# Microelectronics education at MIEM: from materials to system on chip/board.

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## ABSTRACT

*A continuous microelectronics education system has been developed at MIEM. The approach provides all microelectronic products design stages learning and is based on close software/hardware relations and wide collaboration with industry enterprises during education process. The microelectronic products design stages studied inside the microelectronics educational program are considered.*

## 1. INTRODUCTION

The Moscow State Institute of Electronics and Mathematics (technical university) (MIEM) is one of the leading Russian universities in preparing engineers and researchers for electronic and especially for microelectronic industries.

According to industry requirements and in collaboration with the industry enterprises the special microelectronics educational program for students and industry engineers has been developed at MIEM.

This microelectronics program has more than twenty years history and it is regularly corrected and gets additional elements and materials according to microelectronics trends.

The experience of microelectronic industry showed that to provide qualified educations in this area it is necessary to give students deep understanding and experience in all aspects of microelectronic products design: from semiconductor materials, throughout devices and circuits to VLSI, SoC, FPGA, PCB design.

It is known that the most effective way of preparing for an engineering career in the microelectronics industry is to combine deep theoretical knowledge with practice on real devices and circuits and CAD tool experience.

## 2. KEY FEATURES OF MICROELECTRONIC EDUCATION AT MIEM

In this paper the microelectronic educational system with close software/hardware relations developed at MIEM is discussed. The education approach is similar to the VLSI design curricula initially developed by the University of Michigan and later supported by Intel [1]. (It is well known that Intel spends much energy to improve VLSI education world-wide).

From the beginning of electronics and later microelectronics education at MIEM, the educational program gave students a deep knowledge in the fundamentals, combined with practical lab works and project-oriented works using CAD tools.

To provide high quality of education all necessary microelectronic products design stages (levels) are studied inside our microelectronics educational program:

-Semiconductor materials,
-IC manufacturing technology,
-Semiconductor devices and IC elements,
-Digital and analog circuits,
-Large systems level (ICs, SoCs, PCBs).

The key features of our microelectronics educational program are the following:

1. All design stages studied at the educational process provide high quality and universal character of microelectronic education for future engineers and researchers.

2. The system is based on close software/hardware relations during education process. Theoretical knowledges are supported by practical works with hardware and software. We consider such relations to be very important for high quality of microelectronics education

3. Practical works of devices and circuits contain two main tasks:

- first, to study real device characteristics (hardware part),
- second, to simulate the device with modern CAD tool (software part) and to compare with the measured data.

5. Students work with real CAD tools used at microelectronic industry for VLSI design.

6. Education-research centers (by Mentor Graphics, Synopsys, Motorola, Xilinx, Renesas, etc.) provide CAD training and microelectronic equipment experience.

7. Close collaboration with microelectronics industry enterprises takes an important part at education system.

Different aspects of the MIEM educational program were presented and discussed at international conferences and exhibitions [1-3].

Microelectronic equipment design stages and software/hardware elements studied at the educational process are described below.

## 3. EDUCATION-RESEARCH CENTERS – IMPORTANT PART OF EDUCATIONAL STRUCTURE

The world leading software and hardware companies understood the importance of MIEM in microelectronics education and opened education-research centers at MIEM.

Motorola and Renesas Centers provide training for students and industry engineers to the principles of operation and characteristics of modern electronic components, microcontrollers, microprocessors, telecommunication and network equipment.

ZyXEL Center provides training to get and/or improve the experience in the field of the network technologies, information security and network equipment.

Xilinx Center provides education for MIEM students and reeducation for industry engineers in the field of modern digital FPGA systems design with VHDL. The Center has special development boards (with the last versions of FPGA) for projects implementing and debugging.

Cypress Center provides training to get the experience in the field of programmable systems on chip design.

Mentor Graphics training Center is equipped with the modern versions of MG software running on PC computers. The goal of the Center is to teach students the basic techniques for analysis and design of perspective analog and digital systems based on IC chips and PCBs.

In Synopsys Center students get experience in technology/device simulation with TCAD software.

In cooperation with the leading Russian semiconductor companies the students participate in SOI/SOS CMOS, SiGe HBT, BiCMOS devices design projects.

## 4. COLLABORATION WITH MICROELECTRONIC INDUSTRY ENTERPRISES

As has been mentioned the microelectronic educational process at MIEM is carried out in collaboration with the leading microelectronic industry enterprises:

- Institute for Design Problems in Microelectronics of Russian Academy of Sciences;
- Federal State Unitary Enterprise “Measuring Systems Research Institute named after Yu. Ye. Sedakov” (N. Novgorod);
- Federal State Unitary Enterprise “Scientific and Production Association “ Pulsar”;
- Federal State Unitary Enterprise “Scientific and Production Association “Orion”.

