Presentation of a Nanoelectronics Curricula Study

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ABSTRACT

Future developments in nanoelectronics call for major changes in university curricula within engineering. It is found that three major factors influence the curricula: technology development, development of industrial environment, and development of university structures. It is also found that nanoelectronics programs fall into one of three different categories: Physics and nanotechnology, electronics engineering, or computer science. References are given to selected current programs.

1. INTRODUCTION

Technology roadmaps [1] show that the development of microelectronics into deep submicron technologies (nano-technologies) causes fundamental changes in the coming years as the scaling limits of the traditional CMOS processes are reached. These changes have impact both at the system design level, at the circuit and device design level, and at the manufacturing technology level. In order to cope with these changes, new initiatives in engineering education are needed. This paper describes the results of an investigation [2] of university curricula in nanoelectronics carried out as part of the EC-sponsored EuroTraining program[1].

2. DEFINING NANOELECTRONICS

Nanoelectronics is nanotechnology applied in the context of electronic circuits and systems. There are several perspectives to the concept of nanotechnology.

- One is the fact that the nanoscale dimensions of nano-electronic components allow for systems of giga-scale complexity measured in terms of component on a chip or in a package. This scaling feature and the road to giga-scale systems can be described as the 'More Moore' domain of development [3].

- Another is that nanotechnology is very diverse and allows the integration of purely electronic devices with mechanical devices, bio-devices, chemical devices, etc. Also, digital systems can be combined with analog/RF circuits. This technology fusion can be described as the 'More than Moore' domain of development.

- A third is that traditional scaling limits in standard CMOS technology are reached during the next decade, calling for fundamentally new nanoscale electronic devices. This development of nanoelectronic components can be denoted the 'Beyond CMOS' domain of development

From a university educational point of view, all three of the above perspectives are important issues in programs dealing with nanoelectronics. Traditionally, the aspects described above are treated by different university departments and in different educational programs (computer science, electronics engineering, and physics and nanotechnology). A major challenge is to bridge the gaps between these programs in order to educate engineers with a holistic viewpoint.

3. DEVELOPMENT OF EDUCATIONAL PROGRAMS IN NANOELECTRONICS

Educational programs at university level are influenced by several different factors. Major factors are the research based technology development of the subjects included in the programs, the need for relevant industrial competences, and the general trends in development of university programs (Bologna model, internationalisation). Much attention is given to the technology roadmap. Less attention has been paid to the influence on education of changes in industry and in academia.

The electronics industry has seen major changes over the past 40 years. The trend has been a separation of the design process from the semiconductor manufacturing process along with a trend towards fewer semiconductor foundries. Thus, the number of companies actively involved in design at system level and circuit level is much larger than the number of foundries.

Several important developments of the European university structure are in progress. One is the adoption of the Bologna model for the university programs, i.e. three-years undergraduate (bachelor) programs, followed by graduate programs, in many countries consisting of two-years master programs and three-years PhD-programs. This leads to a harmonization of the university programs, paving the way to easier exchange of students and courses between universities. Another is an increasing inter-nationalisation with more programs at master level and PhD level being given in English. It can be expected that with the bachelor-master structure, many students will complete their master studies at another university than their bachelor studies, and often in a different country. Such a trend towards increased student mobility will also support a trend towards specialisation of university programs such that some universities may have very strong programs in, e.g. (nano)electronics engineering while other universities may have their particular strengths in other fields, e.g. biomedical engineering. Only few – if any – engineering universities will be able to sustain top-level programs in all fields of engineering. This trend, together with the increased internationalisation, can form the basis for networks of universities with matching or complementary competences such that they can together offer programs at the highest academic level within more fields of engineering.

Most university programs in nanoelectronics evolve as natural developments of programs in either electronics, (nano)physics or computer science, and they follow the general university trends outlined above.

