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Computer-Aided Learning in Microelectronics, Based on Modeling and Simulation*

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During the last few years, computer-aided learning (CAL) has become a powerful tool for understanding the physics, technology and operation of different types of semiconductors. Generally we find two approaches to this subject. The first is based on the software which serves as an equivalent of the corresponding textbooks. By using the menu and selecting a problem, the user can read some short overview about the topic which is usually illustrated by a picture, schema or animated video shot. Also some questions and tests are available. The second approach utilizes modeling and simulation, and is based on the assumption that the user has basic knowledge of the problem. The flexibility of simulation programs is based on the interactive system of utilization. This approach is more creative because anyone who is interested in a problem can study the influence of technological parameters on the device profile, corresponding electrical characteristics, or circuit behavior. The environment and graphic support of simulation programs are obviously very good, and can visualize the calculated data in a proper way, based on colorfill contour and plots. Generally, modeling and simulation are the most effective way of preparing students for the field of microelectronics—they can get a lot of experience without expensive experimental work.

INTRODUCTION

THE wide use of computers, especially personal computers, is a modern and powerful didactic tool in the field of education and learning. The classic school textbook can be supported by a large number of pictures, schemes or animated video shots, which visualize problems and make them more understandable and interesting. Existing software and computer environments give teachers great potential to develop sets of such educational programs. This is especially important when practical study is difficult, for example analysing a very large or small object, or very fast or slow processes which, with the help of a computer, could be easily visualized on the screen.

The other advantage of using CAL is that the student can imagine problems in various fields of physics, technology, industry, etc. without experimental realization which could be in most cases very expensive. This can be done because many problems have been transformed into mathematical or physical models, which serve as the basis for modeling and simulation on a computer. The wide use of personal computers creates new possibilities in education.

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CAL IN MICROELECTRONICS

The teaching of microelectronics is a good example of where graphically illustrated textbooks as well as computer modeling and simulation, is very useful. The devices are very small, the transfer of signals is very fast and their practical preparation is very expensive and requires special clean rooms. There are almost no fields where semiconductors, both discrete devices and integrated circuits, are not involved, and so better understanding of their internal structure and operation will result in even wider application. The development in this field is very fast and technicians working in industry must follow this progress, as well as understanding new developments and devices. Distribution of learning programs is an easy way to spread new information. There are many schemes for dividing processes in microelectronics into logical groups. One example is illustrated in Fig. 1. One can immediately see how wide the subject is and how varied the education needed.

The other approach, which from our point of view is more creative, is modeling and simulation. The main restriction of this method is that it is applied to people who already have basic knowledge in the desired field. Learning useful modeling and simulation could follow the next schema (Fig. 2), which is based on TMA concept [1]. The whole process is divided into a few stages.

