers with novel properties. It integrates multiple disciplines, technologies, materials, and processes to enable the creation, assembly, measurement, or manipulation of materials, devices and integrated systems at the nano and molecular scales with great potential. Further progress in this field depends on availability of well educated specialists.

The fields of nanoscience and nanotechnology are broad and still exploratory, with connections to almost all disciplines and areas of relevance. Thus the most important matter to be taken into consideration while developing educational materials in nanotechnology is an exponential growth of new information and an accelerated transition from generating new ideas to implementing those ideas in industry.

In this communication we examine the training in the nanotechnology, which derives from microelectronics, surface and interface science, and focuses on fabrication of structures in silicon, carbon and other inorganic materials that will be, as we expect, one of the main direction of the evolution for the nanoelectronics.

2. Current issues in nanoscience education

While planning educational initiatives for nanoscience and nanotechnology, it is very useful to have estimates of how many specialists are needed, because "training people is a key component for long-term success" [1].

According to M.C. Roco, Senior Advisor for Nanotechnology of the National Science Foundation, a need for a multdisciplinary trained nanotechnology workforce in the years 2010-2015 is of 900 000 in the USA, 400 000 in Europe, and about 2 million persons in total [1].

There is an interesting estimate for a proportion of staff with different qualification levels: "experts have estimated that future

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demands will require 15 trained technicians for each scientist in a nanotechnology manufacturing business" [2].

2.1. International initiatives in nano-education

The response from European higher education institutions to the existing need for nano-education focuses mainly on Masters Courses, but other forms of education including short courses, formal PhD programs and undergraduate education, and vocational training courses are also being discussed and developed. European or international standards for good quality education in nanosciences and nanotechnology should be developed and initiatives taken for sharing best practices between professors and vocational trainers. The EU can stimulate this under the People programme in FP7 for university graduates funded by DG Research and the new Lifelong Learning programme funded by DG Education (2007-2013) [3].

A five-year goal of the U.S. National Nanotechnology Initiative (NNI) is ensuring access to the full range of nanoscale research facilities to 50% of US research institutions' faculty and students, while students' access to education in nanoscale science and engineering is enabled in at least 25% of the research universities [1].

The European Materials Research Society (E-MRS) is planning an "European Whitebook on Nano-Science Education" with contributions from scientists of diverse backgrounds and disciplines presenting an overview of the state of the art in this existing fields from European and global (by the International Union of Materials Society - IUMRS) international perspectives [4].

Four leading research and educational institutions in Europe (Chalmers Tekniska Hцgskola, Sweden; Technische Universiteit Delft & Universiteit Leiden, the Netherlands; Technische Universitдt Dresden Germany and Katholieke Universiteit Leuven, Belgium) have proposed a joint Erasmus Mundus Master Course entitled "Nanoscience and nanotechnology". This is an integrated program, with a strong research basis and an international outreach. The objective of this course is to provide top quality multidisciplinary education in nanoscience and nanotechnology [5].

2.2. The Nanotechnology Center at Rzeszow University

However this does not mean that less known educational institutions are not able to train specialists for this field. E-learning is just right to ensure a high quality of education.

At Rzeszow University this problem is of an increased importance because the Nanotechnology Center currently being under construction will be launched in 2010. To meet the forthcoming demand for nanotechnologists, we have to develop and implement relevant teaching strategies here and now. The Nanotechnology Center will become a technology and research base in the southern-eastern Poland for BA, MA and PhD degree courses as well as for research projects concerning the growth, characterization and application of nanostructures based on II-VI semiconductor materials. This decides which methods we pay special attention; however students will be given an overview of basic instrumentation and metrology needs across all nanoscience and nanotechnology. Everybody goes his/her own way to the nanoscience guided by previous research experience; and a way we choose decides what we will do in a new field. We have been kept to the straight and narrow path leading from microelectronics to nanoelectronics - low dimensional structures, such as: quantum wells, quantum dots and super-lattices grown by MBE-technology.

2.3. E-learning in nanotechnology

Combination of multiple time-limiting factors in nanotechnology makes e-learning the most efficient teaching strategy. We have used the e-learning potential to compile a laboratory course on nanostructure characterization. This is a very important component of a curriculum for nanoscience education because a proper measurement of nanostructure parameters critical to realizing its underlying physical ideas is as challenging as the development of nanostructure technology because even classic methods become specific when applying to nanostructures.