The computer science programs form the basis for pro-grams with focus on systems-on-chip, i.e. programs

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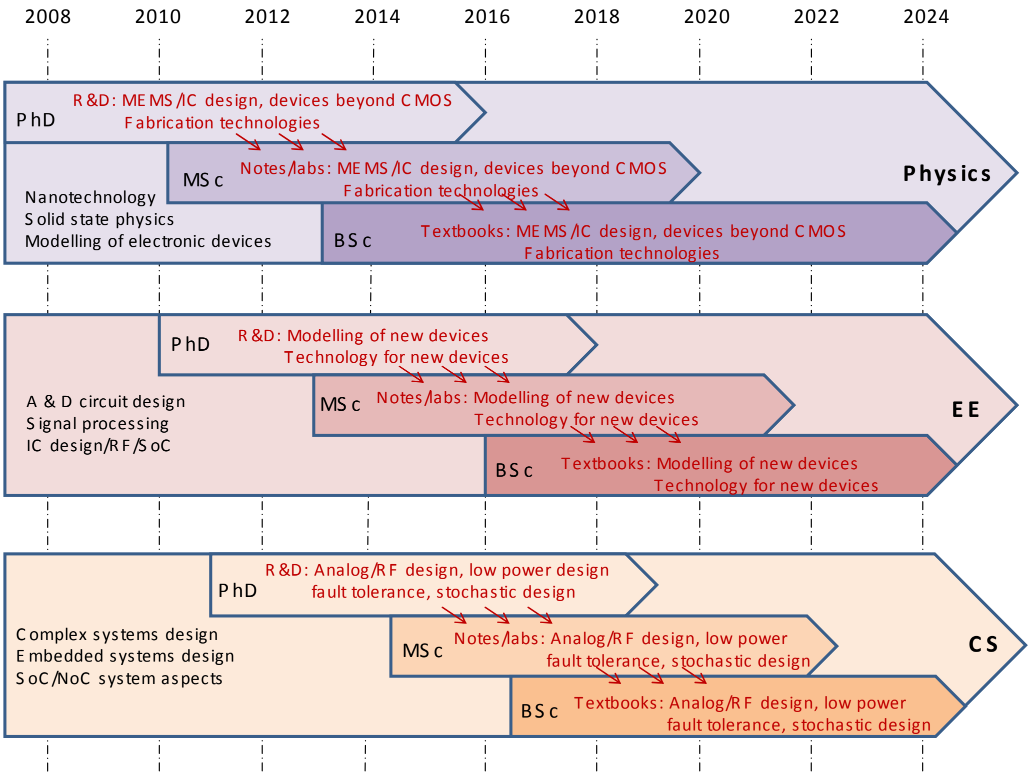

Figure 1 Development cycles for university programs in nanoelectronics

dealing with giga-scale systems ('More Moore') and with an emphasis on high level design which to some extent is independent of the actual physical implementation. The word nano is rarely used as a keyword in such programs.

The programs developed from electrical or electronics engineering focus mainly on design, both analog and digital, based on a component knowledge. Often, they will include new nanoelectronic devices and MEMS devices. Nano is becoming an important keyword in such programs. These programs will often deal with technology fusion in the 'More than Moore' domain.

The programs evolving from physics appear to be programs in physics and nanotechnology with an emphasis on electronic devices and solid-state physics. They focus on new devices and on technology, mostly at the device level. Nanotechnology is an essential keyword in such programs but it should be emphasized that nanotechnology is broader than nanoelectronics. These programs will often deal with the 'beyond CMOS' domain of nanoelectronics.

4. Conclusion

The adaptation of the educational system to the technology road map follows a pattern as shown in figure 1 above. The development of technology is mainly driven by the physics programs and this work is a continuous process as shown in the upper part of the figure. Research work on e.g. MEMS/IC design and fabrication technologies is carried out in PhD programs over a couple of years. When the research topic has matured, its contents are migrated to the master programs possibly supported by lecture notes and labs. The knowledge transfer is often facilitated by employing the PhDs at the engineering schools. When the master program has included the new subjects for a number of years, the course contents or parts of it migrate to the bachelor programs; however, now supported by more mature educational material (typically by textbooks). In the figure, the average migration time is shown as three years. In practice, it will vary between different engineering disciplines. Electronics engineering and computer science follow the same pattern as the physics programs, however with a further time delay (in the figure shown as 3-4 years).

The left part of the figure shows the traditional microelectronics engineering disciplines within each of the three programs. The smaller arrows inside the figure emphasize nanoelectronic subjects and illustrate how they are developed and migrated to master and bachelor levels.

References to several present programs following the outlines above are given in [4-8].

References

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