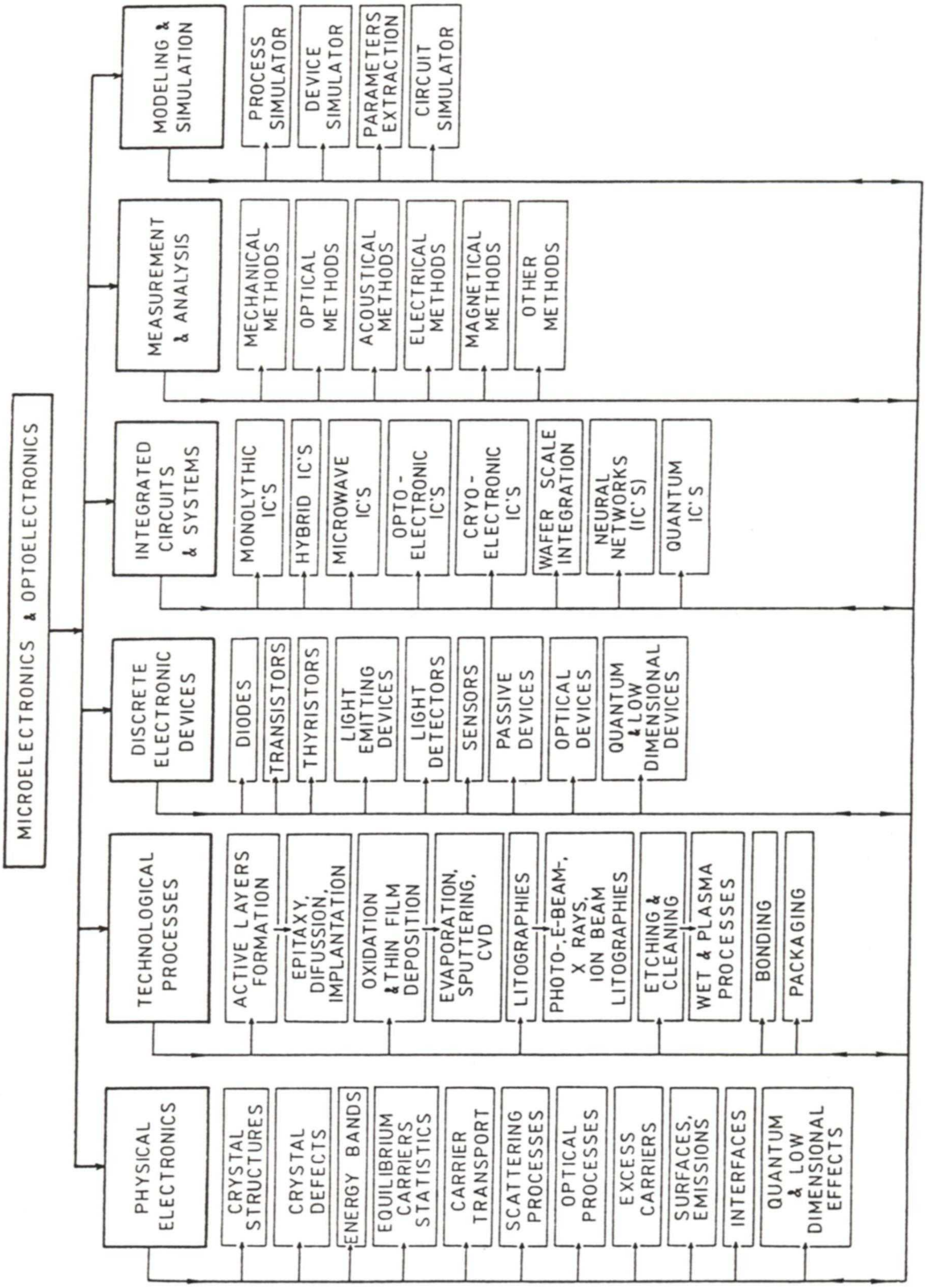

Fig. 1. Example of the learning schema in microelectronics.