Presently a central problem is not how to locate a proper material in the Internet, but how to implement it in a right way. There are both general-purpose and specialized resources. The first to be referred to among general-purpose

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resources is NanoEd Resource Portal launched by NCLT (National Center for Learning and Teaching in Nanoscale Science and Engineering, available at *http://www.nanoed.org/*). The site is designed to both gather and disseminate information on nano-education related topics, including education research, nanoconcepts, teaching materials, seminars, and degree programs. The NCLT is the first national center for learning and teaching of nanoscale science and engineering education in the United States. The center was created in October 2004, through a National Science Foundation award of $15 million for five years. The mission of NCLT is to develop the next generation of leaders in nanoscale science and engineering teaching and learning. Its educational materials are addressed to science teachers and students in grades 7-12, college and university students and faculty, researchers, and post doc students. Additionally the National Science Foundation provided a five-year $20 million grant to the Nanoscale Informal Science Education (NISE) Network (*http://qt.exploratorium.edu/nise-resources/*) to bring researchers and informal science educators together to inform the public about nanoscience and technology.

However extensive materials relevant to our goal, i.e. teaching the nanostructure characterization, are developed by many university laboratories and analytical equipment producers. Some examples of their web sites are discussed below.

3. Characterization and imaging methods in the nanotechnology curriculum

Advances in fundamental nanoscience, design of new nano-materials, and ultimately manufacturing of new nanoscale products will all depend to a great degree on the capability to accurately and reproducibly measure properties and performance characteristics at the nanoscale. The revolution in nanoscale science and technology requires instrumentation for observation and metrology, otherwise we are not able to see and measure what we build. Though Richard Feynman challenged the scientific community to explore the "space at the bottom" since 1959, nanoscale R&D activities have been initiated on a full-scale only few years after Gerd Binnig and Heinrich Rohrer have invented the scanning tunneling microscope for seeing and touching nanostructures on surfaces in 1981. Instrumentation and metrology have been identified by the U. S. National Nanotechnology Initiative (NNI) as one of critical nanotechnology areas as they are both vital to the success and commercialization of nanotechnology.

3.1. Characterization techniques

However a number of methods used in nanostructures research has turned a hundred. Additionally, they are being improved and updated according to specific research goals. Therefore it is a primary task to select the most relevant methods and explain students why they answer the purposes of research. Over the past 30 to 40 years a wide range of surface and microanalytical techniques found an application in nanotechnology have evolved. Each technique has its own unique capabilities that are related to the particular physical interaction involved with that technique. With the exception of SPM/AFM, all of the techniques involve the interaction of some type of particle (electron, ion, or photon) with the sample material. The physics of each particular interaction affect the limits of lateral resolution, depth resolution, and detection sensitivity for each technique. Understanding these interactions, and more importantly the limitations they impose on a technique, can be crucial when selecting an analytical technique for specific problems to be solved. The main parameters characterizing technique - the required spatial resolution and the sensitivity (detection limits) are strictly interconnected.

Students study many of surface analysis techniques being used today: AES -Auger Electron Spectroscopy; XPS / ESCA - X-Ray Photoelectron Spectroscopy / Electron Spectroscopy for Chemical Analysis; SIMS - Secondary Ion Mass Spectrometry; TOF-SIMS - Time-of-Flight Secondary Ion Mass Spectrometry; Raman Spectroscopy.

All these techniques are the “classical” methods developed to surface analyses, however recently their main parameters have been substantially improved to keep pace with nanotechnology increase resolution.

3.2. Nanoscale imaging

Because nano-devices can operate on the level of a few molecules, or even a few atoms, accurate atomic-scale imaging is important. The sphere of nanoscale imaging belongs largely to

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electron microscopy and scanning-probe microscopy. Electron microscopy relies on the fact that electrons have much shorter wavelengths than visible-range photons and can thus resolve much finer details while maintaining a large depth of focus. Electron microscopy is now the most universal and *de facto* obligatory technique for atomic-scale structural characterization.

