Conclusions from the introduction of a Nanoelectronics course in the Studies Curriculum of the Technological Educational Institution of Athens

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Abstract: - The problem of implementation of new courses and material in new curricula within the existing is one that preoccupies the academic communities. This work presents our engrossment and the first conclusions cropped from the introduction of a Nanoelectronics course in the Studies Curriculum of the Department of Electronics of the Technological Educational Institution of Athens in 2008 for the first time. The introduction of this course attracted the students' interest, as is described by the results of the enquiry that took place with the use of suitable questionnaire. On the other hand, the increased students' interest urged them to approach instruction methods outside the classroom reaching even postgraduate studies related to Nanoelectronics and Nanotechnology at large.

Key-Words: - nanoelectronics education, educational programmes, engineering course.

1 Introduction

Nanotechnology, today, plays an important role in various scientific fields such as Physics, Chemistry, Biology, Materials Science and Applied Mechanics so that it is logically distinguished for its strong inter-scientific character. This presupposes the collaboration of scientists of many specializations due to the need for knowledge interchange associated on one hand with tools and techniques and on the other hand with the "know-how" about atomic and molecular interactions within the same scientific field [1].

The quick development of nanotechnology, apart from the general challenges, triggers also our academic communities. Naturally, as far as its inter-scientific character is concerned, it demands new approaches in education and training for research and industry. The academic community reacts slowly to prepare the labour for the emerging opportunities in Nanotechnology. Consequently, there must be a dominant issue and priority in planning new curricula of studies in order to equip the students with at least the basic and necessary knowledge for them to be capable to interact with the emerging world of Nanotechnology [2,3]. Yet, science and engineering undergraduates will need a comprehensive education that includes Nanotechnology in order to navigate successfully the challenges of the 21st century [4].

Embodying the basic principles of Nanotechnology into the undergraduate curricula has already been met by a number of colleges and universities. In recent years, numerous education and outreach efforts have been developed to educate and inform students and the general public about nanotechnology [5, 6]. Many excellent courses on nanotechnology have been reported, and references therein [7], supporting the necessity to introduce Nanotechnology to undergraduate engineering curricula [2].

This paper is mainly focused on the recent effort of the Department of Electronics of the Technological Educational Institution (TEI) of Athens to introduce Nanoelectronics into the undergraduate course. The choice of the proper material to be taught and the results after the first pilot instruction of the subject are discussed here.

2 The introduction of Nanoelectronics to the studies curriculum

2.1 The background. Current status and necessity

B.Sc. programmes following the Bologna model are generally of three or four years duration depending on the country. They correspond to 180 ECTS credits. By definition, undergraduate programmes do not offer specialized knowledge. Consequently, advanced subjects dealing with Nanoelectronics, can only marginally be contained in B.Sc. programmes.

The studies curriculum of the Department of Electronics of the Technological Educational Institution (TEI) of Athens has a 7 + 1 semesters programme. Until 2008 the taught material hadn't included any notions of Nanoelectronics. Some related subjects such as those of Electron Physics, Technology of Electron devices and Microelectronics emphasized on the following:

- Basic notions of Physics, aiming at understanding Solid State Electronics.
- Electrical properties of materials and extensive reference to Semiconductor Physics.
- Analysis of the physical behaviour of doped semiconductors and methods to control their electrical behaviour with emphasis to p-n junction, on which the operation of most semiconductor devices is based. In this way, the operation principles of the basic electron devices as diodes and transistors will be conceptualized.
- Complete technological understanding in order to gain the capability of design and optimization of electronic circuits with commercially available components or with self-constructed components based on technical materials and on physical laws.
- Basic principles of Microelectronics, such as construction stages, photolithographic process, diffusion of dopants, metallization, and chip packaging.
- Design, architecture, miniaturization as well as quality and reliability tests of integrated circuits.

Based on the above, it becomes evident that there is no coverage of even elementary knowledge from the field of Nanoelectronics. This fact would make the electronic engineers incapable to follow related postgraduate courses. The dominant idea behind the introduction of Nanoelectronics into the Electronics curriculum was to teach it at one of the final semesters in order that graduates take advantage of the new knowledge. Thus, the 7th semester (final semester of attendance) was chosen. Let it be noted that during the 8th semester students are supposed to prepare and complete their dissertations as well as they do their practical work.