The leading specialists from these enterprises give lectures and provide real industry training for students. The student study design stages and real microelectronic production equipment. They take part at real industry projects, defense their theses and take an engineer’s or master degree. The ongoing relationship with microelectronic industry provides relevance and real-world orientation of our teaching and research.

## 5. MICROELECTRONIC MATERIALS LEVEL

This level is the first at microelectronic education and includes the next main courses:

- Crystal physics and crystallography, with contains topics:

  crystal lattice, crystalline forms, methods for lattice description, physical properties of crystals, electric and magnetic crystal permittivity, piezoelectric effect, elastic properties of crystals, electro-optical properties of crystals,

  total of 116 hours, including

  34h lectures,

  17h labs.

- Theory of strength and plasticity. The purpose of the course - the deep understanding of atomic mechanisms of strength and deformation processes in materials. It contains topics:

  mechanisms of plasticity, materials strengthening, basic mechanical properties of materials and methods of its definition, elastic and non elastic properties of materials, fluidity, hardness, rupture of materials, high temperature strength, material fatigue, wear-resisting properties of materials.

  total of 182 hours, including

  68h lectures,

  17h labs, term project.

- Materials and elements of electron technology. The course contains topics:

  materials classifications, physical nature of conductivity, superconducting materials, conductive and resistive materials for microelectronics, characteristics and main properties of semiconductor materials, semiconductor structures in microelectronic devices, main physical processes in insulators, magnetic materials, methods of microelectronic materials and devices investigation.

  total of 250 hours, including

  85h lectures,

  35h labs,

  17h term project/

- Methods of material structure and composition investigation contains topics:

  principles and methods of X-ray spectral analysis, emission spectral analysis, methods and applications of electron spectroscope, secondary ion mass spectrometry, diffraction methods for studying the material structure (theoretical bases), X-ray methods for investigating the material structure, methods of determination of lattice parameters, X-ray spectrometer application, methods of electron diffraction analysis, electron microscopy, neutron diffraction analysis,

  total of 220 hours, including

  51h lectures,

  34h labs, term project.

The main specialized department providing education for this level is Electronic Engineering Science of Materials. The department has the laboratories:

- laboratory of metallographic analysis,
- laboratory of physic-mechanical properties of materials studying ,
- laboratory of structural analysis.

The hardware equipment for this level include:

- scanning electron microscope,
- X-ray structure analyzer ,
- X-ray diffraction meter,
- mass-spectrometer,
- spectrophotometer.

The software tool used in educational process is Synopsys TCAD.

## 6. IC MANUFACTURING (TECHNOLOGY) LEVEL

The departments responsible for this level are: Physical Basis of Electronic Engineering, Technological Systems of Electronics, Metrology and Sertification.

The level includes the main courses:

- Technology of materials and electronic devices. It contains topics:

  crystal growing methods, epitaxial film growning methods, glass and ceramic formation methods, methods of quality control, photolithography processes, p-n-junction formation methods, soldering and welding methods, environment influence protection, technology equipment usage.

  total of 170 hours, including

  34h lectures,

  17h labs, term project.

- Micro- and nanotechnology processes. The course contains topics:

physical-chemical methods of surface cleaning, equipment and methods of electron beam deposition, vapor-phase epitaxy , liquid-phase epitaxy, vapor-phase, liquid-phase and ion-plasma etching, oxidation processes, diffusion, doping, ion-implant doping, annealing, lithographic processes.

total of 170 hours, including
34h lectures,
17h labs, term project.

- Physical bases of electron-bombardment technology. The course contains topics:

electron scattering theory, electrons stopping and scattering, models of electron scattering, electron-beam vaporization, electro-plasma interaction.

total of 141 hours, including
17h lectures,
17h labs, term project.

- Physical bases of ion-plasma technology. It contains topics:

ion-material interaction, including ion stopping, nuclear stopping, electron stopping, ion range, ion doping, secondary ion emission.

total of 209 hours, including
85h lectures,
17h labs, term project.

The hardware equipment for this level include:

- scanning electron microscope,
- vacuum evaporation equipment,
- laser equipment,
- equipment for metrological assurance.

It should be pointed that MIEM specialists not only use standard hardware equipment but also design some new one. For example in Figure 1 you can see student working with hardware equipment for nano film formation and investigation.

Figure 1. The last year student works with hardware for nano film formation and investigation.

To provide real industry orientation the modern IC manufacturing processes:

- conventional CMOS process,
- SOI/SOS CMOS process,
- GaAs process etc.

are practically studied at semiconductor enterprises (our partners).

For better understanding of technology features and getting experience in technology simulation, the students use Synopsys TCAD tools in their work.
They simulate real (and near future) semiconductor technology process steps and analyze characteristics of structure layers: doping distribution, depths, resistivity, etc. After they compare simulated parameters with measured ones or with ones known from theoretical course.