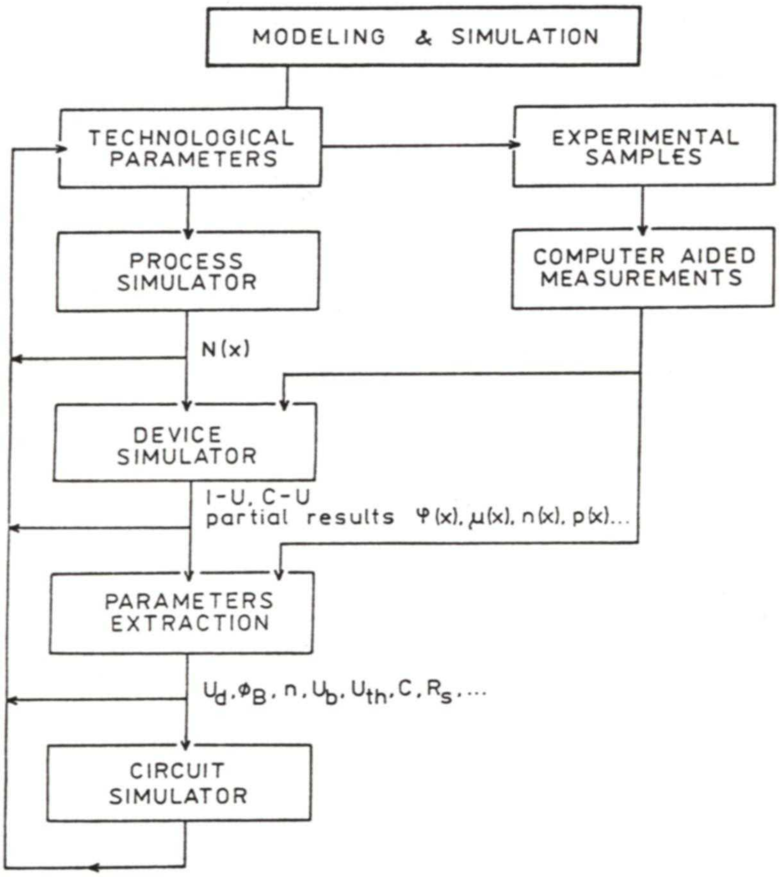

Fig. 2. Modeling and simulation schema in TCAD.

Technological parameters are the input of one-dimensional process simulator, where the technological steps such as the diffusion or ion implantation of impurities, oxidation, etching and others, are simulated. The output obtained is the concentration profile of active impurities. This output serves as the input of a one-dimensional device simulator, where the electrical characteristics of various semiconductor structures, for example P–N junctions, metal–semiconductor junctions or transistors are simulated [2]. The partial results of simulation showing the potential and free carrier distribution or field, concentration and temperature-dependent mobility within the analyzing structures are useful for understanding physical electronics. Using the next stage—parameter extraction [3]—the desired parameters which serve as the input for the circuit simulator could be evaluated and used to discover the electrical characteristics of various circuits. There exists a feedback loop after each stage of simulation. When the simulated characteristics or parameters are different to those specified, a good correlation between simulated and experimental characteristics could be reached by the proper change of technological parameters. Following the proposed schema, the user can obtain insights into technological processes, internal device operation and circuit behavior without expensive experimental work. When the optimization of technological steps is done, the preparation of experimental samples is cheaper. Using computer-aided measurement and analysis, experimental characteristics can be obtained and can be compared with simulated characteristics. The good correlation between them indicates that the proper choice of different models used in simulation process has been made.

The whole simulation schema could be a good base in the teaching of solid-state devices, discrete devices or integrated circuits, while different stages could support knowledge in areas such as physical electronics, semiconductor technology and circuit electronics.

CONCLUSION

A brief description of possible ways of using computer-aided learning in microelectronic technology were presented. Using the first approach, classical textbooks can be supplemented by figures, pictures or animation which help visualize problems, making them more comprehensible and interesting. The other approach, modeling and simulation, provides a clearer understanding of the influence of technology on discrete or circuit semiconductors. It could also be used to optimize technological processes. Nowadays many 2D and

3D simulation programs for computer-aided design have been developed at different laboratories. Some examples include the SUPREM, DAVINCI, PISCES 2B, TOPEX from TMA Palo Alto. GENSIM and SECOND developed at ETH Zurich or MINIMOS from TU Wien. On the other hand, the one-dimensional simulator cannot include the whole complexity of real structure, but its simplicity makes it very useful from the educational point of view.

All four stages of the simulation schema are available for students at the Microelectronics Department of the Slovak Technical University in Bratislava. The first and last (equivalents of SUPREM and SPICE) are commercial and the second and third ones were developed at the department. They will be the subjects of following articles. The introduction of the simulation programs into the lectures and practical training is more interesting for students and their knowledge becomes deeper.

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The set of programs is available at the Microelectronics Department, STU Bratislava, where further information can be obtained.

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