It is divided into two very different techniques: scanning electron microscopy (SEM), and transmission electron microscopy (TEM). In SEM, a focused electron beam is scanned across a conductive surface, releasing secondary electrons that are collected by a detector placed above the object at an angle that determines the perspective view. Magnification is changed by adjusting the size of the scanning area. Resolution ranges down to a couple of nanometers for the most-advanced tools-not fine enough to resolve atomic detail. Transmission electron microscopy takes a different approach: electrons are passed through the specimen, producing a shadow that is magnified by magnetic lenses and projected onto a sensing screen.

In scanning transmission electron microscopy (STEM), a variation of TEM, an electron spot is raster-scanned across the specimen and the secondary transmitted electrons detected. Magnification ranges up to 1 million, allowing the imaging of atomic lattices. High-resolution aberration-corrected electron microscopes (both TEM and STEM) already today can provide valuable measurements at the sub-Engstrom level. In general, resolution is accepted as the ability to determine if an image feature represents two objects rather than one. In high-resolution electron microscopy these objects are atoms.

Scanning probe microscopy (SPM) is a branch of microscopy that forms images of surfaces using a physical probe that scans the specimen. An image of the surface is obtained by mechanically moving the probe in a raster scan of the specimen, line by line, and recording the probe-surface interaction as a function of position. By using such a probe, researchers are no longer restrained by the wavelength of light or electrons. The resolution obtainable with this technique can resolve atoms.

Scanning Probe Microscopy is a general term, used to describe a growing number of techniques that use a sharp probe to scan over a surface and measure some property of that surface. Some examples are STM (scanning tunneling microscopy), AFM (atomic force microscopy), and NSOM (Near-Field Scanning Optical Microscopy). Many scanning probe microscopes can image several interactions simultaneously. The manner of using these interactions to obtain an image is generally called a mode.

3.3. Web-based resources

A useful list of excellent surface science courses, from introductory to graduate levels, each emphasizing different aspects of the subject is available on the UK Surface Analysis Forum (ttp://www.uksaf.org/tutorials.html).

Evans Analytical Group has collected and presented on its web site (www.eag.com) materials on most known methods of surface characterization, their practical use and the interpretation of measurement results.

Interesting materials on specific techniques are posted on web-sites supported by producing companies, e.g. Kratos (www.kratos.com) provides materials on XPS, and Jeol (www.jeol.com) – on SEM and TEM.

Though in comparison with other methods SPM is a fairly new one, nevertheless there are extensive e-collections related to different aspects of those methods. We would like to emphasize some of them. First of all – the James Madison University SPM Education website (http://spmeducation.virginiananotech.com/) - the clearinghouse for SPM experiments, techniques, labs and ideas that have been published in the scientific educational literature or developed by educators to be used primarily for educational purposes.

As to SPM producing companies, NT-MDT Co. should be mentioned first and foremost (http://www.ntmdt.com).

Nanoscience Instruments publishes the Nanoadvisor educational newsletter, which offers reviews on nanoscience programs, funding, resources, and nano-teaching information (http://www.nanoscience.com/).

4. Literature-based study of imaging and characterization methods

Research publications, both printed and electronic, provide information on the most current accomplishments which is indispensable to successful learning any subject. In

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nanotechnology, however, they also somehow compensate a lack of expensive equipment which many educational institutions can not afford.

4.1. Formats of research publications

Published research generally follows an established format. It is important that students understand each part of the research paper. Typically it includes the following parts [6]:

- **Abstract** "serves to briefly answer the basic questions about what was studied, how it was done, and the results. Its primary purpose is to allow readers to make an initial evaluation of whether a study is of interest without having to read the complete paper". Structured abstracts make it easier for readers to select appropriate articles. The introduction, methods, results, and discussion (IMRAD) format [7] is well known and widely adopted for structured abstracts in original articles.
- **Introduction "**explains *why* the study will be conducted... It also expands a little more on *how* the research will be conducted. The introduction can be divided into two major parts: the Background section and the Purpose section. *Background* …should reflect a comprehensive knowledge of the body of research on the subject and should brief the reader on both the previous studies that support the concepts or theories of the current study and those that do not…*Purpose* … dictates how a study will be conducted: the research design, the variables that will be measured, how information will be collected and analyzed, and what conclusions may be drawn".
- **Methodology** "…explains how the research was conducted and should give information in enough detail for the reader to evaluate the study. It should also enable the reader to understand to whom or what the study results apply".
- **Results** section provides the data and its analyses.
- **Discussion** section "gives the reader some insight into the study subject area and often sheds new light on the results and their meaning. Alternative explanations for the results and the implications of the research may also be presented". Sometimes conclusions may be not adequately supported by the data for many reasons (collection of insufficient or inadequate data, overgeneralization of results, methodological problems, or inherent limitations of the study design). This is why it is important to review the methodology section.
- **References** always can tell experts "if key research has been omitted from the reference list…Also, a reference list that includes both older and newer relevant research can reassure the reader that the author has thoroughly reviewed the entire body of research for background and has not just considered the last few or first few studies conducted on the topic".