## 7. SEMICONDUCTOR DEVICES AND VLSI ELEMENTS LEVEL

MIEM provides deep studding of microelectronic device physics. The following specialized departments are responsible for education at this level: Physical Basis of Electronic Engineering, Electronics and Electrical Engineering, Radioelectronics.

The following courses are used at this level to provide deep studding of VLSI element physics:

- Solid-State physics. The course contains topics:

solid states classification, crystal lattice vibration, electron conductivity of metals, isolators properties, optical properties of crystals, magnetic properties of crystals, super conduction, electron emission, contact effects.

total of 236 hours, including
68h lectures,
17h labs, term project.

- Semiconductor physics. The course contains topics:

band theory of solids, electron and holes statistics, nonequilibrium charge carriers, charge carriers scattering mechanism, kinetic phenomena at semiconductors, generation and recombination of nonequilibrium charge carriers, diffusion and drift of nonequilibrium charge carriers, surface effects at semiconductor devices.

total of 170 hours, including
51h lectures,
34h labs.

- Solid-State electronics. The course contains topics:

metal-semiconductor contact, p-n-junction theory, rectifier theory, Zener diode physics, bipolar junction transistor theory, p-n-junction FET, MOSFET structures, Schottky transistor.

total of 130 hours, including
34h lectures,
17h labs, term project.

- Quantum and optical electronics. The course contains topics:

the interaction of electromagnetic radiation with atoms, generation and amplification of electromagnetic radiation, linear crystal optics, nonlinear optics, optical effects at semiconductors and heterostructures, solid-state and liquid lasers, gas lasers, light emitting diodes, semiconductor lasers, optoelectronic sensor, optical radiation driving, optical methods of information transfer and processing.

total of 150 hours, including

34h lectures,

17h labs, term project.

- Physical basics of semiconductor device reliability. The course contains topics:

the problem of reliability of electron devices, reliability control, reliability improvement practices, foundations of the theory of probability and mathematical statistics, probability distribution functions and coefficients, foundations of the theory of reliability, failures in electron devices: classification and mechanisms, external influence on electron devices, effects of electrical and thermal exposure and their influence on reliability of electron devices, reliability assurance tests, prediction of reliability of electron devices, mechanisms of degradation processes in materials and devices.

total of 116 hours, including

34h lectures,

17h labs.

TCAD simulation is necessary element in modern technology development. So we use TCAD (Synopsys) tool at educational process to simulate semiconductor devices characteristics. Students study the influence of device structure parameters (doping distribution, layer thickness, etc) on device characteristics (threshold voltage, current gain, transit time, etc.).

- Microelectronics course contains topics:

MOSFET characteristics, equivalent circuit, parameters, thyristors, thermistor, voltage-depended resistor, hall-effect sensor, magnetic sensitive transistor, resistance strain gauge, pressure-sensitive diode, SPICE models for different types of transistors, integrated circuit classification, digital and analog circuits, integrated bipolar transistor, NPN and PNP integrated transistors, multiemitter transistor structure, integrated injection structures, integrated rectifiers, complementary MOS FET structures, passive elements of integrated circuits, HEMT transistors, FLASH memory, GaAs transistors, Gunn effect,

total of 130 hours, including

34h lectures,

17h labs, term project.

SPICE models for semiconductor devices and parameter extraction technique are necessary and important part of our educational process.

Practical labs are performed at electronics and microelectronics laboratories and usually contain two parts:

- Experimental (hardware) part – measurements and study of real semiconductor device characteristics,
- Software part - SPICE model parameter extraction from measured data and device simulation with SPICE program.

Advanced and postgraduate students work at research laboratories and study real elements of VLSI ICs (SOI CMOS, SiGe…), measure their characteristics using probe station (see for example Figure 2), Keithley 2602 source-meter, extract SPICE model parameters using ICCAP tool and simulate with Mentor Graphics Eldo and Cadence Spectre tools.

Figure 2. The post graduate student performs his research work of SOI CMOS MOSFETS using probe station.

The specific work performed by Electronics and Electrical Department in collaboration with microelectronic enterprises are [4]:

- radiation hardness analysis and modeling ,
- electro-thermal modeling of power elements and blocks of integrated circuits.

Graduate and postgraduate students take part in these works with interest.

## 8. DIGITAL AND ANALOG CIRCUIT LEVEL

- Micro circuit technique course provides basic knowledge of digital and analog circuits and contains topics:

For digital electronics - BJT and MOSFET switches, simple logic gates, R-S-flip-flip, static and dynamic memory cells.

For analog electronics - BJT amplifier stage, voltage regulators, current generators, OA stages, OA applications.

The course is provided by Electronics and Electrical Engineering Department together with Radioelectronics Department.