2.2 Aims and planning

The main aim of the subject is to give the students the possibility to acquire basic knowledge that has developed further than Microelectronics at a very smaller scale between 1 and 100nm. The creation of a proper background so that the graduates of the B.Sc. course be able to attend normally postgraduate study courses or other educational programmes related to Nanotechnology remains a strategic educational aim. Moreover, the material introduced in the module aims to offer the students a broad overview of important areas to focus on the combined topics of Nanoelectronics.

Most skepticism before the determination of the subject content within the curriculum was spent to investigate the students' acquaintance with some basic notions associated with the following fields of knowledge:

- Semiconductor and Device Physics.
- Microelectronics – VLSI.
- Quantum Physics.

Thus, a knowledge test structured on a group of multiple choice questions covering adequately the above fields has been formed. This method was selected because it has the advantage of a large number of questions in a predetermined examination time, while with the use of an appropriate technique, the partial gradings will indicate any weakness in understanding specific teaching units or knowledge gaps.

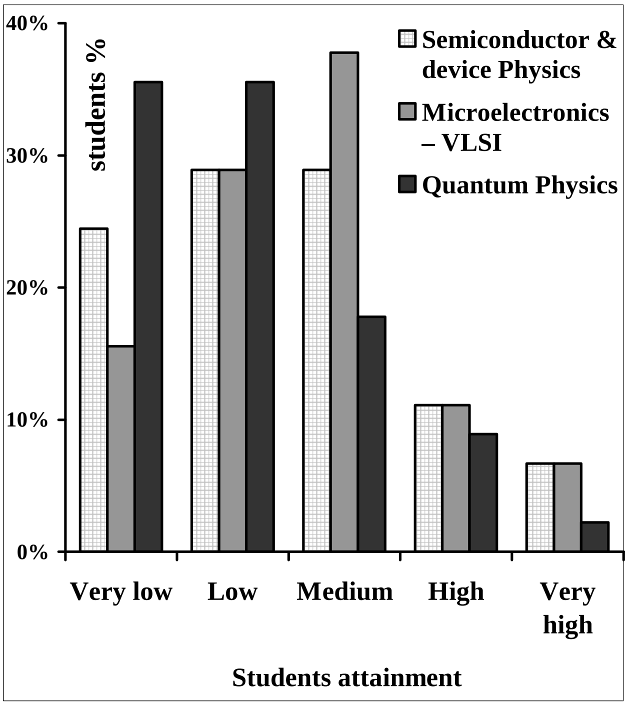

Figure 1. The students' attainments with respect to the three relevant fields.

Forty five 7th semester students participated in the test. Their attainments were appraised to a scale: "very low", "low", "medium", "high" and "very high". The results are depicted in Fig. 1 and show the following: In the fields of Semiconductor and device Physics as well as in Microelectronics – VLSI, practically one out of two students has acquired an adequate level of knowledge (medium, high, and very high) while the knowledge in the field of Quantum Physics is limited (one out of three students seems to have acquired an adequate level of knowledge). Thus, at a first approximation related to the content of the material to be taught, it was decided primarily that the subject should be focused on an introduction to Nanoelectronics and secondarily that it should be taught more from the perspectives of concept development and qualitative analysis rather than mathematical derivations.

Finally, the course design should incorporate the following three units:

a) **Fundamental physical principles coacting Nanoelectronic devices:** The physical phenomena at the mesoscopic and nanometric scales are studied as well as the fundamental characteristics of the solid state of materials associated with notions like quantum dot, quantum wire and quantum well. In general in this introductive unit, phenomena the understanding of which is imperative for the study of a large number of nanoelectronic devices are studied and discussed.

b) **Single-electron Nanoelectronic devices:** Phenomena and devices involving few or even single electron, emphasizing the tunnel effect and Coulomb blockade. The study is focused on the interpretation of fundamental behaviour principles of single-electron structures and devices emphasizing the new trend that is differentiated from the conventional electronic technology.

c) **Quantum dots, wires and wells**. Presentation of the models of quantum dots, quantum wires and quantum wells emphasizing on structures that can be realized with the use of semiconductor materials. Reference is given to the ballistic transport effect and to the differentiation of the notion of resistance (conductance and resistance quantization) from the conventional notion. A reference is made to the ballistic transport in carbon nanowires as well as a concise presentation of basic notions related to the spin transport and to the operation principle of a spin valve.