4.2. Reading strategy to study techniques applied in nanotechnology

A workshop which involves a thorough consideration of research articles is the final stage of learning characterization and imaging methods. These articles are selected by teachers according to their instructional utility and are analyzed by students according to the following 7-step strategy:

1. Students' reading is controlled in a step-by-step manner when they are offered all parts of an article one after another.
2. An object of studies is analyzed, e.g. a method of fabrication, possible application, methods providing the most complete characterization. Students suggest a set of methods, the research purpose is discussed.
3. Methods used by authors are considered; specific equipment used in experiments are discussed with a focus on its potentials and limits; user manuals available from a producer or on a Web site are read. Students make assumptions regarding an outcome to be achieved if the selected methods are applied.
4. Sample preparation for the investigation methods are considered (e.g. ion beam milling, angle lap etc.). This stage is not always paid a proper attention. However it is this point that ensures correct findings, especially for nanostructures.
5. Results achieved with each specific method are analyzed with a focus on their completeness, reliability and informative capacity.
6. All results are considered as whole; authors' conclusions are discussed.

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7. Directions of further studies are suggested. Two options are possible depending on a purpose of the research under discussion:
   - a purpose was to characterize a structure. Possible continuation may be additional studies with an extended set of methods,
   - a purpose was to study a particular phenomenon. Then the question is whether this structure is optimum to observe that phenomenon and, if it is not, which structure would be better. Answering the latter question requires not only the knowledge of research methods and nanostructure physics, but basic experience in materials science and technology as well.

Students' efficient work during the workshop is supported through continuous referring to different resources including not only common electronic tutorials developed at our university but mostly web-based resources, both research and industrial. The quality of students' learning depends on how accurate is teacher's selection of materials to be used at workshops. This requires that a teacher should make a great deal of pre-workshop literature research.

5. Conclusions

Nanotechnology poses new challenges to education in many ways because existing paradigms are evolving – new physical ideas are being discovered and then some technologies are revolutionary transformed, other ones are getting out-of-date, or completely new approaches are introduced to solve the problems which seem to have been solved.

E-learning allows a timely response to new trends regarding the fundamentals of nanotechnology methods and provides application examples to explain students which method or combination of methods is good for a particular experiment, how to plan an experiment, and how to interpret its results.

6. References

[1] M.C. Roco. International Strategy for Nanotechnology Research and Development, J. of Nanoparticle Research, 2001, 3, 353-360.

[2] J. Lighteather. Nanoscience Education, challenges and opportunities. Presentation at the Expert Group Meeting "North-South Dialogue on Nanotechnology, Challenges and Opportunities", 10-12 February, 2005, Trieste.

[3] M. Ineke. Nano-education from a European perspective. Journal of Physics: Conference Series, 2008, 100, 1-7.

[4] P.A. Glasow. How should the Higher Education in Materials Sciences and Technology be performed in Europe. 2007, E-MRS.EU.Quest.29.08.07.doc.

[5] Erasmus Mundus Master Nanoscience and Nanotechnology, 2008, available at www.emm-nano.org/indexnano.htm.

[6] How to Understand and Interpret Food and Health-Related Scientific Studies. Review from the International Food Information Council Foundation.

[7] T. Nakayama, N.Hirai, S. Yamazaki, and M. Naito. Adoption of structured abstracts by general medical journals and format for a structured abstract. J Med Libr Assoc. 2005 April; 93(2): 237–242.