Students get a deeper understanding of digital electronics taking the course:

Computer hardware components and its simulation. The course contains topics:

Different logic gates, different kinds of flip-flops, registers, counters, memory ICs, SPICE simulation of logic circuits.

total of 116 hours, including

34h lectures,

17h labs.

At practical (hardware) work students study characteristics of real logic gates; flip-flops; different types of registers and counters.

In analog electronics students study the real analog circuits: transistor amplifiers, OpAmps, oscillators, voltage regulators and so on.

The software tools for this level are:

- Electronics Workbench, SPICE (different versions),
- Mentor Graphics Eldo,
- Cadence Spectre.

Students simulate analog and digital circuits from single gates to large circuits, compare results with measured ones and with theoretical data (see Figure 3).

Figure 3. The student discusses his IC design project with lecturer.

## 9. LARGE SYSTEM LEVEL (VLSI, SOCS, PCBS)

The courses are provided by the departments: Electronics and Electrical Engineering, Computer Science, Computer Systems and Networks. The following main courses are used at this level.

- VHDL language . The course contains topics:
  Hardware description languages, VHDL operators and data types, VHDL basic constructs, objects description, VHDL additional constructs, functional verification of VHDL descriptions, circuit description with VHDL, VHDL basic libraries.
  total of 105 hours, including
  34h lectures,
  51h labs.

Labs help to learn the usage of VHDL operators and other constructions, to get experience in project implementation with real FPGA/CPLD devices.

Development boards (from Digilent) with XILINX Spartan-2, 3 FPGA are widely used at education process. Using development boards for education is one of the most efficient ways to learn FPGA design and their practical application.

- CAD systems. The course contains topics:
  Computed aided design stages and principles, placement and routing algorithms, PCB design methodology, IC design methodology, design libraries.
  total of 86 hours, including
  34h lectures,
  34h labs with CAD systems, term project.

Students perform analog/digital IC design with TANNER and Mentor design systems. To perform the project successively it is required to use CAD tools extensively: for circuit simulation and for layout design.

- Microprocessor systems. The course contains topics:
  Intel processor: architecture, command system, memory organization, interrupts, protected mode. RISC microprocessors and microcontrollers. Modern microcontrollers: architecture, memory, ports, interrupts, bus types, USB-bus, bult-in DAC and ADC converter, power consume control, digital signal processors.
  total of 140 hours, including
  68h lectures,
  51h labs, term project.

Microprocessors and microcontrollers are studied using professionally packed evaluation Motorola's, modern Renesas and Cypress modules and corresponding software tools . The students learn how to write simple programs in assembly and C languages, how to download them to the microcontroller and how to debug the program. Our experience shows that application boards are very interesting for students and motivate them to more deep theoretical knowledge. In Figure 4 you can see the student performing his term work with CYPRESS development board with CY8C29466-24PVXI microcontroller.

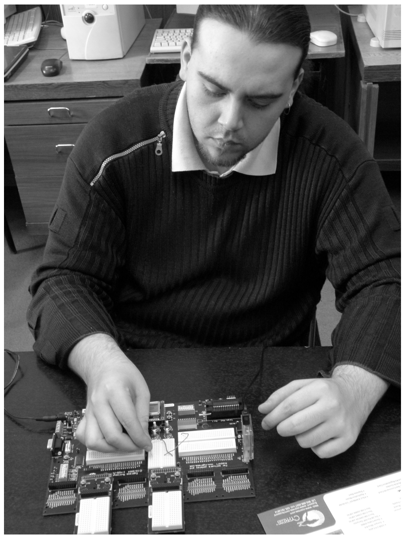

Figure 4. The student performs his term work using CYPRESS development board with CY8C29466-24PVXI microcontroller.

- Computer networks. The course contains topics:
  Principles of computer network organization, transfer protocols, local network organization and access, global networks, networks design, telecommunication hardware, network security, network administration.
  total of 116 hours, including
  34h lectures,
  17h labs.

As mentioned earlier ZyXEL Center provides practical training for students and engineers to get and/or improve the experience in the field of the ZyXEL network technologies.

It should be pointed that MIEM provides high quality microelectronic education not only for students, but also for industry engineers in the form of additional education. Xilinx Center provides additional VHDL courses and ZyXEL Center is responsible for additional education in the fields of network programming and hardware.

## 10. CONCLUSIONS

The microelectronics education system at MIEM based on:

- wide hardware/software products application of leading microelectronic companies,
- continues and throughout learning process: from semiconductor material to system on chip/board,

is described.

Specially created authorized educational-research Centers (Mentor Graphics, Synopsys, Motorola, Xilinx, Renesas, Cypress) provide CAD training and microelectronic equipment experience.

Collaboration with industry enterprises provide high quality education for students, post graduate students, reeducation for industry engineers, joint research projects, practical training.

## REFERENCES


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