All of the above are part of an ambitious teaching material within an undergraduate course. The challenge is to get a high effectiveness after two or three consecutive semesters when the appraisal results will be more accurate. This teaching material is programmed to be covered within thirteen lectures of three-hours duration each. Before the beginning of the course it had been arranged for a complete set of educational material including notes, questions and exercises to be available to the students. A complementary tutorial was also planned in order to explain the importance of electrical measurements to the science of Nanotechnology and presents practical considerations in making these measurements.

3 Results and conclusions from the teaching experience solution

The first encouraging sign is that the lectures attracted the interest of a more than satisfactory number of students taking into account that these lectures were not compulsory. Initially, on the first week of lectures, 55 students of the Department of Electronics plus 5 students from other engineering departments. Finally, on completion of the programme it was found that 40 students as a whole attended it normally. Given that the taught material of Nanoelectronics is orientated towards the most modern technology and that due to this fact it requires a large amount of workload, we come to conclude that the majority of the students who attended, did so as if it was a normal compulsory subject.

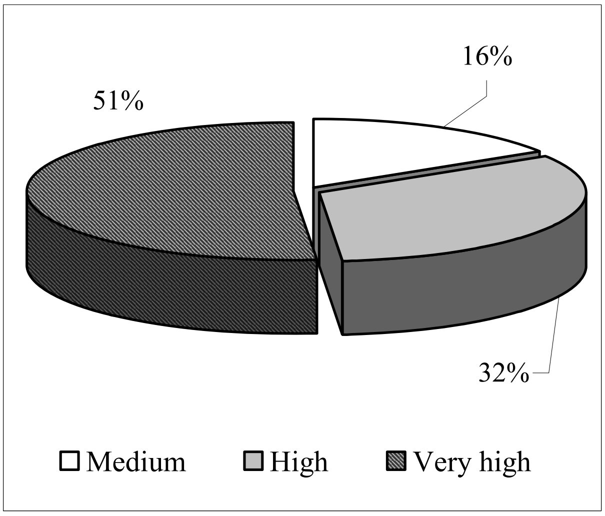

Figure 2a. Evaluation of the content of the taught subject.

On completion of the lectures the students gave a written appraisal report about the subject and about the first pilot teaching whose main points are depicted in the diagrams of Fig. 2. More precisely, we present the views of the students regarding the interest caused by the taught subject (Figure 2a), their opinions about the teaching aids and the available educational material (Figure 2b), and the way the instruction was realized especially regarding the understanding of new notions (Figure

2c). Finally, the students evaluated the difficulty of the subject and the respective work load (Figure 2d).

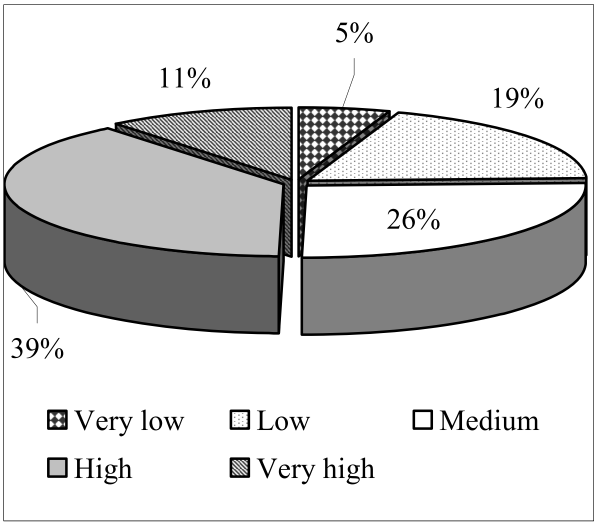

Figure 2b. Suitability of the courseware.

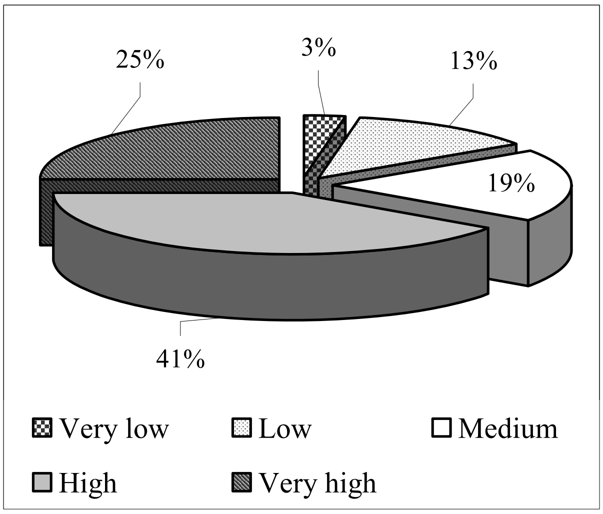

Figure 2c.Assessment of teaching method.

In the course of lecturing the students showed a large interest about the content of the subject. The ascertainment to this claim comes out of the fact that a significant number of students looked up additional sources through the internet for more information. In this way a creative discussion between the instructor and the students was developed, covering not only the spectrum of Nanoelectronics but also that of Nanotechnology in general. Moreover, some of the students think about doing postgraduate studies in Nanoelectronics. Given that this interest was expressed by the students, the lecturer caught the opportunity to present briefly several postgraduate study courses of both Greek and foreign universities dealing with Nanoelectronics.

A complete bundle of questions and exercises of graded difficulty was given by the lecturer after completion of the course, as a final study aid before the examination. Although until now the results of the written examination are not known yet, the instructor feels that the percentage of success will be high enough to exceed the mean value of the percentage attained during the few recent years in the subjects of the last semester of studies.

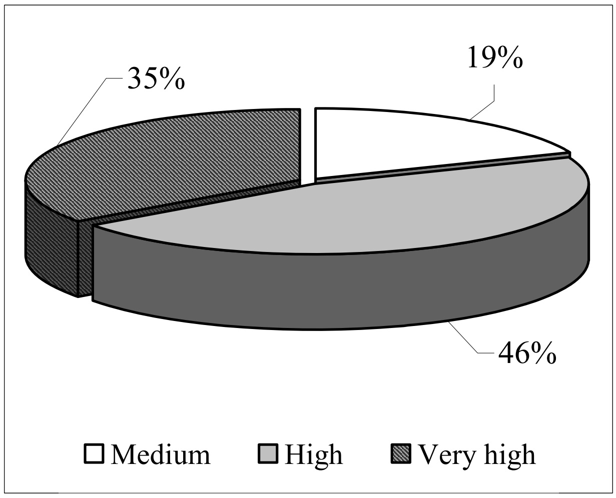

Figure 2d. Evaluation of difficulty level and work load.

Taking into account that an undergraduate syllabus cannot offer all necessary knowledge in the field of Nanoelectronics but just an introduction to the basic notions, there must be some specific motivations for the undergraduate students in order to orientate more and more of them towards following Nanoelectronics and Nanotechnology postgraduate courses and research programmes. Such motivations might be scholarships, summer internship programs, creative environment for diploma works. Also the university professors should create the advertising materials about the challenges and potential of Nanoelectronics in a popular form to address the communities' students.

This kind of advertising is imperative because the younger generation have not been informed about most of the applications of Nanoelectronics and of Nanotechnology in general although they are used in our everyday life and will be used more in the days to come. An imperative solution is the establishment of distance learning courses or series of short courses (with duration of a few days). The above described aims can be accomplished if the lifelong learning programmes that will be funded for the following six years in the frame of the NSRF (National Strategic Reference Framework) 2007–2013 are exploited properly.

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